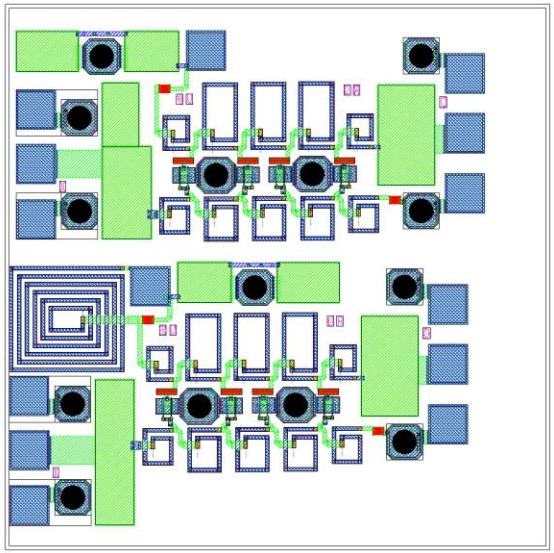
JHU Fall 12 MMIC Design

Measured Results

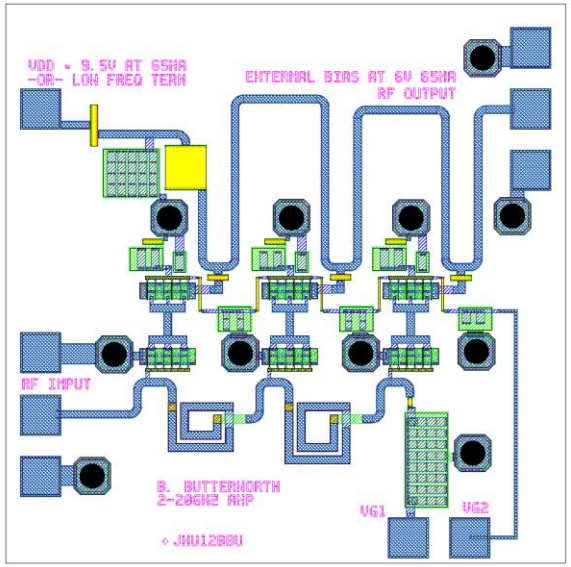


2011/2012 Distributed Amplifiers JEP

Many of the 2012 student designs were broadband distributed amplifiers, with a couple of voltage controlled oscillator designs (VCO), broadband low noise amplifiers, and a balanced amplifier. Most worked very well. Attached are s-parameter plots, noise figure measurements, etc. summarizing the testing of the Fall 2012 MMIC Design Class. Some additional measurements of circuits filling out the rest of the quarter tile include frequency doublers, distributed amplifiers, VCOs, and other amplifiers.

2012 TQP13 Tile

Brandon Butterworth Distributed Amp



Very broadband high gain (~15 dB), from DC to 22 GHz. Had to be careful biasing the cascode PHEMT stages after inadvertantly burning out the first die. Very Good noise fig. (<2 dB) 6-14 GHz.

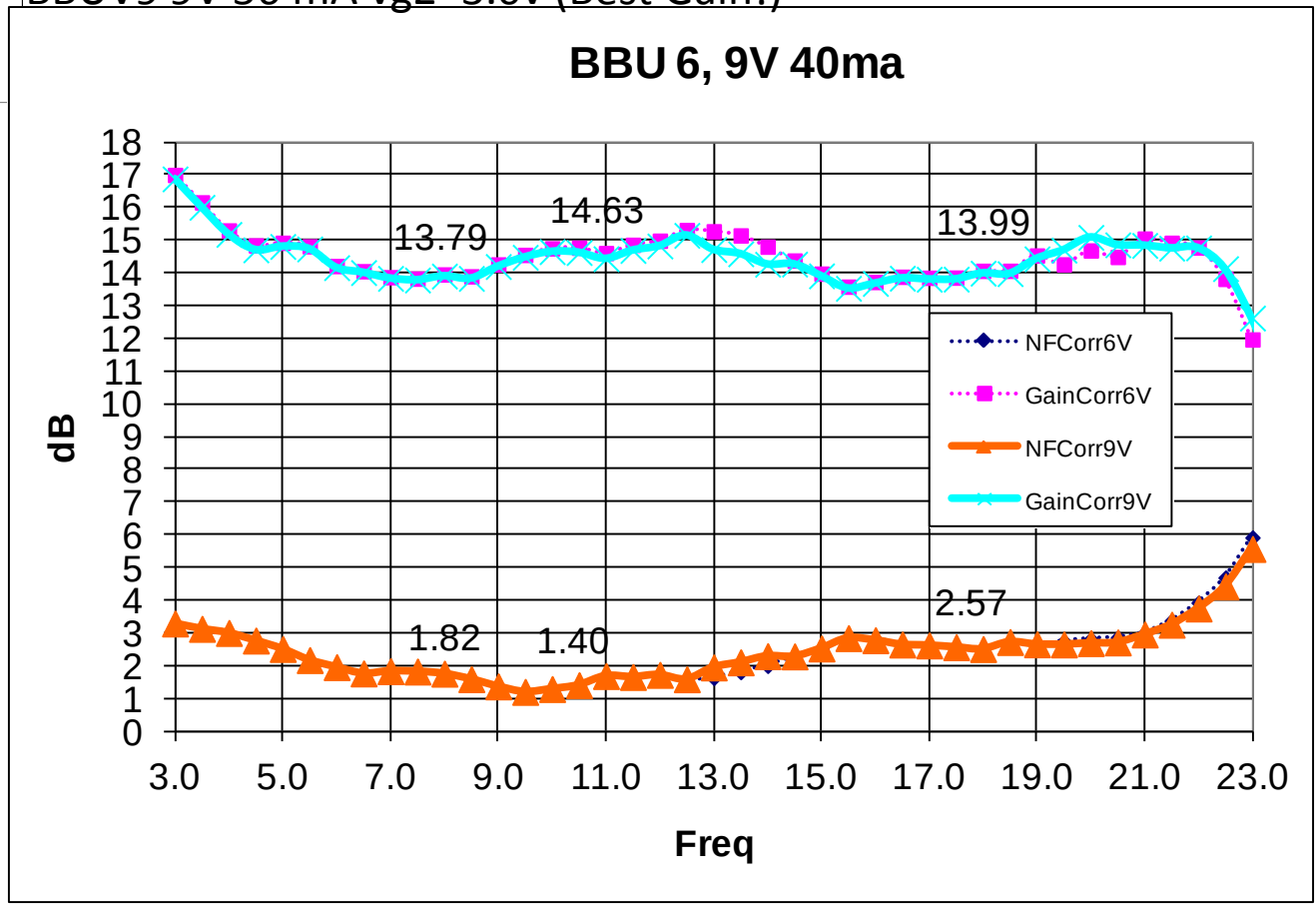
BBUV4 4V 12 mA vg2=2.0v

BBUV5 5V 15 mA vg2=2.5v

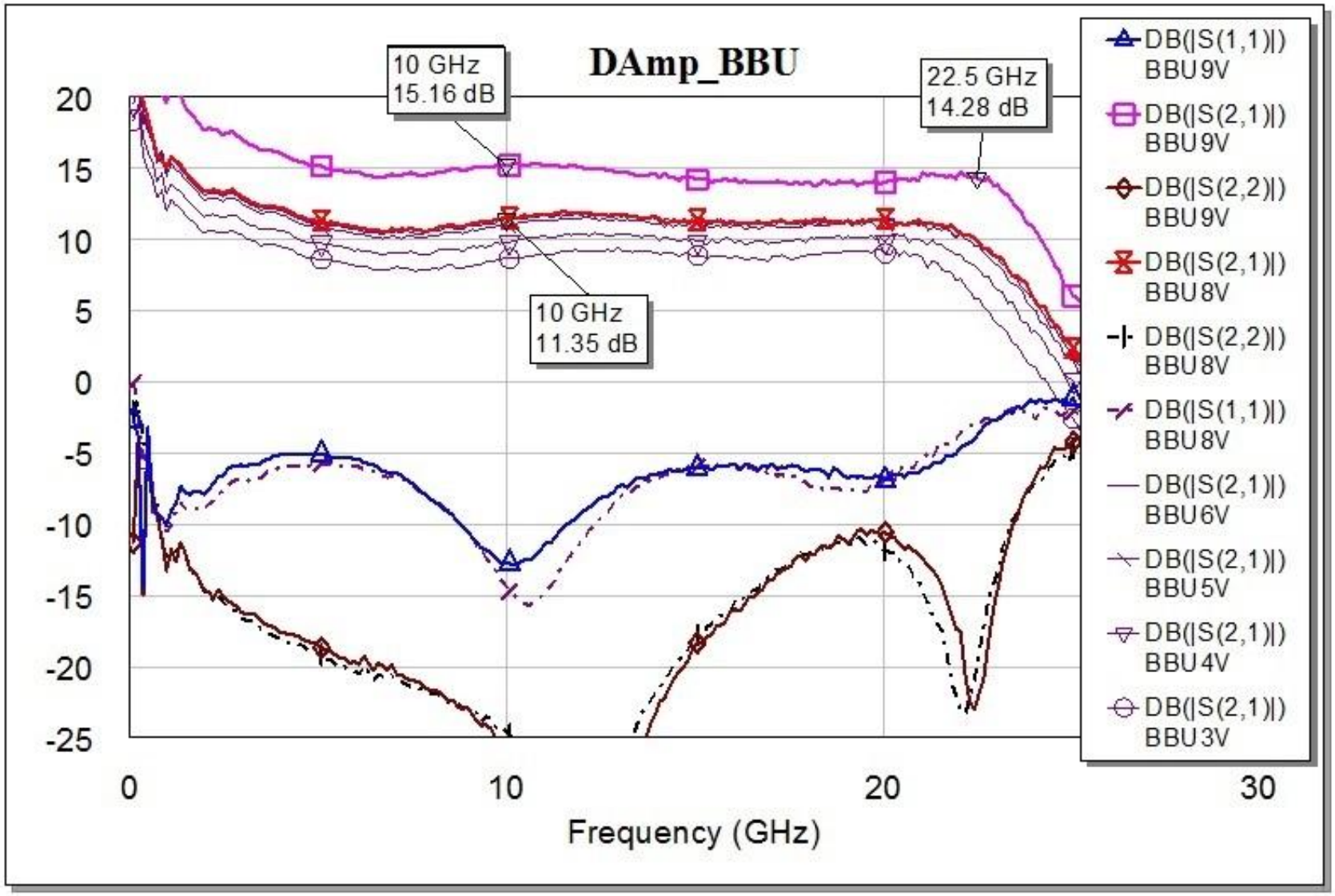
BBUV6 6V 17 mA vg2=3.0v

BBUV8 8V 19 mA vg2=3.0v

BBUV9 9V 56 mA vg2=3.0v (Best Gain!)

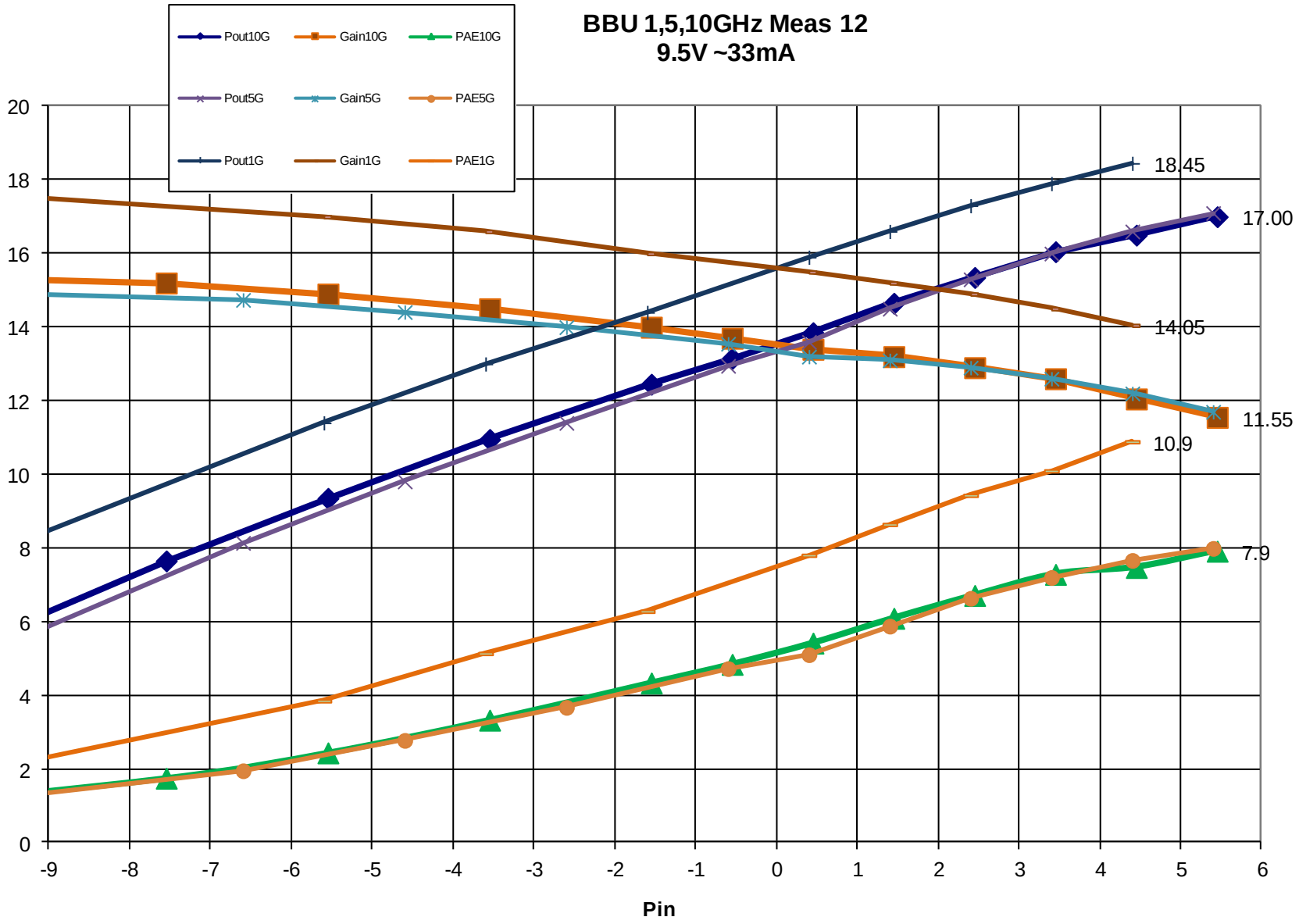


Brandon Butterworth Distributed Amp



Brandon Butterworth Distributed Amp

Performance at 1, 5, 10 GHz AB Bias 9.5V at 33 mA, vg1=0v, vg2=3v



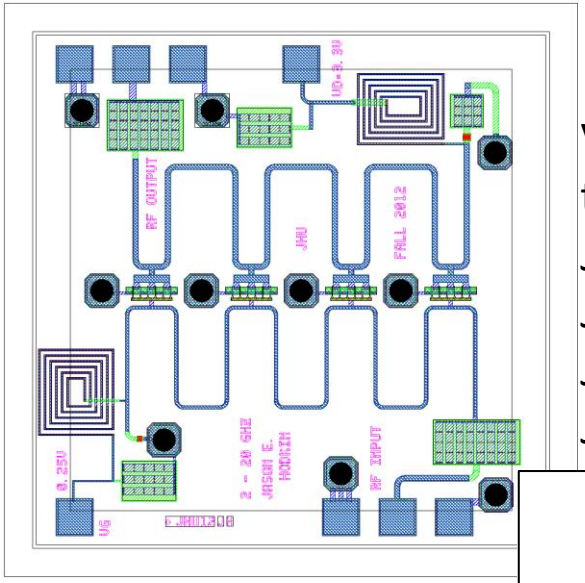
Brandon Butterworth Distributed Amp

DC-25 GHz Fall12 TQP13				9.5V ; 33 mA			
Pin(corr)	**Pout(corr)**	**Gain**	**I1(9.5V)**	**PDC(mw)**	**Pout(mw)**	**Drn Eff**	**PAE**
-10.60	7.10	17.70	33	313.5	5.13	1.6	1.6
-5.60	11.40	17.00	37	351.5	13.80	3.9	3.8
-3.60	13.00	16.60	40	380.0	19.95	5.3	5.1
-1.60	14.40	16.00	45	427.5	27.54	6.4	6.3
0.40	15.90	15.50	51	484.5	38.90	8.0	7.8
1.40	**16.60**	15.20	54	513.0	45.71	8.9	**8.6**
2.40	17.30	14.90	58	551.0	53.70	9.7	9.4
3.40	17.90	14.50	62	589.0	61.66	10.5	10.1
4.40	**18.45**	**14.05**	65	617.5	**69.98**	**11.3**	**10.9**

Performance at 1, 5, 10 GHz
AB Bias 9.5V at 33 mA,
vg1=0v, vg2=3v

5 GHz	Die#1	**1-5 GHz Fall12 TQP13**				4V ; 53 mA			
Pin(SG)	**Pout(SA)**	**Pin(corr)**	**Pout(corr)**	**Gain**	**I1(9.5V)**	**PDC(mw)**	**Pout(mw)**	**Drn Eff**	**PAE**
-20.0	-8.10	-21.60	-6.50	15.10	32	304.0	0.22	0.1	0.1
-10.0	1.84	-11.60	3.44	15.04	32	304.0	2.21	0.7	0.7
-5.0	6.54	-6.60	8.14	14.74	34	323.0	6.52	2.0	1.9
-3.0	8.21	-4.60	9.81	14.41	35	332.5	9.57	2.9	2.8
-1.0	9.80	-2.60	11.40	14.00	38	361.0	13.80	3.8	3.7
1.0	11.35	-0.60	12.95	13.55	42	399.0	19.72	4.9	4.7
2.0	12.00	0.40	13.60	13.20	45	427.5	22.91	5.4	5.1
3.0	12.90	1.40	14.50	13.10	48	456.0	28.18	6.2	5.9
4.0	13.70	2.40	15.30	12.90	51	484.5	33.88	7.0	**6.6**
5.0	14.40	3.40	16.00	12.60	55	522.5	39.81	7.6	**7.2**
6.0	15.00	4.40	16.60	12.20	59	560.5	45.71	8.2	7.7
7.0	15.50	5.40	17.10	11.70	63	598.5	**51.29**	8.6	**8.0**

10 GHz	Die#1	**1-5 GHz Fall12 TQP13**				4V ; 53 mA			
Pin(SG)	**Pout(SA)**	**Pin(corr)**	**Pout(corr)**	**Gain**	**I1(9.5V)**	**PDC(mw)**	**Pout(mw)**	**Drn Eff**	**PAE**
-10.0	0.40	-12.55	2.95	15.50	33	313.5	1.97	0.6	0.6
-5.0	5.10	-7.55	7.65	15.20	34	323.0	5.82	1.8	1.7
-3.0	6.80	-5.55	9.35	14.90	36	342.0	8.61	2.5	2.4
-1.0	8.40	-3.55	10.95	14.50	38	361.0	12.45	3.4	3.3
1.0	9.90	-1.55	12.45	14.00	41	389.5	17.58	4.5	4.3
2.0	*10.60*	-0.55	13.15	13.70	43	408.5	20.65	5.1	4.8
3.0	*11.30*	0.45	13.85	13.40	45	427.5	24.27	5.7	5.4
4.0	*12.10*	1.45	14.65	**13.20**	48	456.0	29.17	6.4	**6.1**
5.0	12.80	2.45	15.35	**12.90**	51	484.5	34.28	**7.1**	**6.7**
6.0	13.50	3.45	16.05	12.60	55	522.5	40.27	7.7	7.3
7.0	13.95	4.45	16.50	12.05	59	560.5	44.67	8.0	7.5
8.0	14.45	5.45	17.00	11.55	62	589.0	50.12	8.5	**7.9**



Jason Hodkin Distributed Amp

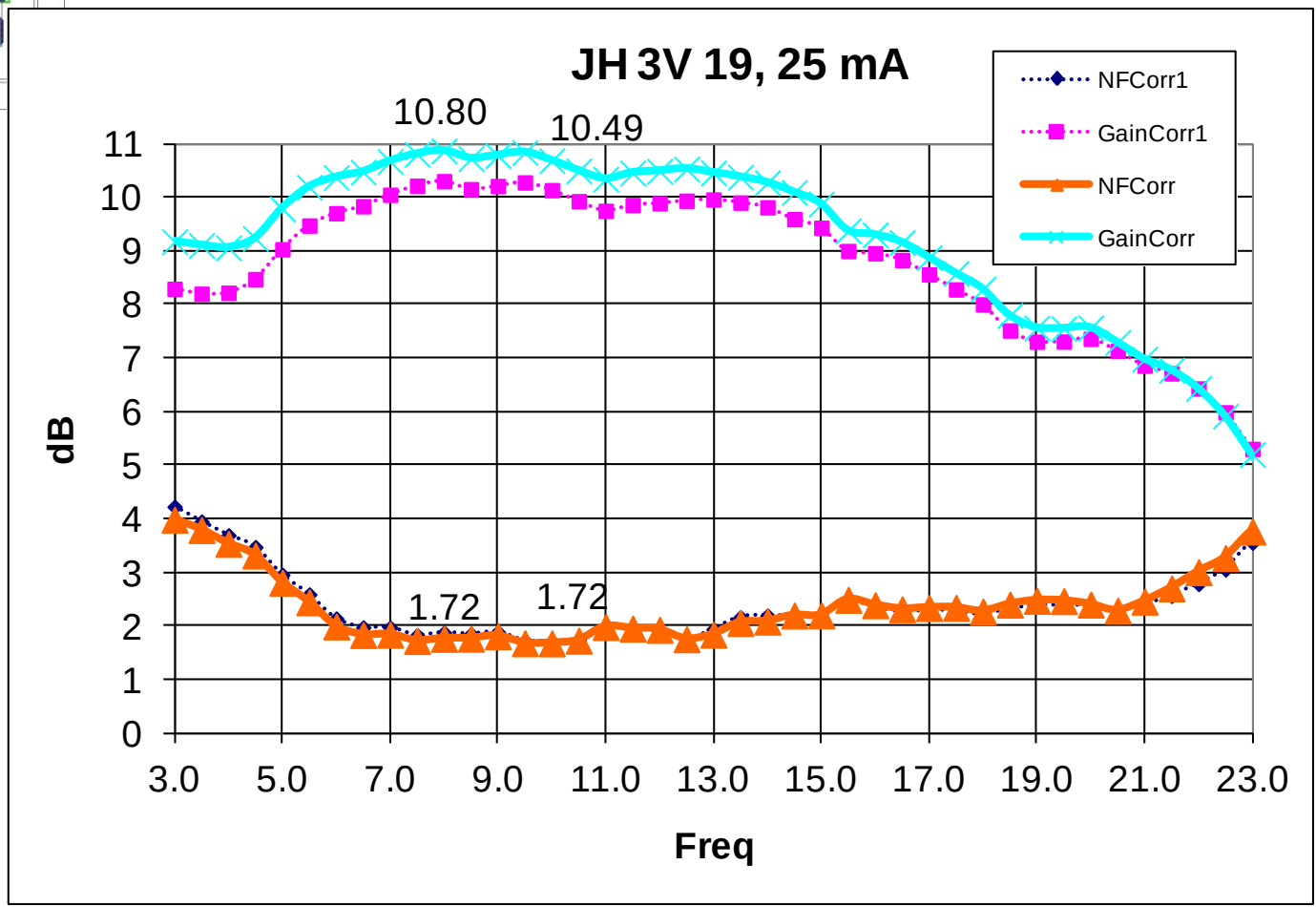
Very broadband gain, rolling off from a high of about 11 at 9 GHz to 7 dB at 20 GHz. Good noise figure (<2 dB) from 6 to 13 GHz.

