JHU EE787 Fall 2005 MMIC Results

Dr. Michel Reece and Prof. John Penn

Designs Fabricated by TriQuint Semiconductor

ADS Support by Gary Wray—Agilent

MWO Support by Mark Saffian—AWR

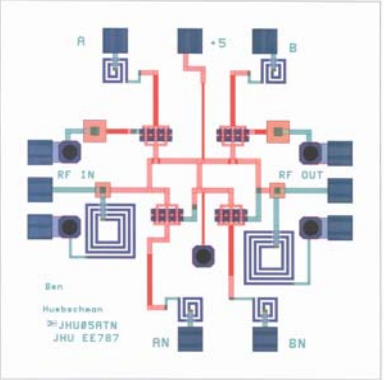
TriQuint TQTRX Library, and ADS or MWO software used for student designs

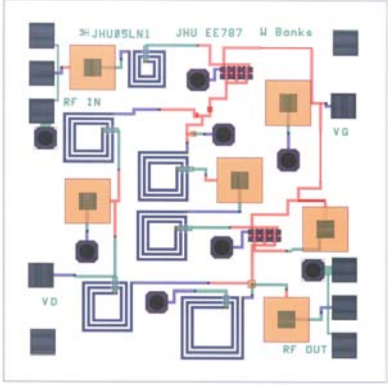
Ten MMICs were designed by students for the Fall 2005 JHU MMIC Design Course as part of a duplex transceiver employing a receive array for the C-band HiperLAN wireless local area network (WLAN) and for the industrial, scientific, and medical (ISM) frequencies. All designs were tested in the Summer of 2005 after fabrication by TriQuint Semiconductor. The MMIC measurements compare favorably to simulations; overall, the designs were very successful. All designs used TriQuint's TQPED process with 0.5 um PHEMTs, a change from the previous year's designs that used TriQuint's MESFET process (TQTRX most recently). Since there were only eight different designs, the low noise amplifier (LNA) and small signal amplifier (SSA) designs were repeated by two groups of designers. One of the low noise amplifier designs achieved extremely low DC power consumption with a goal of 5 to 10 mW of DC power consumption and 10 dB gain. Almost all the designs worked reasonably well and are documented following. The vector modulator MMIC had a much smaller range of amplitude and phase control than desired. It is not yet clear what caused the discrepancy between simulated results and actual measurements. However, the IQ demodulator design, with a very similar in architecture, worked quite well. Overall, DC biases and small signal parameters were close to simulations. Output powers tended to be several dB below predictions for the amplifier designs.

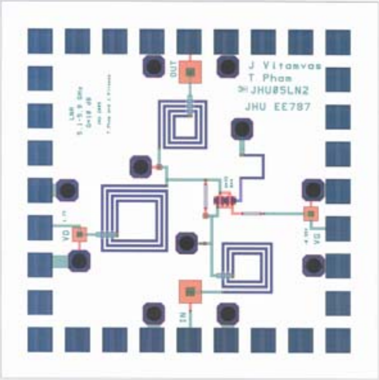
Thanks again to TriQuint, Agilent, and also to AWR, for their wonderful support of the JHU EE787 MMIC Design Course.

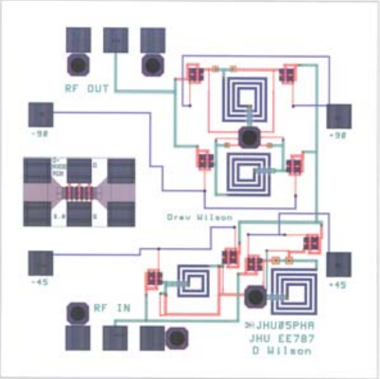
Fall 2005 JHU EE787 MMIC Design Student Projects
Supported by TriQuint, AWR, and Agilent Eesof
Professors John Penn and Dr. Michel Reece

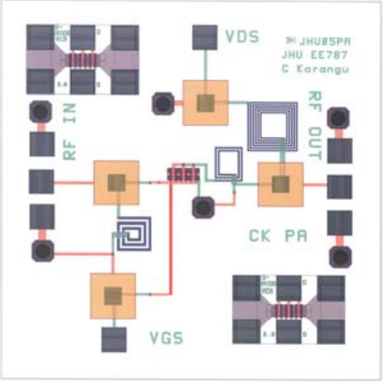
Attenuator – Ben Huebschman
Low Power Low Noise Amp - Trang Pham & John Vitamvas
Small Signal Amp 1 – Heather Merryman & Tom Wu
Small Signal Amp 2 – Thomas Neu
Vector Modulator & I/Q Down Converter – Greg Eckenrode & Tom Beglin
Low Noise Amplifier - Wilart Banks
Phase Shifter – Drew Wilson
Power Amplifier – Caroline Karangu
Voltage Controlled Osc. - Ed Heine

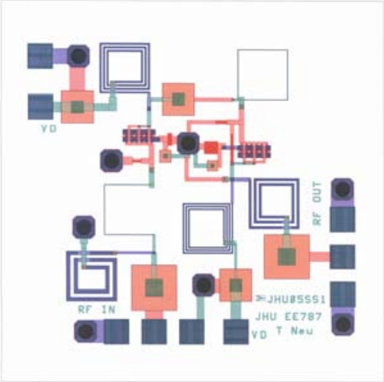


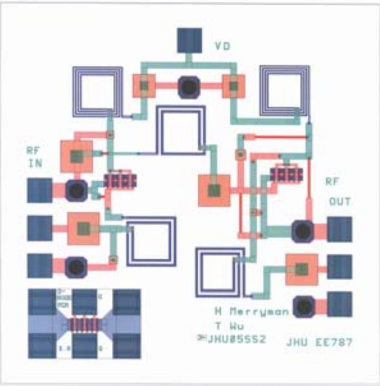


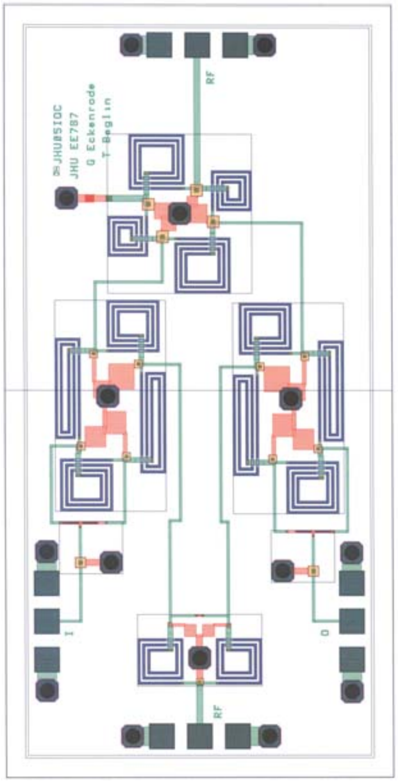


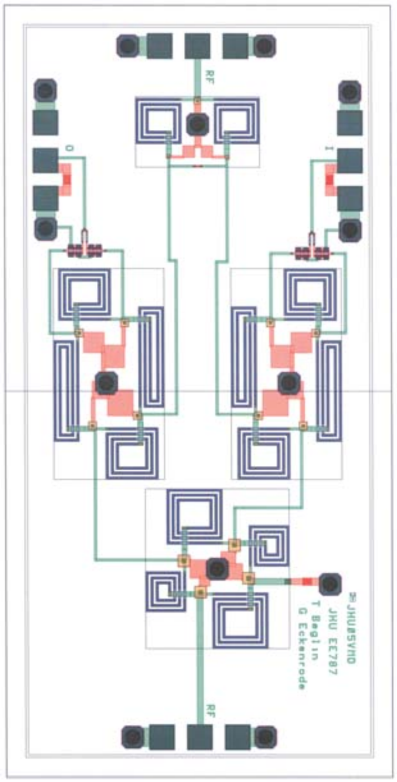


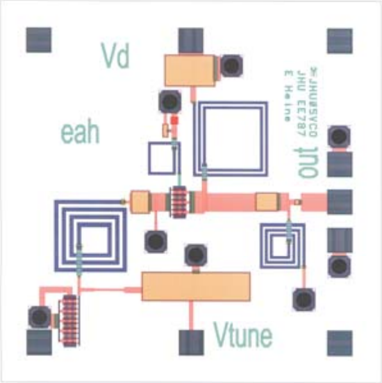






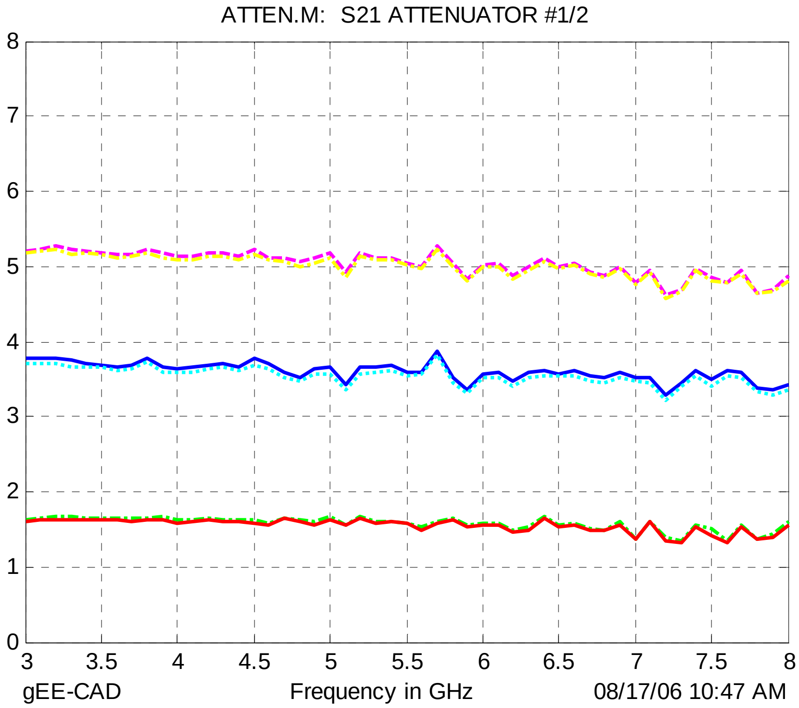




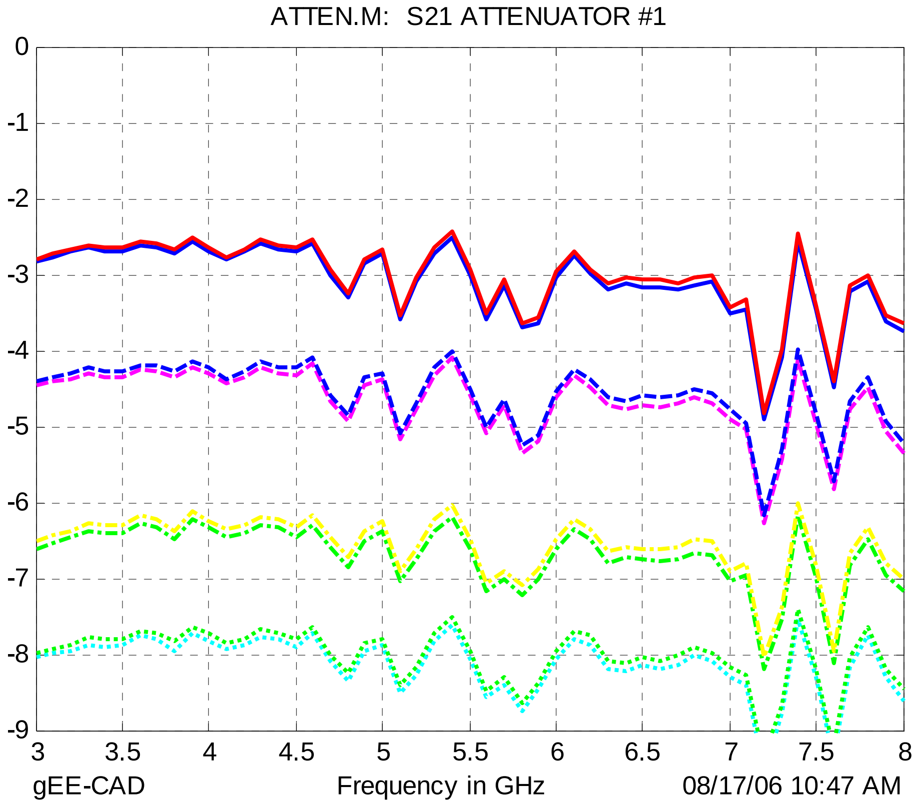


Attenuator – Ben Huebschman

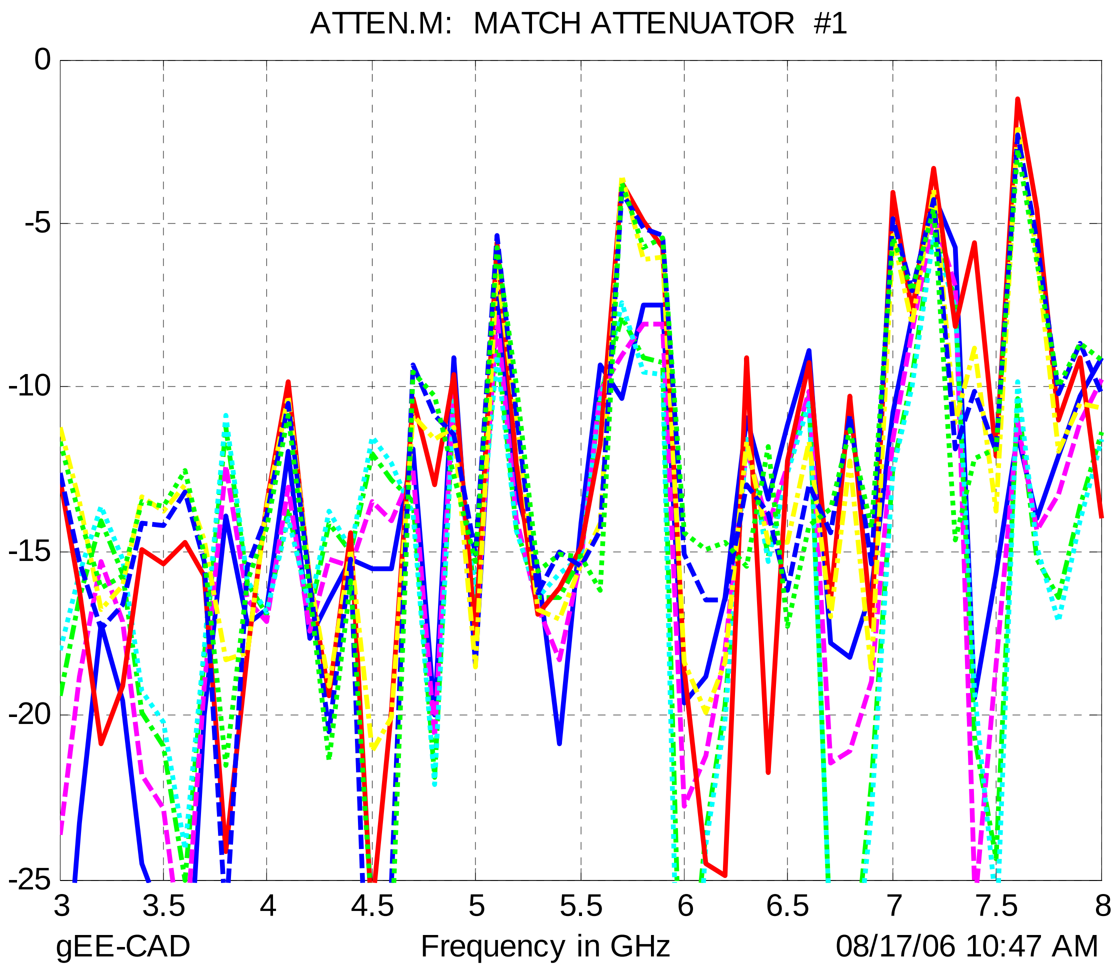
A C-Band Attenuator was designed for the 5.15 to 5.35 GHz and 5.725 to 5.875 GHz WLAN and ISM bands. This design uses PHEMTs as switch devices to create a two bit attenuator with steps of 2 dB. Minimum insertion loss was about 3dB as measured and as simulated. Results were very similar to the ADS predictions. The measured data is a little “noisy”, but notice the broad band response of the design.



Relative Insertion Loss for 0, 2, 4, and 6 dB steps.



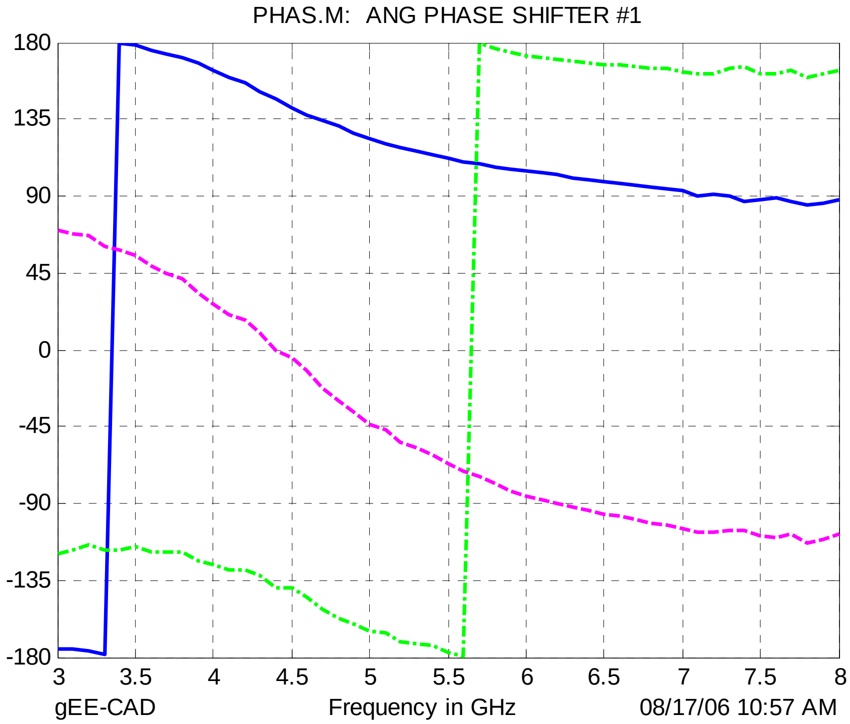
Absolute Insertion Loss for 0, 2, 4, and 6 dB steps.



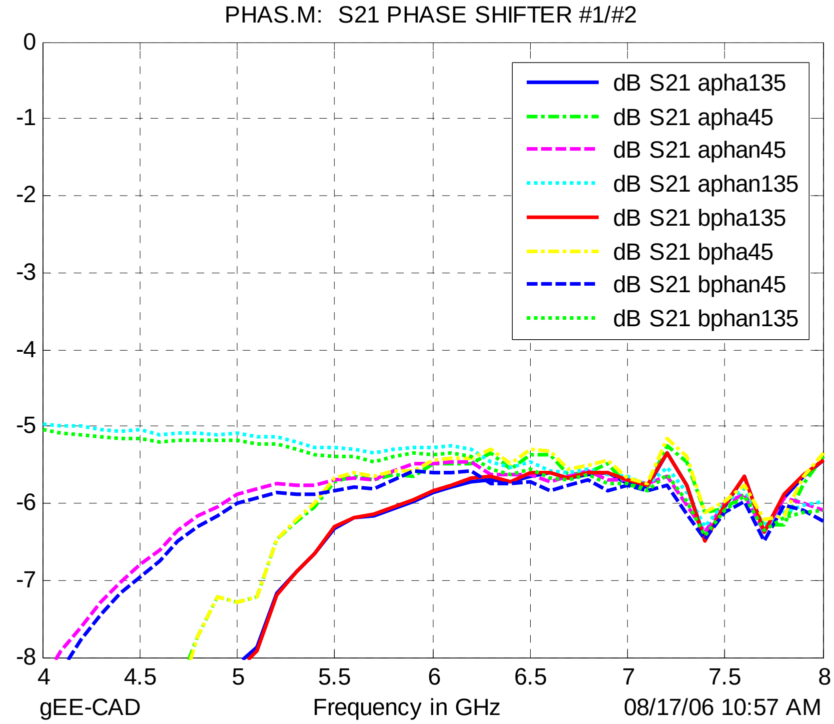
“Noisy” Input/Output Measurements for 0, 2, 4, and 6 dB steps.

