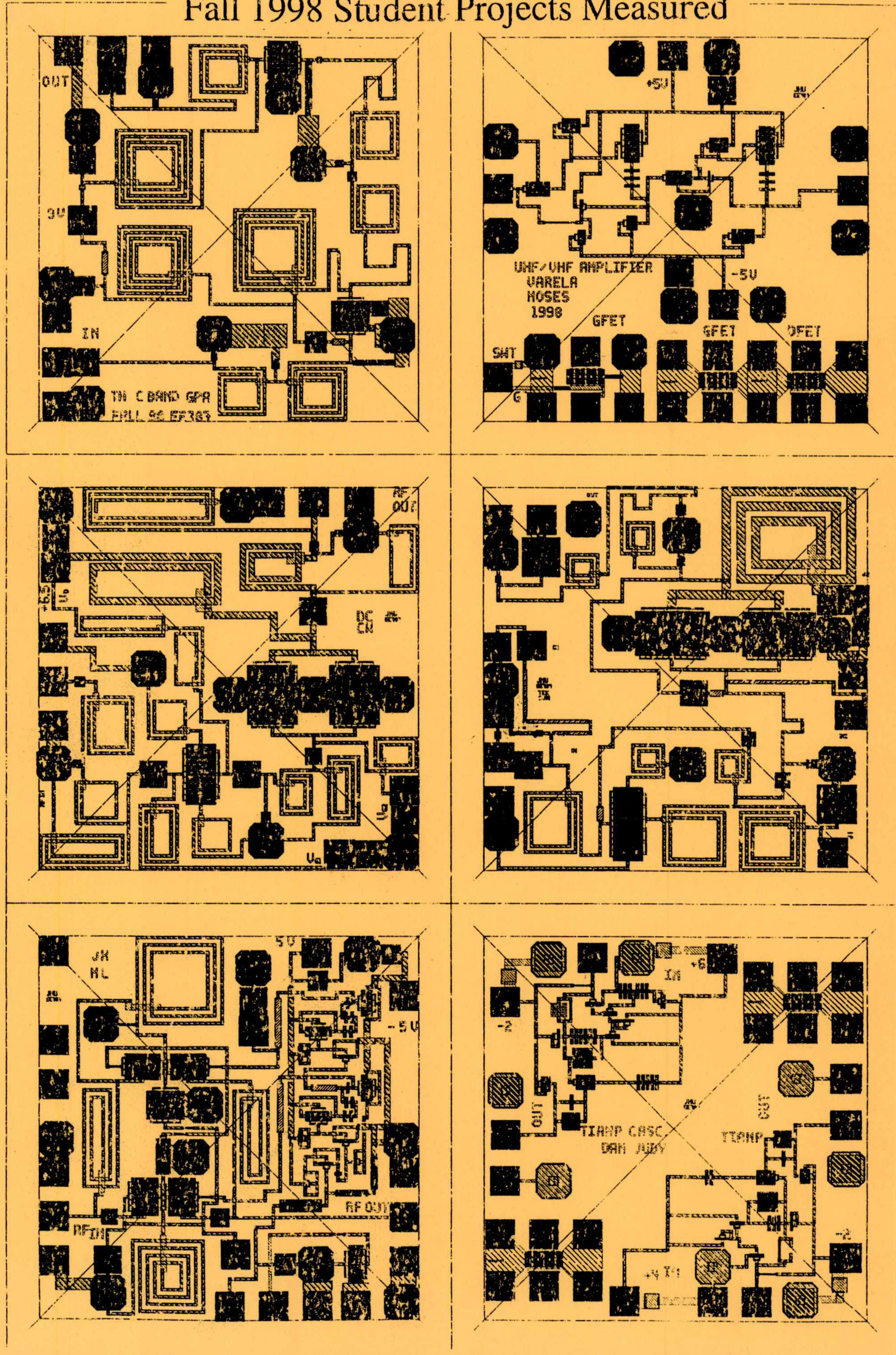
MMIC Design
JHU EE787
Fall 1998 Student Projects Measured