JH2I25 2V 25mA

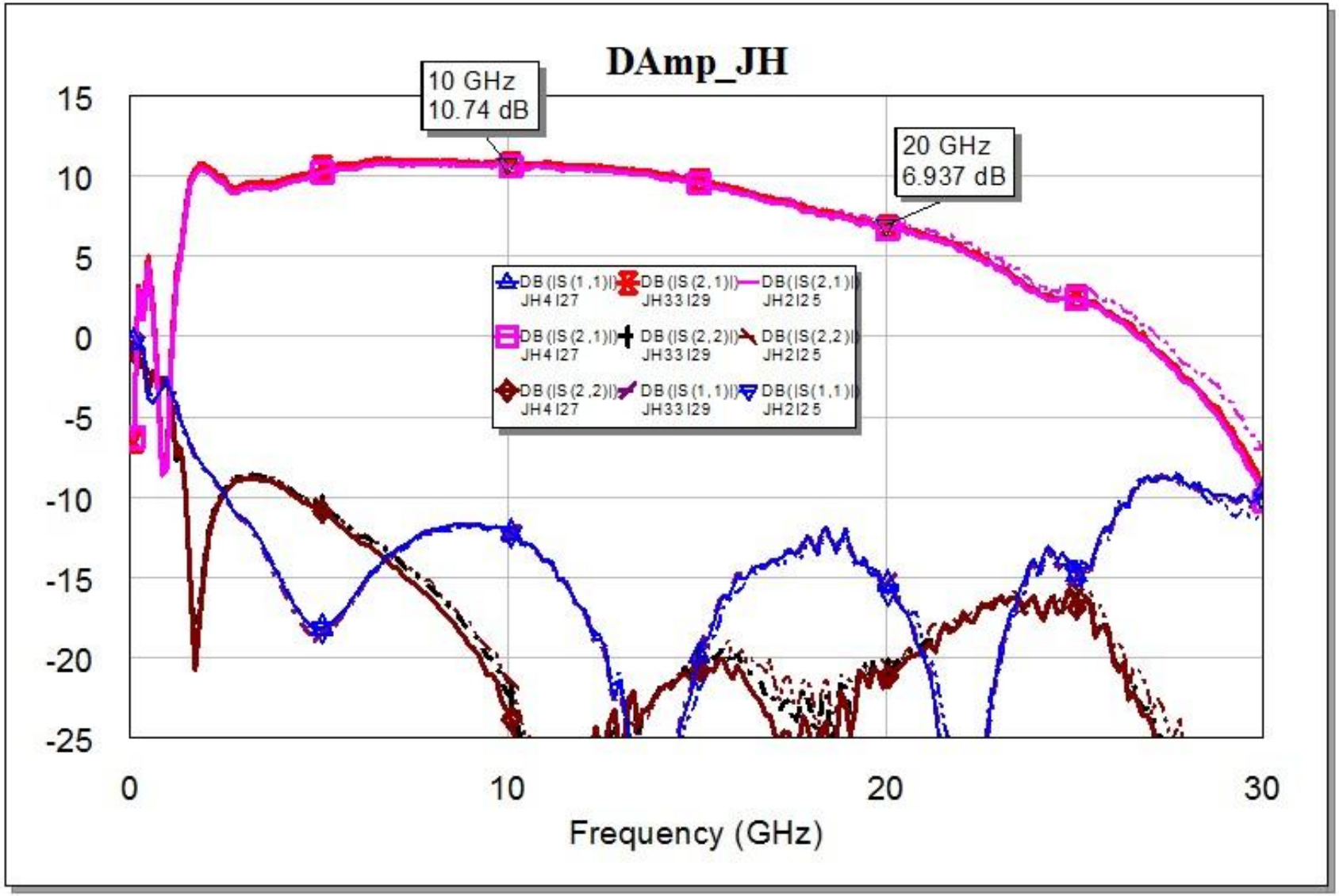
JH33I20 3.3V 20 mA vgs=0V

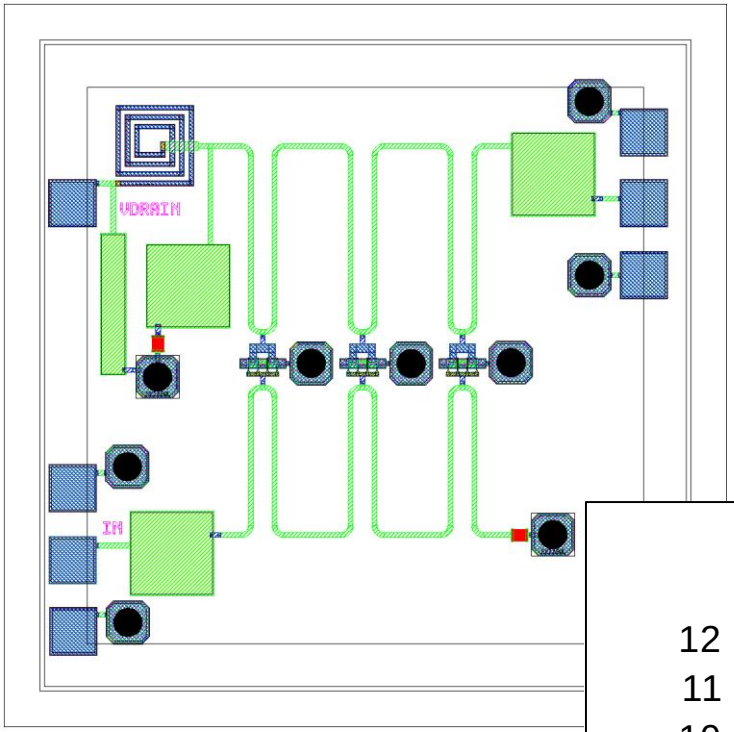
JH33I29 3.3V 29 mA vgs=0.2V

JH4I27 4.0V 27 mA vgs=0.2V



Jason Hodkin Distributed Amp





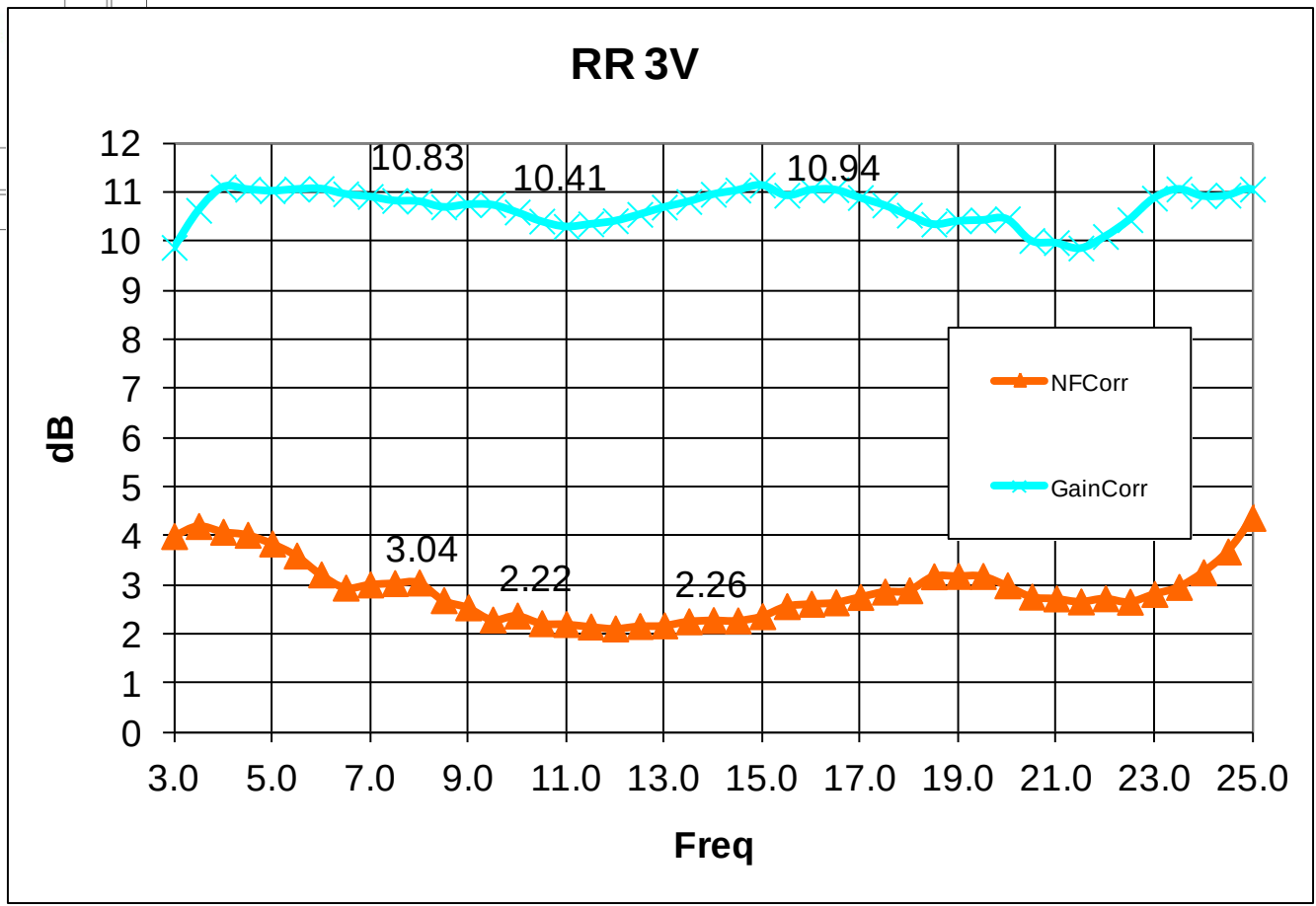
Robert Reyes Distributed Amp

Very broadband, flat gain of about 10 dB from 3-26 GHz. Good noise figure too.

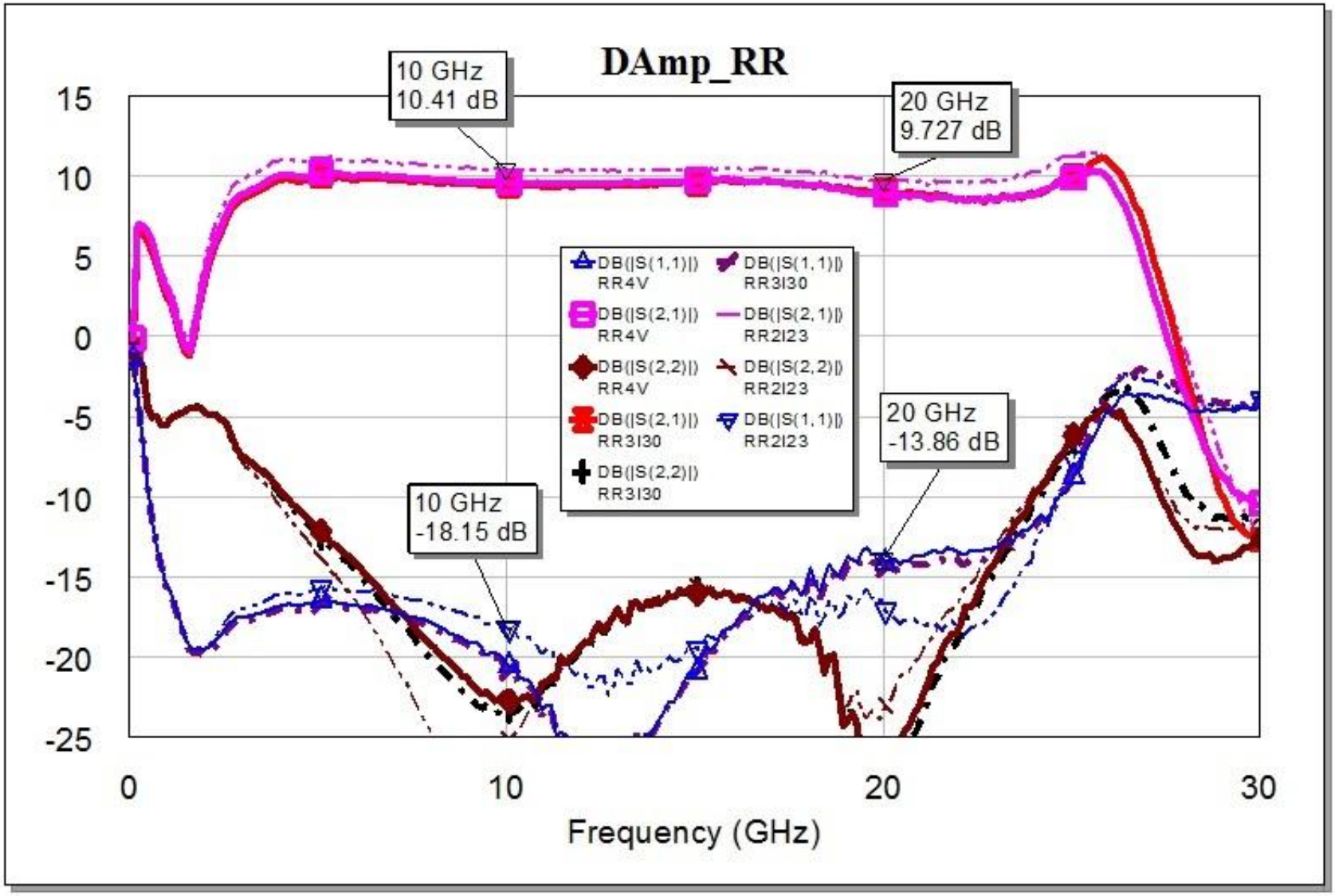
RR4V 4V 39 mA

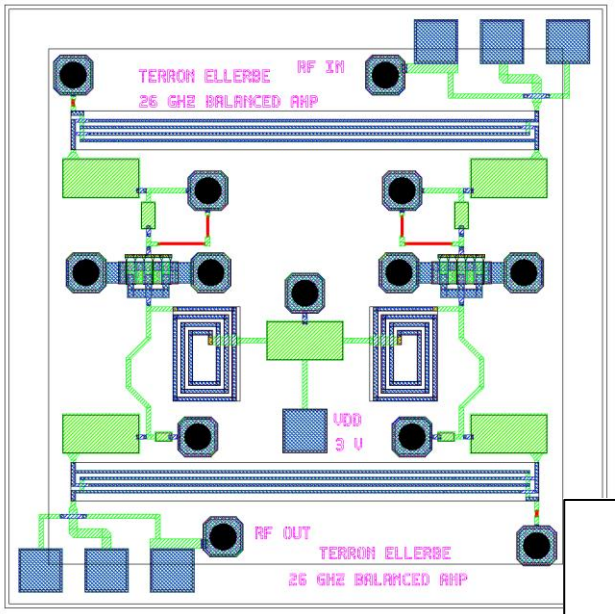
RR2I23 2V 23mA

RR3I30 3V 30mA



Robert Reyes Distributed Amp





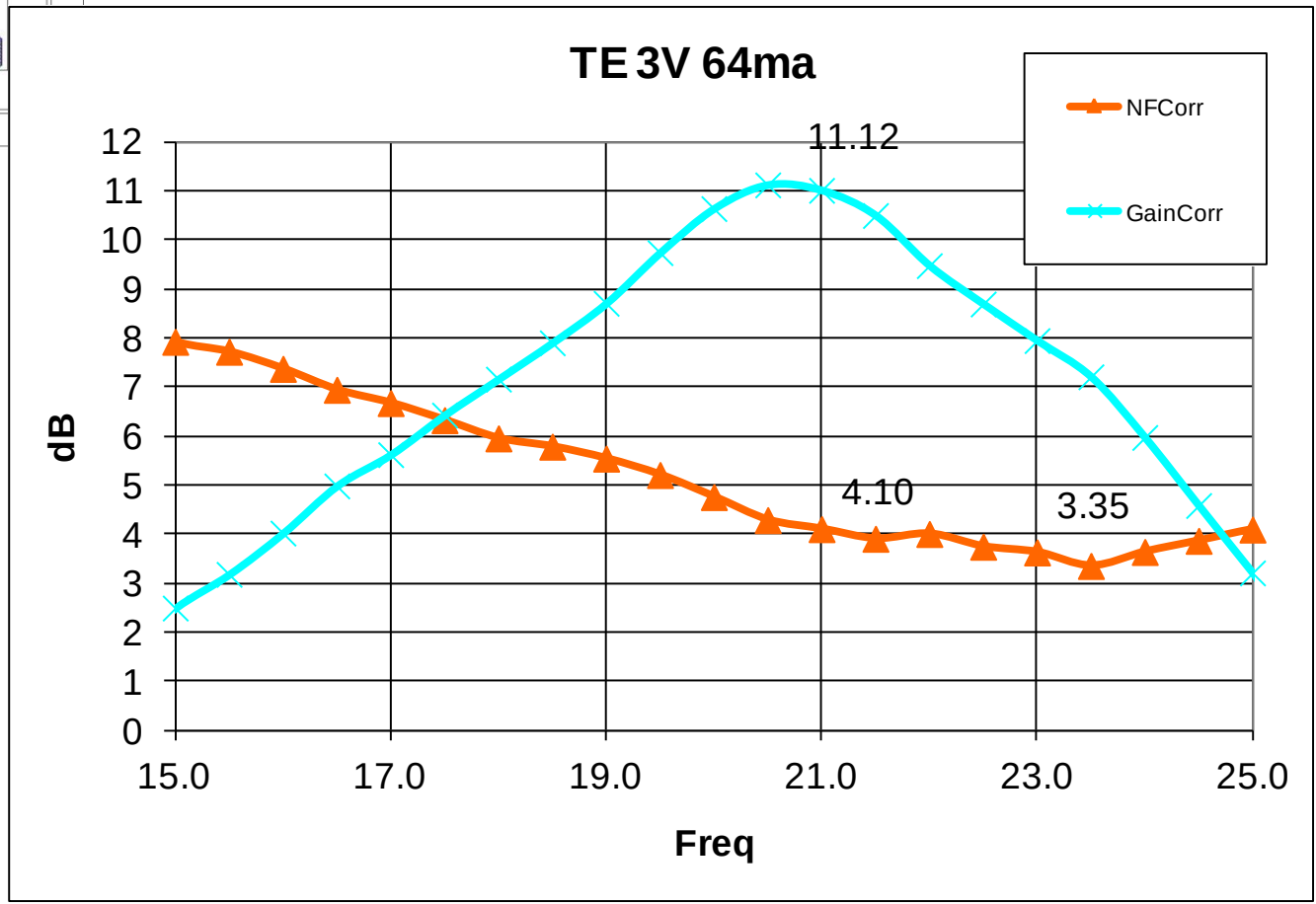
Terron Ellerbe Balanced Amp

The Balanced Amplifier worked well, but shifted down in frequency from the original design (26->21 GHz). Very typical result at these frequencies using standard microstrip models. An EM simulation would likely compare more closely with the measurements.