Phase Shifter – Drew Wilson

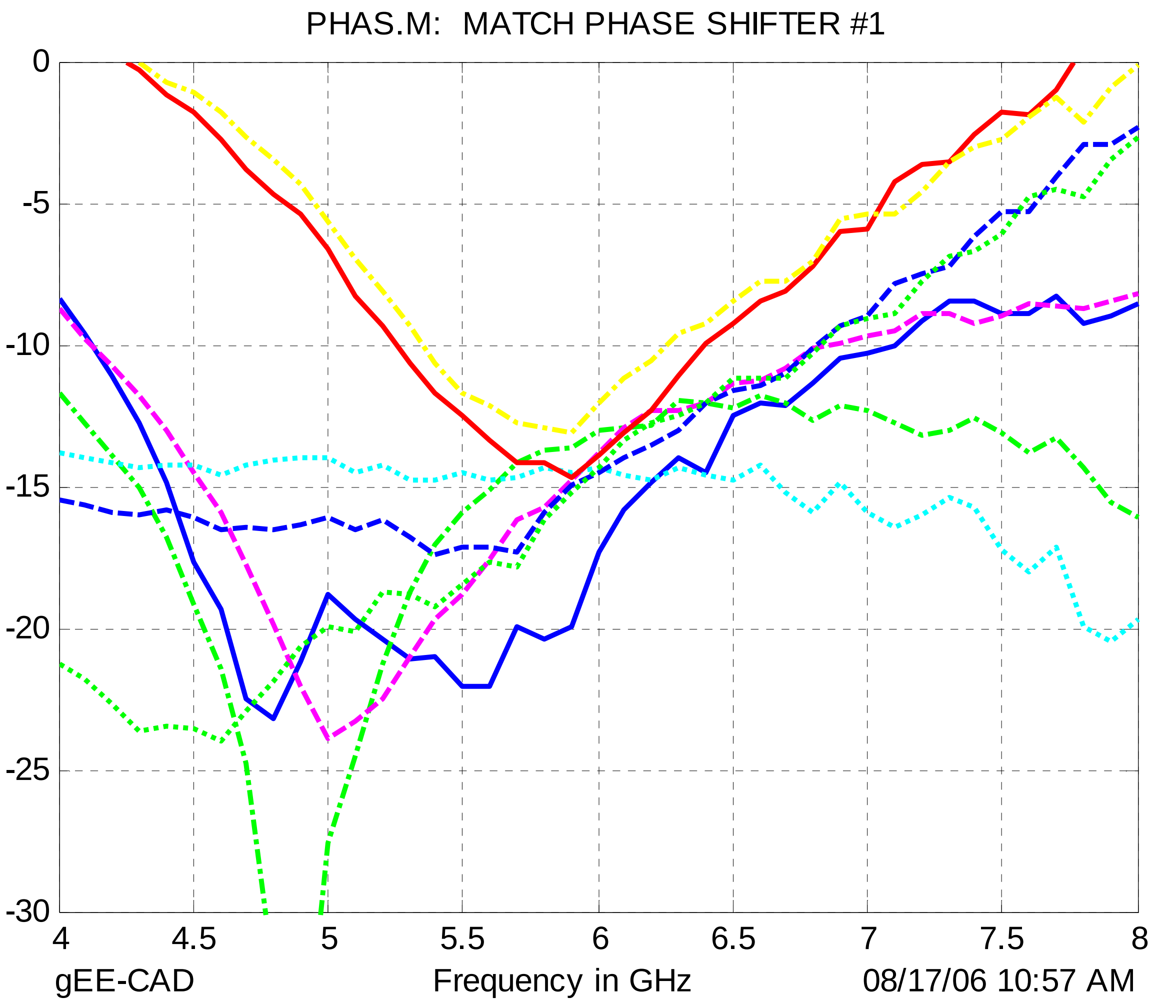
A C-Band Phase Shifter was designed for the 5.15 to 5.35 GHz and 5.725 to 5.875 GHz WLAN and ISM bands. This design uses PHEMTs as switch devices to create a two bit phase shifter with 90 degree steps. Insertion loss was expected to vary between states over the band, but notice how well balanced the insertion loss is from 6 to 8 GHz with usable phase shifts. The 90 degree bit actually is a little off until 7 GHz (blue) and the 180 degree bit is “right on” around 5.6 to 5.7 GHz (green). Input and Output match is also shown for all four phase states.



Relative Insertion Phase for 0, 90, 180, and 270 degree steps.



Absolute Insertion Loss for 0, 90, 180, and 270 degree steps (two different die shown).



Input and Output Match for all Phase Steps

Voltage Controlled Osc. - Ed Heine

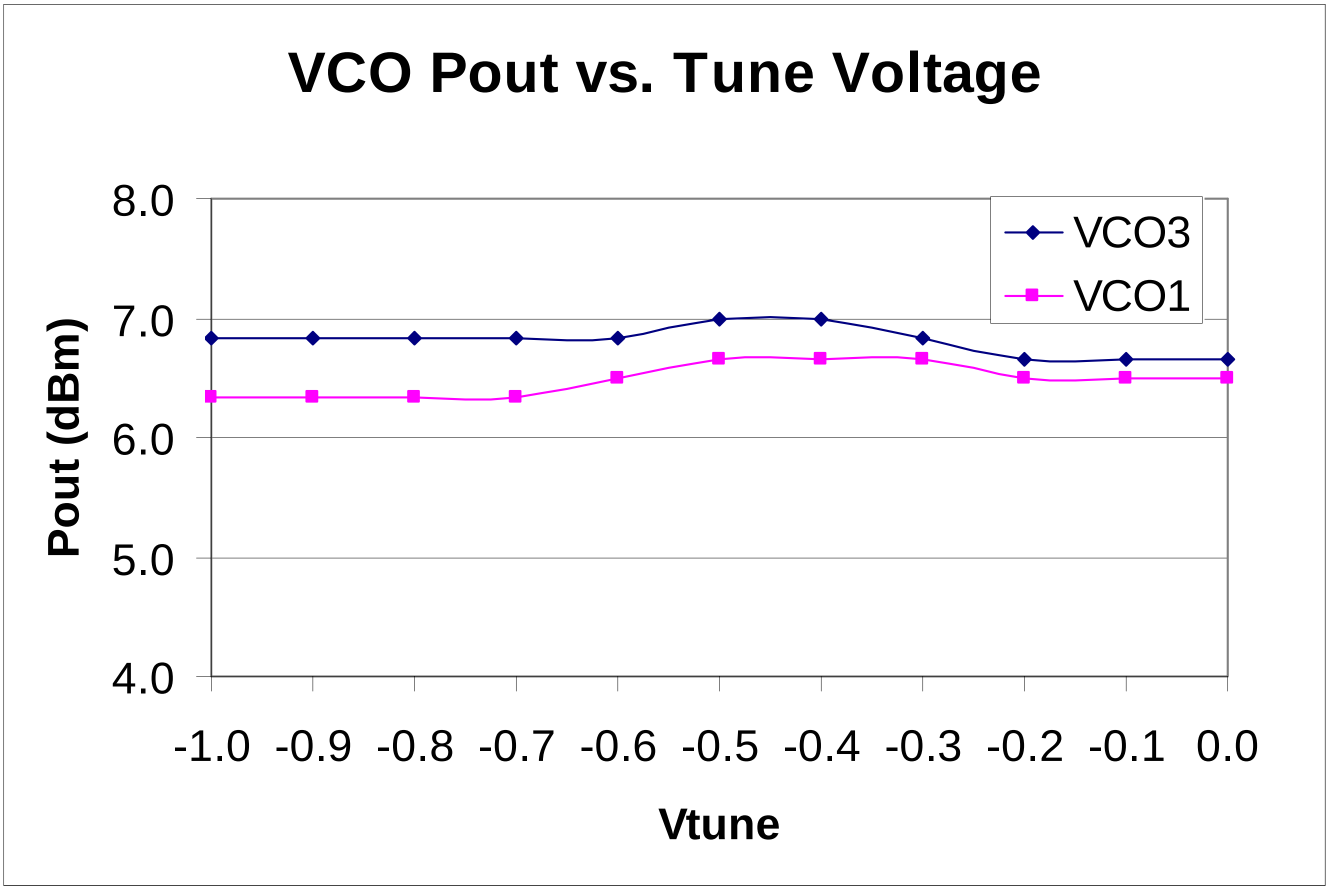
A C-Band Voltage Controlled Oscillator (VCO) was designed using Microwave Office. It was not expected that a single VCO design would cover both ISM and WLAN bands. Bias was measured at 3V to be 15mA IDS as expected. Phase noise was measured on the spectrum analyzer and compared well with expected results. There was a bit of “hysteresis” or bi-stability in the oscillator due to its design for low phase noise, so data was taken with the bias voltage swept in the same direction for both die. Output frequency was a little higher than expected but typical compared to previous VCO designs in the JHU course. The VCO worked fairly well compared to simulations, especially considering the difficult phase noise predictions. Below are the output powers and frequencies of two measured devices.

Measured MWO VCO
Ed Heine

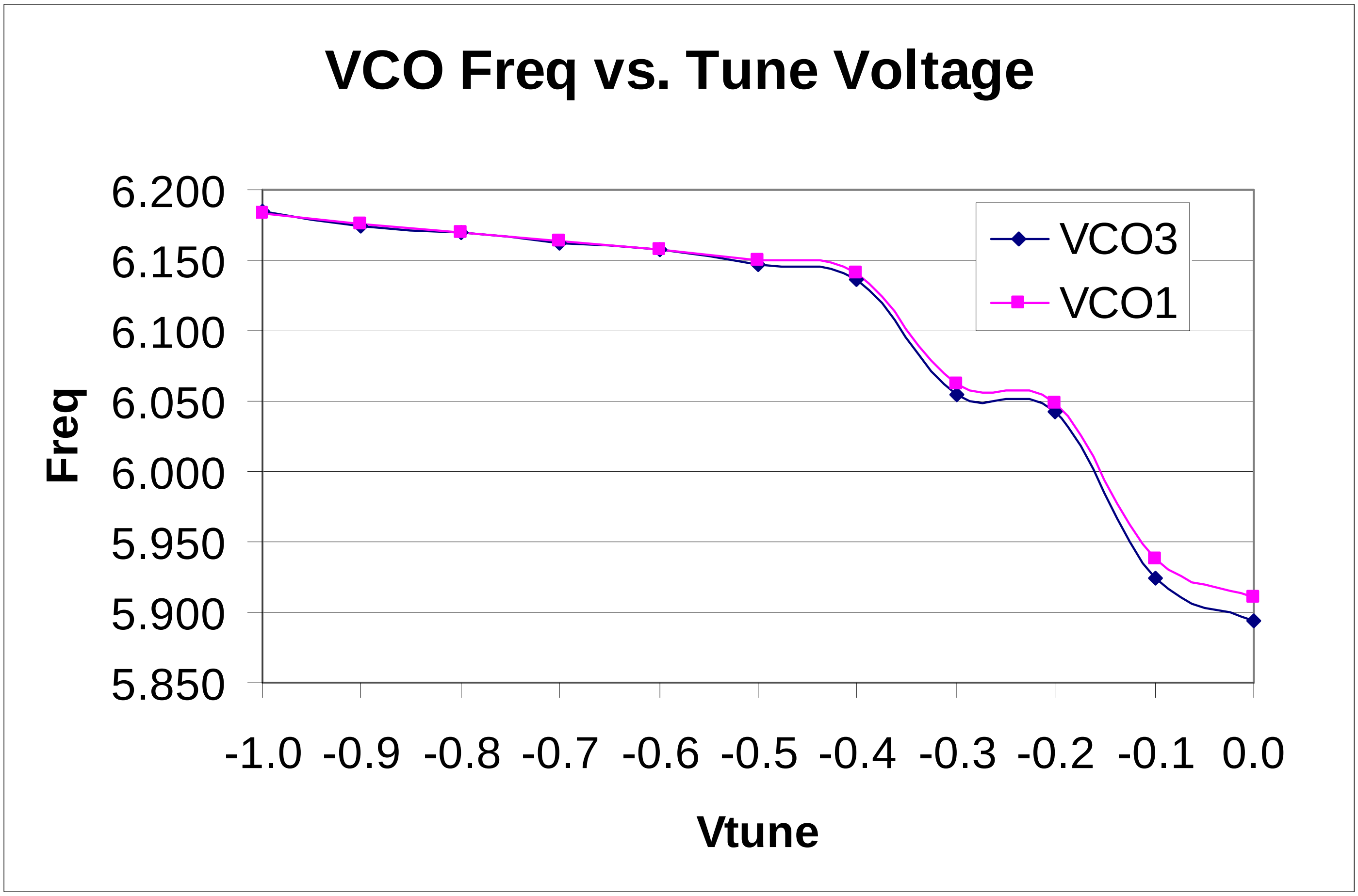
Bi-stable Operation. Need to turn out lights, etc. Different frequency with voltage going up than down--hysteresis.
Loss of output cables and probe estimated to ~1.66 dB X1, ~2 dB X2. Add to Pout(measured).

ADS VCO	**3V at 15mA**		**Die #3**			
VBias (V)	**Freq (GHz**	**Pout(ms)**	**Pout(corr)**	**X2 Pout(ms)**	**dbc/hz 100k**	**dbc/hz 1M**
0.0	5.894	5.0	**6.7**			
-0.1	5.924	5.0	**6.7**			
-0.2	6.042	5.0	**6.7**			
-0.3	6.055	5.2	**6.8**			
-0.4	6.137	5.3	**7.0**		-93.8	-110
-0.5	6.147	5.3	**7.0**			
-0.6	6.157	5.2	**6.8**			
-0.7	6.162	5.2	**6.8**			
-0.8	6.170	5.2	**6.8**			
-0.9	6.175	5.2	**6.8**			
-1.0	6.185	5.2	**6.8**			
-1.5	6.357	5.2	**6.8**			
Range:	0.291					
Center:	6.040					

ADS VCO	**3V at 15mA**		**Die #1**			
VBias (V)	**Freq (GHz**	**Pout(ms)**	**Pout(corr)**	**X2 Pout(m**	**dbc/hz 10(**	**dbc/hz 1M**
0.0	5.910	4.8	**6.5**	-15.83		
-0.1	5.938	4.8	**6.5**	-13.67		
-0.2	6.048	4.8	**6.5**	-12.33		
-0.3	6.063	5.0	**6.7**	-11.50		
-0.4	6.141	5.0	**6.7**	-11.00		-111
-0.5	6.150	5.0	**6.7**	-11.00		
-0.6	6.157	4.8	**6.5**	-11.33		
-0.7	6.163	4.7	**6.3**	-11.83		
-0.8	6.169	4.7	**6.3**	-12.67		
-0.9	6.175	4.7	**6.3**	-27.00		
-1.0	6.183	4.7	**6.3**	-28.17		
Range:	0.273					
Center:	6.046					



Very Consistent Output Power over the Tuning Range for Two Different VCOs.



Output Frequency Versus Tuning Voltage for Two Different VCOs.

Medium Power Amp – Caroline Karangu

A C-Band Medium Power Amplifier was designed for the 5.15 to 5.35 GHz and 5.725 to 5.875 GHz WLAN and ISM bands. This design uses a single stage PHEMT device to achieve good power output and efficiency. Measured output power, gain, PAE, and s-parameters are following: The design was at 5V but was also measured at 4V and 3V VDS with comparable output power and gain but with increased efficiency. Output Power was a little lower than expected (16 dBm vs 20-21 dbm) but was consistent with other measured devices for this wafer fab. DC bias was close to expected.

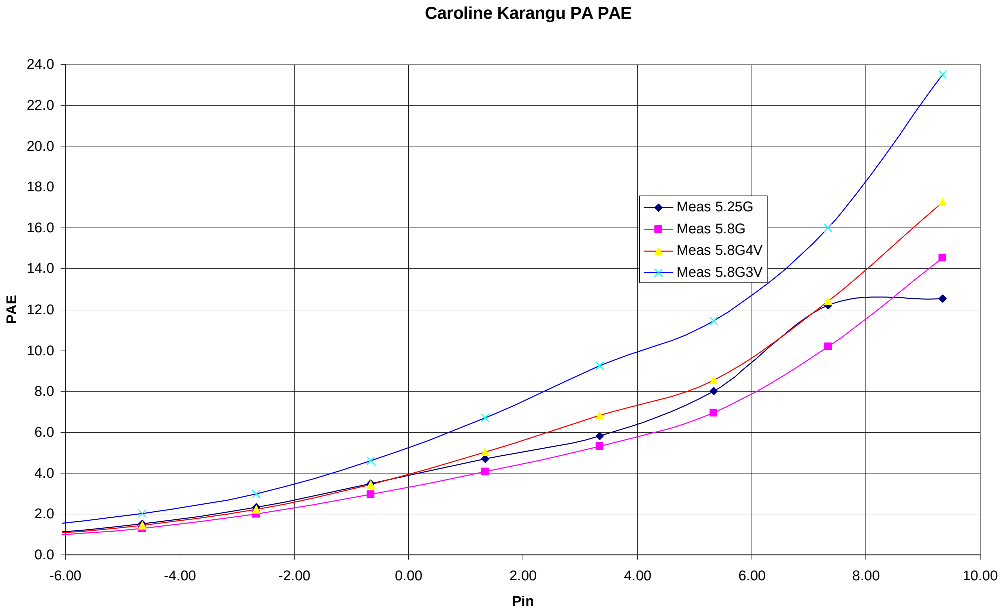
Power Amp at 5V VDS (5.25 & 5.8 GHz)

5.25GHz	Die#2	**PA CK**				Corrected			
Pin(SG)	**Pout(SA)**	**Pin(corr)**	**Pout(corr)**	**Gain**	**I1(5V)**	**PDC(mw)**	**Pout(mw)**	**Drn Eff**	**PAE**
-9.0	-0.67	-10.66	0.99	11.65	73	365	1.26	0.3	0.3
-7.0	1.17	-8.66	2.83	11.49	73	365	1.92	0.5	0.5
-5.0	3.17	-6.66	4.83	11.49	73	365	3.04	0.8	0.8
-3.0	5.00	-4.66	6.66	11.32	72	360	4.63	1.3	1.2
-1.0	6.83	-2.66	8.49	11.15	71	355	7.06	2.0	1.8
1.0	8.50	-0.66	10.16	10.82	70	350	10.38	3.0	2.7
3.0	9.83	1.34	11.49	10.15	67	335	14.09	4.2	3.8
5.0	10.83	3.34	12.49	9.15	62	310	17.74	5.7	5.0
7.0	12.17	5.34	13.83	8.49	55	275	24.15	8.8	7.5
9.0	13.67	7.34	15.33	7.99	48	240	34.12	14.2	12.0
11.0	14.17	9.34	15.83	6.49	46	230	38.28	16.6	12.9