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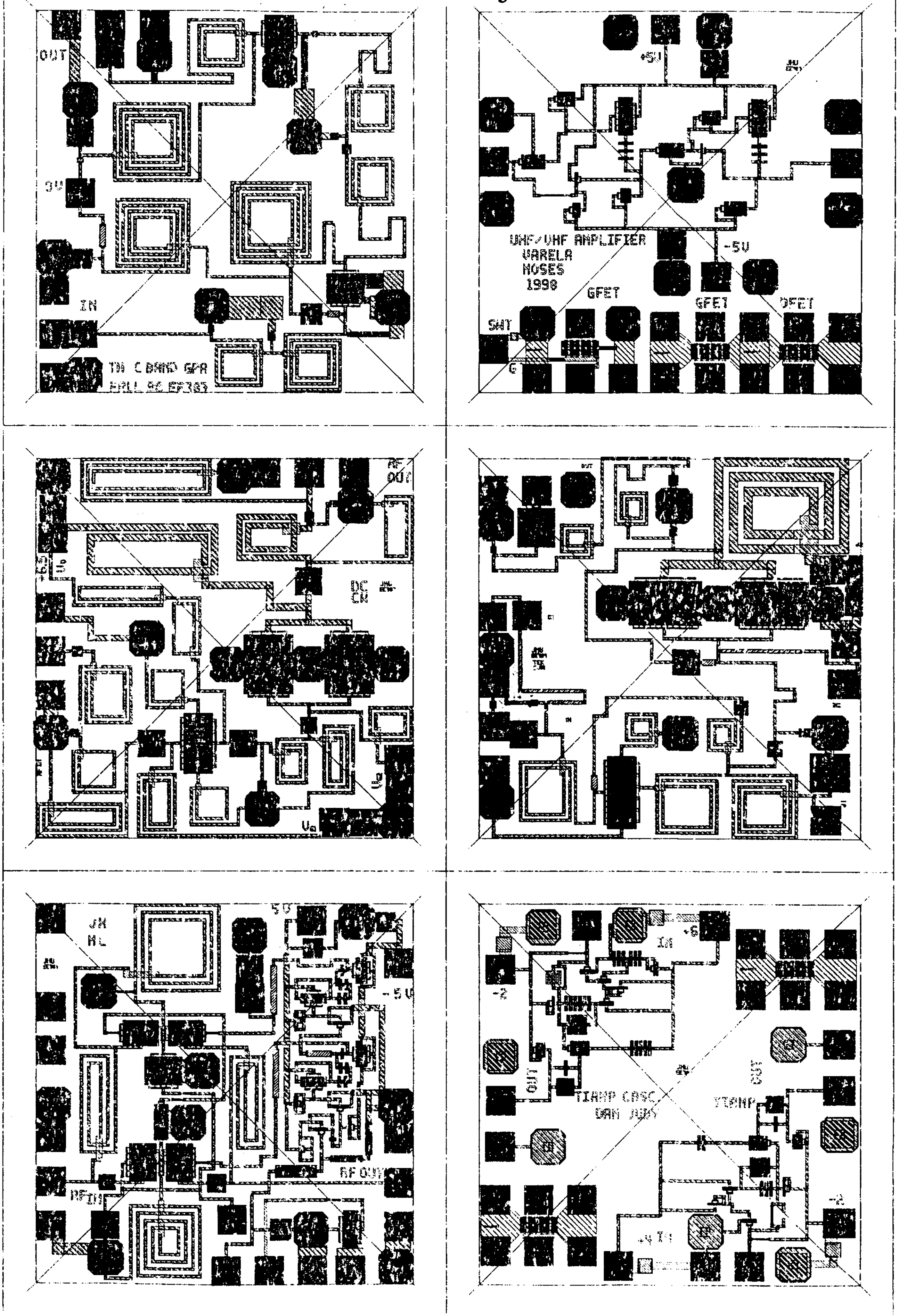


MMIC Design
JHU EE787
Fall 1998 Student Projects Measured

Craig Moore and John Penn

Summary: Following are the results of testing the Fall 1998 JHU MMIC EE787 Class designs. Five EE787 MMIC chips were fabricated by TriQuint plus one special graduate student project--a transimpedance amplifier by Dan Judy. The projects for the Fall 1998 JHU EE787 class formed a broad band chip set for wireless transceiver applications in the C-band (4.5 – 6 GHz) allocation. They included two C-band power 1 Watt amplifier designs, one general purpose C-band amplifier, one UHF/VHF general purpose amplifier (DC-2Ghz), and one quadrature modulator design. Also included in this Fall's fabrication run were several individual probable FETs. The UHF/VHF amplifier and the special student project transimpedance amplifier had ample room on the 60x60 mil die for these additional test structures. Attached are the results of those measurements which included S-parameter measurements and DC IV-curves. Walter Curtice helped probe test the devices (GFETs, DFETs, and EFETs) and was a big help in using HP's ICCAP software to measure the FET characteristics. All of the measured FET devices were extremely close to nominal. There was some difficulty in measuring a GFET layed out in a switch configuration. The difficulty was probably due to calibration issues using a new HP network analyzer that replaced the previous HP8510 analyzer at the Dorsey Center of Johns Hopkins University.