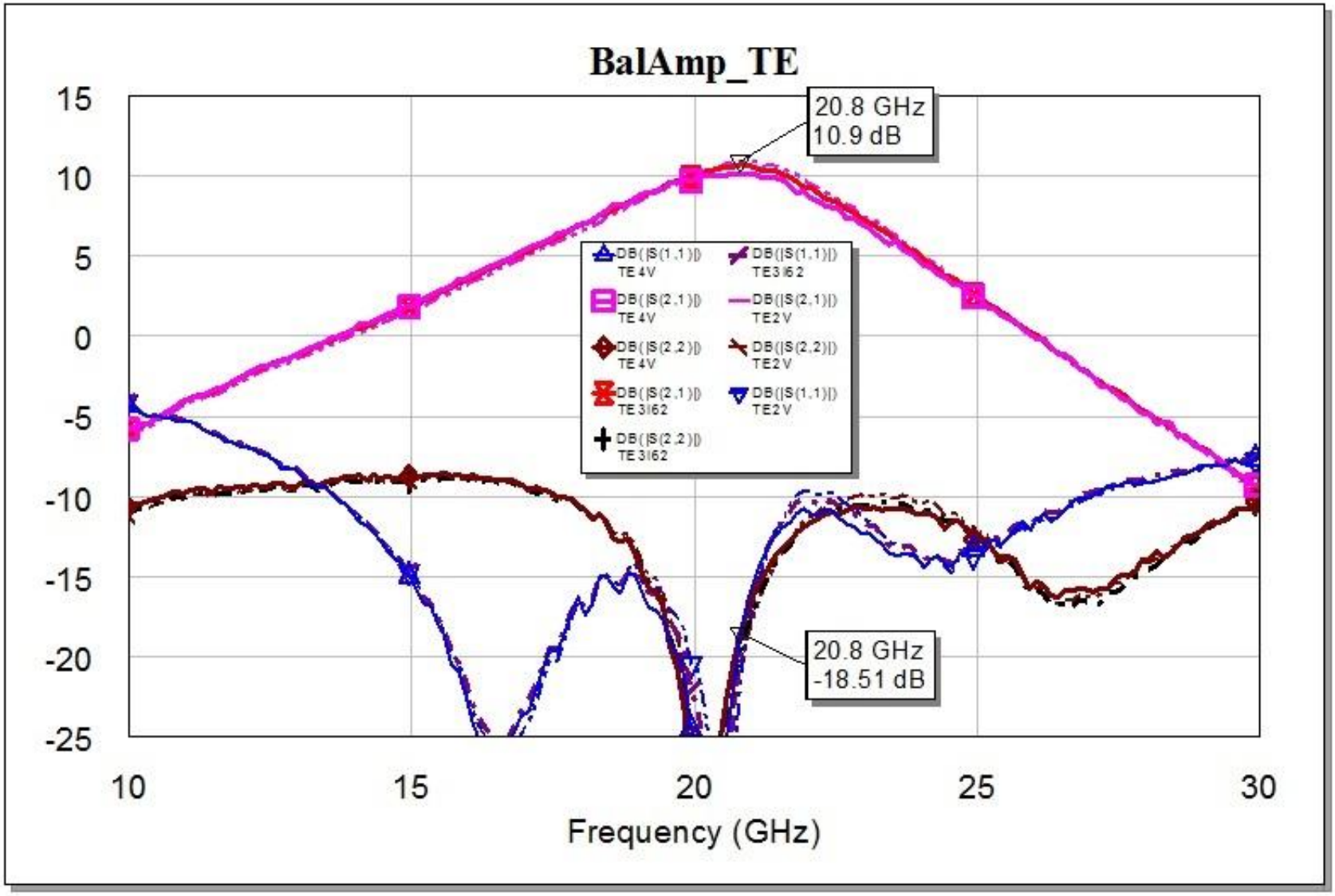
TE2V 2V 50 mA

TE3V 3V 62 mA

TE4V 4V 77 mA



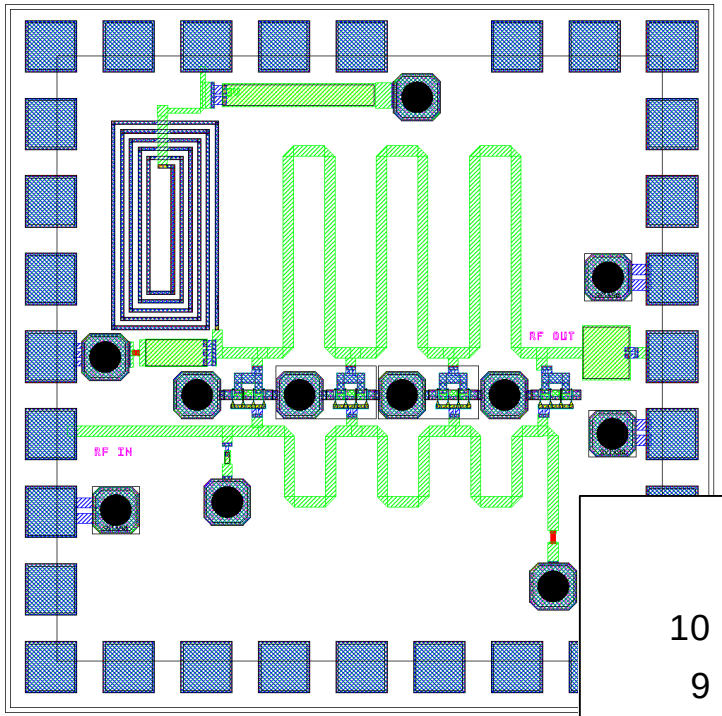
Terron Ellerbe Balanced Amp

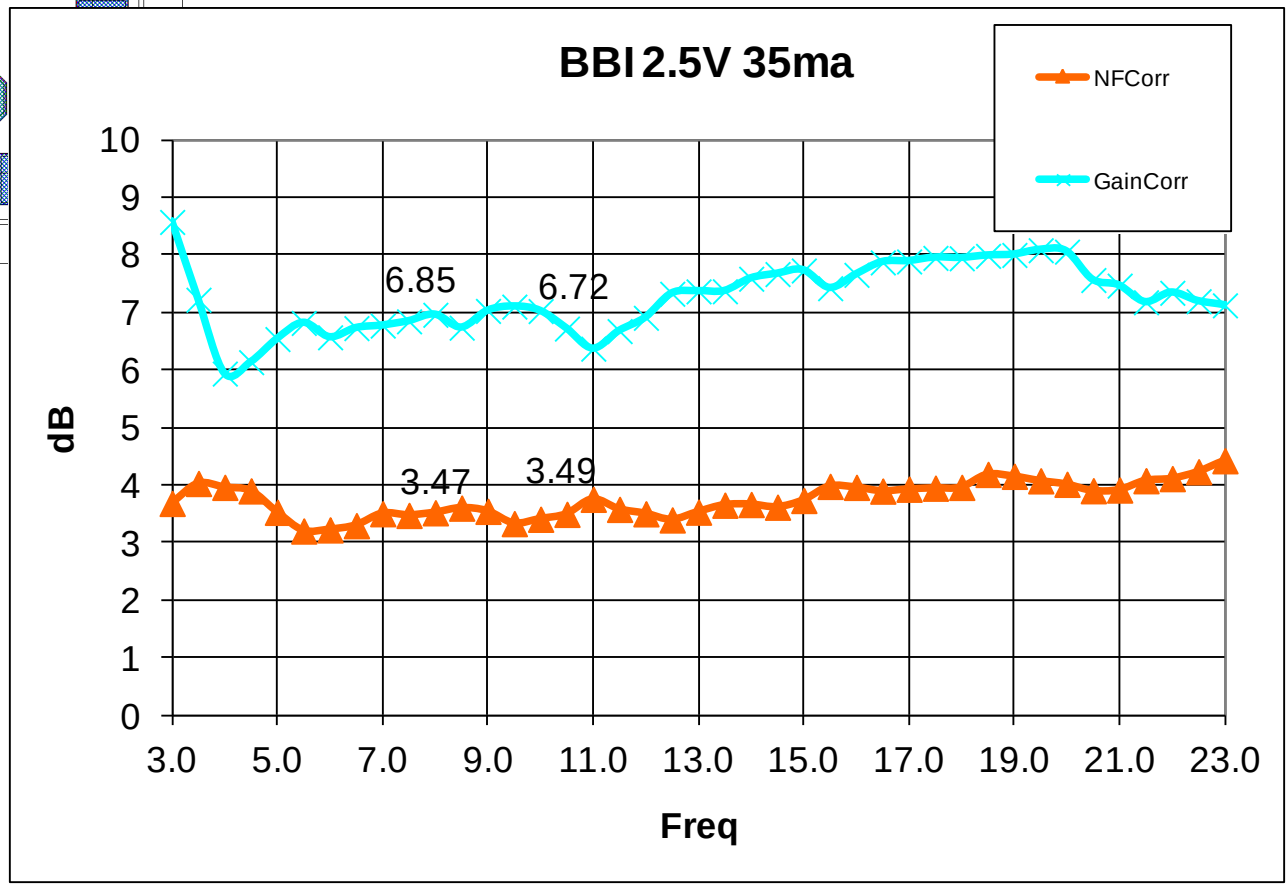


Brian Billman Balanced Amp

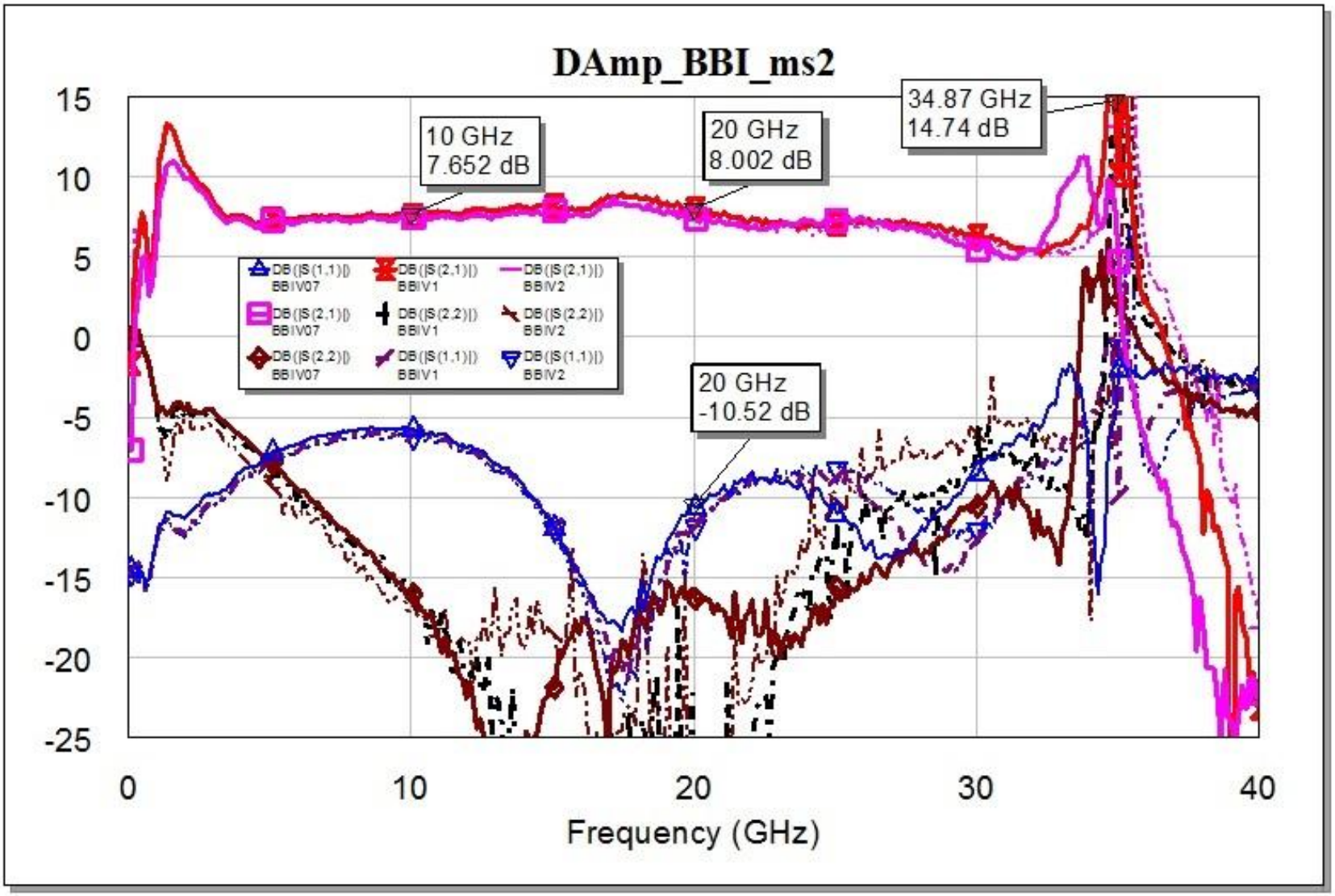
At higher DC biases, this design had a high frequency stability issue near 35 GHz, similar to the distributed amplifier problems noted in the Distributed Amplifier (John Penn, RF & Microwaves Magazine Feb 2013 article). Had fairly flat gain and good noise figure over a broad band.

BBIV1_3 1.3V 27 mA
BBIV1_6 1.6V 29 mA
BBIV3_0 2.0V 31 mA

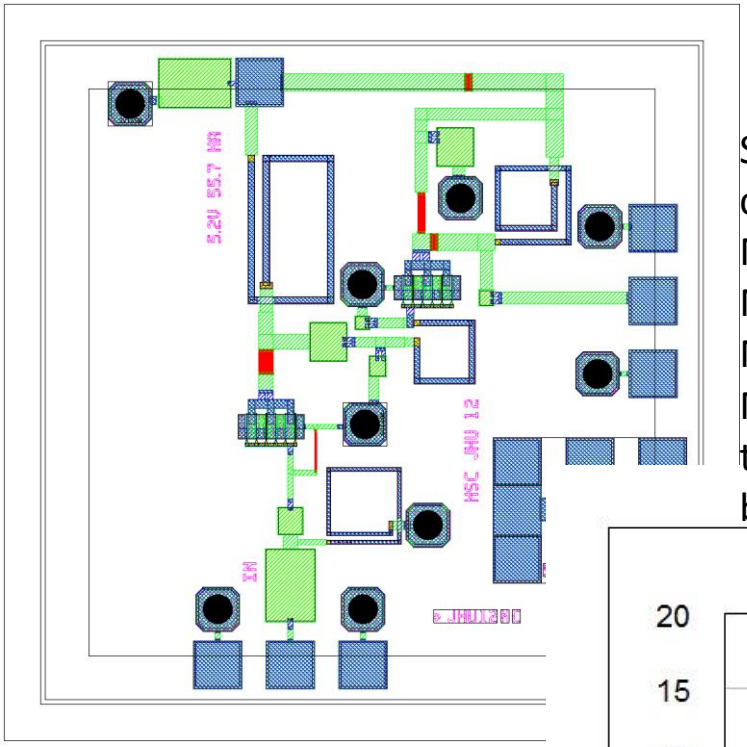




Brian Billman Balanced Amp



Michael Coon Low Noise Amp



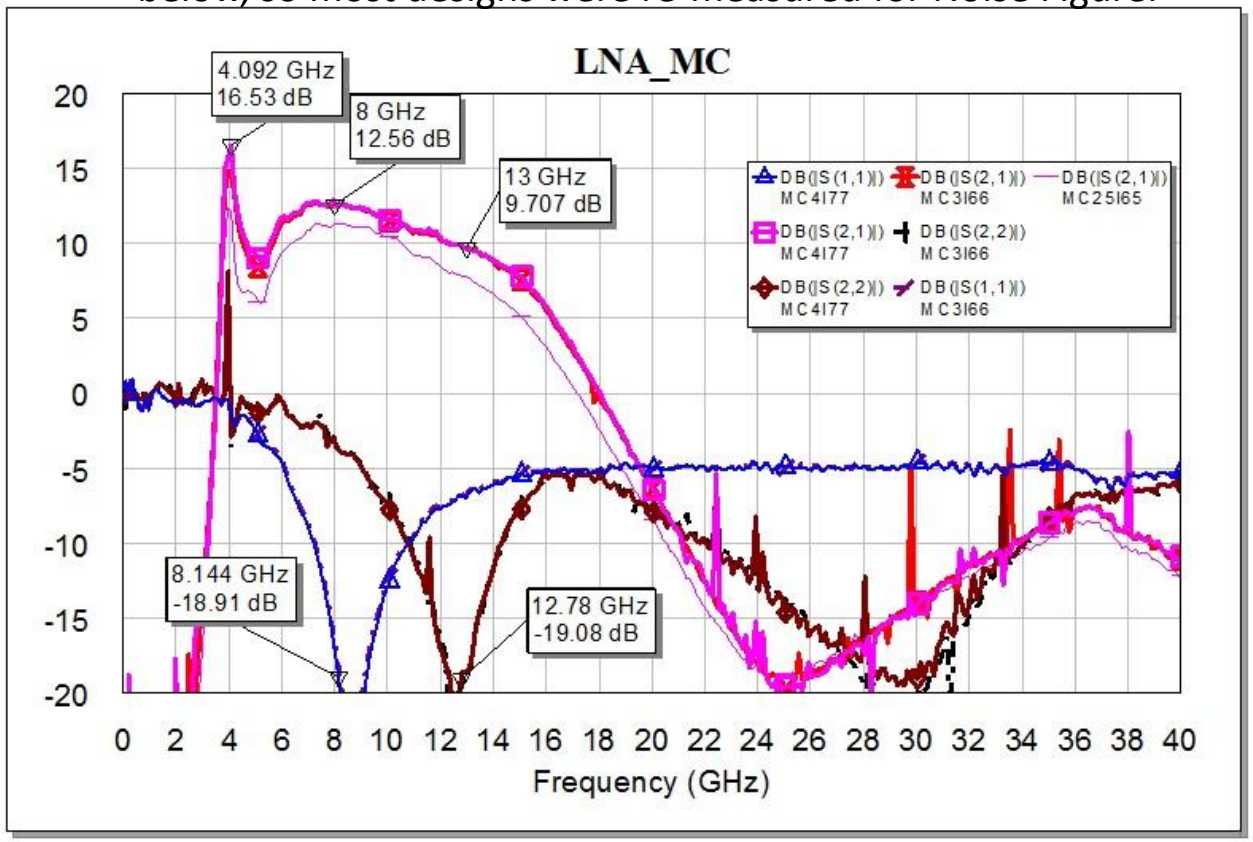
Some Low Frequency stability issues in test setup, but got some clean measurements at slightly lower DC bias points.

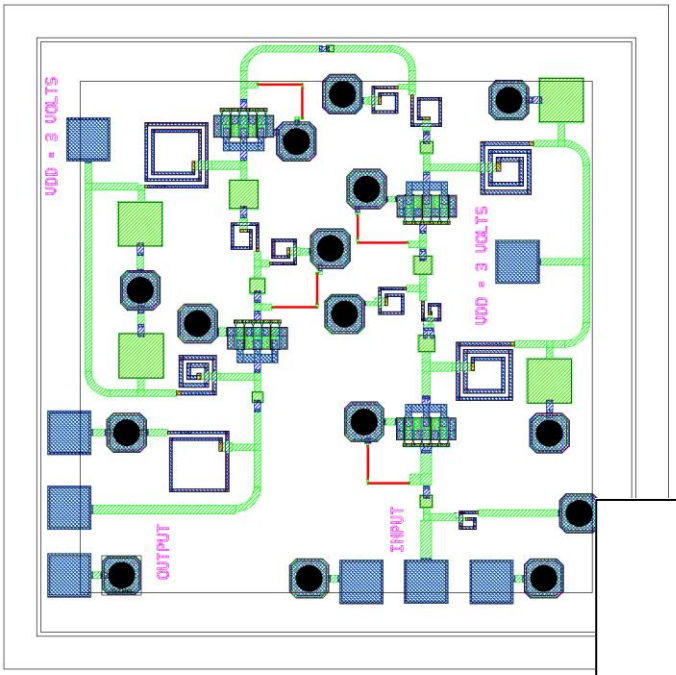
MC25I65 2.5V 65 mA

MC3I66 3.0V 66 mA

MC4I67 4.0V 67 mA

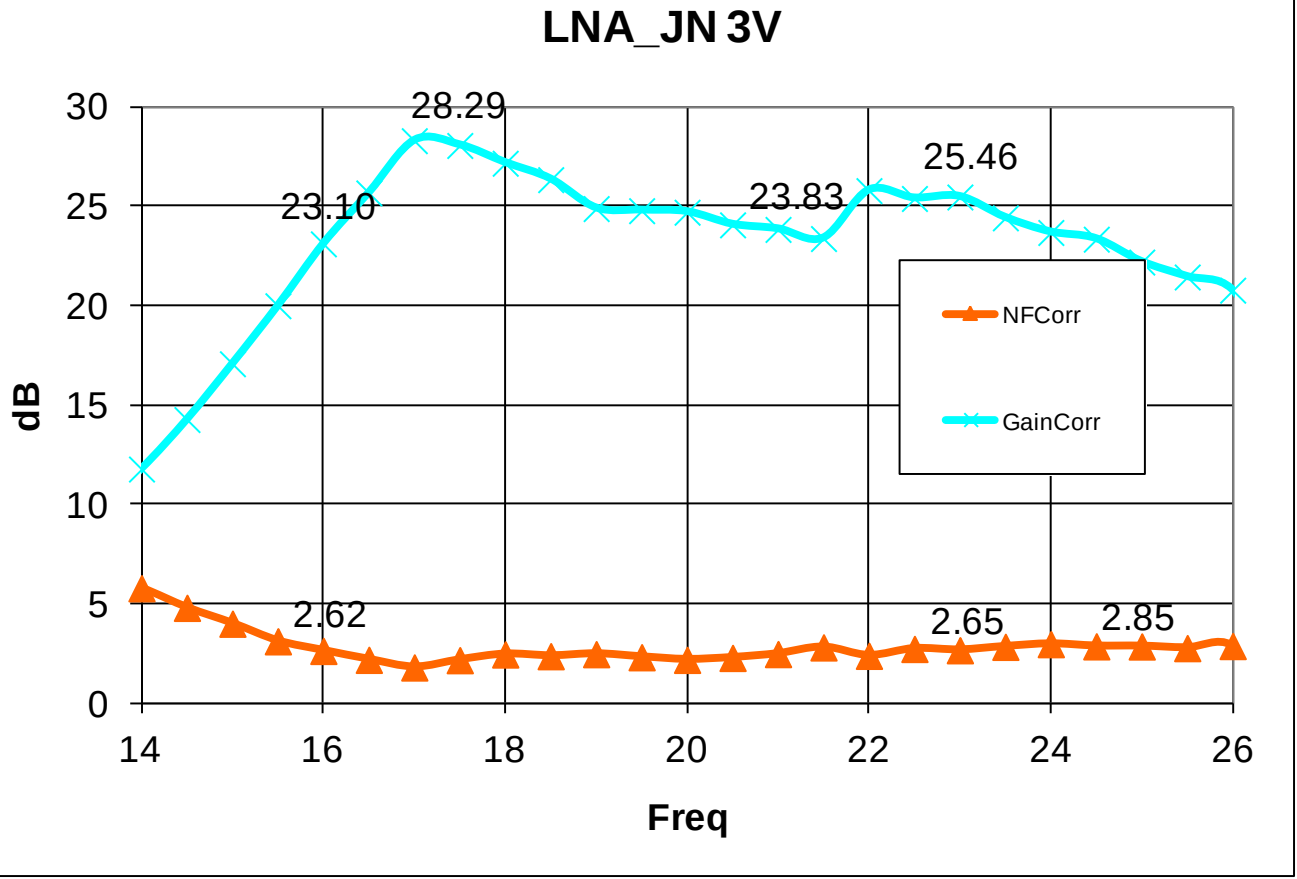
Missed getting NF measurements. The NF meter failed during the testing, but later seemed to only have a problem at 3 GHz and below, so most designs were re-measured for Noise Figure.



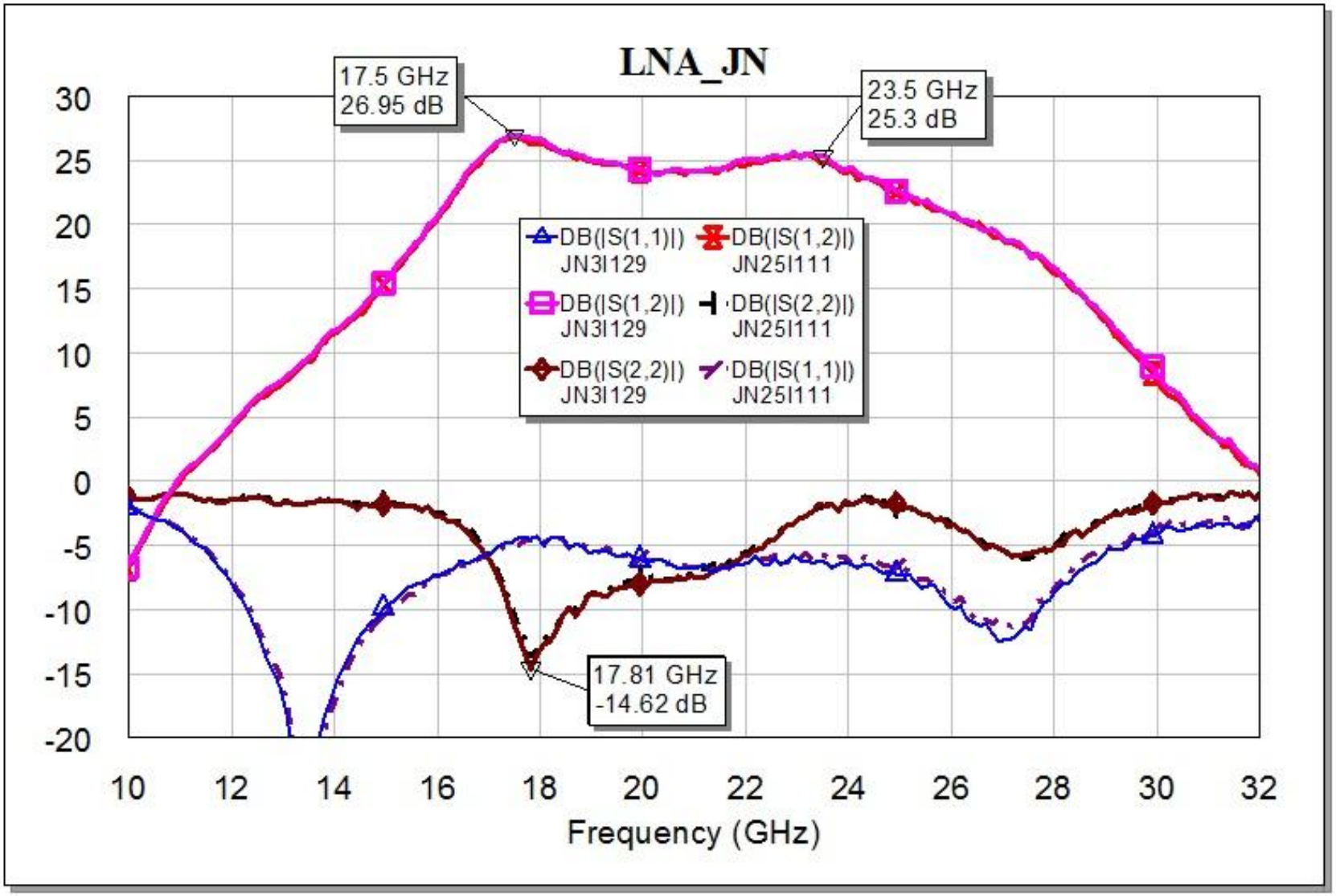


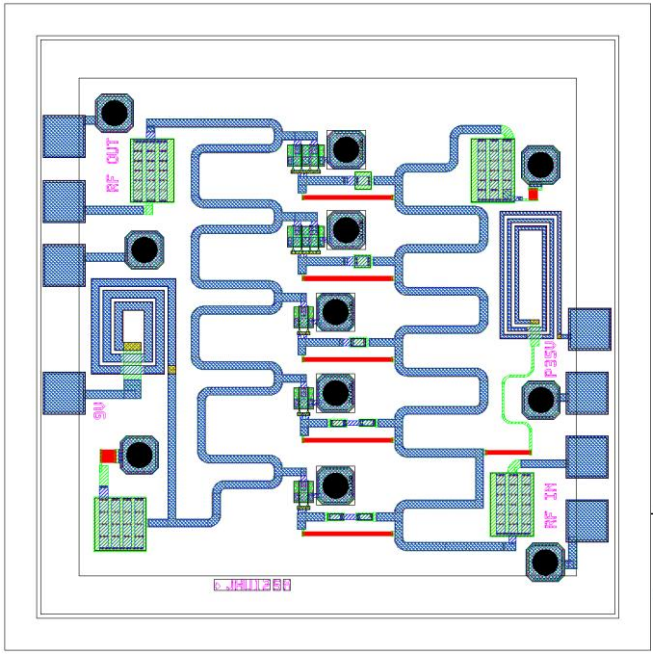
John Novak Broad Band Low Noise Amp

JN15I88 1.5V 88 mA
JN25I111 2.5V 111mA
JN3I139 3.0V 129 mA.
Measured s-parameters and noise figure of broadband LNA design. Very good gain over the band (~17-26 GHz) and good noise figure.