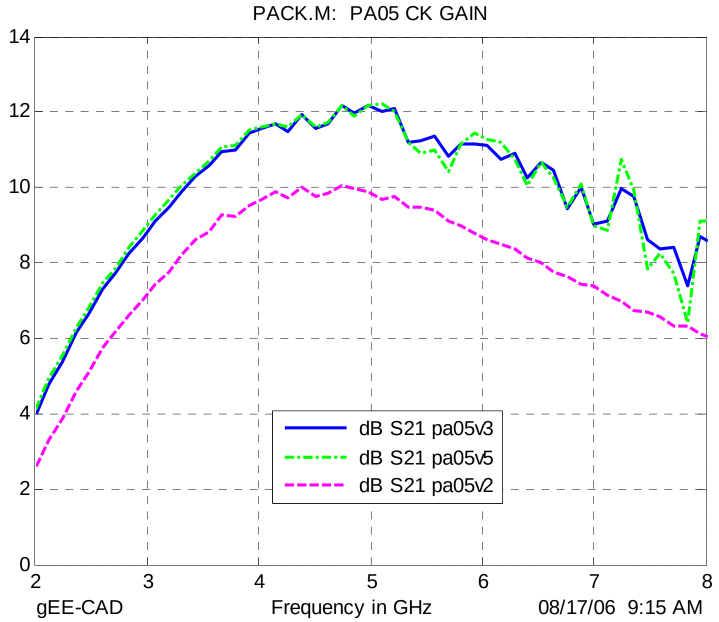
5.8GHz	Die#2	**PA CK**				Corrected			
Pin(SG)	**Pout(SA)**	**Pin(corr)**	**Pout(corr)**	**Gain**	**I1(5V)**	**PDC(mw)**	**Pout(mw)**	**Drn Eff**	**PAE**
-9.0	-1.17	-10.66	0.49	11.15	73	365	1.12	0.3	0.3
-7.0	0.67	-8.66	2.33	10.99	73	365	1.71	0.5	0.4
-5.0	2.83	-6.66	4.49	11.15	73	365	2.81	0.8	0.7
-3.0	4.67	-4.66	6.33	10.99	72	360	4.30	1.2	1.1
-1.0	6.50	-2.66	8.16	10.82	72	360	6.55	1.8	1.7
1.0	8.33	-0.66	9.99	10.65	71	355	9.98	2.8	2.6
3.0	9.83	1.34	11.49	10.15	69	345	14.09	4.1	3.7
5.0	11.00	3.34	12.66	9.32	65	325	18.45	5.7	5.0
7.0	12.00	5.34	13.66	8.32	59	295	23.23	7.9	6.7
9.0	13.33	7.34	14.99	7.65	52	260	31.55	12.1	10.1
11.0	14.67	9.34	16.33	6.99	46	230	42.95	18.7	14.9

5.8 G 4V				Corrected			
Pout(SA)	**Pout(corr)**	**Gain**	**I1(4V)**	**PDC(mw)**	**Pout(mw)**	**Drn Eff**	**PAE**
-0.67	0.99	11.65	75	300	1.26	0.4	0.4
1.17	2.83	11.49	75	300	1.92	0.6	0.6
3.17	4.83	11.49	74	296	3.04	1.0	1.0
5.00	6.66	11.32	74	296	4.63	1.6	1.5
6.83	8.49	11.15	73	292	7.06	2.4	2.2
8.67	10.33	10.99	72	288	10.79	3.7	3.4
10.17	11.83	10.49	69	276	15.24	5.5	5.0
11.33	12.99	9.65	65	260	19.91	7.7	6.8
12.00	13.66	8.32	58	232	23.23	10.0	8.5
13.00	14.66	7.32	48	192	29.24	15.2	12.4
14.17	15.83	6.49	43	172	38.28	22.3	17.3

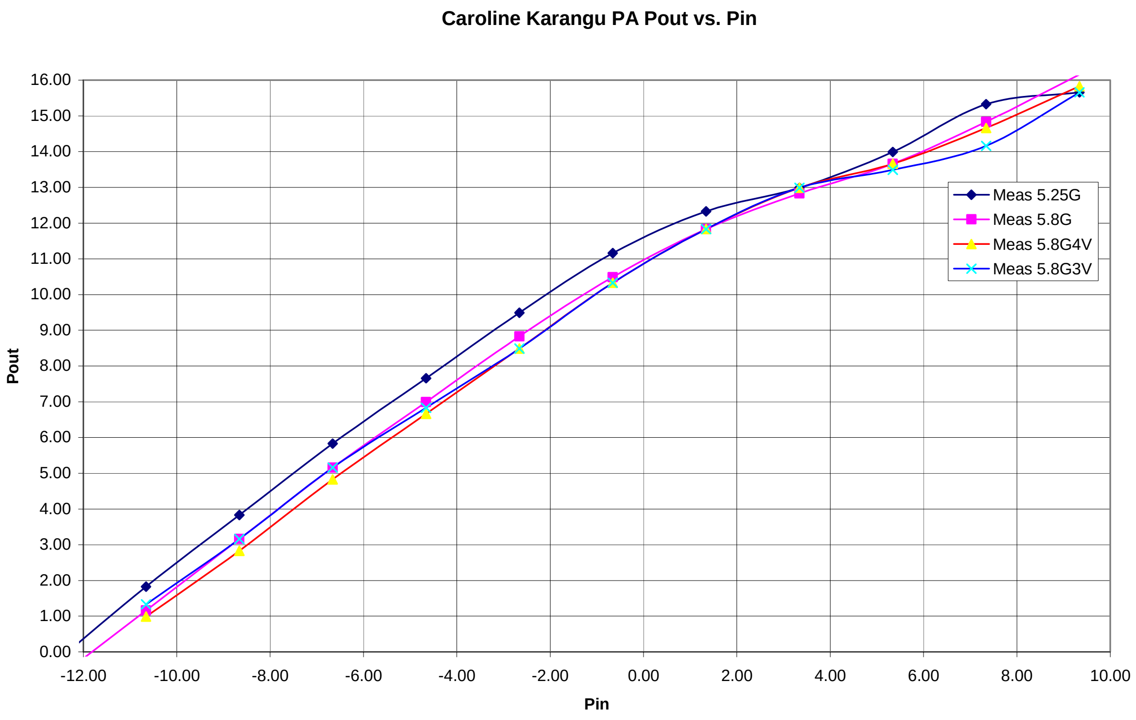
5.8 G 3V				Corrected			
Pout(SA)	**Pout(corr)**	**Gain**	**I1(3V)**	**PDC(mw)**	**Pout(mw)**	**Drn Eff**	**PAE**
-0.33	1.33	11.99	76	228	1.36	0.6	0.6
1.50	3.16	11.82	76	228	2.07	0.9	0.8
3.50	5.16	11.82	75	225	3.28	1.5	1.4
5.17	6.83	11.49	74	222	4.82	2.2	2.0
6.83	8.49	11.15	73	219	7.06	3.2	3.0
8.67	10.33	10.99	72	216	10.79	5.0	4.6
10.17	11.83	10.49	69	207	15.24	7.4	6.7
11.33	12.99	9.65	64	192	19.91	10.4	9.2
11.83	13.49	8.15	55	165	22.34	13.5	11.5
12.50	14.16	6.82	43	129	26.06	20.2	16.0
14.00	15.66	6.32	40	120	36.81	30.7	23.5



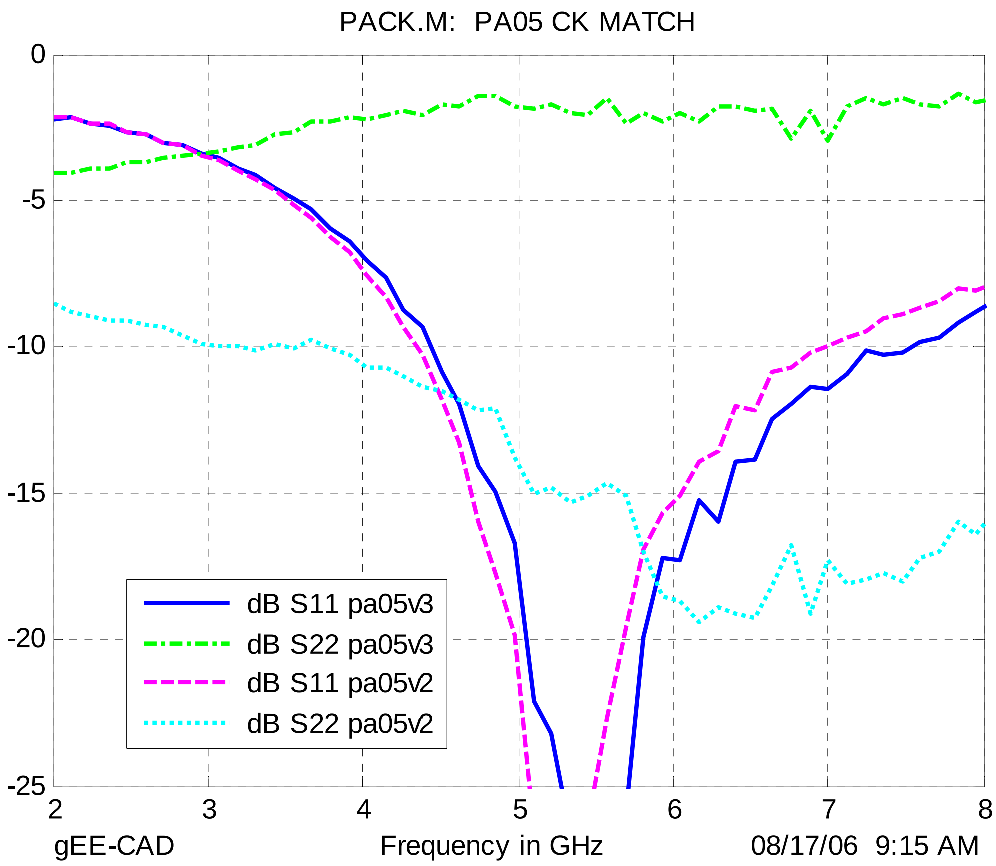
Power Added Efficiency vs. Input Power Pin (Note Improvement using 3V VDS)



Gain at 2, 3, and 5V VDS



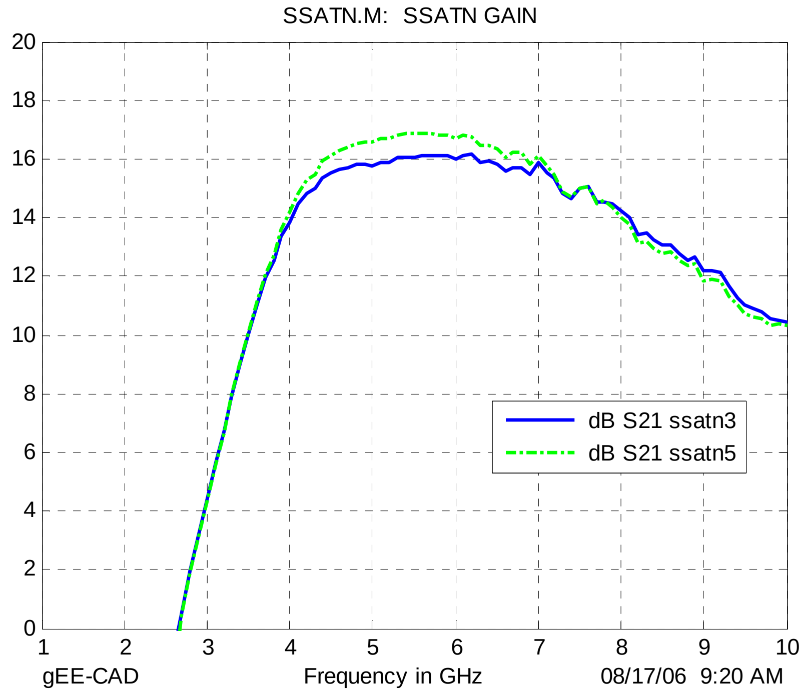
OutPut Power Pout vs. Input Power Pin(Comparable 3V, 4V, and 5V at 5.25 and 5.8 GHz)



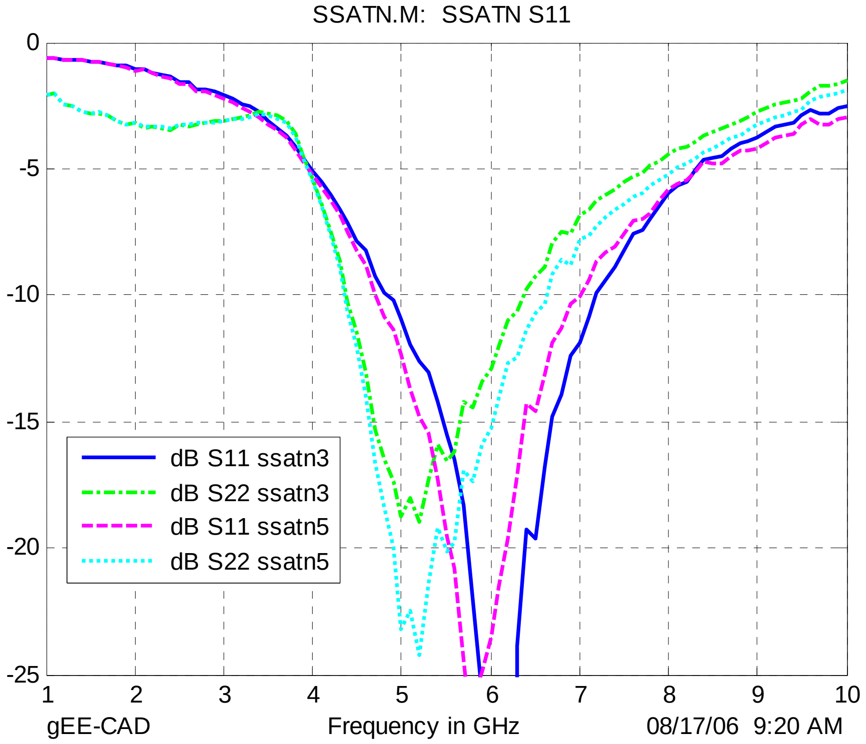
Input and Output Match at 2, 3 V VDS

Small Signal or General Purpose Amp – Tommy Neu

A C-Band General Purpose Amplifier was designed for the 5.15 to 5.35 GHz and 5.725 to 5.875 GHz WLAN and ISM bands. This design uses two stages of 300 um PHEMT devices to achieve good gain and output power—note the good input and output match over the band. Each stage had its own bias input. Typical power consumption was 35 mA and 27 mA at 3V for stages 1 and 2 and 40 and 37 mA at 5V. Output power was measured at 5.0 and 5.5 GHz and was about 4 dB lower than predictions—which is consistent with other designs on this fab.

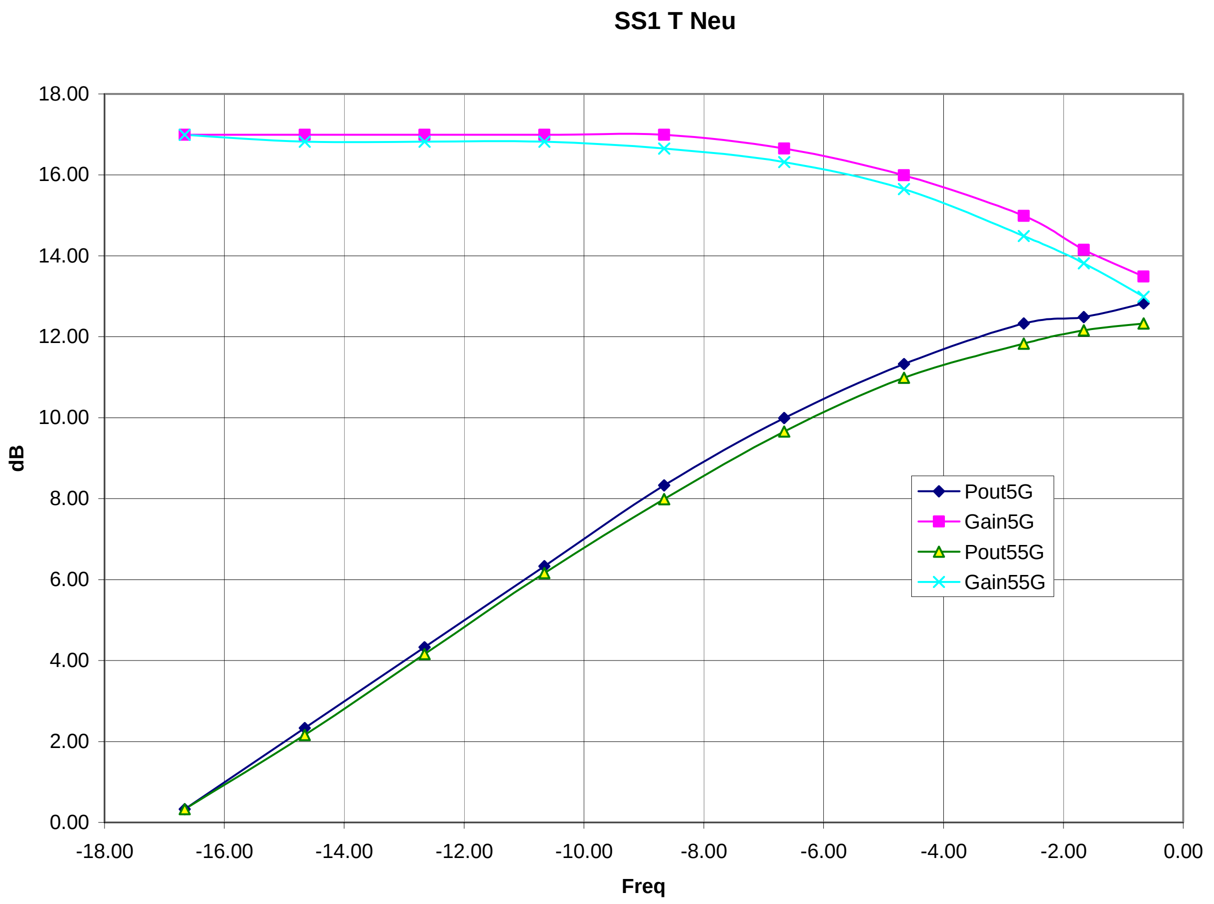


Gain at 3, and 5V VDS



Good Input/Output Match at 3, and 5V VDS over the band

Measured Output Power and Efficiency for the Small Signal Amplifier



Meas. PA 5.25/5.8 GHz Pout vs. Pin

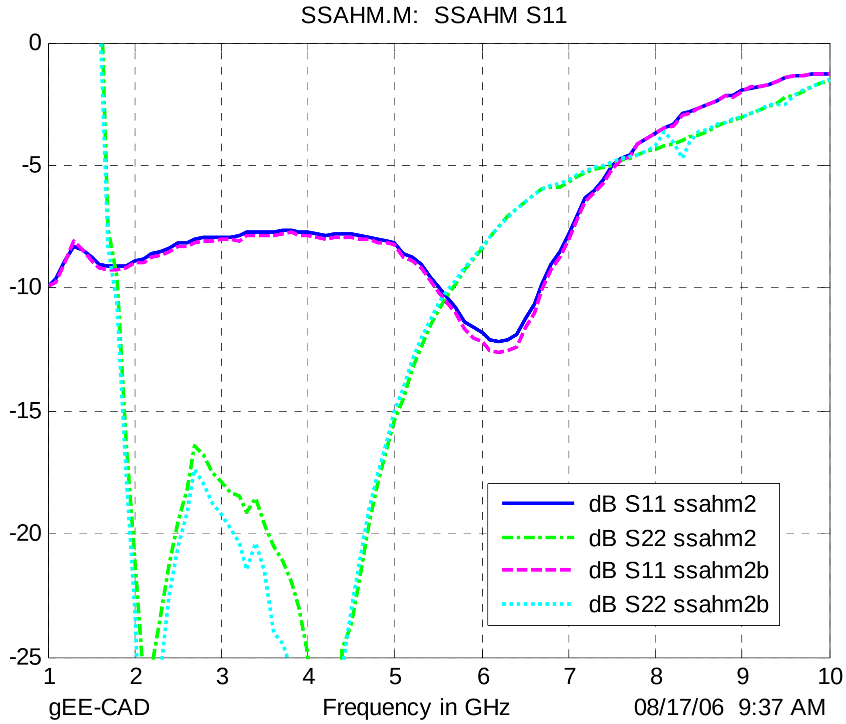
5V at 40/37 mA Meas 6/2/06 Loss 1.66 dB at 5.0/5.5 GHz on input and output

5.0 GHz	Die#1	**SS1 Tneu**					Corrected			
Pin(SG)	**Pout(SA)**	**Pin(corr)**	**Pout(corr)**	**Gain**	**Istg1(5V)**	**Istg2(5V)**	**PDC(mw)**	**Pout(mw)**	**Drn Eff**	**PAE**
-15.0	-1.33	-16.66	0.33	16.99	40.00	37	385	1.08	0.3	0.3
-13.0	0.67	-14.66	2.33	16.99	40.00	37	385	1.71	0.4	0.4
-11.0	2.67	-12.66	4.33	16.99	40.00	37	385	2.71	0.7	0.7
-9.0	4.67	-10.66	6.33	16.99	40.00	37	385	4.30	1.1	1.1
-7.0	6.67	-8.66	8.33	16.99	40.00	37	385	6.81	1.8	1.7
-5.0	8.33	-6.66	9.99	16.65	40.00	37	385	9.98	2.6	2.5
-3.0	9.67	-4.66	11.33	15.99	40.00	36	380	13.58	3.6	3.5
-1.0	10.67	-2.66	12.33	14.99	39.00	36	375	17.10	4.6	4.4
0.0	10.83	-1.66	12.49	14.15	39.00	36	375	17.74	4.7	4.5
1.0	11.17	-0.66	12.83	13.49	39.00	36	375	19.19	5.1	4.9