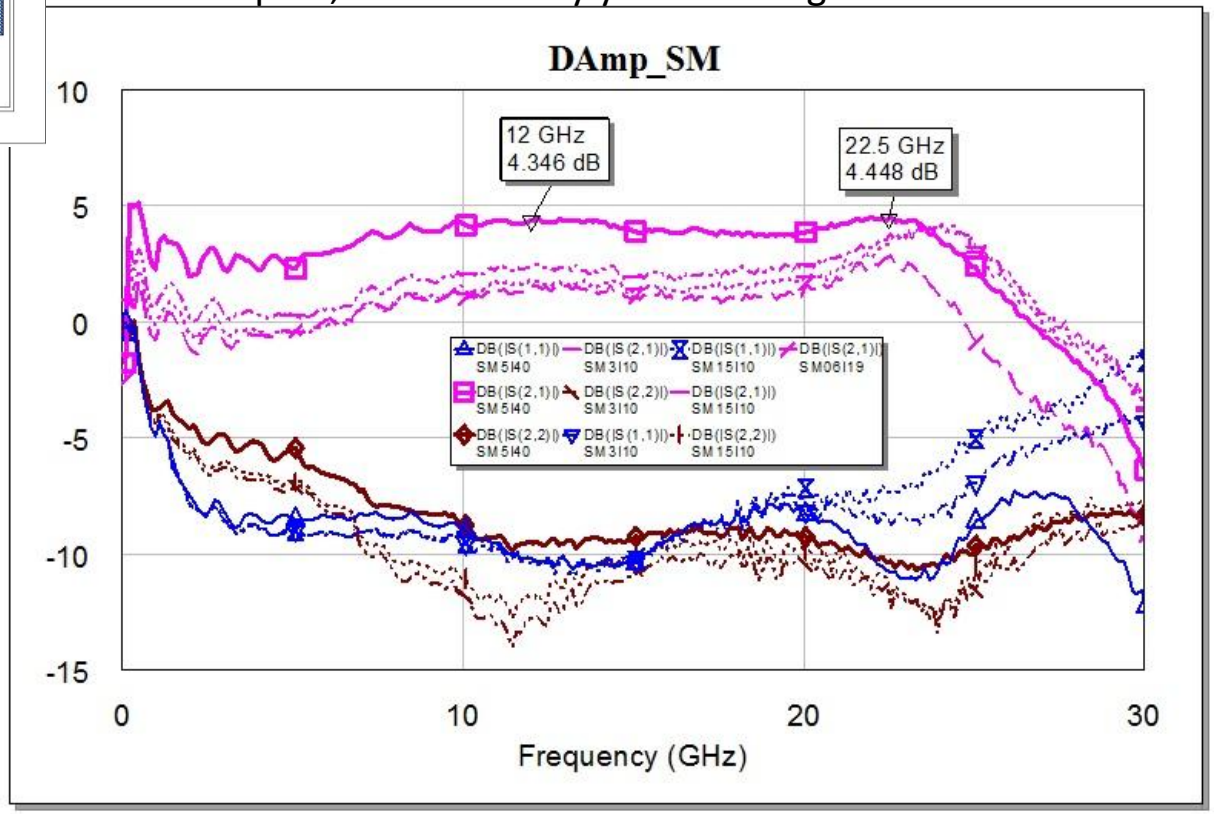
John Novak Broad Band Low Noise Amp

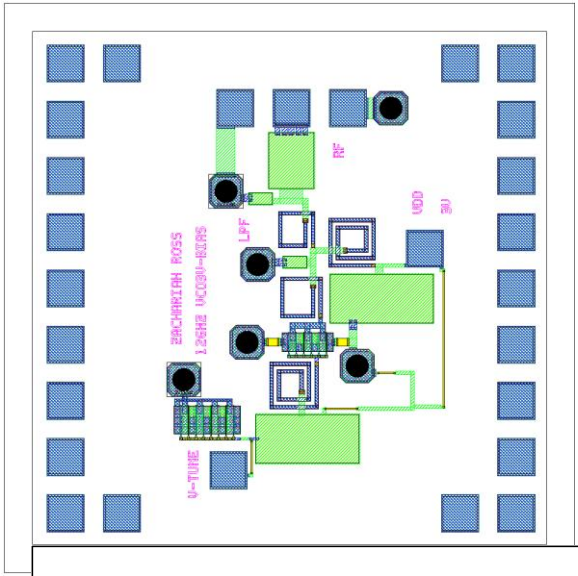




Shannon Marshall Distributed Amp

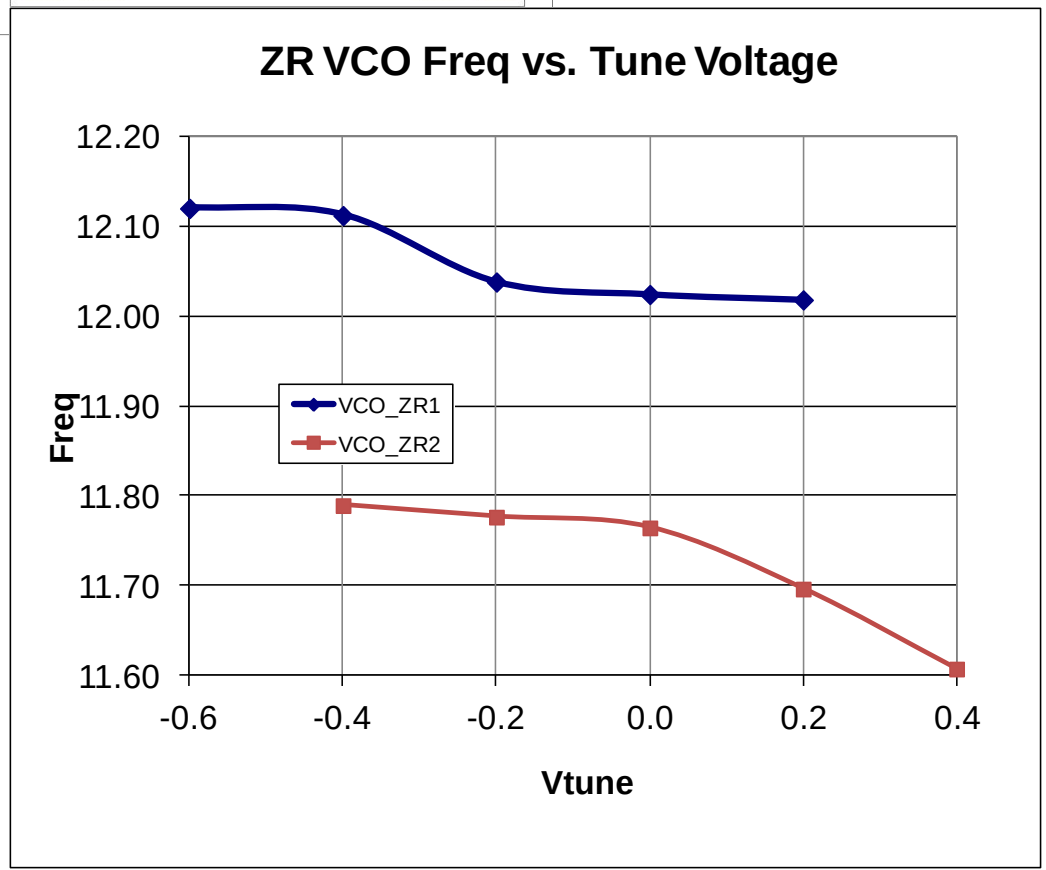
Low Frequency stability issue at 19-20 MHz in test setup!
SM3I10 3V 10 mA vgs=0
SM15I10 1.5V 10 mA vgs=0V
SM06I10 0.6V 19 mA vgs=0.35V
Got some Gain at lower DC biases, but could not seem to kill the low frequency oscillations in the probe setup—a common problem last year too. If 100 pf caps could be bonded close to the DC inputs, it would likely yield better gain.





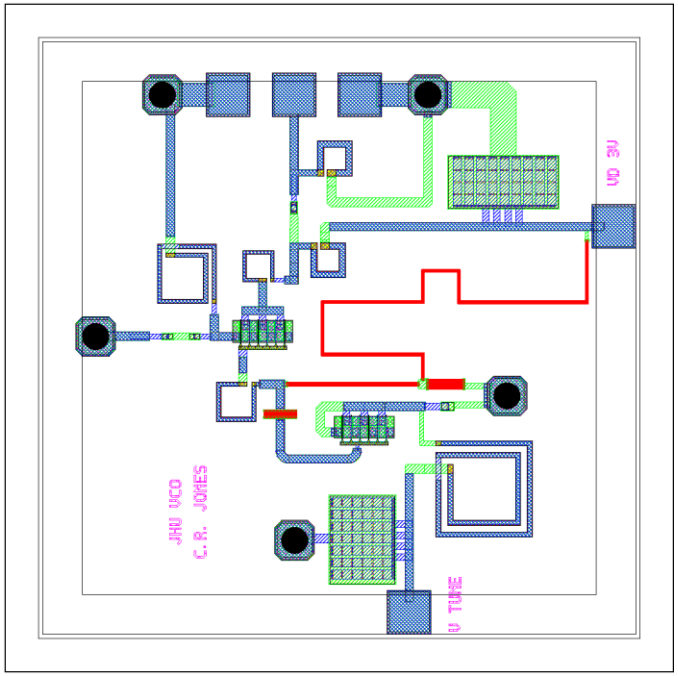
Zach Ross 12 GHz VCO

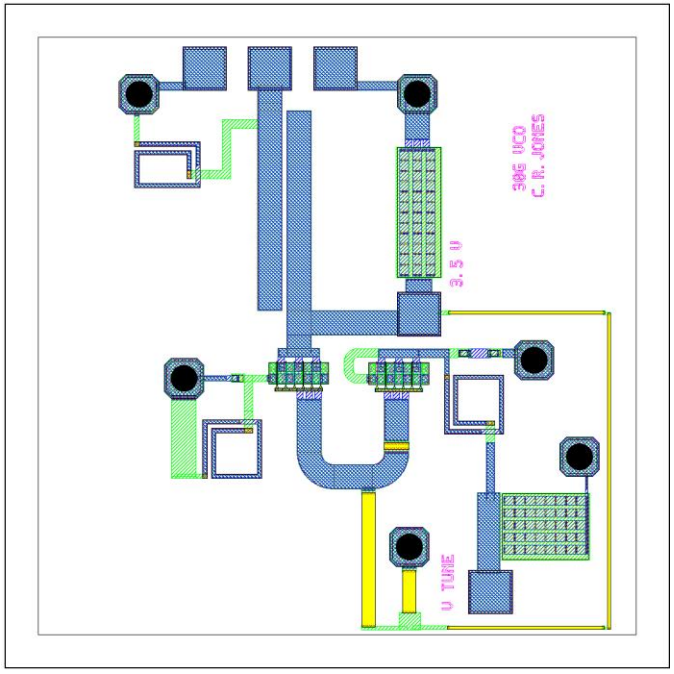
The VCO design at 12 GHz worked fairly close to expectations.
Two die were measured with similar results.



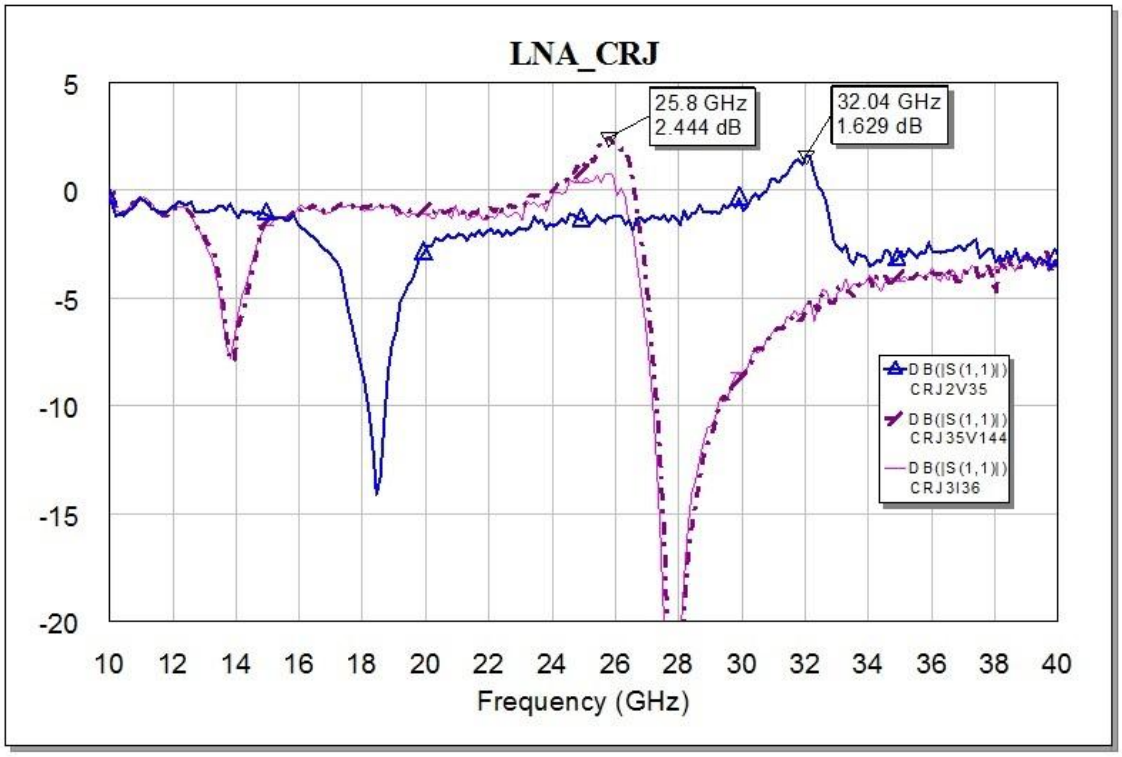
4/22/2013			
VCO	**3.0V at 17mA**		**Die #2**
VBias (V)	**Freq (GHz**	**Pout(ms)**	**Pout(corr)**
-0.4	11.790	6.3	8.7
-0.2	11.777	6.1	8.5
0.0	11.765	6.5	8.9
0.2	11.697	6.2	8.6
0.4	11.608	6.8	9.2
0.0	11.700	6.2	8.6
0.0	12.000	7.0	9.4
-0.6	12.030	7.0	9.4

4/18/13?			
VCO	**3.0V at 13mA**		**Die #1**
VBias (V)	**Freq (GHz**	**Pout(ms)**	**Pout(corr)**
-0.6	12.120	4.8	7.2
-0.4	12.112	4.9	7.3
-0.2	12.039	5.3	7.7
0.0	12.025	4.9	7.3
0.2	12.019	5.0	7.4
0.1	11.783	4.3	6.7
0.2	12.019	5.0	7.4
0.3	11.769	5.0	7.4
0.5	11.755	5.0	7.4

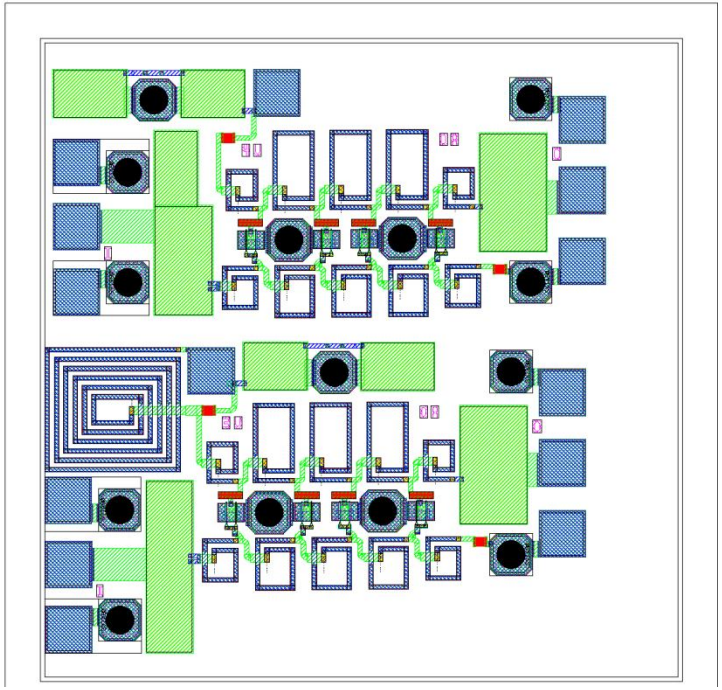


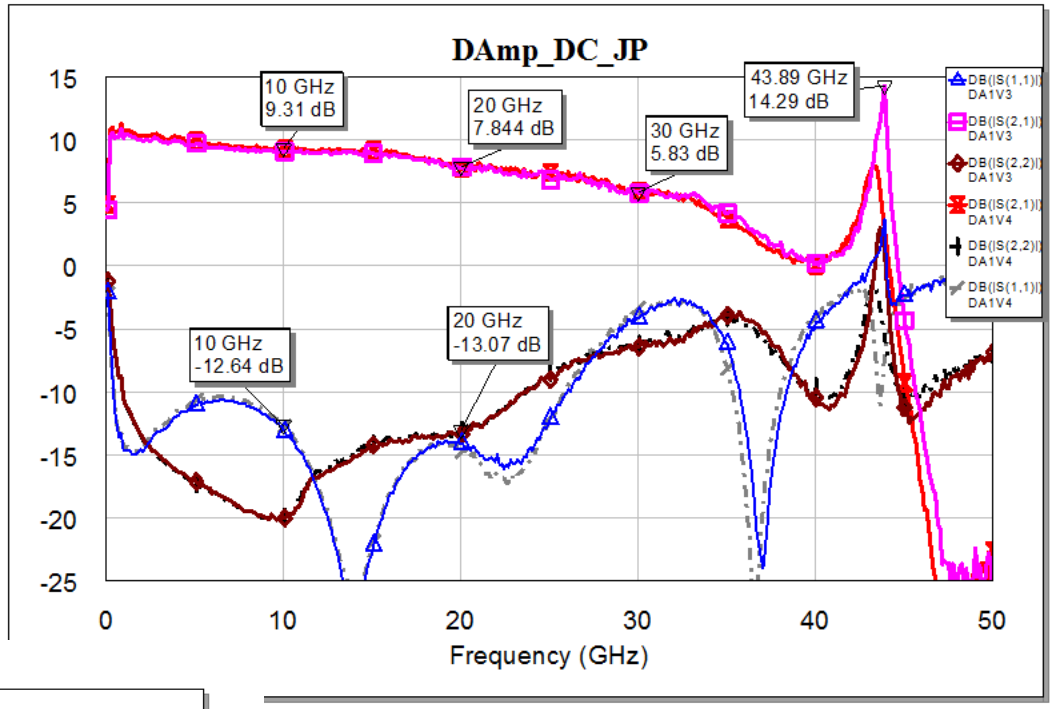


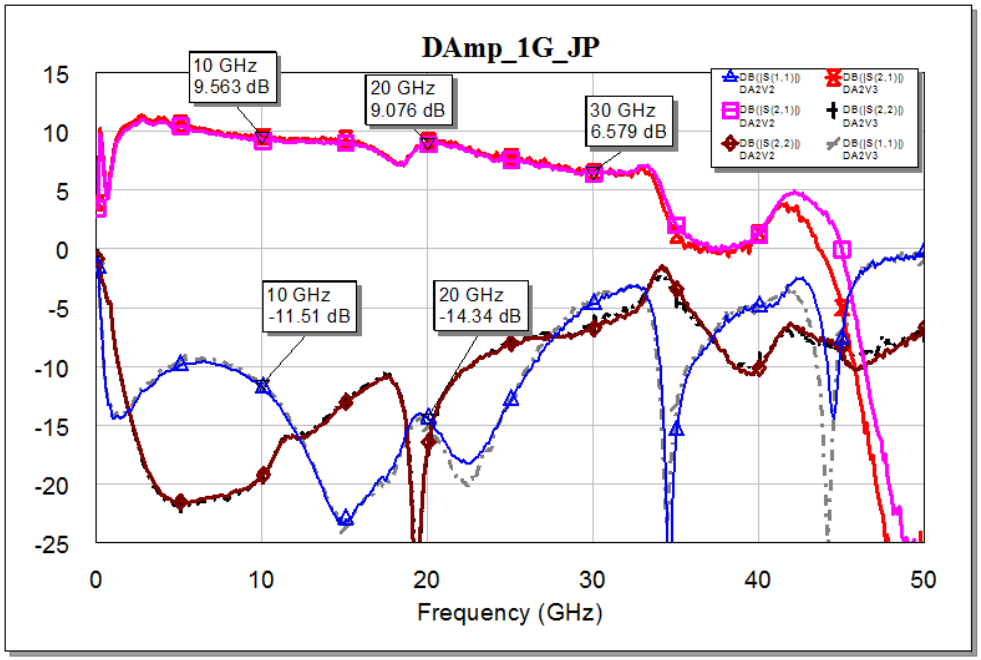
C. Reese Jones 30 GHz V1, V2 VCO



CRJ3I36 3.0V 36 mA
CRJ35I44 3.5V 44 mA
Measured on 8510, appears to have potential at ~26GHz for first design and ~32 GHz for second design. Tested first design with 26.5 GHz spectrum analyzer but did not seem to have enough gain to build up the oscillation. Noted previously that device gain might be too low at these frequencies for a VCO design, but it looks like it is close to oscillating.

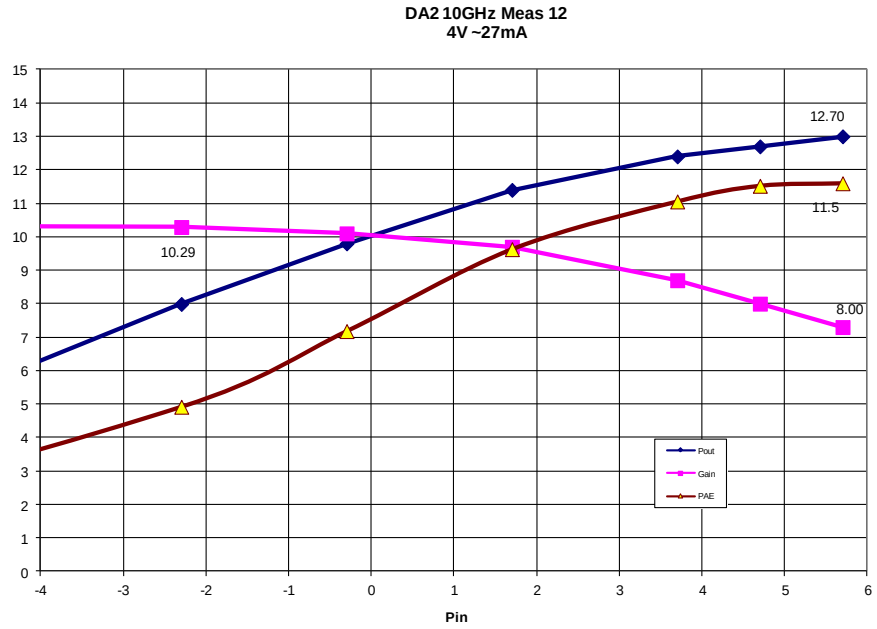


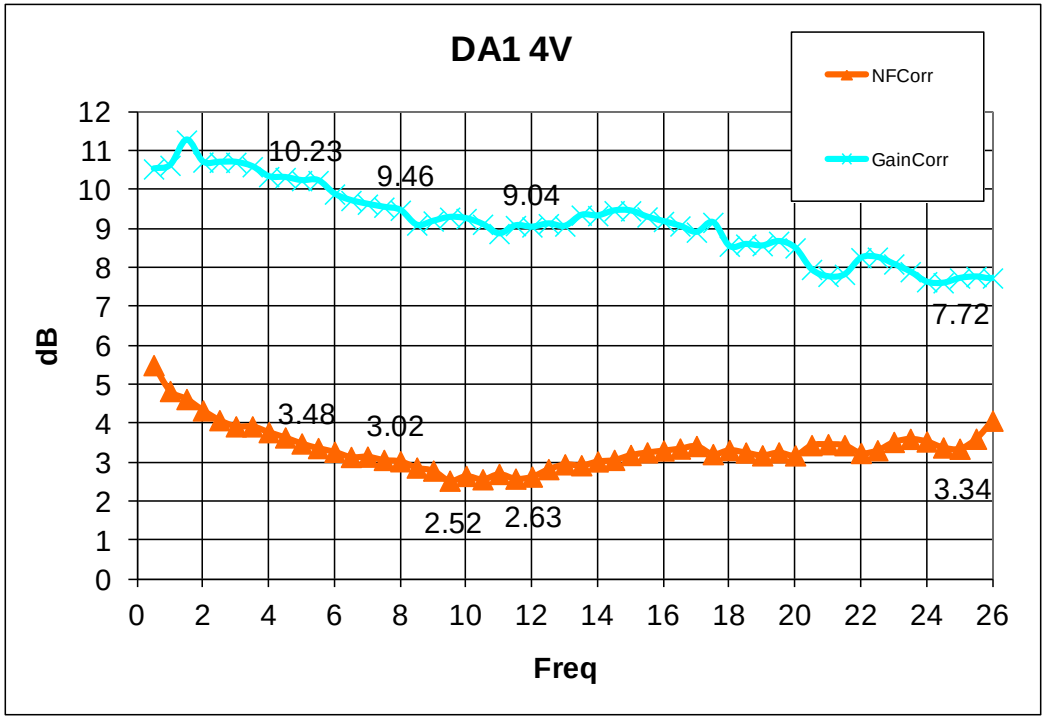


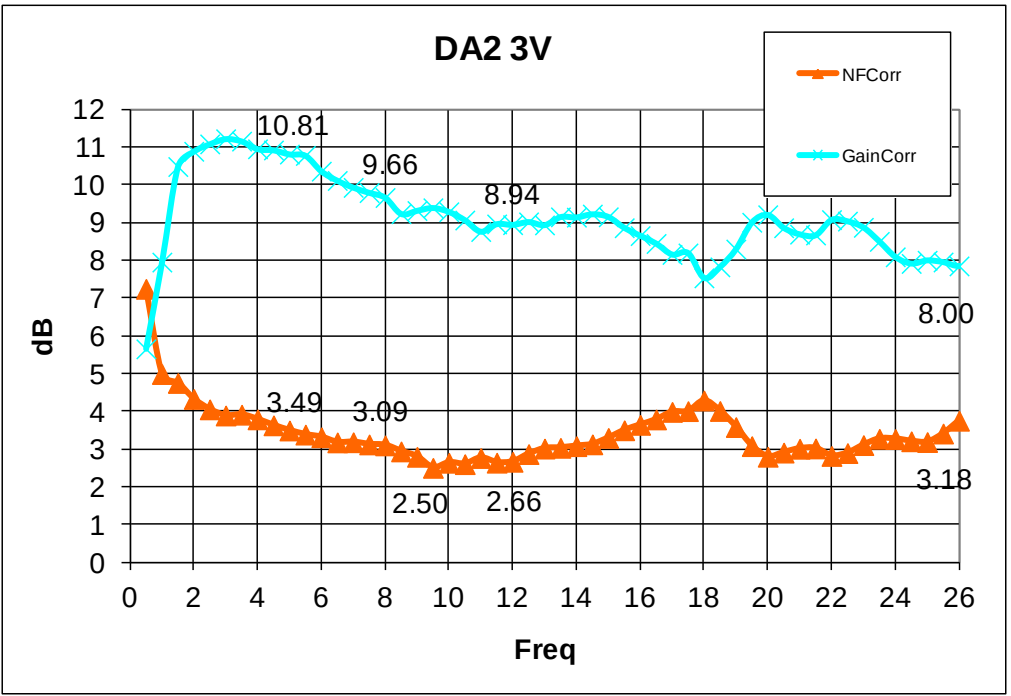


John Penn Distributed Amplifier (2011 revisited)

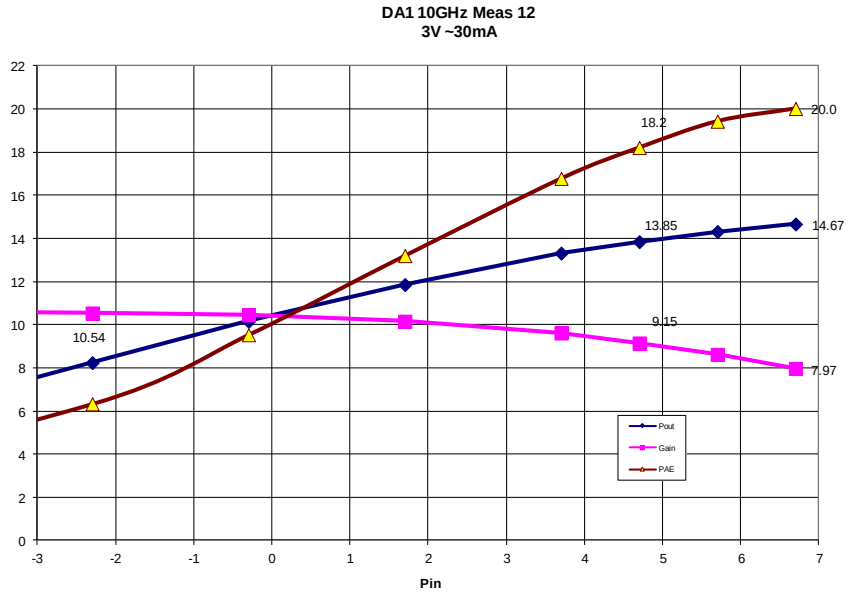
The original 2011 design inadvertently was fabbed without the intended 5Ω drain resistors. Article on 2011 design was in Feb 2013 RF & Microwaves Magazine. This 2012"redo" had better stability, though the DC-30 GHz version still has a gain spike at 44 GHz.







John Penn Distributed Amplifier (2012)

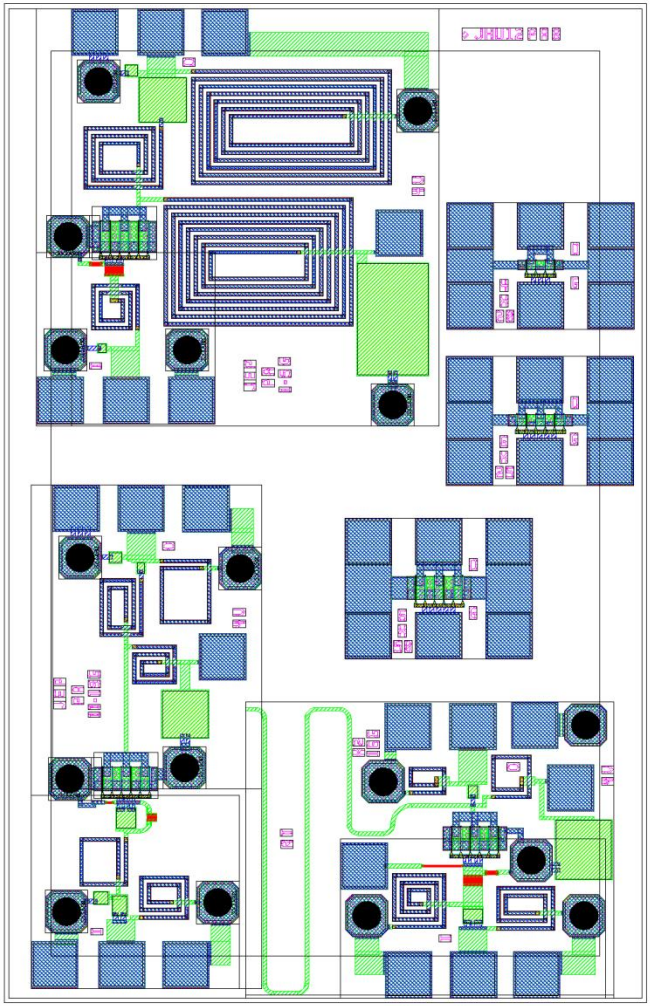


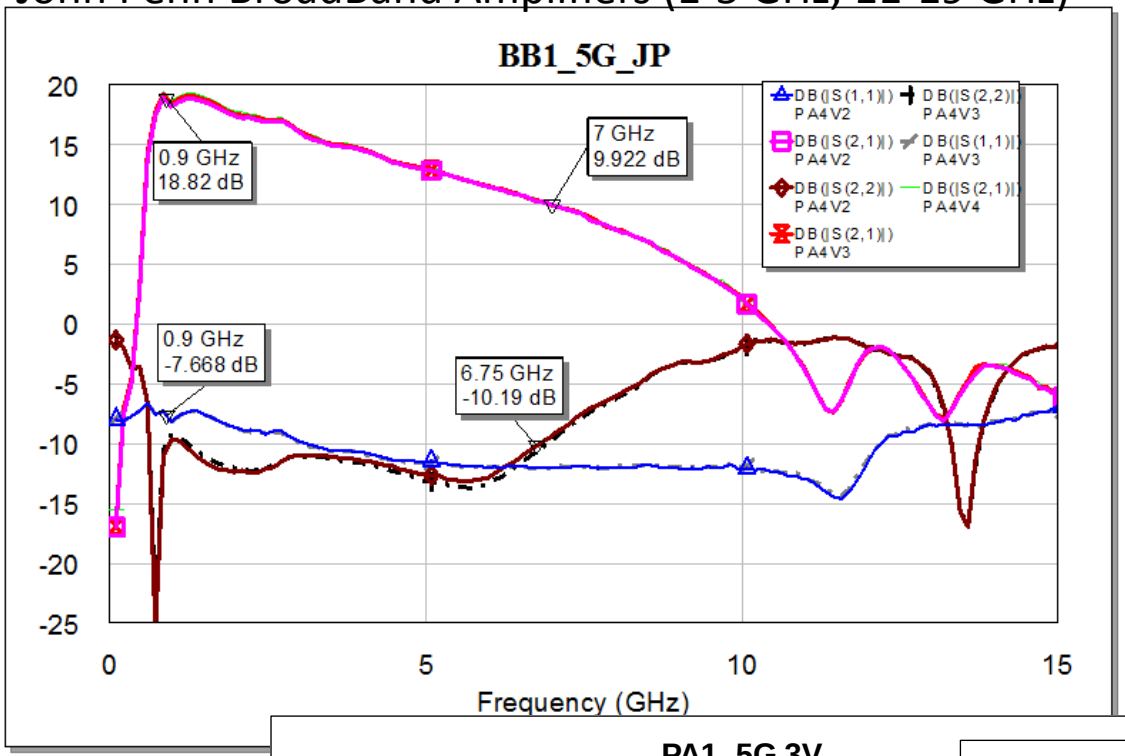
John Penn Distributed Amplifier Performance (2012)

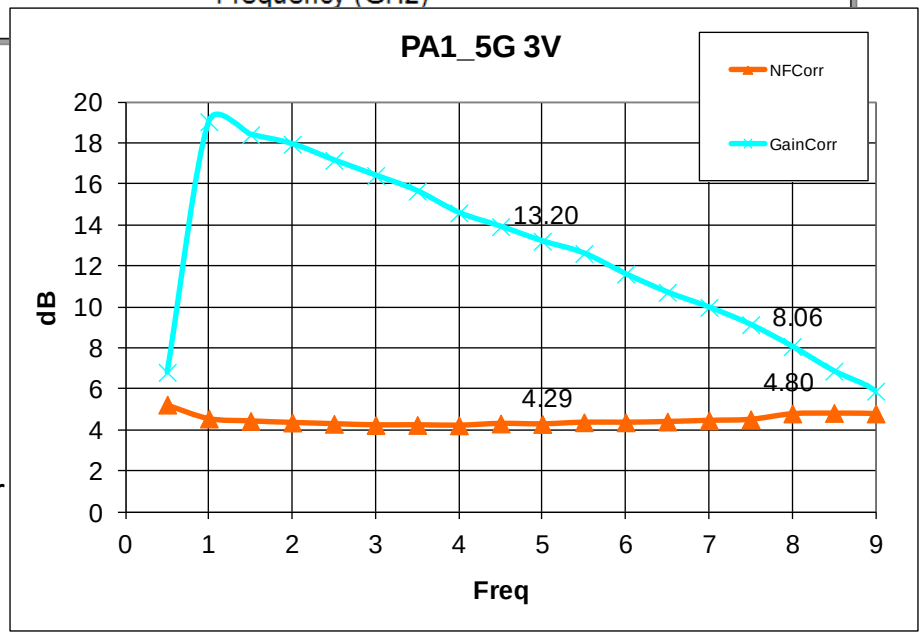
10 GHz	Die#1	**DA1_2 4V 10 GHz Fall12 TQP13**				4V ; 27 mA			
Pin(SG)	**Pout(PM)**	**Pin(corr)**	**Pout(corr)**	**Gain**	**I1(4V)**	**PDC(mw)**	**Pout(mw)**	**Drn Eff**	**PAE**
-10.0	-4.20	-12.30	-1.90	**10.40**	27	108.0	0.65	0.6	0.5
-5.0	0.72	-7.30	3.02	10.32	27	108.0	2.00	1.9	1.7
0.0	5.69	-2.30	7.99	10.29	29	116.0	6.30	5.4	4.9
2.0	7.50	-0.30	9.80	10.10	30	120.0	9.55	8.0	7.2
4.0	9.10	1.70	11.40	9.70	32	128.0	13.80	10.8	9.6
6.0	10.10	3.70	12.40	8.70	34	136.0	17.38	12.8	11.1
7.0	10.40	4.70	12.70	8.00	34	136.0	18.62	13.7	11.5
8.0	10.70	5.70	13.00	**7.30**	35	140.0	**19.95**	14.3	**11.6**

10 GHz	Die#1	**DA2_1 3V 10 GHz Fall12 TQP13**				3V ; 30 mA			
Pin(SG)	**Pout(PM)**	**Pin(corr)**	**Pout(corr)**	**Gain**	**I1(3V)**	**PDC(mw)**	**Pout(mw)**	**Drn Eff**	**PAE**
-10.0	-3.80	-12.30	-1.50	**10.80**	30	90.0	0.71	0.8	0.7
-5.0	1.10	-7.30	3.40	10.70	31	93.0	2.19	2.4	2.2
0.0	5.94	-2.30	8.24	10.54	32	96.0	6.67	6.9	6.3
2.0	7.86	-0.30	10.16	10.46	33	99.0	10.38	10.5	9.5
4.0	9.56	1.70	11.86	10.16	35	105.0	15.35	14.6	13.2
6.0	11.02	3.70	13.32	9.62	38	114.0	21.48	18.8	16.8
7.0	11.55	4.70	13.85	9.15	39	117.0	24.27	20.7	18.2
8.0	12.02	5.70	14.32	8.62	40	120.0	27.04	22.5	19.4
9.0	12.37	6.70	14.67	**7.97**	41	123.0	**29.31**	**23.8**	**20.0**

John Penn BroadBand Amplifiers (1-5 GHz, 11-19 GHz)



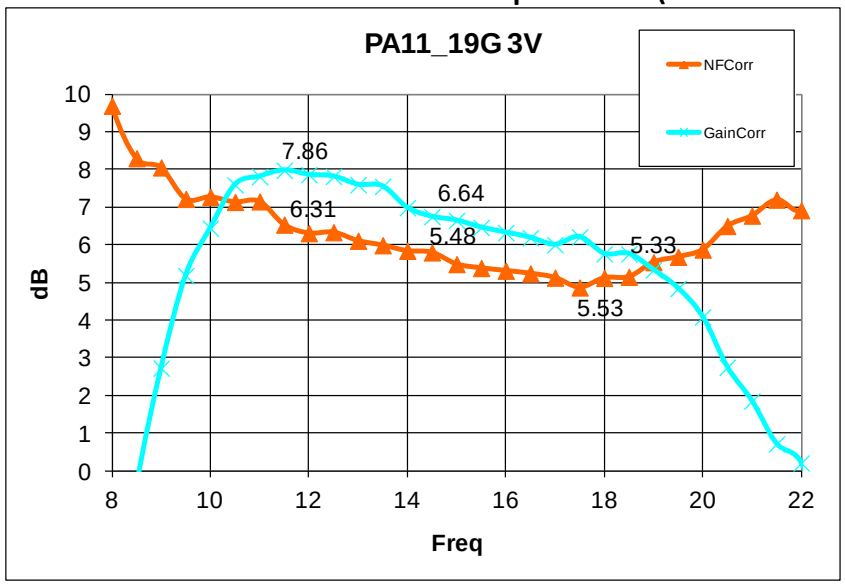


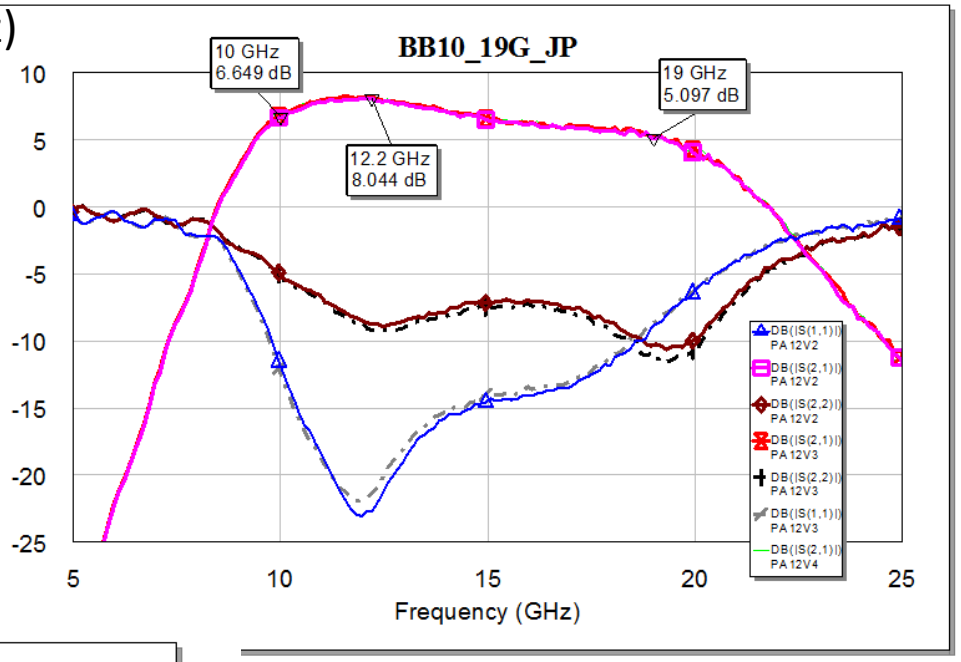


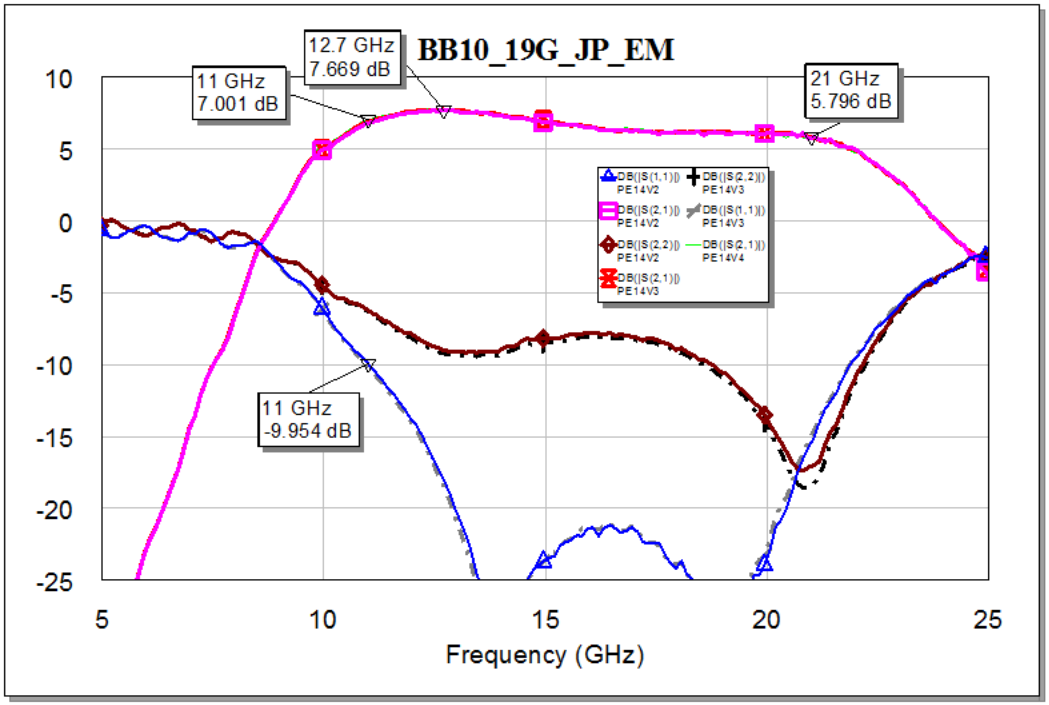
Broadband PA 1-5 GHz (1)
PA4V2 2V 38 mA --Die #1
PA4V3 3V 45 mA --Die #1
PA4V4 4V 55 mA --Die #1
Broadband PA 11-19 GHz (2)
PA12V2 2V 29 mA --Die #1
PA12V3 3V 36 mA --Die #1
PA12V4 4V 43 mA --Die #1

Note: designed for Power, not NF.