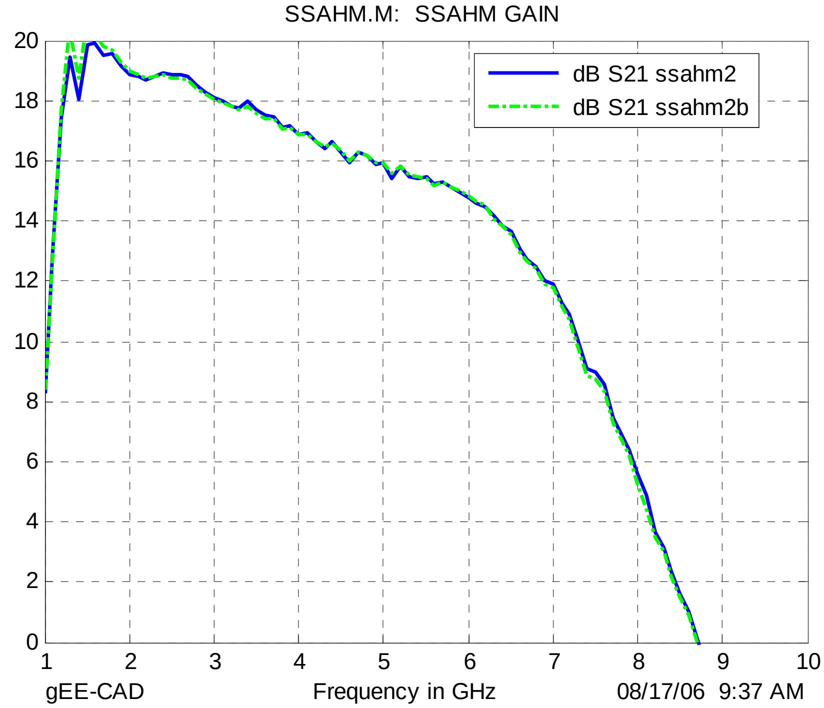
5.5 GHz	Die#1	**SS1 Tneu**					Corrected			
Pin(SG)	**Pout(SA)**	**Pin(corr)**	**Pout(corr)**	**Gain**	**Istg1(5V)**	**Istg2(5V)**	**PDC(mw)**	**Pout(mw)**	**Drn Eff**	**PAE**
-15.0	-1.33	-16.66	0.33	16.99	40.00	37	385	1.08	0.3	0.3
-13.0	0.50	-14.66	2.16	16.82	40.00	37	385	1.64	0.4	0.4
-11.0	2.50	-12.66	4.16	16.82	40.00	37	385	2.61	0.7	0.7
-9.0	4.50	-10.66	6.16	16.82	40.00	37	385	4.13	1.1	1.1
-7.0	6.33	-8.66	7.99	16.65	40.00	37	385	6.30	1.6	1.6
-5.0	8.00	-6.66	9.66	16.32	40.00	37	385	9.25	2.4	2.3
-3.0	9.33	-4.66	10.99	15.65	40.00	36	380	12.56	3.3	3.2
-1.0	10.17	-2.66	11.83	14.49	39.00	36	375	15.24	4.1	3.9
0.0	10.50	-1.66	12.16	13.82	39.00	36	375	16.44	4.4	4.2
1.0	10.67	-0.66	12.33	12.99	39.00	36	375	17.10	4.6	4.3

Small Signal or General Purpose Amp – Heather Merryman and Tom Wu

A C-Band General Purpose Amplifier was designed for the 5.15 to 5.35 GHz and 5.725 to 5.875 GHz WLAN and ISM bands. This design uses two stages of standard 300 um PHEMT devices to achieve good gain with reasonable output power. DC bias was close to the predicted 130 mA at 5V. Gain was very broadband though a little lower than that predicted by ADS simulations.



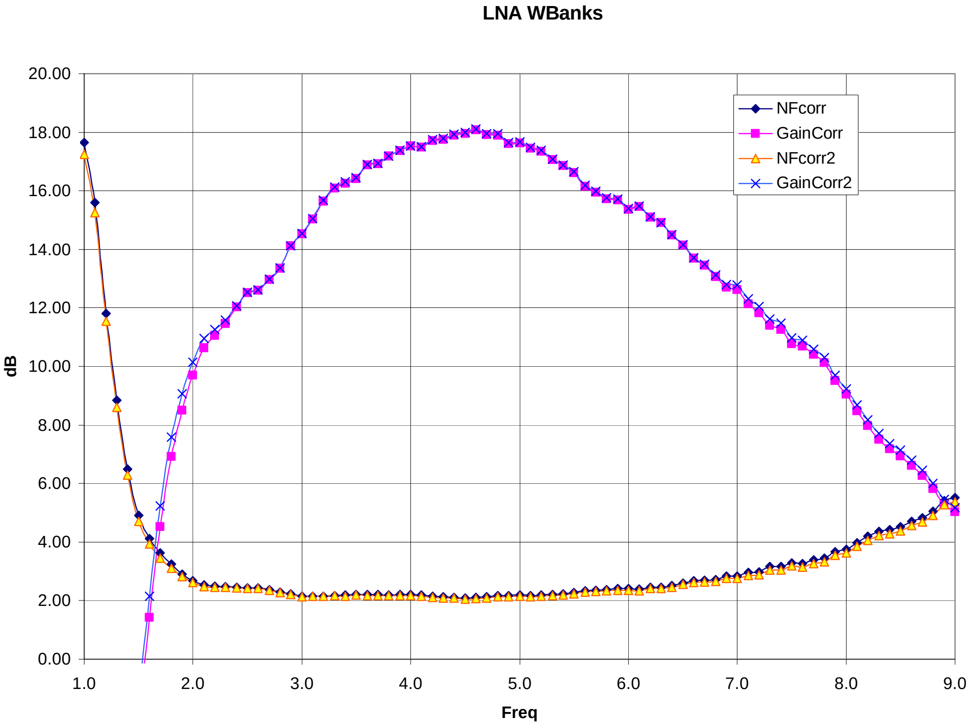
Input/Output Match for two different die



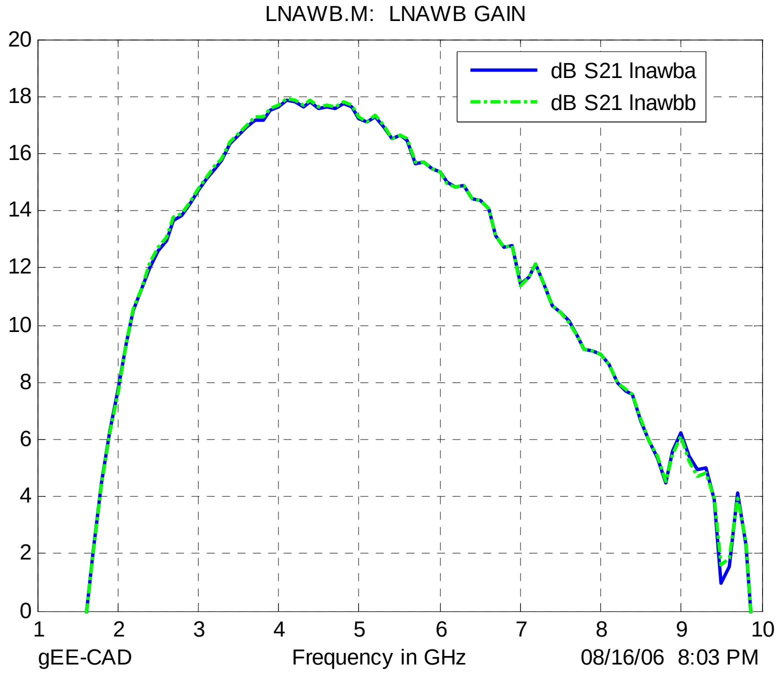
Very Broadband Gain for two different die

Low Noise Amp – Wilart Banks

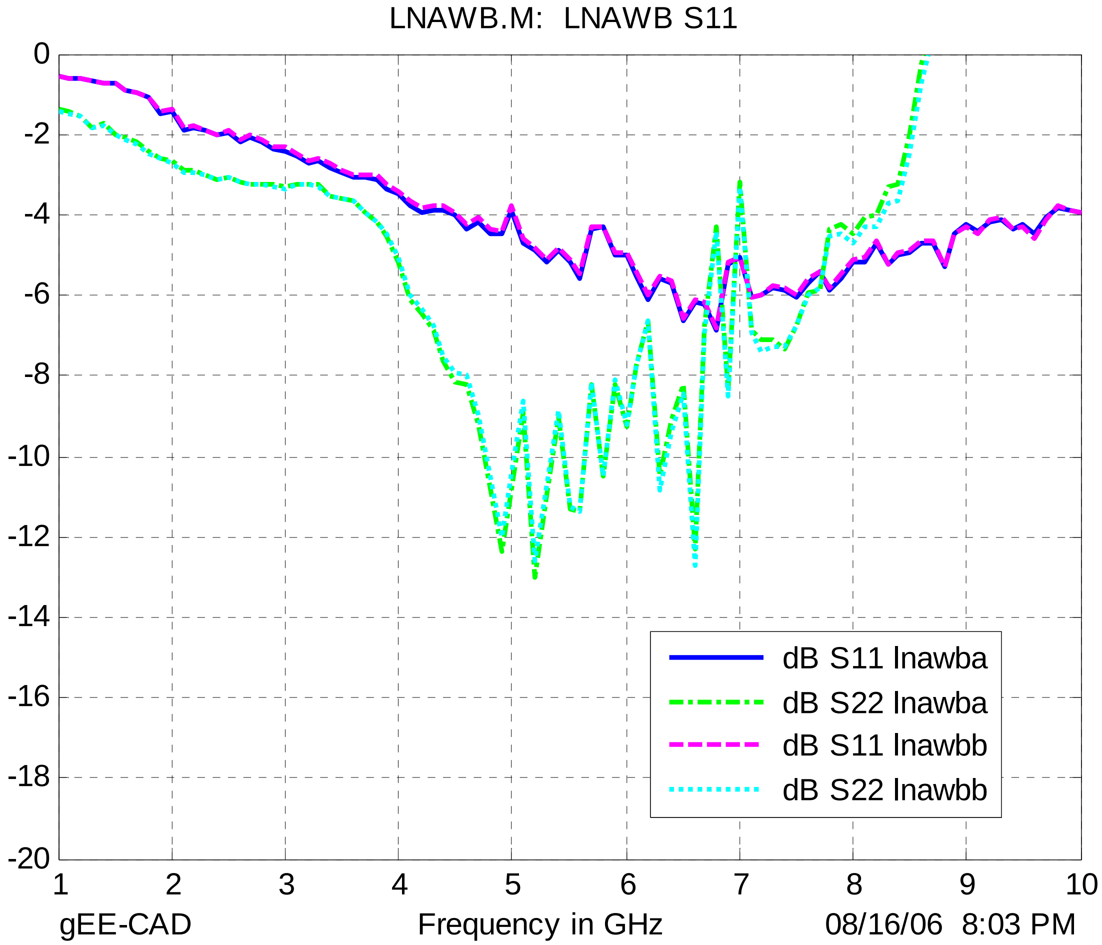
A C-Band Low Noise Amplifier was designed for the 5.15 to 5.35 GHz and 5.725 to 5.875 GHz WLAN and ISM bands. This design uses two stages of 300 um PHEMT devices to achieve good gain and noise figure. Noise figure was a very broad band 2 dB from about 2 GHz to 6.5 GHz with 18 dB of gain at the low end of the band. Two die were measured with similar results using a bias of VDS = 3V and IDS = 30 mA. VGS was approximately -0.47 to -0.57 V for the two die measured. Bias was very close to that predicted by the simulations.



Noise Figure and Gain Measured with Noise Figure Meter (Losses Subtracted Out)



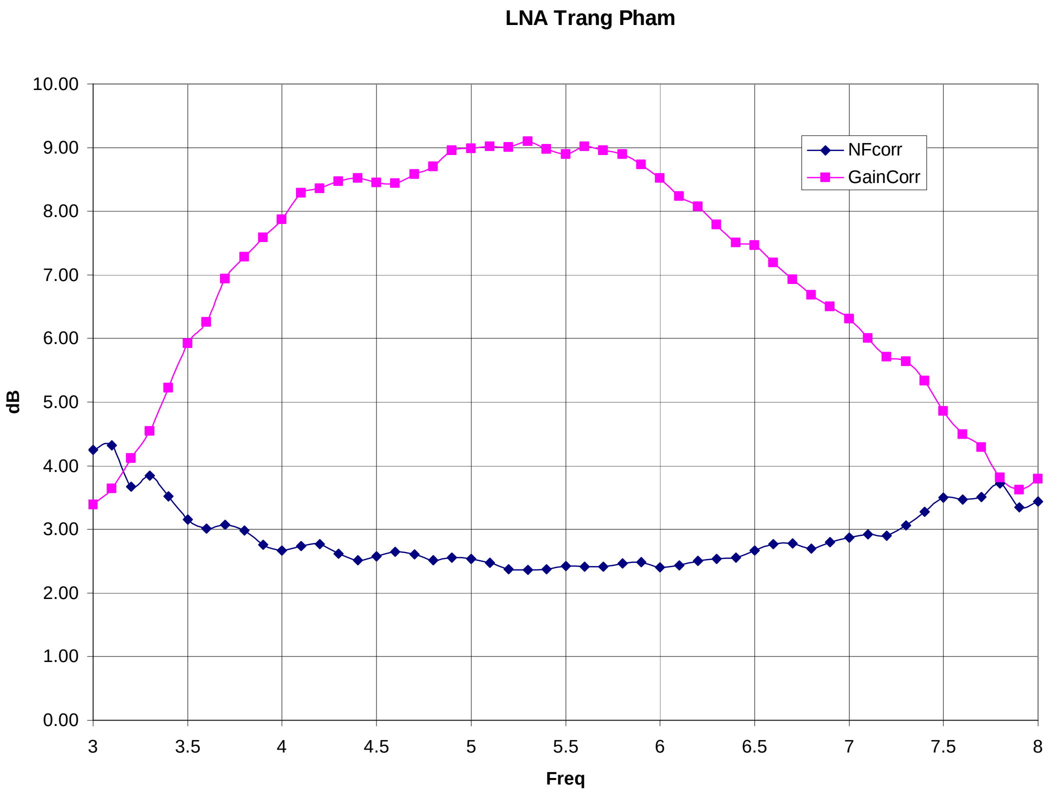
Measured Gain (Two Die -- 3V @ 60 mA)



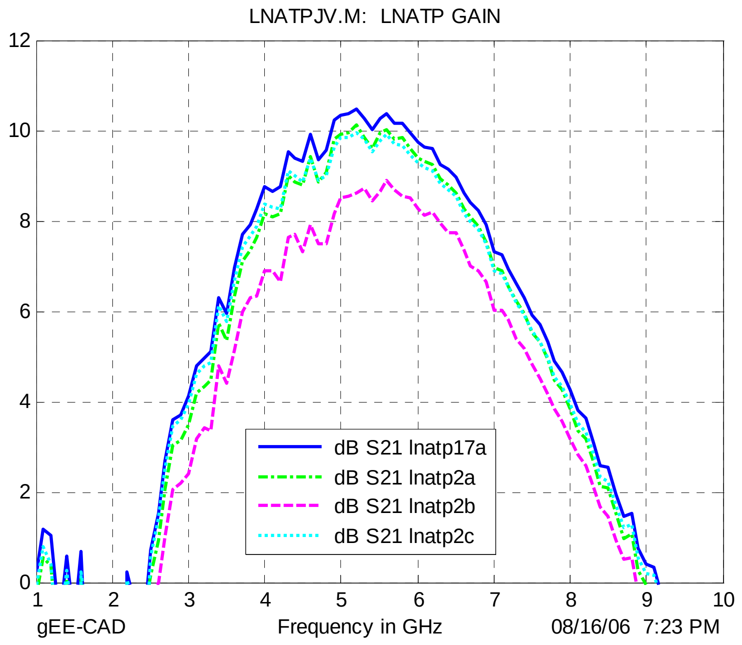
Measured Input/Output Match S11/S22 (Two Die -- 3V @ 60 mA)

Low Power Low Noise Amp - Trang Pham & John Vitamvas

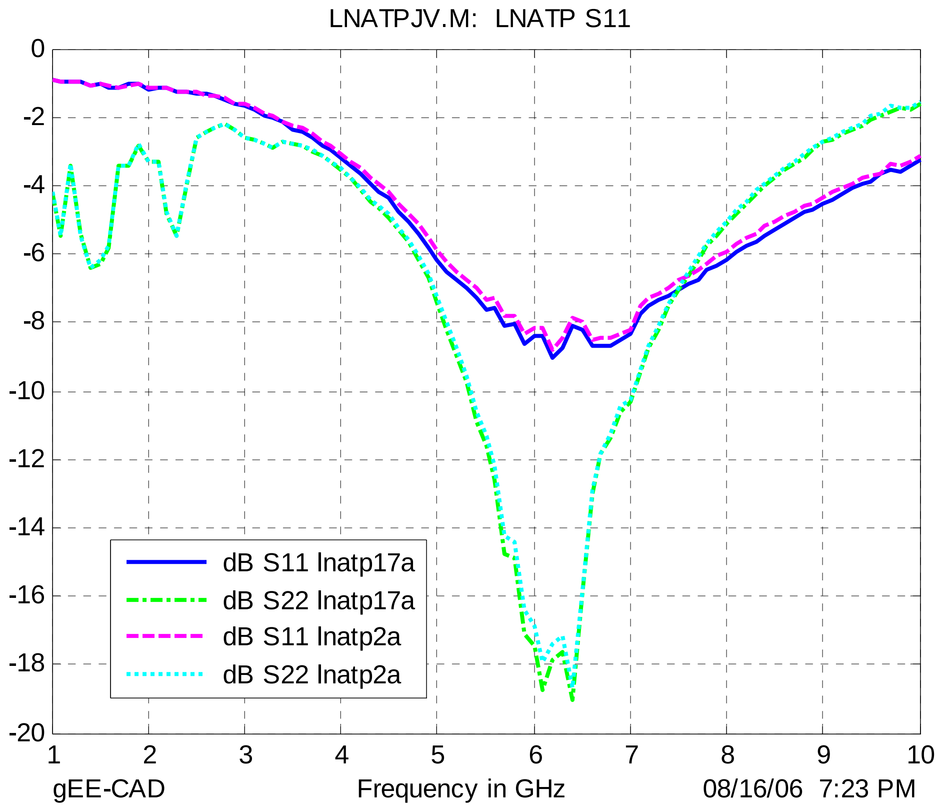
A C-Band Low Power Low Noise Amplifier was designed for the 5.15 to 5.35 GHz and 5.725 to 5.875 GHz WLAN and ISM bands. The goal was to design an LNA with 5 to 10 mW of DC power consumption. To keep the design simple, the LNA was made with a single stage using a relatively small PHEMT device. It was tested at 1.7 to 2.0 V with 5 to 6 mA of bias. Following are the plots of measured s-parameters and noise figure data. After correction for losses, the noise figure is just over 2.0 dB in the band.