John Penn BroadBand Amplifiers (11-19 GHz)







Two Versions—one “EM tuned” (11-21 GHz) to offset expected down shift in frequency from nominal models (10-19 GHz). Designed for broadband power and efficiency, not noise figure.

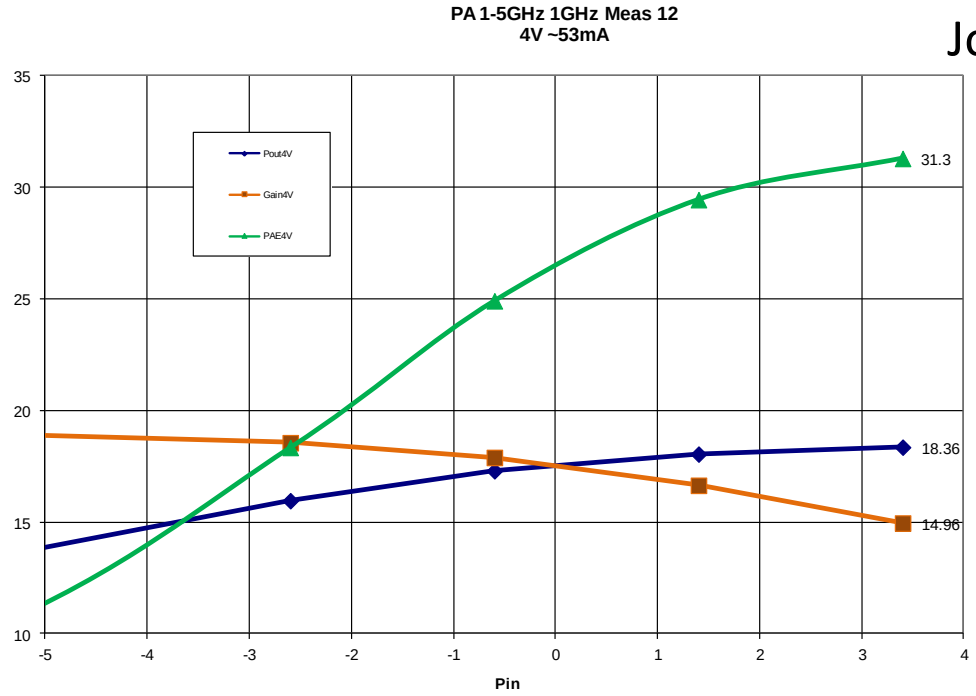
Broadband PA 11-19 GHz (2)

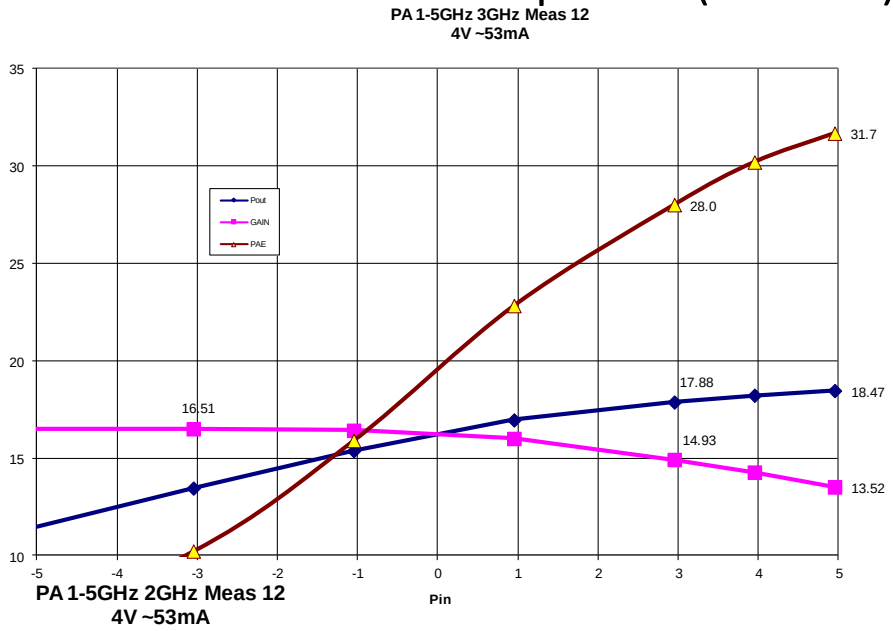
PA12V2 2V 29 mA --Die #1

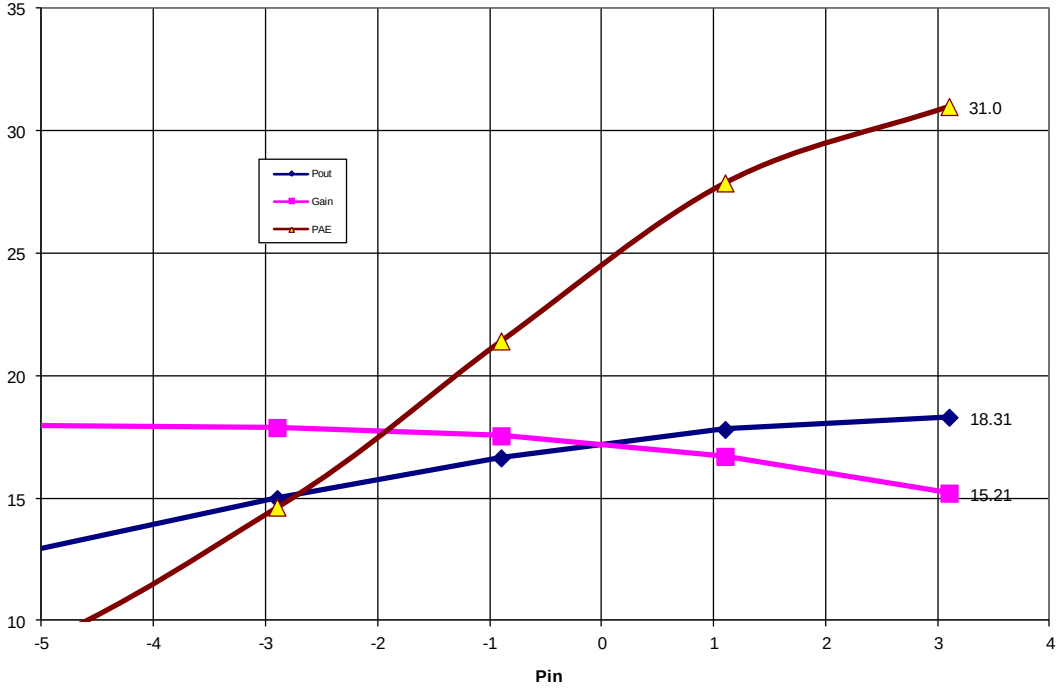
PA12V3 3V 36 mA --Die #1

PA12V4 4V 43 mA --Die #1

John Penn BroadBand Amplifiers (1-5 GHz)







John Penn BroadBand Amplifiers (1-5 GHz)

1 GHz	Die#1	**1-5 GHz Fall12 TQP13**				4V ; 53 mA			
Pin(SG)	**Pout(SA)**	**Pin(corr)**	**Pout(corr)**	**Gain**	**I1(4V)**	**PDC(mw)**	**Pout(mw)**	**Drn Eff**	**PAE**
-10.0	7.78	-10.60	8.38	18.98	53	212.0	6.89	3.2	3.2
-5.0	12.77	-5.60	13.37	18.97	53	212.0	21.73	10.2	10.1
-2.0	15.36	-2.60	15.96	18.56	53	212.0	39.45	18.6	18.3
0.0	16.70	-0.60	17.30	17.90	53	212.0	53.70	25.3	24.9
2.0	17.45	1.40	18.05	16.65	53	212.0	63.83	30.1	29.5
4.0	17.76	3.40	**18.36**	14.96	53	212.0	68.55	32.3	**31.3**

2 GHz	Die#1	**1-5 GHz Fall12 TQP13**				4V ; 53 mA			
Pin(SG)	**Pout(SA)**	**Pin(corr)**	**Pout(corr)**	**Gain**	**I1(4V)**	**PDC(mw)**	**Pout(mw)**	**Drn Eff**	**PAE**
-10.0	6.13	-10.90	7.03	17.93	53	212.0	5.05	2.4	2.3
-5.0	11.19	-5.90	12.09	17.99	53	212.0	16.18	7.6	7.5
-2.0	14.09	-2.90	14.99	17.89	53	212.0	31.55	14.9	14.6
0.0	15.75	-0.90	16.65	17.55	53	212.0	46.24	21.8	21.4
2.0	16.91	1.10	17.81	16.71	53	212.0	60.39	28.5	27.9
4.0	17.41	3.10	**18.31**	15.21	53	212.0	67.76	32.0	**31.0**

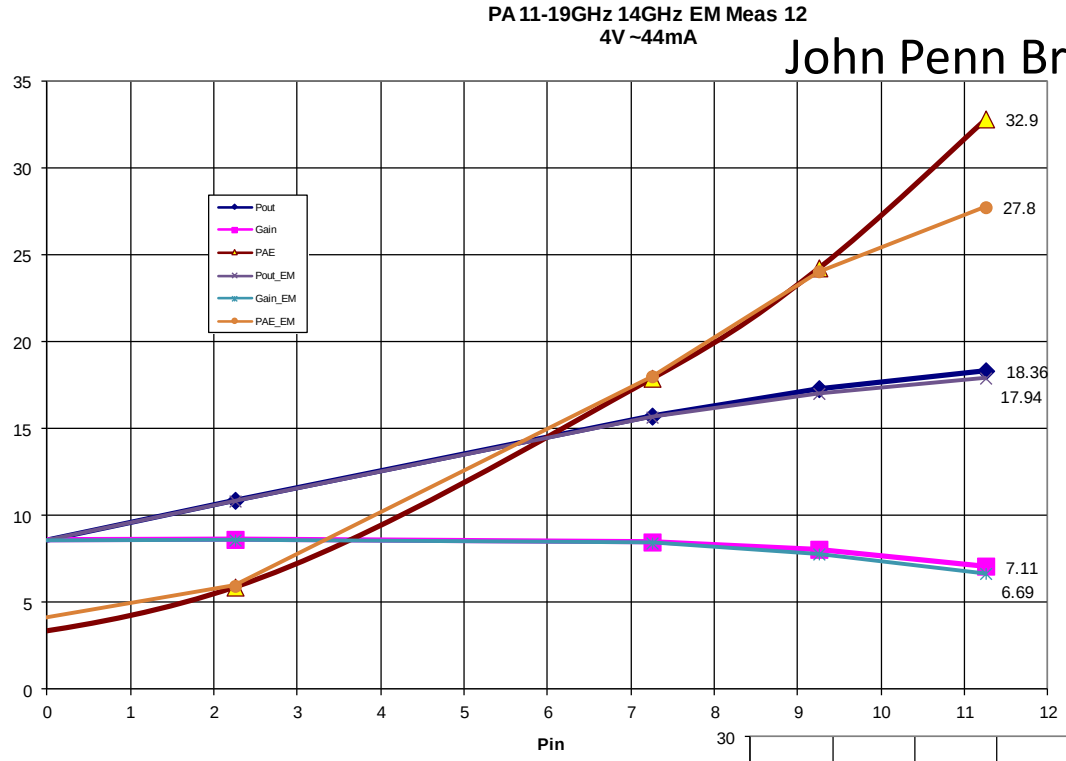
3 GHz	Die#1	**1-5 GHz Fall12 TQP13**				4V ; 53 mA			
Pin(SG)	**Pout(SA)**	**Pin(corr)**	**Pout(corr)**	**Gain**	**I1(4V)**	**PDC(mw)**	**Pout(mw)**	**Drn Eff**	**PAE**
-10.0	4.33	-11.05	5.38	16.43	53	212.0	3.45	1.6	1.6
-5.0	9.40	-6.05	10.45	16.50	53	212.0	11.09	5.2	5.1
-2.0	12.41	-3.05	13.46	16.51	53	212.0	22.18	10.5	10.2
0.0	14.33	-1.05	15.38	16.43	53	212.0	34.51	16.3	15.9
2.0	15.91	0.95	16.96	16.01	53	212.0	49.66	23.4	22.8
4.0	*16.83*	2.95	17.88	14.93	53	212.0	61.38	29.0	28.0
5.0	*17.18*	3.95	18.23	14.28	53	212.0	66.53	31.4	30.2
6.0	*17.42*	4.95	18.47	**13.52**	53	212.0	70.31	33.2	**31.7**
2.0	16.02	0.95	17.07	16.12	53	212.0	50.93	24.0	23.4
4.0	17.21	2.95	18.26	15.31	53	212.0	66.99	31.6	30.7
5.0	17.56	3.95	18.61	14.66	53	212.0	72.61	34.3	33.1
6.0	17.80	4.95	18.85	13.90	53	212.0	76.74	36.2	**34.7**

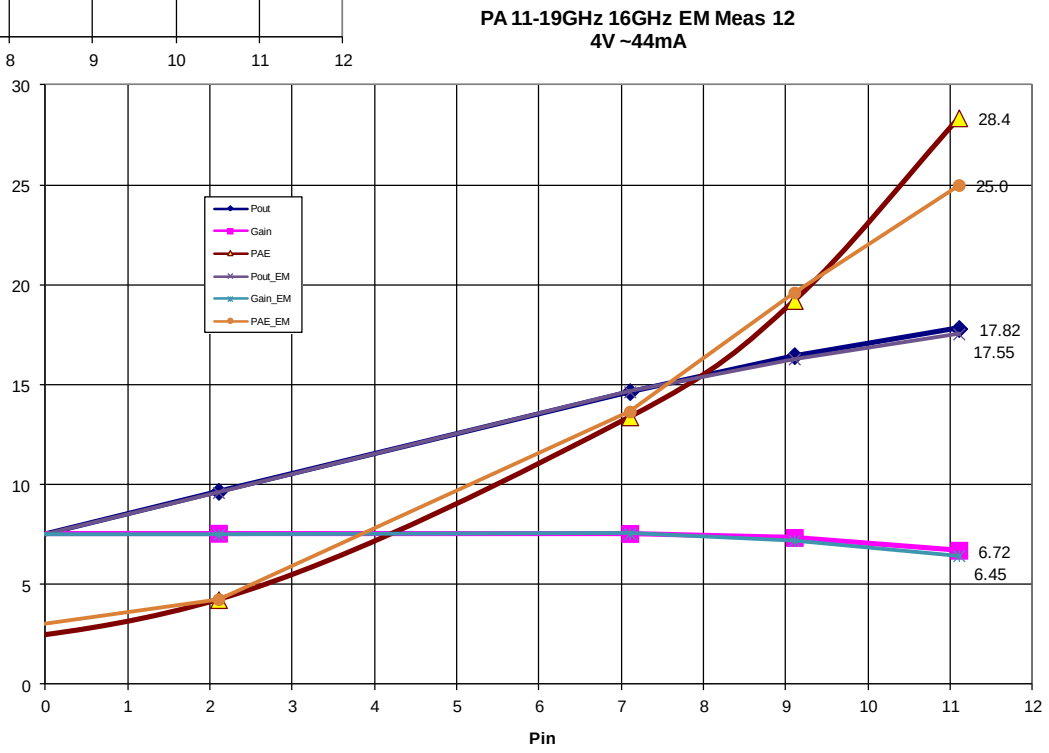
John Penn BroadBand Amplifiers (1-5 GHz)

4 GHz	Die#1	**1-5 GHz Fall12 TQP13**				4V ; 53 mA			
Pin(SG)	**Pout(SA)**	**Pin(corr)**	**Pout(corr)**	**Gain**	**I1(4V)**	**PDC(mw)**	**Pout(mw)**	**Drn Eff**	**PAE**
-10.0	1.43	-11.35	2.78	14.13	53	212.0	1.90	0.9	0.9
-5.0	6.54	-6.35	7.89	14.24	53	212.0	6.15	2.9	2.8
-2.0	9.55	-3.35	10.90	14.25	53	212.0	12.30	5.8	5.6
0.0	11.59	-1.35	12.94	14.29	53	212.0	19.68	9.3	8.9
2.0	13.46	0.65	14.81	14.16	53	212.0	30.27	14.3	13.7
4.0	15.07	2.65	16.42	13.77	53	212.0	43.85	20.7	19.8
5.0	*15.77*	3.65	17.12	13.47	53	212.0	51.52	24.3	23.2
6.0	*16.35*	4.65	17.70	13.05	53	212.0	58.88	27.8	26.4
7.0	*16.82*	5.65	18.17	**12.52**	53	212.0	65.61	31.0	**29.2**
2.0	14.14	0.65	15.49	14.84	53	212.0	35.40	16.7	16.2
4.0	15.88	2.65	17.23	14.58	53	212.0	52.84	24.9	24.1
5.0	16.57	3.65	17.92	14.27	53	212.0	61.94	29.2	28.1
6.0	17.15	4.65	18.50	13.85	53	212.0	70.79	33.4	32.0
7.0	17.62	5.65	18.97	**13.32**	53	212.0	78.89	37.2	**35.5**

5 GHz	Die#1	**1-5 GHz Fall12 TQP13**				4V ; 53 mA			
Pin(SG)	**Pout(SA)**	**Pin(corr)**	**Pout(corr)**	**Gain**	**I1(4V)**	**PDC(mw)**	**Pout(mw)**	**Drn Eff**	**PAE**
-10.0	0.01	-11.60	1.61	13.21	53	212.0	1.45	0.7	0.7
-5.0	5.11	-6.60	6.71	13.31	53	212.0	4.69	2.2	2.1
-2.0	8.16	-3.60	9.76	13.36	53	212.0	9.46	4.5	4.3
0.0	10.16	-1.60	11.76	13.36	53	212.0	15.00	7.1	6.7
2.0	12.08	0.40	13.68	13.28	53	212.0	23.33	11.0	10.5
4.0	13.98	2.40	15.58	13.18	53	212.0	36.14	17.0	16.2
5.0	*14.73*	3.40	16.33	12.93	53	212.0	42.95	20.3	19.2
6.0	*15.32*	4.40	16.92	12.52	53	212.0	49.20	23.2	21.9
7.0	*15.89*	5.40	17.49	**12.09**	53	212.0	56.10	26.5	**24.8**
8.0	*16.38*	6.40	17.98	**11.58**	53	212.0	62.81	29.6	**27.6**
2.0	12.46	0.40	14.06	13.66	53	212.0	25.47	12.0	11.5
4.0	14.22	2.40	15.82	13.42	53	212.0	38.19	18.0	17.2
5.0	14.97	3.40	16.57	13.17	53	212.0	45.39	21.4	20.4
6.0	15.56	4.40	17.16	12.76	53	212.0	52.00	24.5	23.2
7.0	16.13	5.40	17.73	**12.33**	53	212.0	59.29	28.0	**26.3**
8.0	16.62	6.40	18.22	**11.82**	53	212.0	66.37	31.3	**29.2**

John Penn BroadBand Amplifiers (11-19 GHz)





John Penn BroadBand Amplifiers (11-19 GHz)

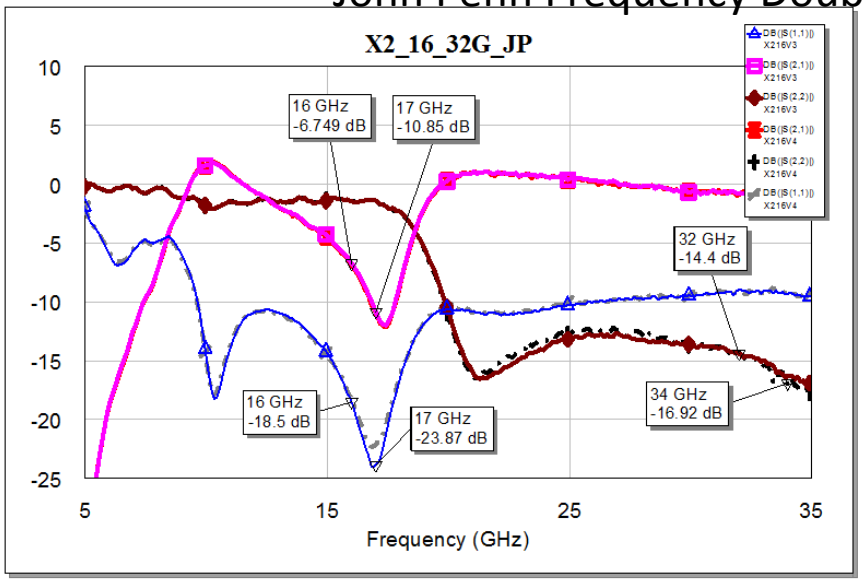
12 GHz	Die#1	**11-19 GHz Fall12 TQP13**				4V ; 45 mA			
Pin(SG)	**Pout(SA)**	**Pin(corr)**	**Pout(corr)**	**Gain**	**I1(4V)**	**PDC(mw)**	**Pout(mw)**	**Drn Eff**	**PAE**
-5.0	-1.32	-7.40	1.08	8.48	45	180.0	1.28	0.7	0.6
0.0	3.67	-2.40	6.07	8.47	45	180.0	4.05	2.2	1.9
5.0	8.71	2.60	11.11	8.51	45	180.0	12.91	7.2	6.2
10.0	13.35	7.60	15.75	8.15	45	180.0	37.58	20.9	17.7
12.0	14.66	9.60	17.06	7.46	47	188.0	50.82	27.0	22.2
14.0	15.43	11.60	17.83	6.23	42	168.0	60.67	36.1	27.5

14 GHz	Die#1	**11-19 GHz Fall12 TQP13**				4V ; 45 mA			
Pin(SG)	**Pout(SA)**	**Pin(corr)**	**Pout(corr)**	**Gain**	**I1(4V)**	**PDC(mw)**	**Pout(mw)**	**Drn Eff**	**PAE**
-5.0	-1.89	-7.75	0.86	8.61	45	180.0	1.22	0.7	0.6
0.0	3.09	-2.75	5.84	8.59	45	180.0	3.84	2.1	1.8
5.0	8.15	2.25	10.90	8.65	45	180.0	12.30	6.8	5.9
10.0	13.00	7.25	15.75	8.50	45	180.0	37.58	20.9	17.9
12.0	14.58	9.25	17.33	8.08	47	188.0	54.08	28.8	24.3
14.0	15.61	11.25	18.36	7.11	42	168.0	68.55	40.8	32.9

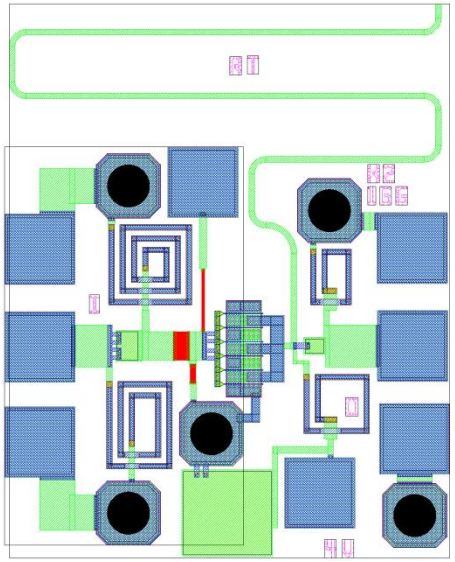
16 GHz	Die#1	**11-19 GHz Fall12 TQP13**				4V ; 45 mA			
Pin(SG)	**Pout(SA)**	**Pin(corr)**	**Pout(corr)**	**Gain**	**I1(4V)**	**PDC(mw)**	**Pout(mw)**	**Drn Eff**	**PAE**
-5.0	-3.23	-7.90	-0.33	7.57	45	180.0	0.93	0.5	0.4
0.0	1.73	-2.90	4.63	7.53	45	180.0	2.90	1.6	1.3
5.0	6.77	2.10	9.67	7.57	45	180.0	9.27	5.1	4.2
10.0	11.76	7.10	14.66	7.56	45	180.0	29.24	16.2	13.4
12.0	13.56	9.10	16.46	7.36	47	188.0	44.26	23.5	19.2
14.0	14.92	11.10	17.82	6.72	42	168.0	60.53	36.0	28.4

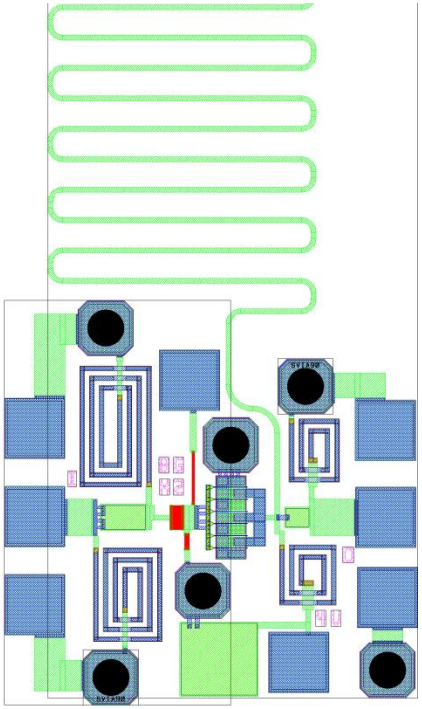
14 GHz	Die#1	**11-19 GHz EM Fall12 TQP13**				4V ; 44 mA			
Pin(SG)	**Pout(SA)**	**Pin(corr)**	**Pout(corr)**	**Gain**	**I1(4V)**	**PDC(mw)**	**Pout(mw)**	**Drn Eff**	**PAE**
-5.0	-1.92	-7.75	0.83	8.58	44	176.0	1.21	0.7	0.6
0.0	3.08	-2.75	5.83	8.58	44	176.0	3.83	2.2	1.9
5.0	8.11	2.25	10.86	8.61	44	176.0	12.19	6.9	6.0
10.0	12.94	7.25	15.69	8.44	44	176.0	37.07	21.1	18.0
12.0	14.31	9.25	17.06	7.81	44	176.0	50.82	28.9	24.1
14.0	15.19	11.25	17.94	6.69	44	176.0	62.23	35.4	27.8

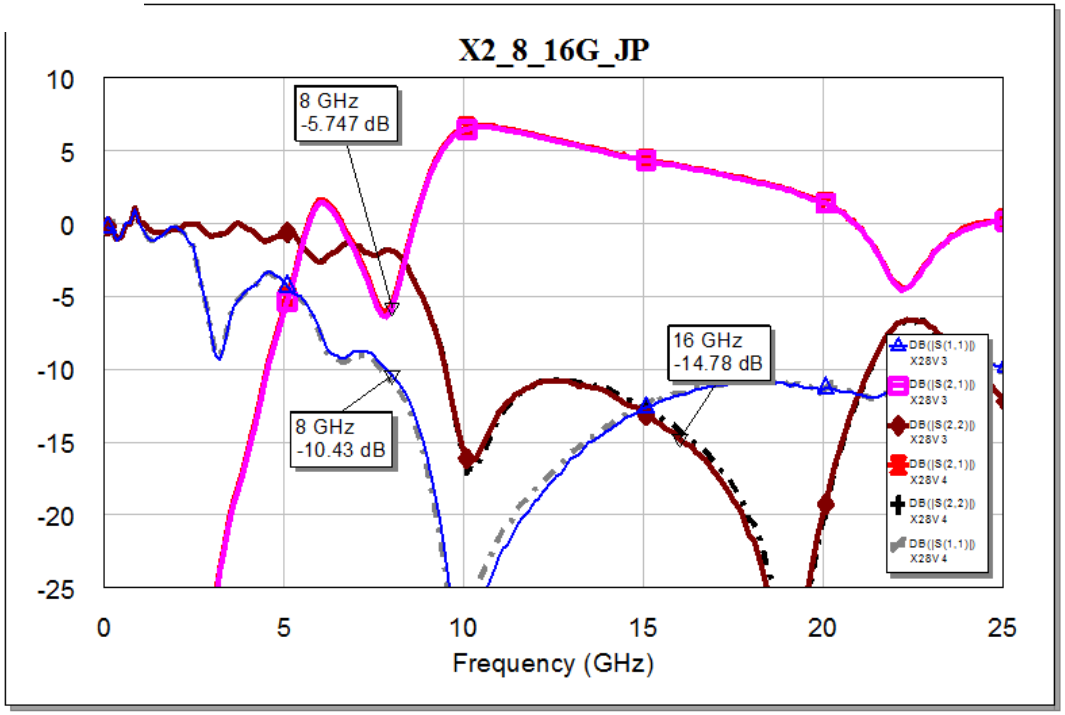
John Penn Frequency Doublers (8 to 16 GHz, 16 to 32 GHz)



These 2012 designs "re-tune" the harmonic stub from the 2011 designs. An article was in High Frequency Magazine in Feb 2013. The "EM" simulation of the stub was close to the measured peak attenuation.

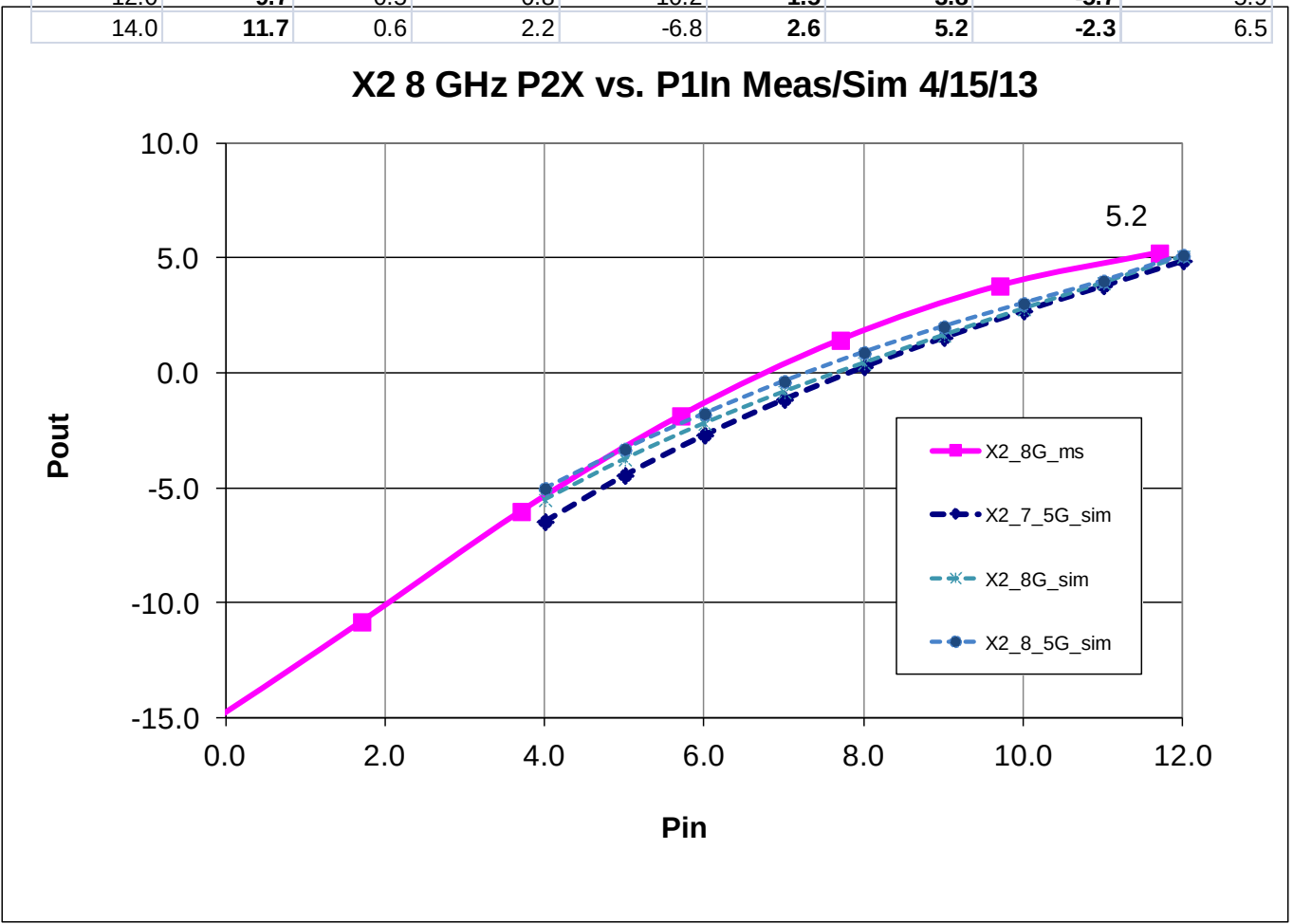


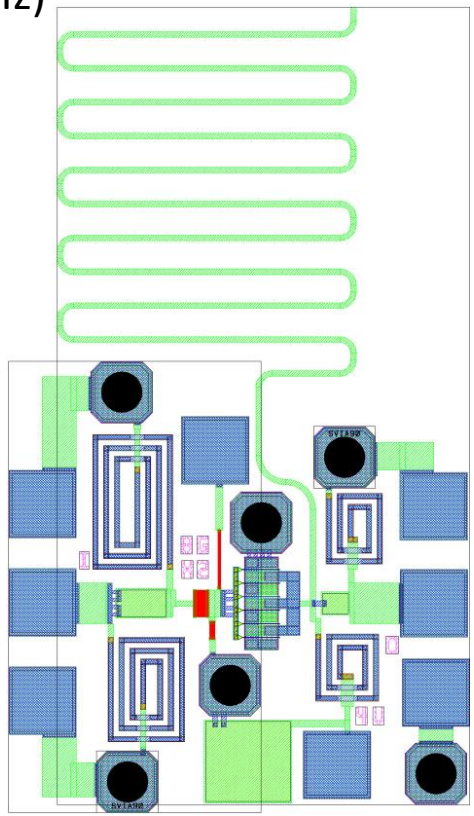




John Penn Frequency Doublers (8 to 16 GHz, 16 to 32 GHz)

Doubler 8G		4V at 39mA, vg=-1.5v			Die #1	7.8GHz		
SG	Pin(corr)	Pout8G(m	Pout16G(ms	Pout24G(ms	Pout(corr)	Pout2X(corr)	Pout3X(corr)	Cnvloss
-4.0	**-6.3**	-14.3	-30.9		**-12.3**	**-27.9**		21.6
-2.0	**-4.3**	-12.4	-27.0		**-10.4**	**-24.0**		19.7
0.0	**-2.3**	-10.4	-22.7		**-8.4**	**-19.7**		17.4
2.0	**-0.3**	-8.5	-18.4		**-6.5**	**-15.4**		15.1
4.0	**1.7**	-6.6	-13.8	-33.2	**-4.6**	**-10.8**	**-28.7**	12.5
6.0	**3.7**	-4.9	-9.0	-24.8	**-2.9**	**-6.0**	**-20.3**	9.7
8.0	**5.7**	-3.4	-4.8	-18.7	**-1.4**	**-1.8**	**-14.2**	7.5
10.0	**7.7**	-1.9	-1.6	-14.3	**0.2**	**1.5**	**-9.8**	6.3
12.0	**9.7**	-0.5	0.8	-10.2	**1.5**	**3.8**	**-5.7**	5.9
14.0	**11.7**	0.6	2.2	-6.8	**2.6**	**5.2**	**-2.3**	6.5

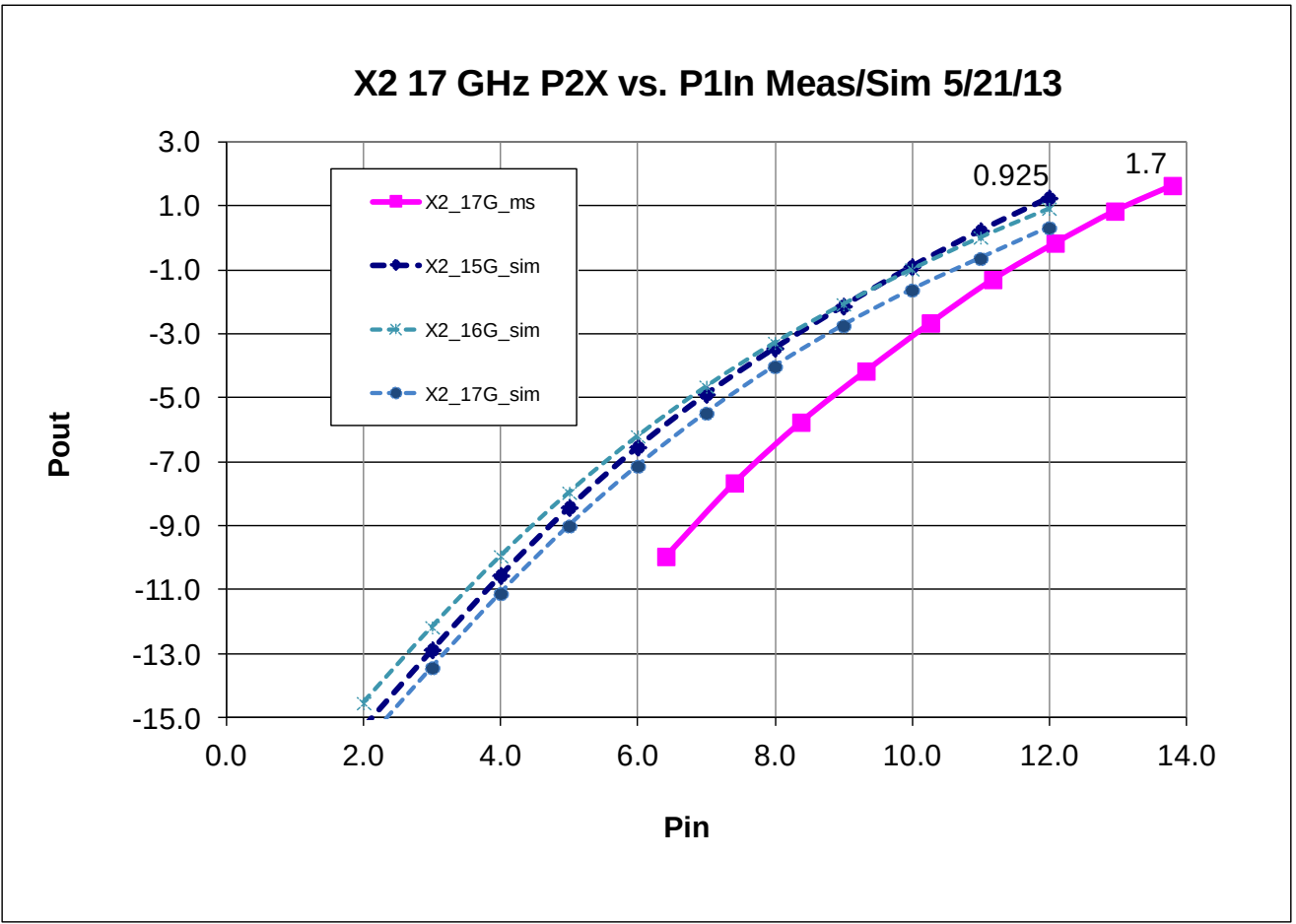


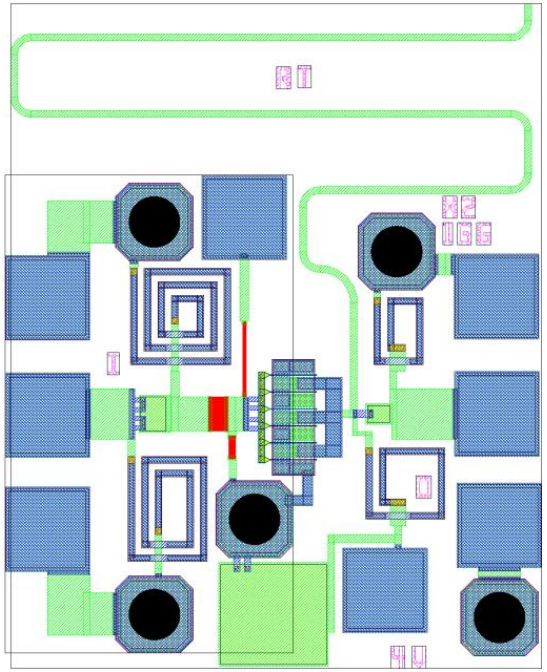


The 8 GHz doubler performance closely matched the original simulation for the design. ~6dB conversion loss (X2)

John Penn Frequency Doublers (8 to 16 GHz, 16 to 32 GHz)

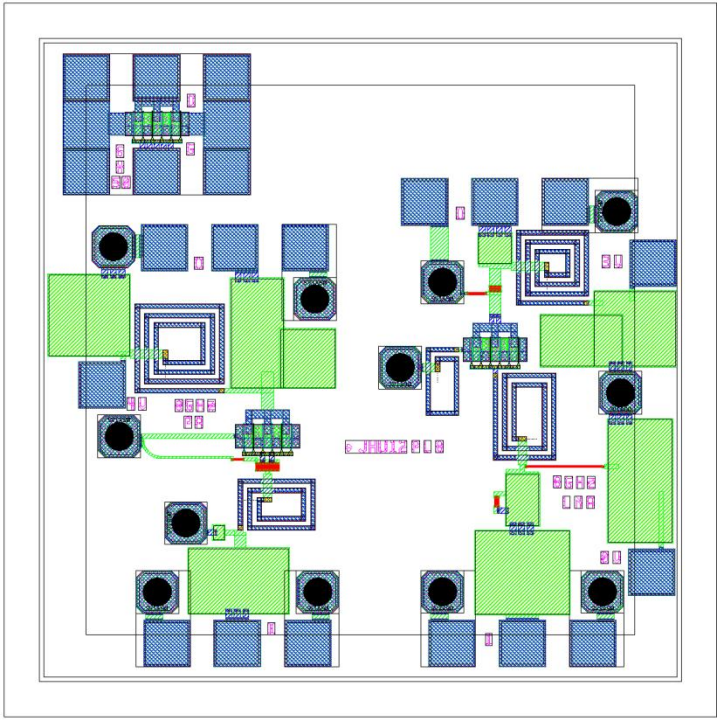
5/21/2013		17.0 GHz						
Doubler 16G		4V at ~34mA, vg=-3v			Die #2			
Pin(SG)	Pin(A)	PoutX1(m	PoutX2(r	Pout(corr)	Pout2X(cc	Cnvloss	dBc	I(4V)
-8.00	**6.4**	-8.08	-17.00	**-2.4**	**-10.0**	16.4	7.6	40.3
-7.00	**7.4**	-7.11	-14.70	**-1.4**	**-7.7**	15.1	6.3	43.8
-6.00	**8.4**	-6.22	-12.80	**-0.5**	**-5.8**	14.1	5.2	47.7
-5.00	**9.3**	-5.32	-11.20	**0.4**	**-4.2**	13.5	4.5	52.2
-4.00	**10.3**	-4.44	-9.70	**1.3**	**-2.7**	12.9	3.9	57.0
-3.00	**11.2**	-3.60	-8.34	**2.1**	**-1.3**	**12.5**	3.4	62.2
-2.00	**12.1**	-2.81	-7.20	**2.9**	**-0.2**	**12.2**	3.1	67.5
-1.00	**13.0**	-2.07	-6.20	**3.6**	**0.9**	**12.1**	2.8	72.8
0.00	**13.8**	-1.42	-5.40	**4.3**	**1.7**	**12.2**	2.6	77.8

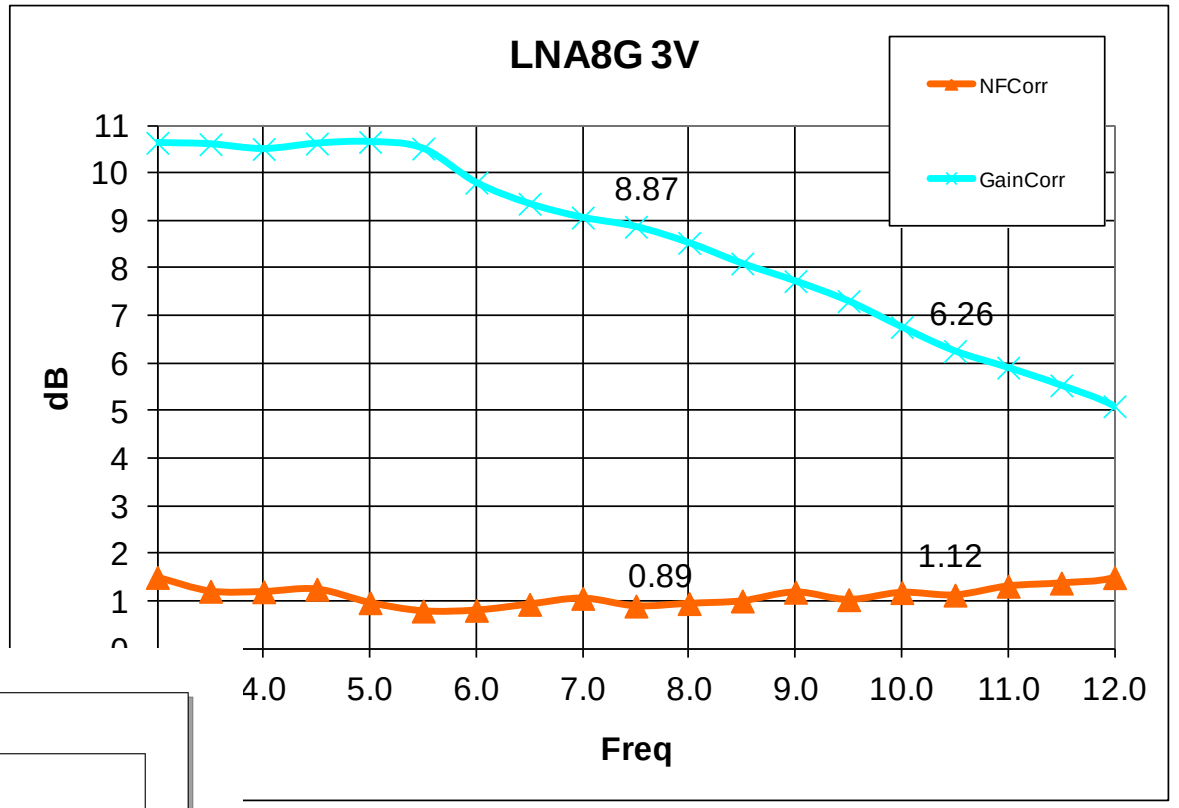


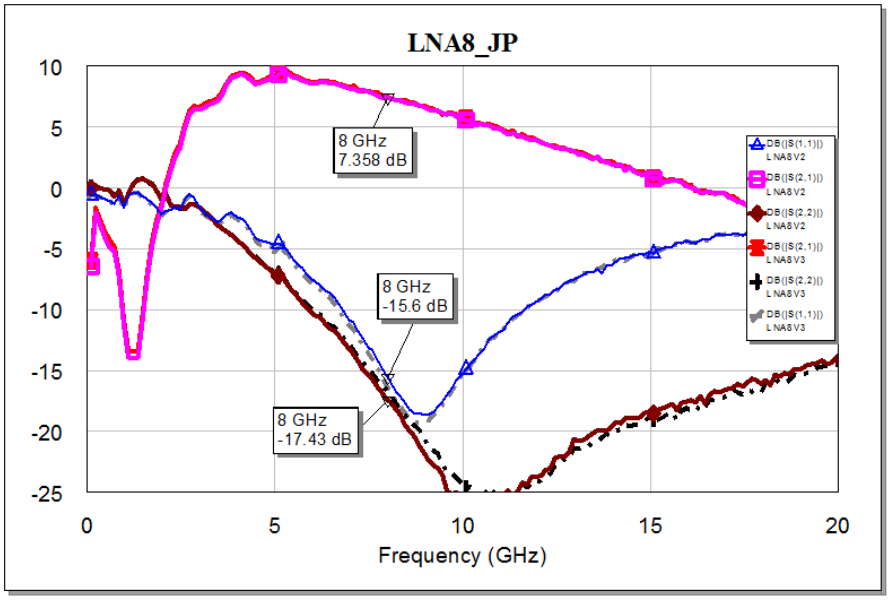


The 16 GHz doubler performance closely matched the original simulation for the design. ~12dB conversion loss (X2)