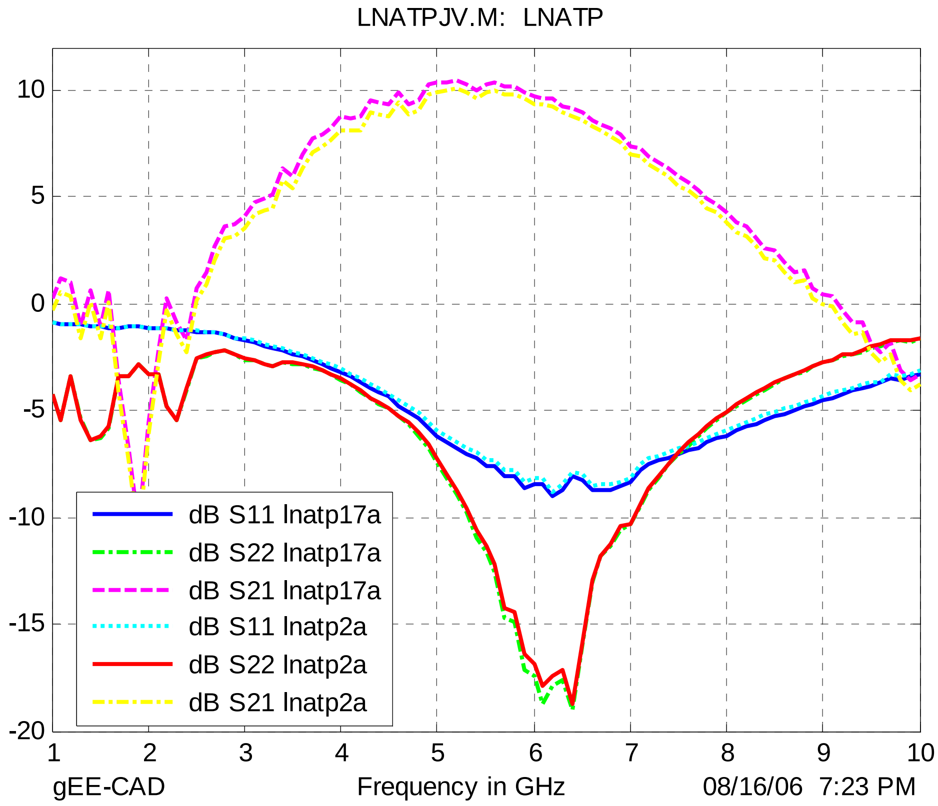
Noise Figure and Gain Measured with Noise Figure Meter (Losses Subtracted Out)



Gain (S21) of Three Different Die at 2V and 1.7V (5-6 mA IDS).



Input and Output Match (S11/S22) of a Single MMIC Die at 2V and 1.7V (5-6 mA IDS).

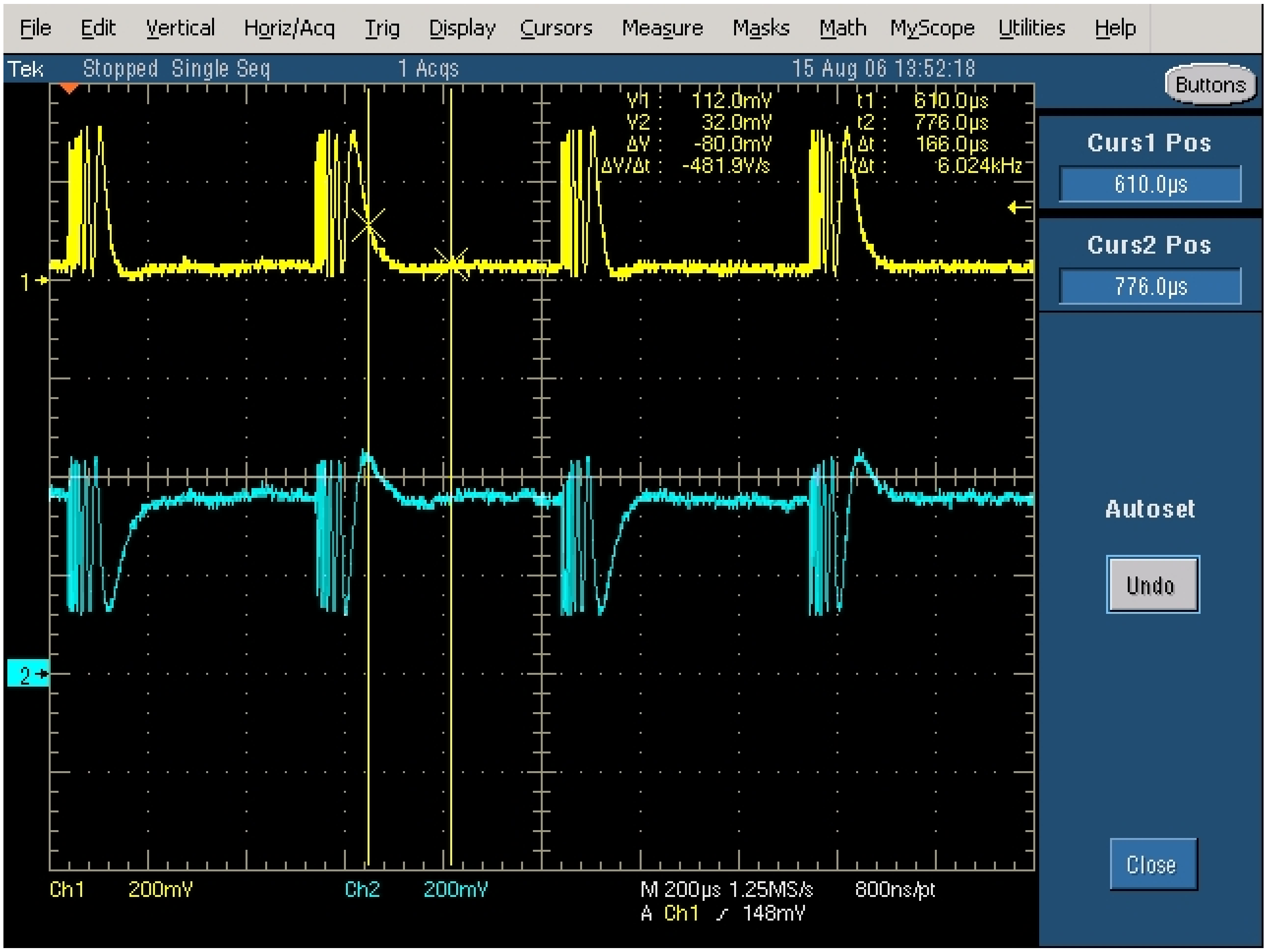


All s-parameters of a Single MMIC Die at 2V and 1.7V (5-6 mA IDS).

Tom Beglin & Greg Eckenrode – Vector Modulator and IQDemodulator

A C-Band Vector Modulator and an IQ Demodulator was designed for the 5.15 to 5.35 GHz and 5.725 to 5.875 GHz WLAN and ISM bands. The two designs use a similar architecture with the Vector Modulator for up-converting or transmitting data, and the IQ Demodulator for the down-conversion or reception of data.

The IQ Demodulator MMIC was tested on a probe station using two signal generators phase locked together at 5.8 GHz. A separate signal generator was used to provide an external FM modulation signal to one of the generators. The I/Q demodulator outputs were connected to an oscilloscope via DC needle probes and cables from the probe station. Loss on the low frequency I/Q signals was ignored; while for the RF signals, the loss was about 1.75 dB per connection at 5.8 GHz for the Cascade probe and cables. Attached are some of the oscilloscope screen plots and a summary of the performance. One RF generator was used for the LO and had a fairly high level to drive the diodes into non-linear operation. It was measured with +12 and +14 dbm on the signal generator, at approximately the desired input level of +12 dbm at the MMIC. Below this drive level, the output started to drop significantly (non-linearly). Likewise, the second RF generator was set to 0, -4, and -8 dbm noting the linear response of the I/Q outputs. A square wave of 1 KHz was input and the response of the I/Q outputs was captured. It looks similar to a chirp signal (radar) starting at high frequency and then sweeping to lower frequency with the I and Q signals 90 degrees out of phase. Each square wave edge causes a similar response—see plot showing a couple cycles of the square wave and a zoomed in plot showing the initial impulse response to a single edge of the square wave.



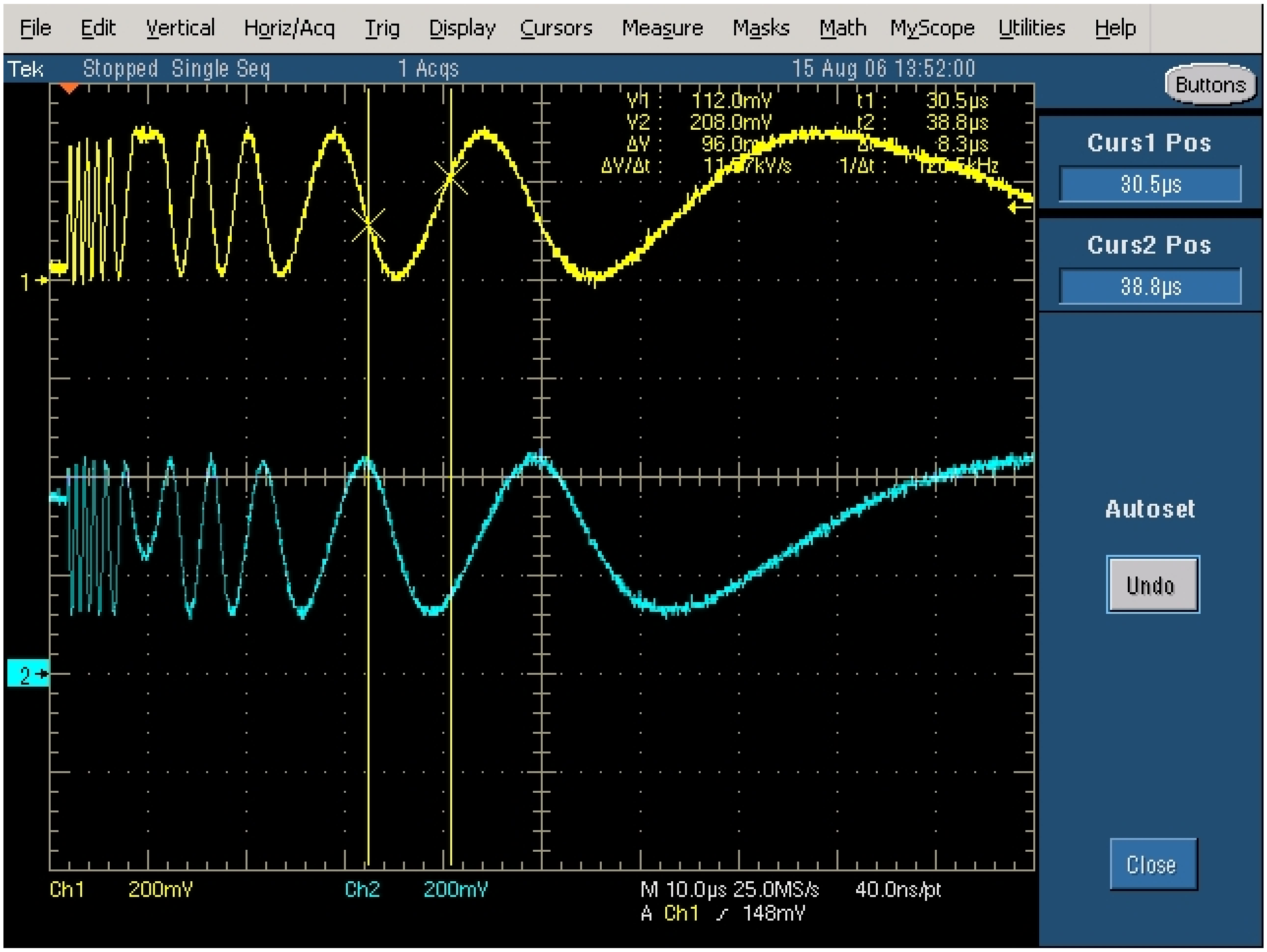
```
Tek   Stopped  Single Seq          1 Acqs               15 Aug 06 13:52:18

  V1 :    112.0mV        t1 :   610.0µs
  V2 :     32.0mV        t2 :   776.0µs
  ΔV :    -80.0mV        Δt :   166.0µs
ΔV/Δt :  -481.9V/s      1/Δt :    6.024kHz

Curs1 Pos   610.0µs
Curs2 Pos   776.0µs

Ch1    200mV          Ch2    200mV          M 200µs 1.25MS/s     800ns/pt
                                            A  Ch1  ⨍  148mV
```

Plot of I/Q response to 1 KHz FM square wave modulation (320 mV pk-pk ~-5.9 dBm)



Tek Stopped Single Seq 1 Acqs 15 Aug 06 13:52:00

V1 : 112.0mV
V2 : 208.0mV
ΔV : 96.0mV
ΔV/Δt : 11.57kV/s
t1 : 30.5µs
t2 : 38.8µs
Δt : 8.3µs
1/Δt : 120.5kHz

Curs1 Pos 30.5µs
Curs2 Pos 38.8µs

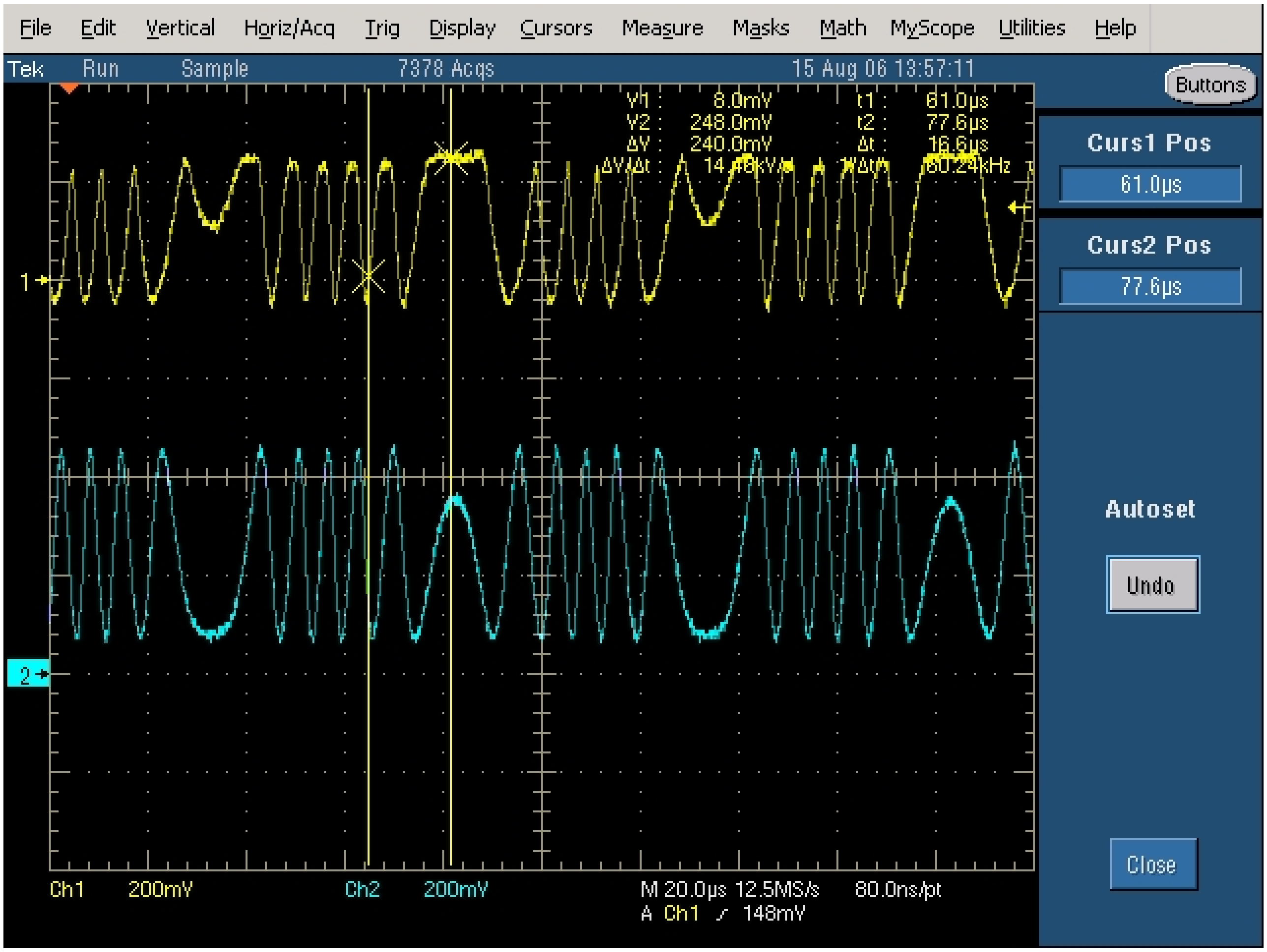
Ch1 200mV Ch2 200mV M 10.0µs 25.0MS/s 40.0ns/pt
A Ch1 ⟋ 148mV

Plot of I/Q impulse response to 1 KHz FM square wave edge (320 mV pk-pk ~-5.9 dBm)

Then a sine wave modulation was input, which was expected to generate pure sine waves on the I/Q outputs separated by 90 degrees of phase. As can be seen, the outputs look like sine waves 90 degrees out of phase but with periodic phase shifts or phase reversals. The period of the phase jumps repeats every 50 usec, but it is not clear why the test setup creates this result. Possibly this is some effect of the phase syncing of the two signal generators. The IQDemodulator MMIC appeared to work very well.

LO (SigG)	LO (MMIC)	RF (SigG)	RF (MMIC)	I/Q output (V pk-pk/dbm)
+12	+10.25	-8	-9.75	160 mV / -12.0 dbm
+12	+10.25	-4	-5.75	240 mV / -8.4 dbm
+12	+10.25	0	-1.75	400 mV / -4.0 dbm
+14	+12.25	0	-1.75	410 mV / -3.8 dbm

* Note: I/Q output power calculated from voltage waveforms assuming a 50 ohm load



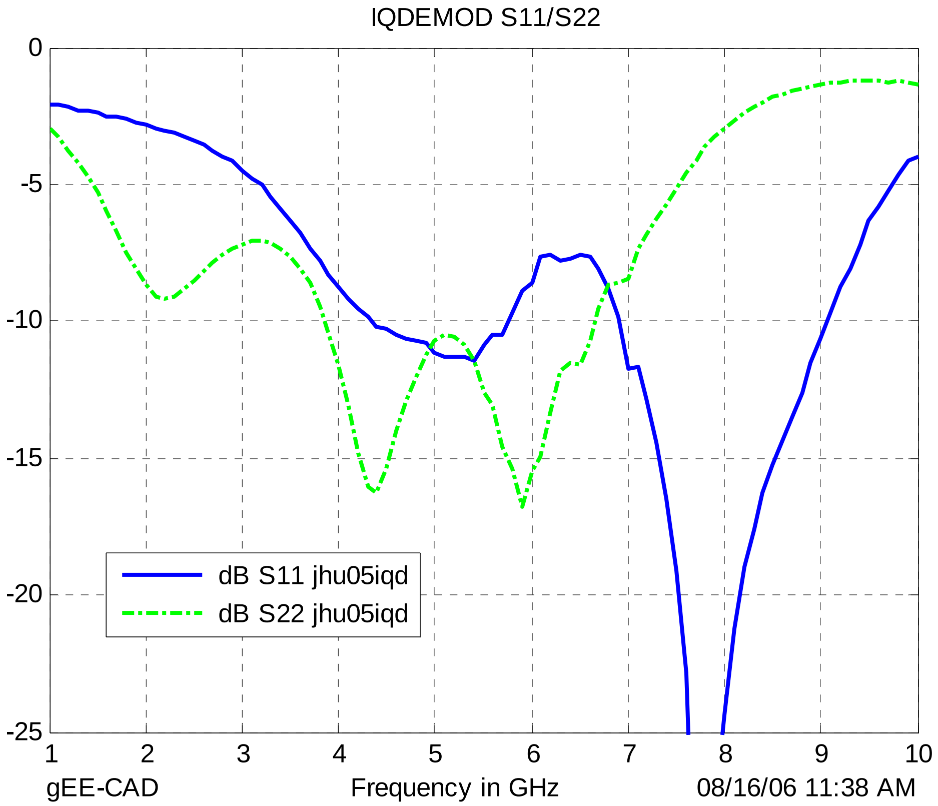
V1 : 8.0mV
V2 : 248.0mV
ΔV : 240.0mV
ΔV/Δt : 14.46kV/s
t1 : 61.0µs
t2 : 77.6µs
Δt : 16.6µs
1/Δt : 60.24kHz

Curs1 Pos 61.0µs
Curs2 Pos 77.6µs

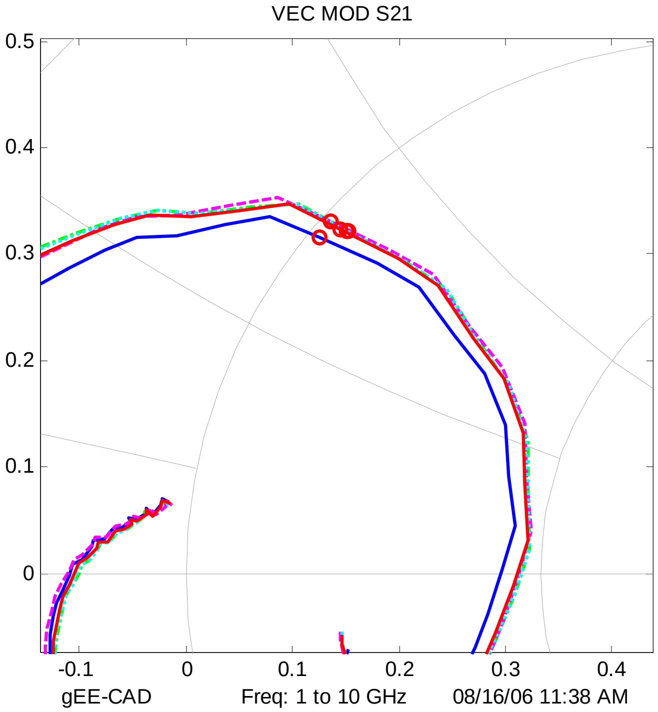
Ch1 200mV
Ch2 200mV
M 20.0µs 12.5MS/s 80.0ns/pt
A Ch1 ⟋ 148mV

Plot of I/Q impulse response to FM sine wave with 10.25 dBm/-1.75 dbm LO/RF input

The architectures of the IQ Demodulator and Vector modulator are similar. A lumped element brachline is used to provide a 0 and 90 degree split with a lumped element Wilkinson used to provide an in-phase split (or combiner). For the Vector Modulator, two attenuators for the I/Q inputs are created from a lumped element branchline hybrid connected to matching PHEMTs used as variable resistors (attenuators). In the IQ Demodulator, two mixers are created from a lumped element branchline hybrid connected to PHEMT diodes for the I/Q outputs. Since the architectures are similar, the input and output match of the two designs are also similar. Following is a plot of the typical input and output match of the C-band designs. Match is typically better than 10 dB over the 5.15 to 5.9 GHz band. Also following is a Smith Chart plot of S21 with markers at 5.5 GHz. I/Q biases were varied from -0.7V to +0.5V with only a small amount of amplitude and phase change. Ideally, varying I/Q would sweep out a roughly square shape centered on the Smith Chart. Not sure why there was little variation, though the DC needle probes were definitely making contact as evidenced by measured current through the 50 ohm resistors that provide match for the I/Q inputs.



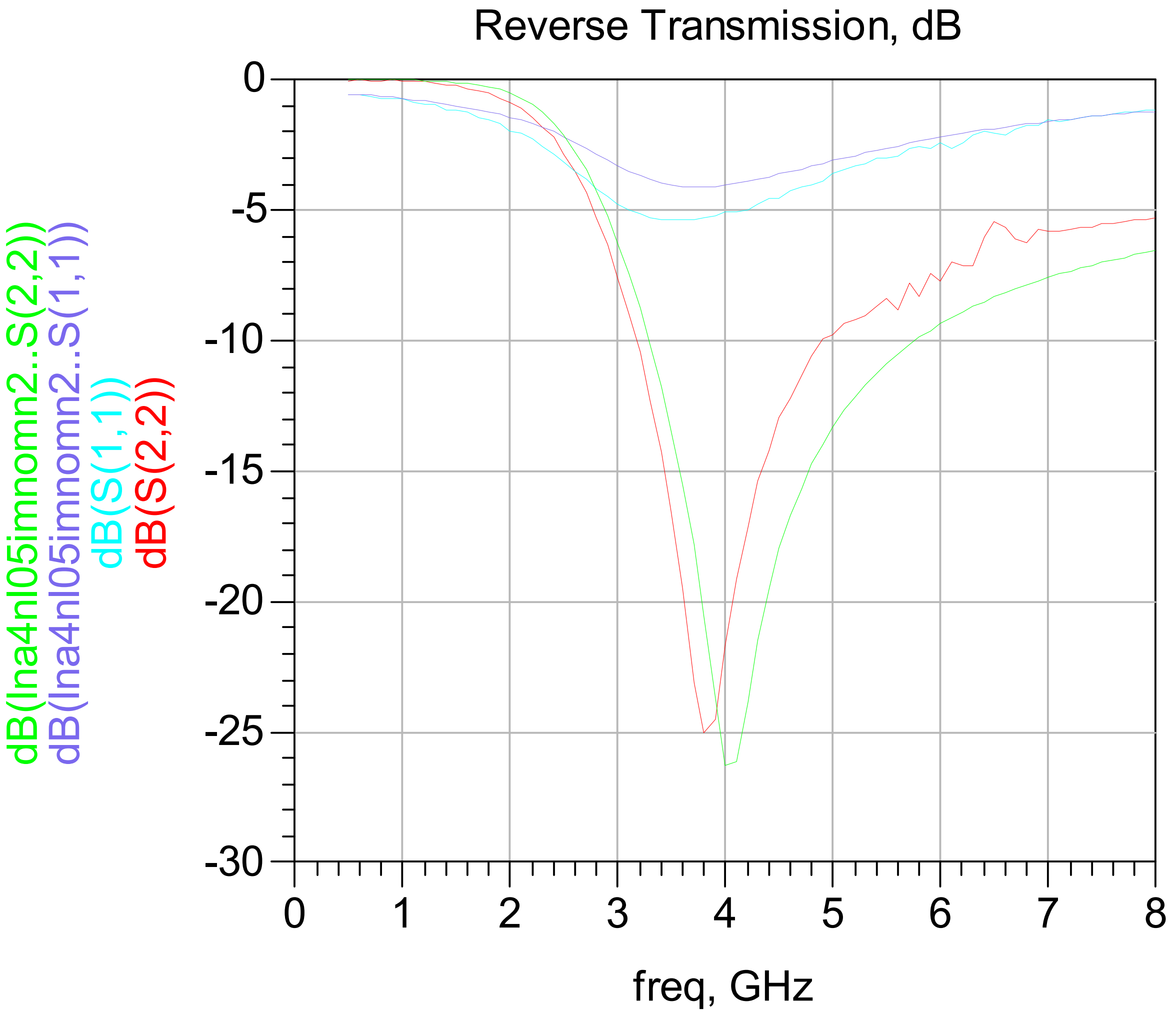
Typical Input/Output Match Vector Modulator/IQ Demodulator



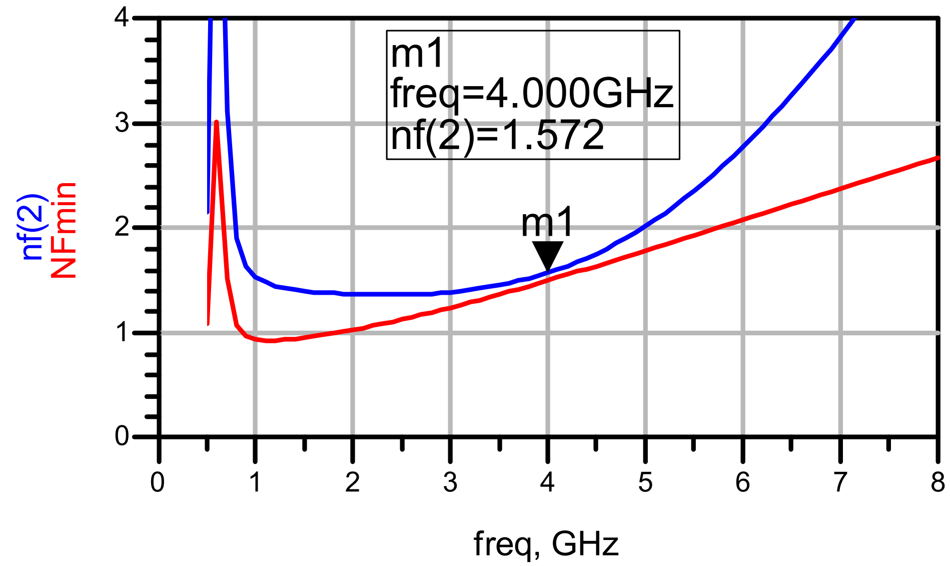
S21 Vector Modulator with I/Q varied over -0.7V to +0.5V—Note markers at 5.5 GHz

Class Design Examples: Low Noise Amplifier and Power Amplifier (4 GHz) by John Penn

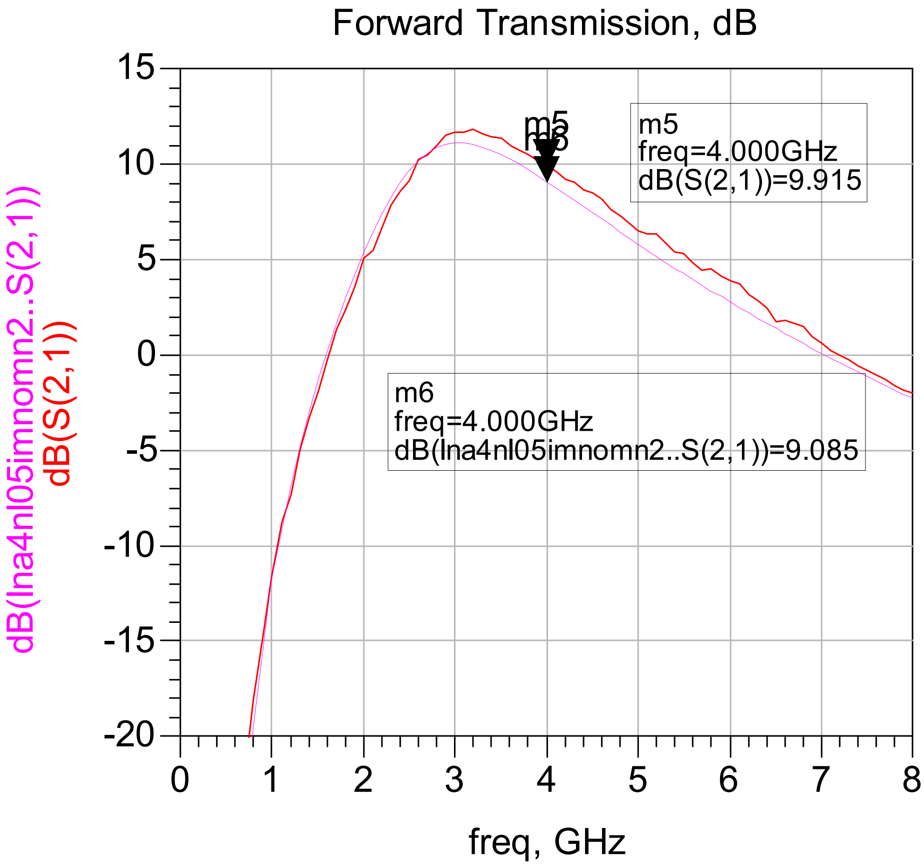
During the course the students are shown a design example of a low noise amplifier and a medium power amplifier at 4 GHz. In the past couple of years layouts were completed for the LNA and PA design in Agilent's ADS and later Microwave Office MWO on a single 60 x 60 mil die (54 x 54 after dicing) using TriQuint's TQTRX MESFET process. This year (2005), the LNA and PA examples were re-designed using ADS and TriQuint's 0.5 um PHEMT (TQPED) process. Measured data was taken of the two designs and follows. The s-parameters were measured twice—early in the student testing and later in the summer of 2006 using new high quality cables plus new probe tips and a new calibration. Measurements using the later setup produced more consistent data and are shown in the plots. Other test circuits were also designed to be used for future lectures and class examples. Output Power was a little lower than expected which seems to be consistent with other student designs on this wafer fabrication. Typically the measured output power was 4 to 5 dB lower than ADS simulations for both the LNA and PA design.



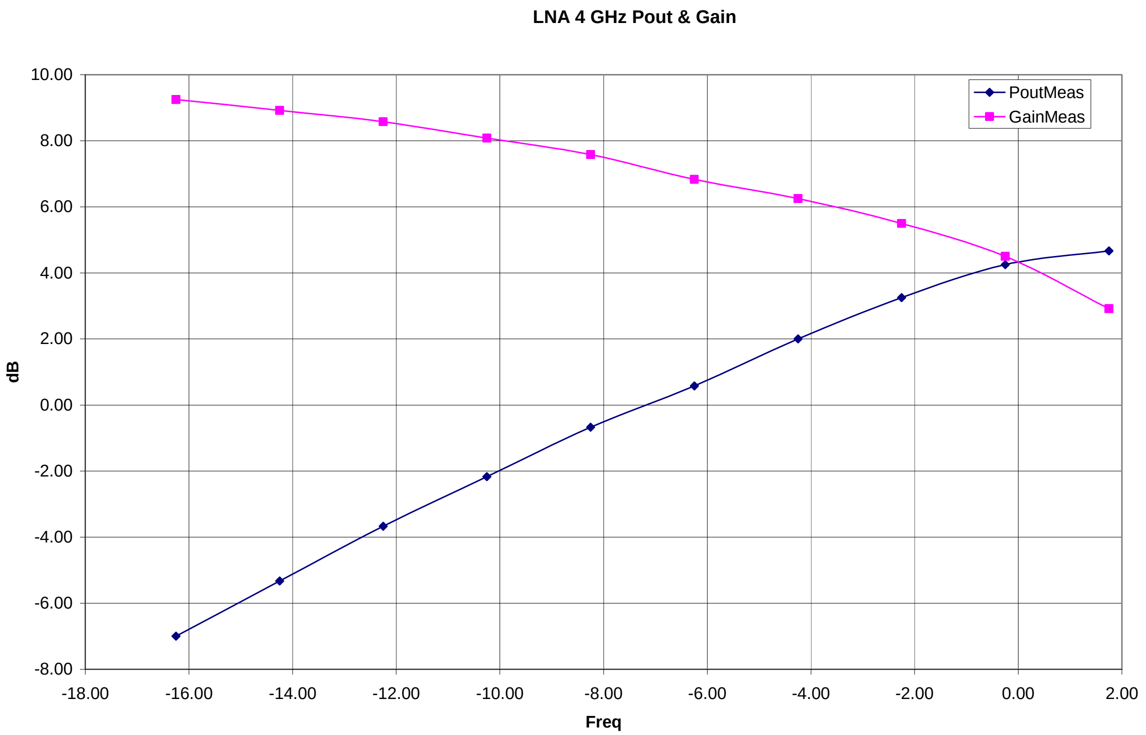
Meas Match vs. Simulation (ADS Non-Linear TOM model)



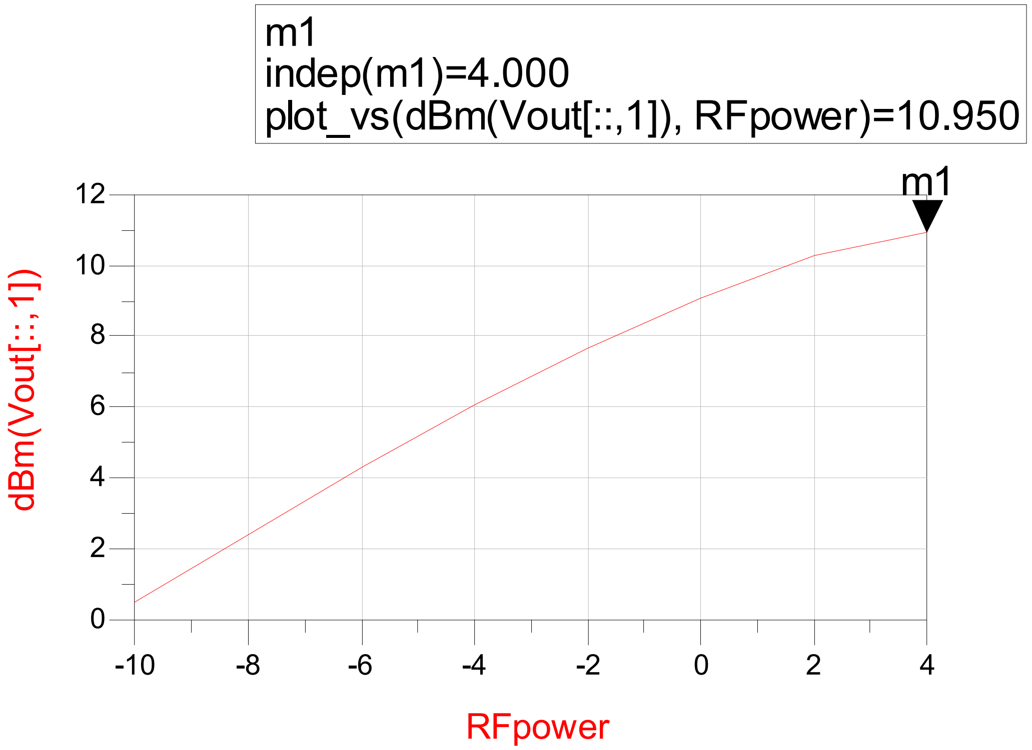
Predicted Noise Figure of LNA – 1.6 dB (ADS Non-Linear TOM Model)



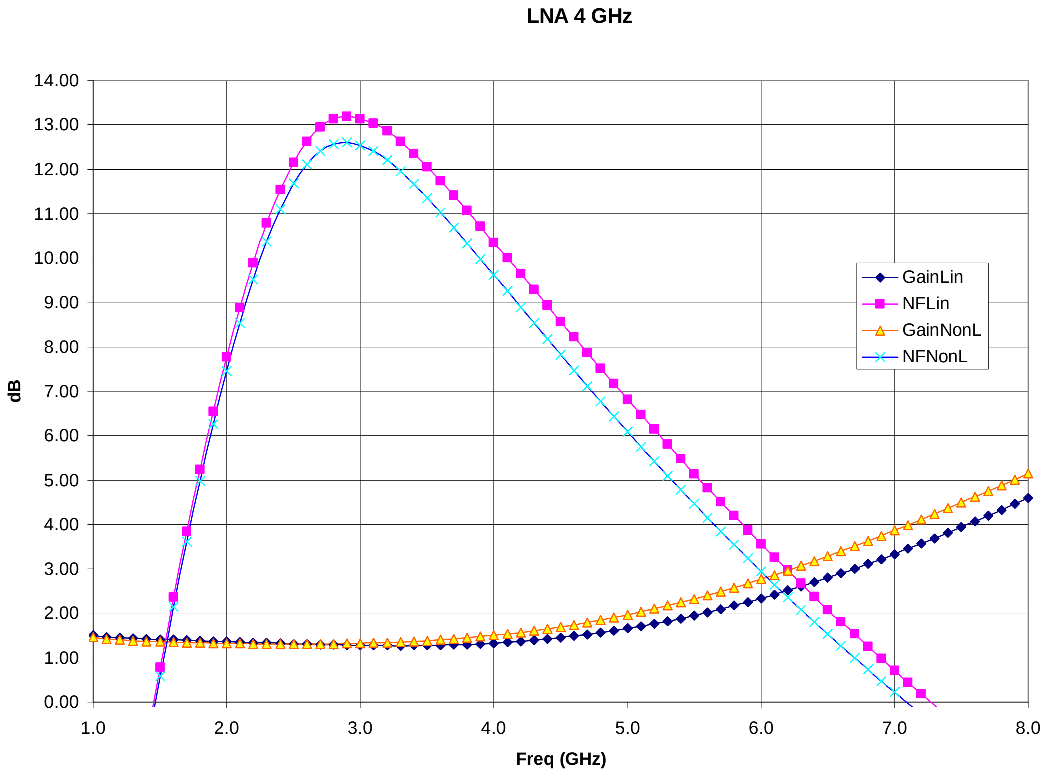
Meas Gain vs. Simulation of LNA – ~10 dB (ADS Non-Linear TOM model)