John Penn 8 GHz Power Amp, Low Noise Amp Design Examples

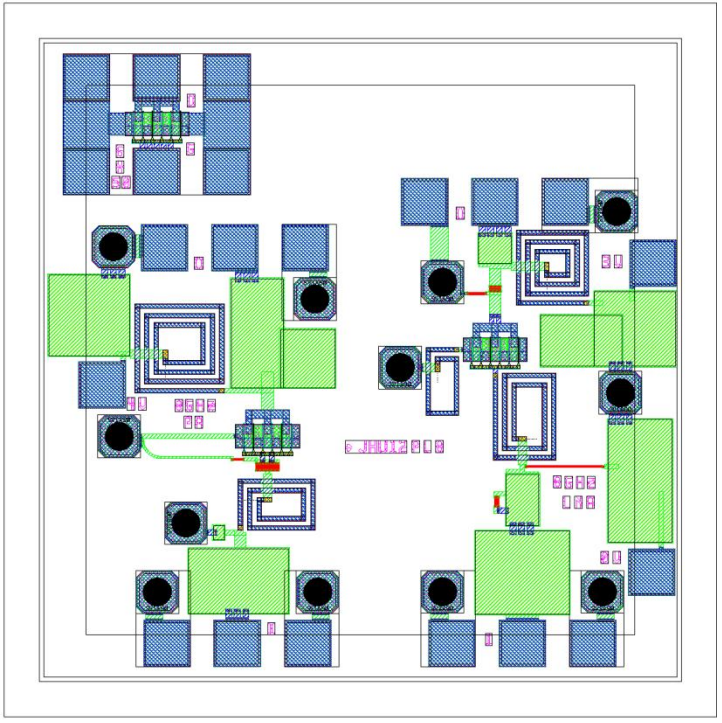


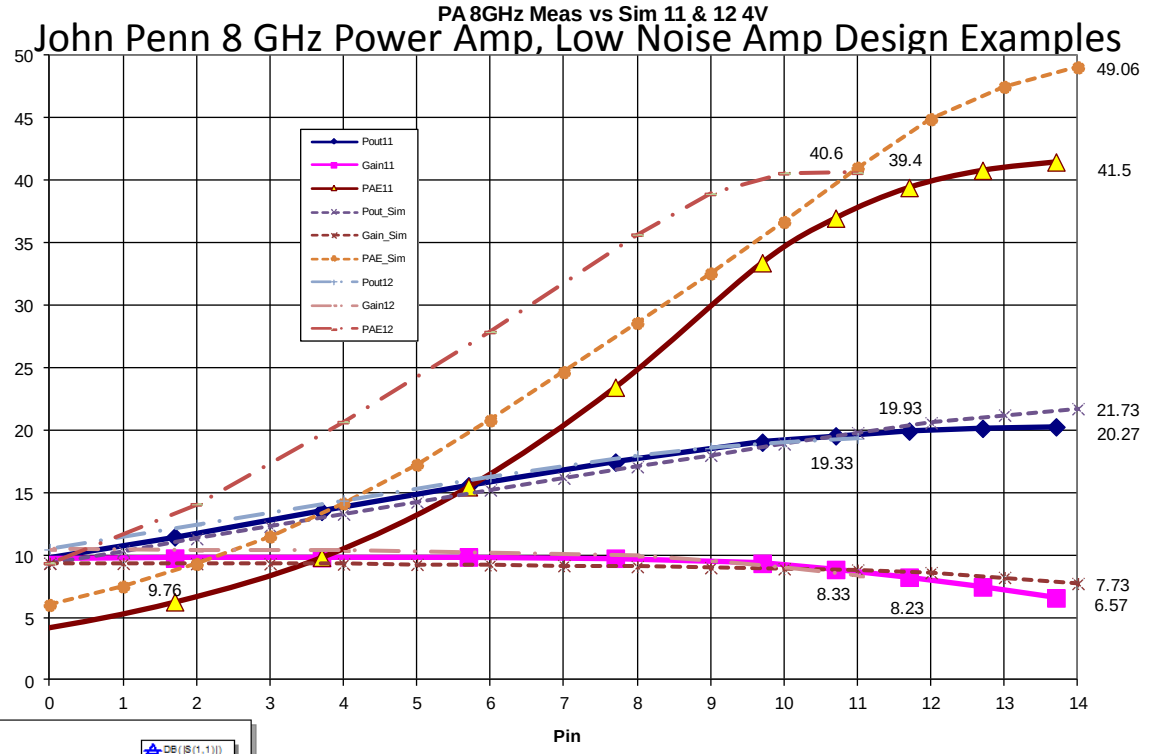


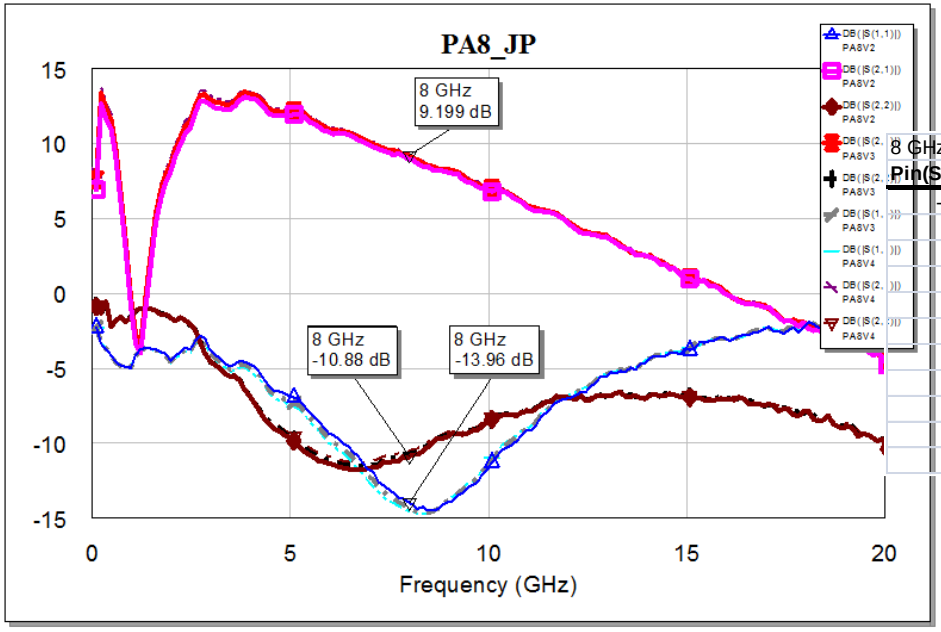


Class Amp Examples: Same as 2011 Fab
Low Noise Amp 8 GHz
LN8V2 2V 16 mA vgs=0V --Die #1
LN8V3 3V 20 mA vgs=0V --Die # 1
Power Amp 8 GHz
PA8V2 2V 17 mA vgs=0V --Die #1
PA8V3 3V 23 mA vgs=0V --Die #1
PA8V4 4V 29 mA vgs=0V --Die #1

John Penn 8 GHz Power Amp, Low Noise Amp Design Examples

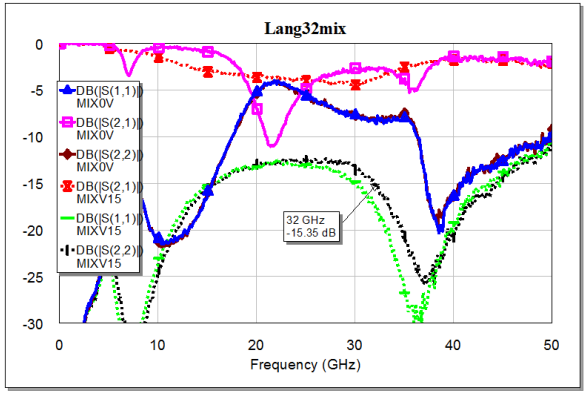


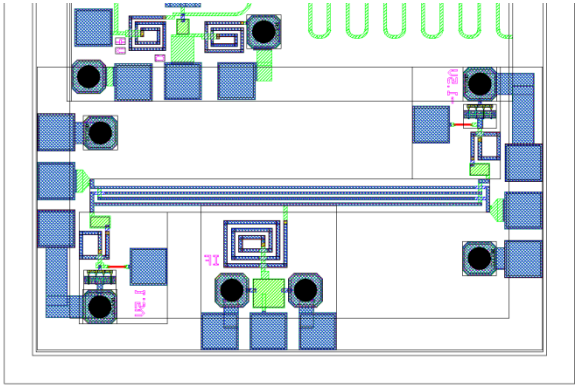


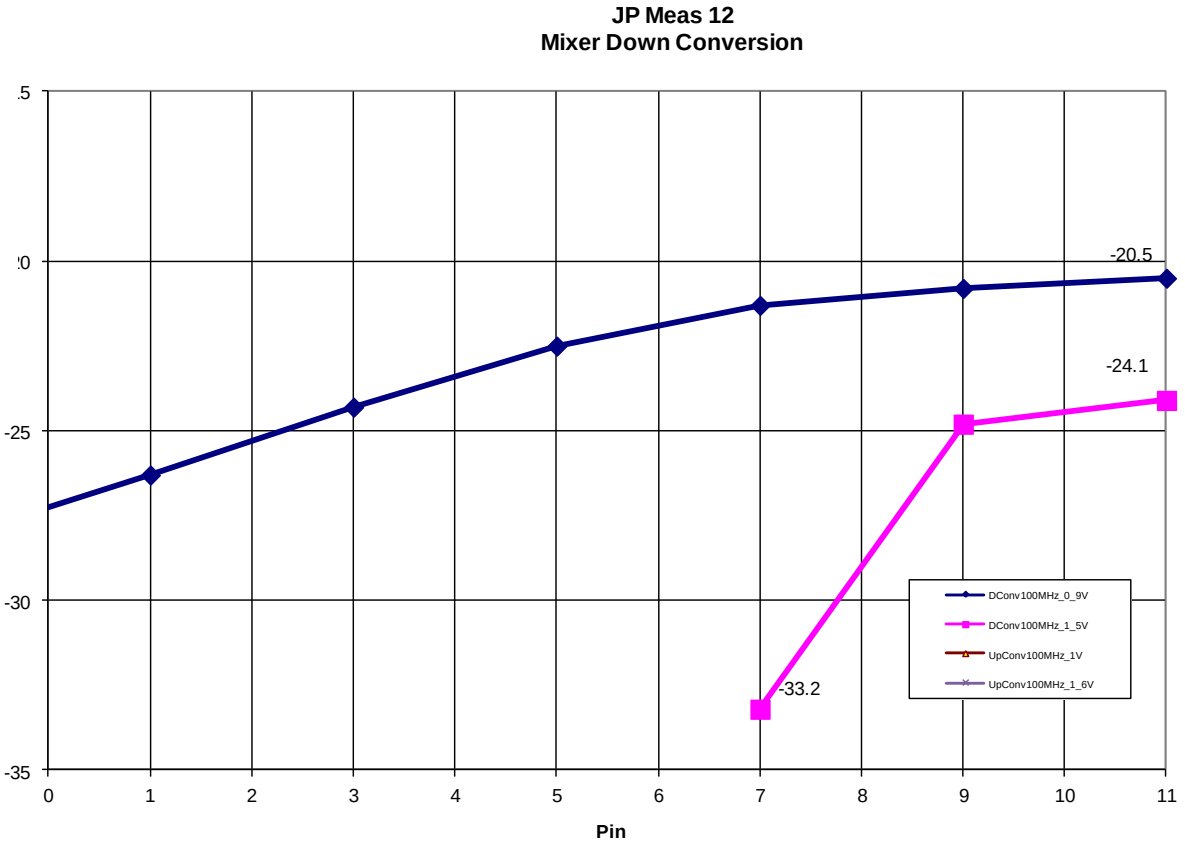


8 GHz	Die#1	8 GHz Fall12 TQP13				4V ; 27 mA			
Pin(SG)	**Pout(SA)**	**Pin(corr)**	**Pout(corr)**	**Gain**	**I1(4V)**	**PDC(mw)**	**Pout(mw)**	**Drn Eff**	**PAE**
-10.0	-3.56	-12.00	-1.56	10.44	27	108.0	0.70	0.6	0.6
-5.0	1.45	-7.00	3.45	10.45	27	108.0	2.21	2.0	1.9
0.0	6.46	-2.00	8.46	10.46	27	108.0	7.01	6.5	5.9
2.0	8.45	0.00	10.45	10.45	27	108.0	11.09	10.3	9.3
4.0	10.39	2.00	12.39	10.39	28	112.0	17.34	15.5	14.1
6.0	12.36	4.00	14.36	10.36	30	120.0	27.29	22.7	20.6
8.0	14.22	6.00	16.22	10.22	34	136.0	41.88	30.8	27.9
10.0	15.92	8.00	17.92	9.92	39	156.0	61.94	39.7	35.7
11.0	16.56	9.00	18.56	9.56	41	164.0	71.78	43.8	38.9
12.0	17.02	10.00	19.02	9.02	43	172.0	79.80	46.4	40.6
13.0	17.33	11.00	19.33	**8.33**	**45**	180.0	85.70	**47.6**	**40.6**

John Penn Diode Mixer

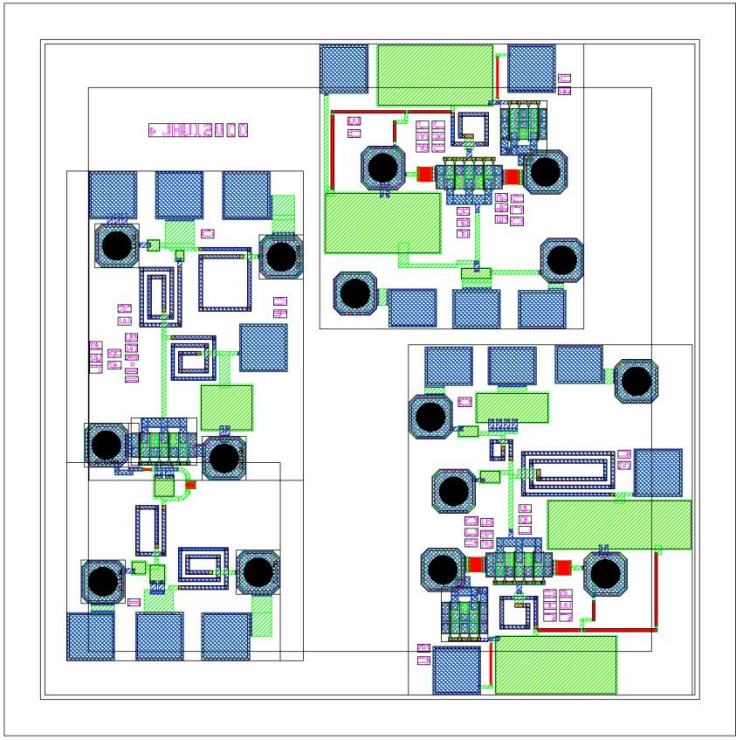






4/25/2013				RF25.2 GHz and IF 800 MHz -5 dBm se		
	LO = 26 GHz			~5dB loss to LO		
1) RF 25.2 GHz				~1 dB loss to IF		
Down Conversion			**IF=800 MH**	Vb=+/-1.5V	**IF=100 MHz**	Vb=0V
LO 26G	**LO (corr)**	**IF (meas)**	**RF (corr)**	**Loss (gain)**	**IF (meas)**	**Loss (gain)**
0	-5	-47.5	-14.5	**-32.0**		
6	1	-41.8	-14.5	**-26.3**		
8	3	-39.8	-14.5	**-24.3**		
10	5	-38.0	-14.5	**-22.5**		
12	7	-36.8	-14.5	**-21.3**	-48.7	**-33.2**
14	9	-36.3	-14.5	**-20.8**	-40.3	**-24.8**
16	11	-36.0	-14.5	**-20.5**	-39.6	**-24.1**

Diode Mixer using a Lange Coupler
Works best with 1.5 V forward bias on the diodes. Still works OK at high LO drive w/o bias.
Simple LC IF Filter.



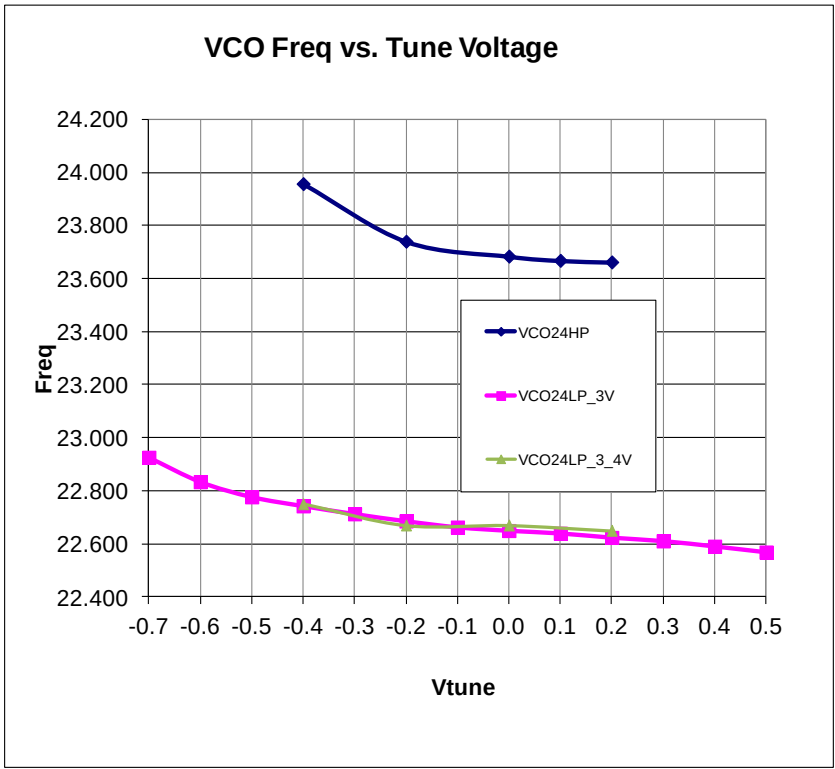
John Penn Voltage Controlled Oscillators (24 GHz)

The 2011 Class had 10 and 20 GHz VCO designs. These 24 GHz VCO designs are similar with a re-tuning of the previous design. The High Pass output match tends to be more robust in oscillation but has higher harmonics than the Low Pass output match. Die has LP/HP 24 GHz VCOs and a broadband 11-20 GHz amplifier.

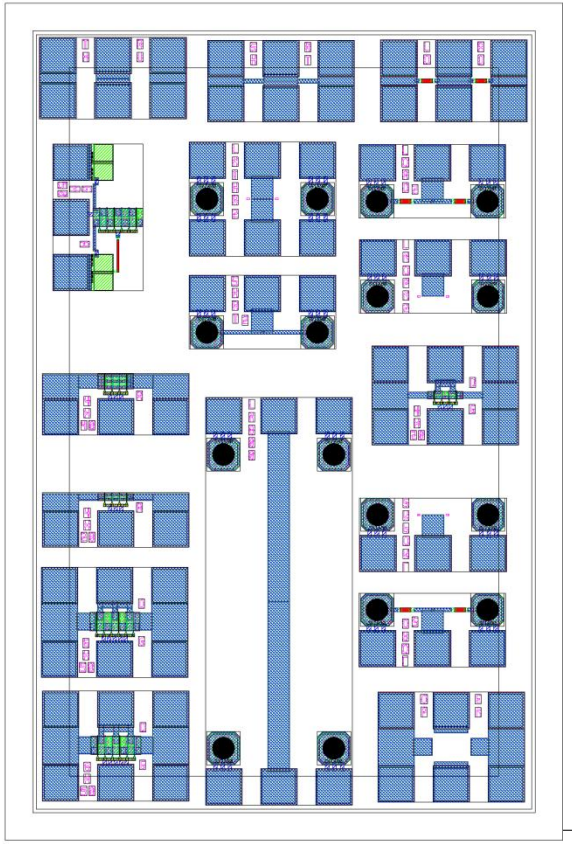
Measured MWO VCO 24 GHz HPF			
John Penn			
4/15/2013			

HPF VCO VBias (V)	3V at 24mA Freq (GHz	Pout(ms)	Die #1 Pout(corr)
-0.4	23.956	2.7	**7.2**
-0.2	23.739	3.6	**8.1**
0.0	23.683	3.5	**8.0**
0.1	23.667	3.2	**7.7**
0.2	23.661	3.0	**7.5**

LPF VCO VBias (V)	3V at 20mA Freq (GHz	Pout(ms)	Die #1 Pout(corr)
-0.7	22.925	-4.4	**0.1**
-0.6	22.833	-6.1	**-1.6**
-0.5	22.776	-7.0	**-2.5**
-0.4	22.742	-7.1	**-2.6**
-0.3	22.712	-6.8	**-2.3**
-0.2	22.685	-8.2	**-3.7**
-0.1	22.662	-8.5	**-4.0**
0.0	22.649	-8.8	**-4.3**
0.1	22.639	-8.9	**-4.4**
0.2	22.623	-9.0	**-4.5**
0.3	22.610	-9.1	**-4.6**
0.4	22.59	-8.8	**-4.3**
0.5	22.568	-9.8	**-5.3**



John Penn Test Circuits, Cal Structures, etc.



Various Cal structures, 800 um mlin, PHEMTs, Switches, etc.