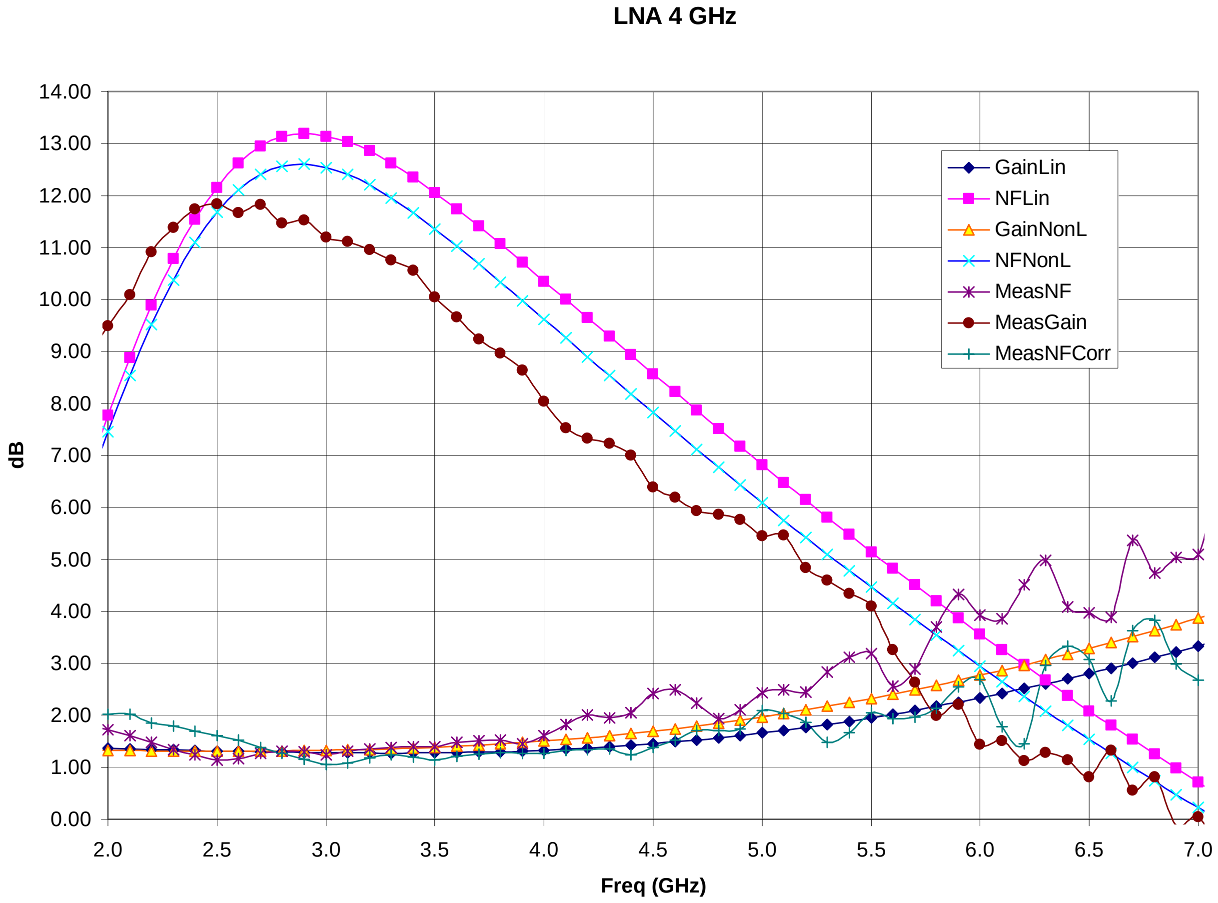
Measured Output Power and Gain of LNA



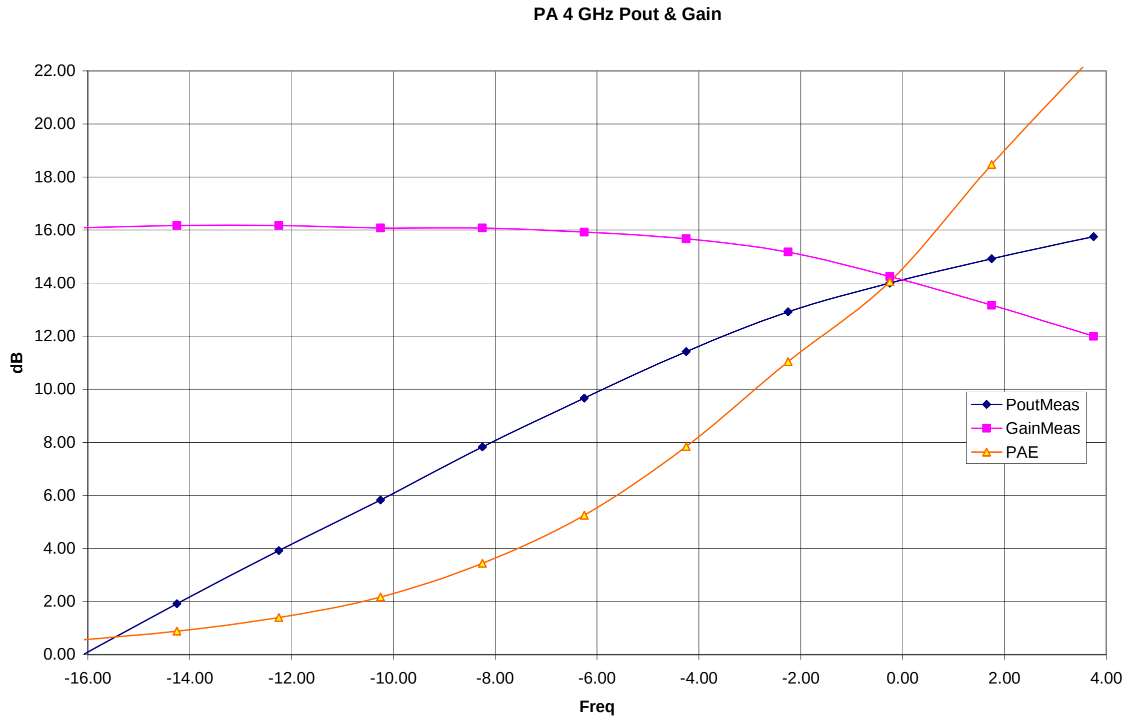
Predicted Output Power of LNA (ADS)



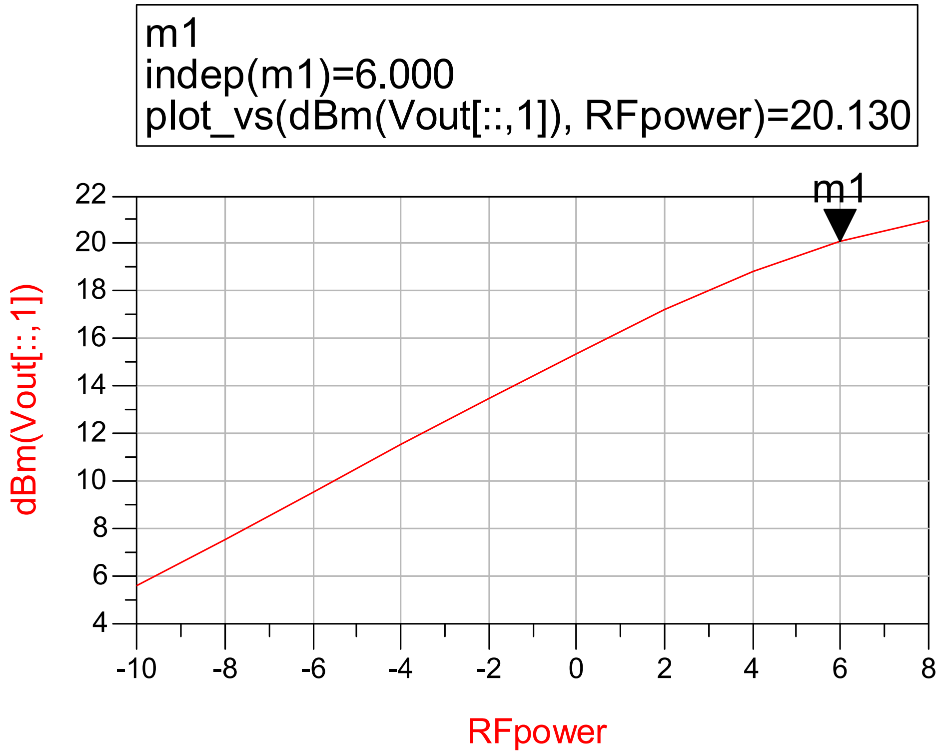
Predicted Noise Figure and Gain of LNA w/ Measured Linear versus TOM Non-Linear Model (ADS)



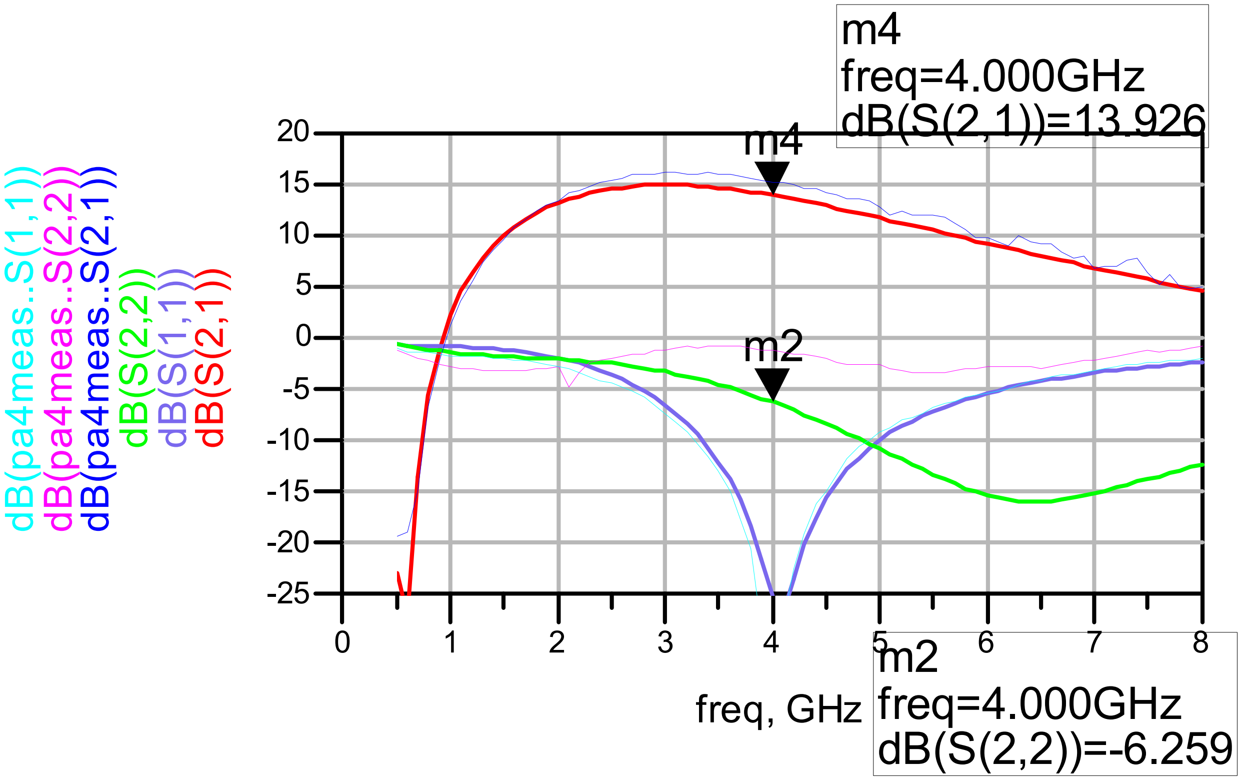
Predicted Noise Figure and Gain of LNA versus Measured (very similar)



<u>Measured Output Power of PA – 16 dBm (ADS)</u>



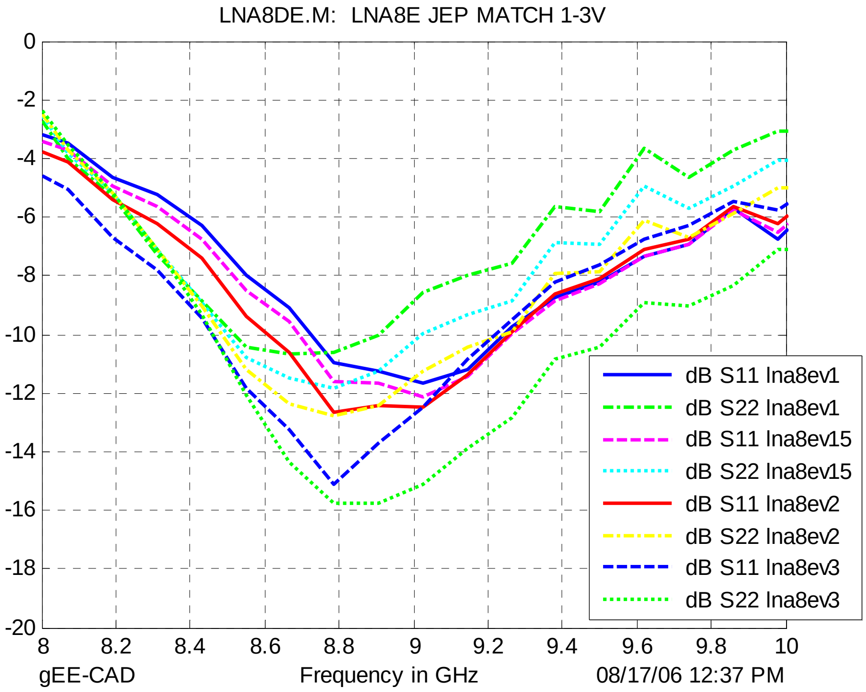
<u>Predicted Output Power of PA – 20 to 21 dBm (ADS)</u>



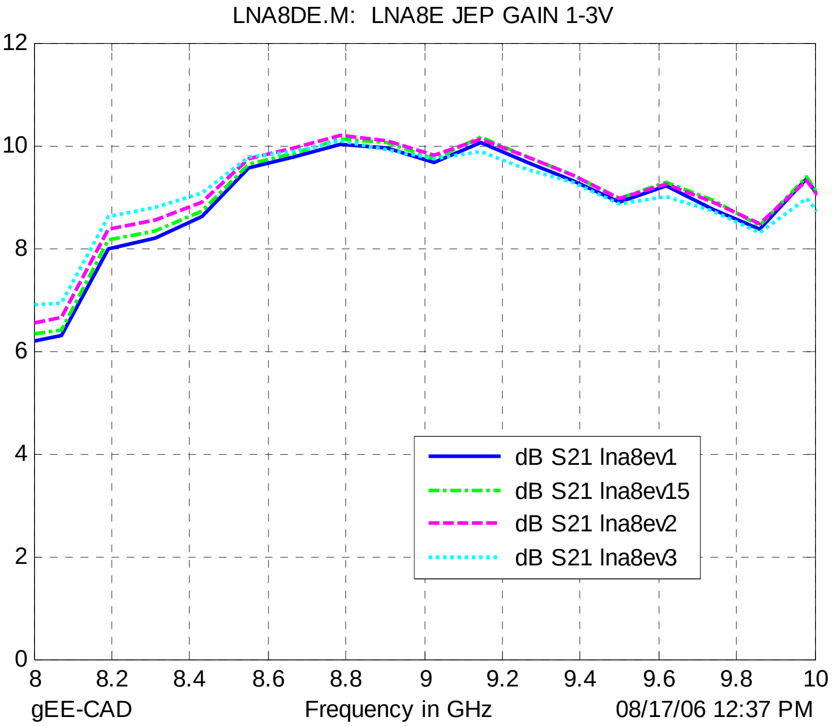
Meas vs. Simulation Power Amp S-Parameters (vs. ADS TOM Non-Linear Model)

Other Class Design Examples: Low Noise Amplifier DFET vs. EFET (8 GHz) by John Penn

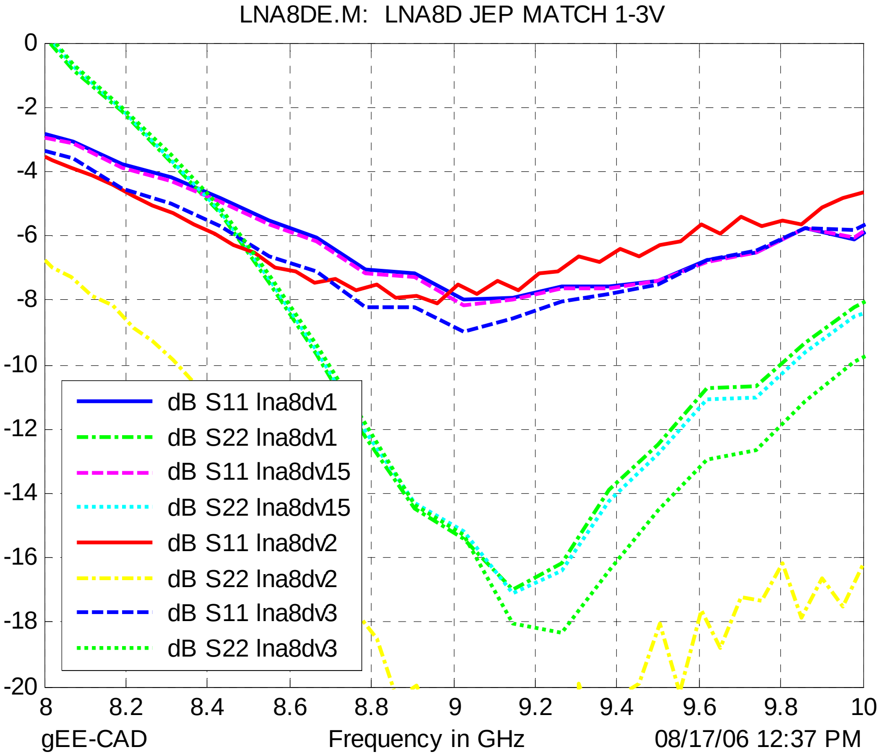
An extremely low power low noise amplifier was designed to compare the use of the DFET vs. the EFET for the TQPED process. Predictions were that the EFET would have slightly better noise figure and better gain (~ 2 dB) for the same DC power consumption. LNA test circuits with 50 um devices were tested from 1V to 3V VDS with a mere 1-2 mA of IDS currently. As predicted, the EFET had better performance for the few mW of DC power consumption. Gain and Match shifted a bit from predictions but the small PHEMT device was a higher Q and is harder to match to than a standard 300 um sized device. The layouts for the DFET and EFET LNA were virtually identical with a small difference (i.e. “tweak”) for tuning the input and output match.



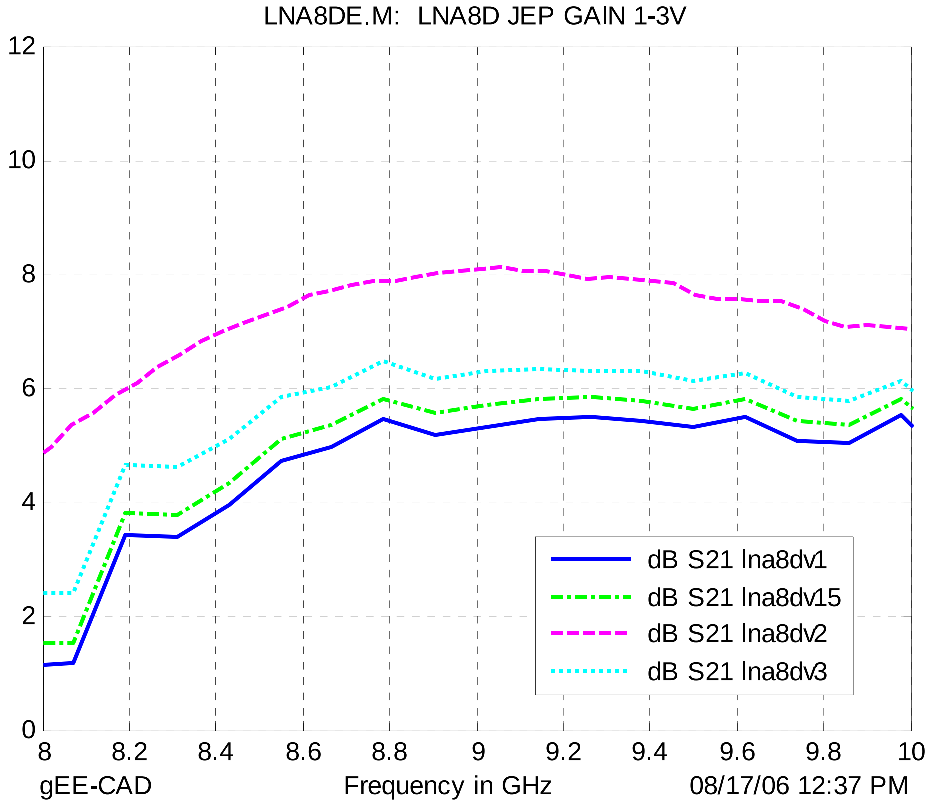
Input/Output Match of EFET LNA at 1 to 3 V VDS and 1 mA IDS.



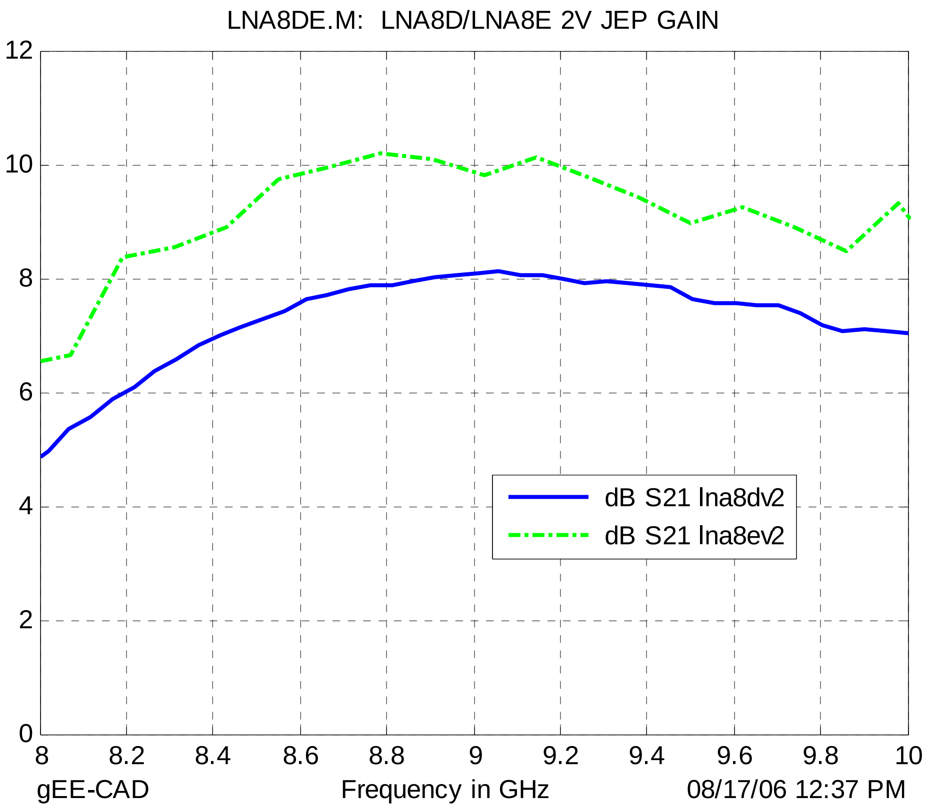
Gain S21 of EFET LNA at 1 to 3 V VDS and 1 mA IDS.



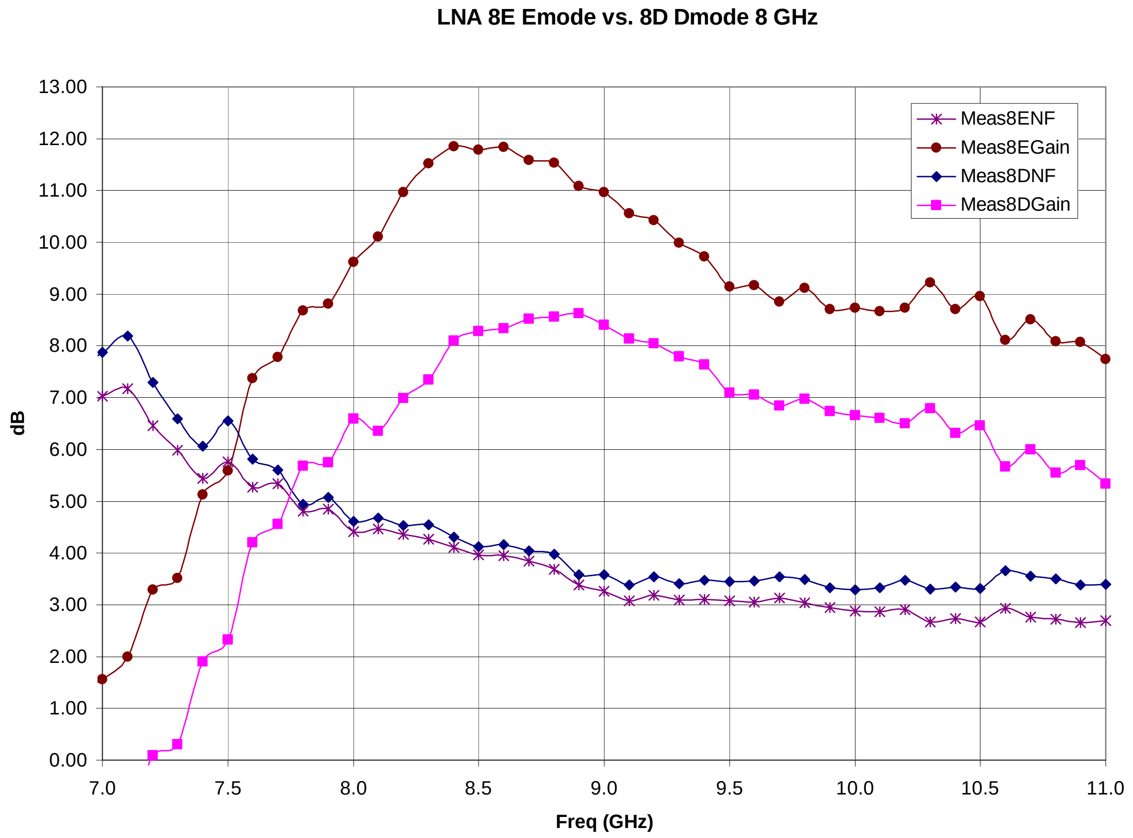
Input/Output Match of DFET LNA at 1 to 3 V VDS and 1 mA IDS.



Gain S21 of DFET LNA at 1 to 3 V VDS and 1 mA IDS (Note lower gain vs. EFET LNA).



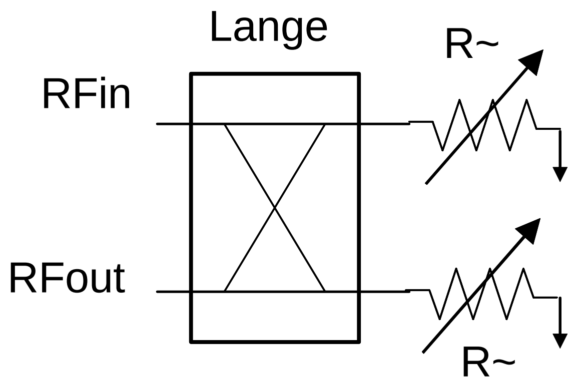
Measured Gain of EFET (green) and DFET (blue) LNAs at 2V and 1 mA IDS.



Comparison of Measured Noise Figure and Gain of EFET and DFET LNAs

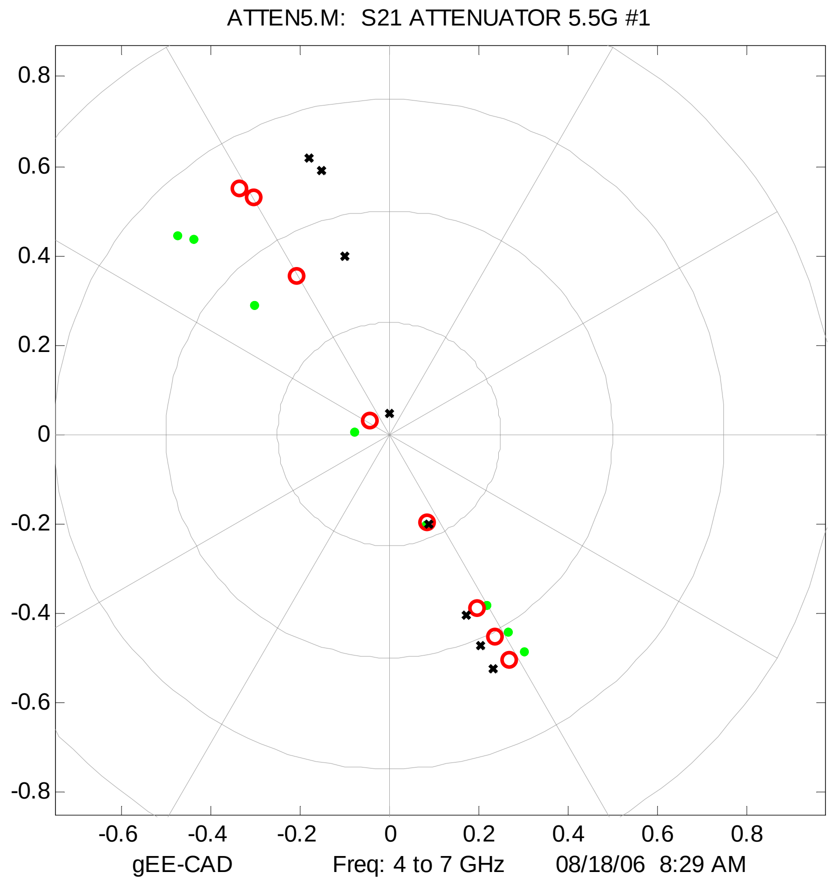
Other Class Design Examples: Attenuators at 5.5 GHz and 8 GHz by John Penn

One key piece of the vector modulator design is an attenuator. A simple attenuator made from a lumped element branchline hybrid uses PHEMTs as variable resistors. The parasitic capacitance of the PHEMTs as switches skews the desired response from a straight line to a curved line. Smaller devices and lower frequencies will yield less parasitic effect, but if you make the device too small, it will not yield the desired attenuation range. For example if the variable resistor could change from 10 ohms to 250 ohms you would get comparable attenuation at 10 and 250 ohms but with a 180 degree phase shift. Varying from 10 to 50 ohms goes from a maximum to a minimum amplitude and increasing from 50 to 250 ohms increases the output from a minimum to a maximum but with a 180 degree phase shift relative to resistances less than 50 ohms. Test circuits for 5.5 GHz and 8.5 GHz were measured with good results at 5.5 and poor but potentially useable results at 8.5 to 9 GHz (not shown).

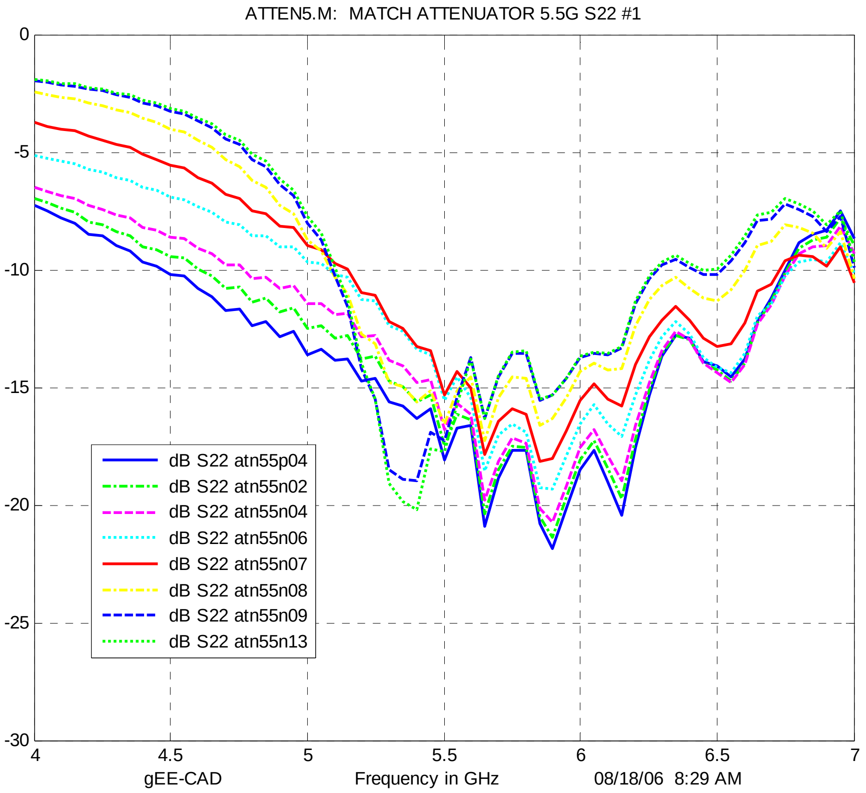


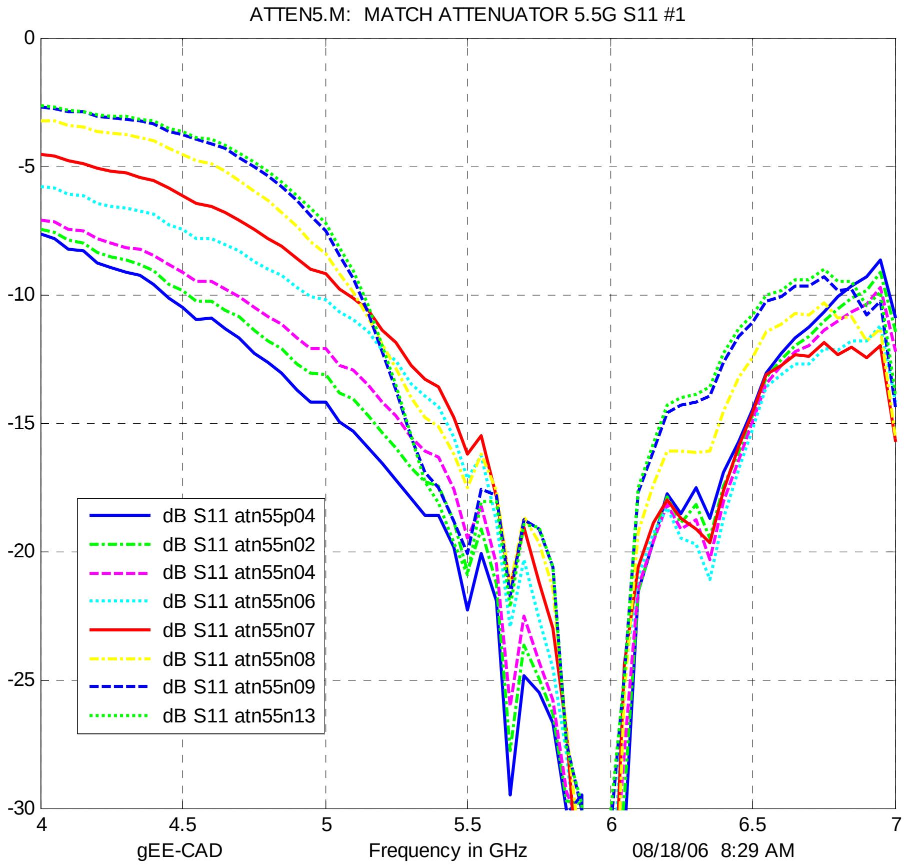
Res.	Attenuation (G)
0	+1
10	+0.67
25	+0.33
50	0
100	-0.33
250	-0.67
Inf.	-1

Attenuator using Lange or Brachline Coupler Plus a Pair of Identical Variable Resistors.

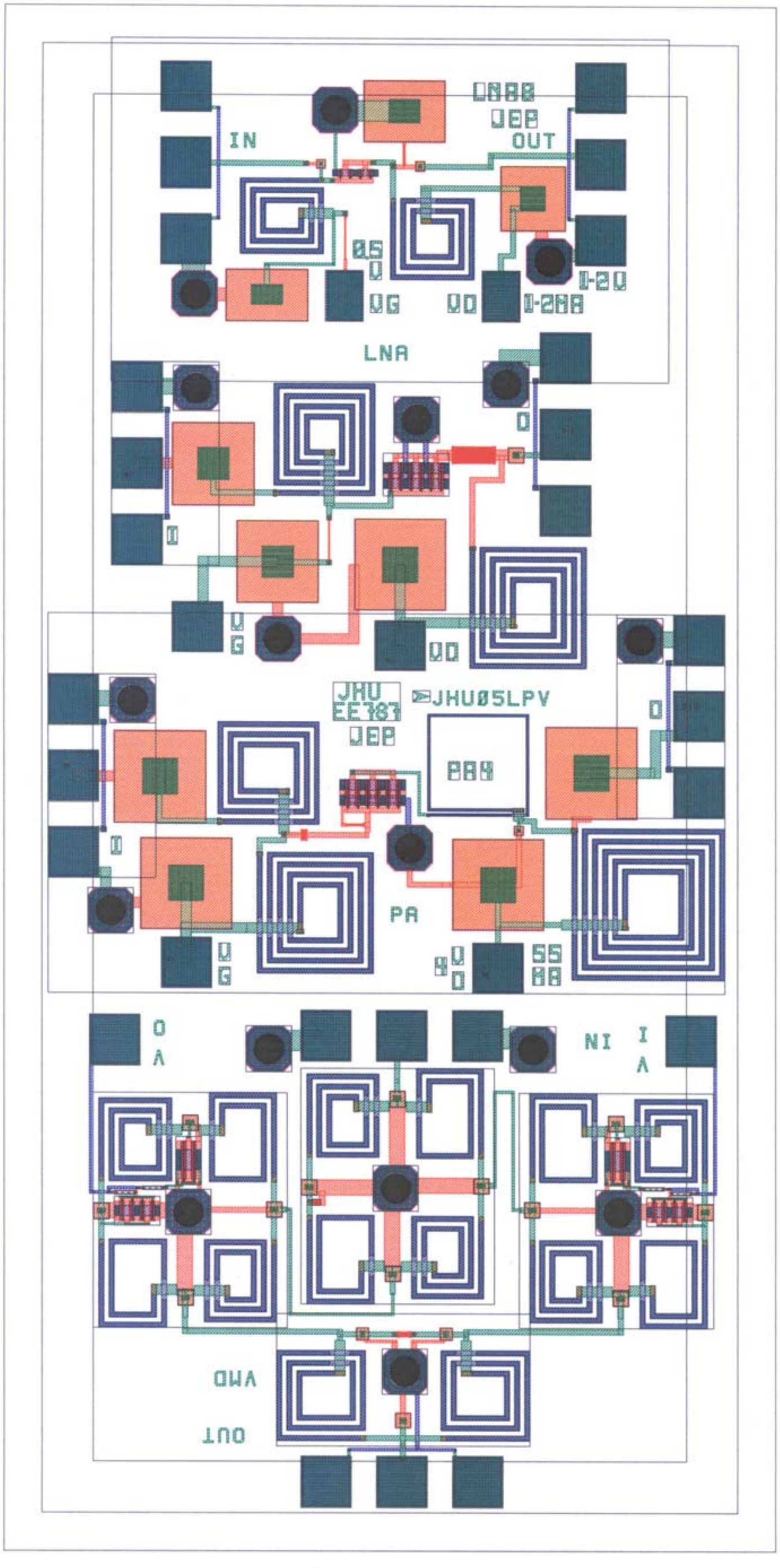


Measured C-Band Attenuator (5.4 G-green, 5.5G-red, 5.6G black)





C-Band Attenuator Input/Output Match



One of the EE787 JHU Test Circuits with a Very Low Power 8 GHz LNA (top), 4 GHz LNA (2nd from top), 4 GHz PA (2nd from bottom), and a 8-9 GHz Vector Modulator (bottom).