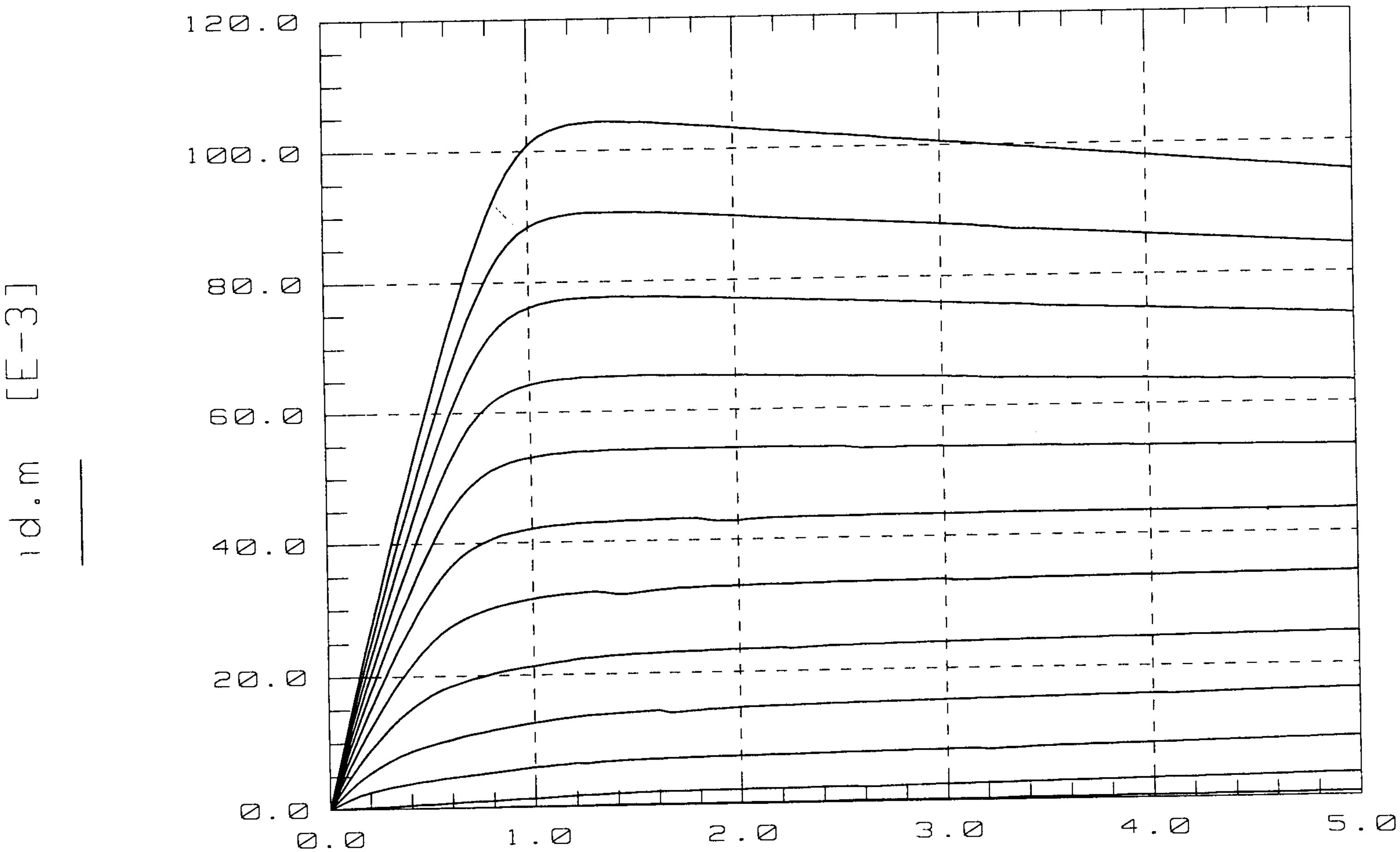
The projects worked more or less except for one of the power amplifier designs. Measured bias conditions in the designs were very close to predictions. The power amlifier that worked well produced 0.8W at 25% Power Added Efficiency using "probed" measurements. The other power amplifier was unstable under large biases when measured under probe conditions. Possibly this design might be stable if packaged, but this is just speculation. The quadrature modulator worked well but was probably shifted down in frequency from the original simulations. Likewise, the C-band general purpose amplifier worked fairly well except that output match was lower than expected and the broadband gain was slightly shifted down in frequency from the simulations. The two lower frequency designs, the UHF amp and the transimpedance amplifier had somewhat dissappointing results compared to simulations. This could have been due to modeling issues. The TOM2 model used for the 1997 and 1998 JHU EE787 MMIC Design classes had problems with higher bias currents, larger drain voltages, and lower frequencies (~2 GHz). The new TOM3 model used in this fall's EE787 class is much better than the TOM2 model used previously. Not only does it converge better in simulations, but its predictions are much closer to the linear models and to the FETs measured from the Fall 98 class wafer fabrication. For some bias conditions, the TOM2 would predict an unstable S22 which differed dramatically from the linear model. Fortunately, the newer TOM3 model for the GFET shows excellent agreement with linear models and measurements.

Once again I would like to thank all those at TriQuint who have supported this graduate course for so many years. Also, thanks to HPEEsof (now, Agilent) for all their help, particularly Gary Wray.

Attached are measurements of the individual DFETs, GFETs, and EFETs from the fall 98 MMIC fabrication. Measurements agree well with the linear models and with the newer TOM3 model. Following the FET results are the student project results.

Plot CG_curt3/dc/idvd_vg/id_vs_vd (On)

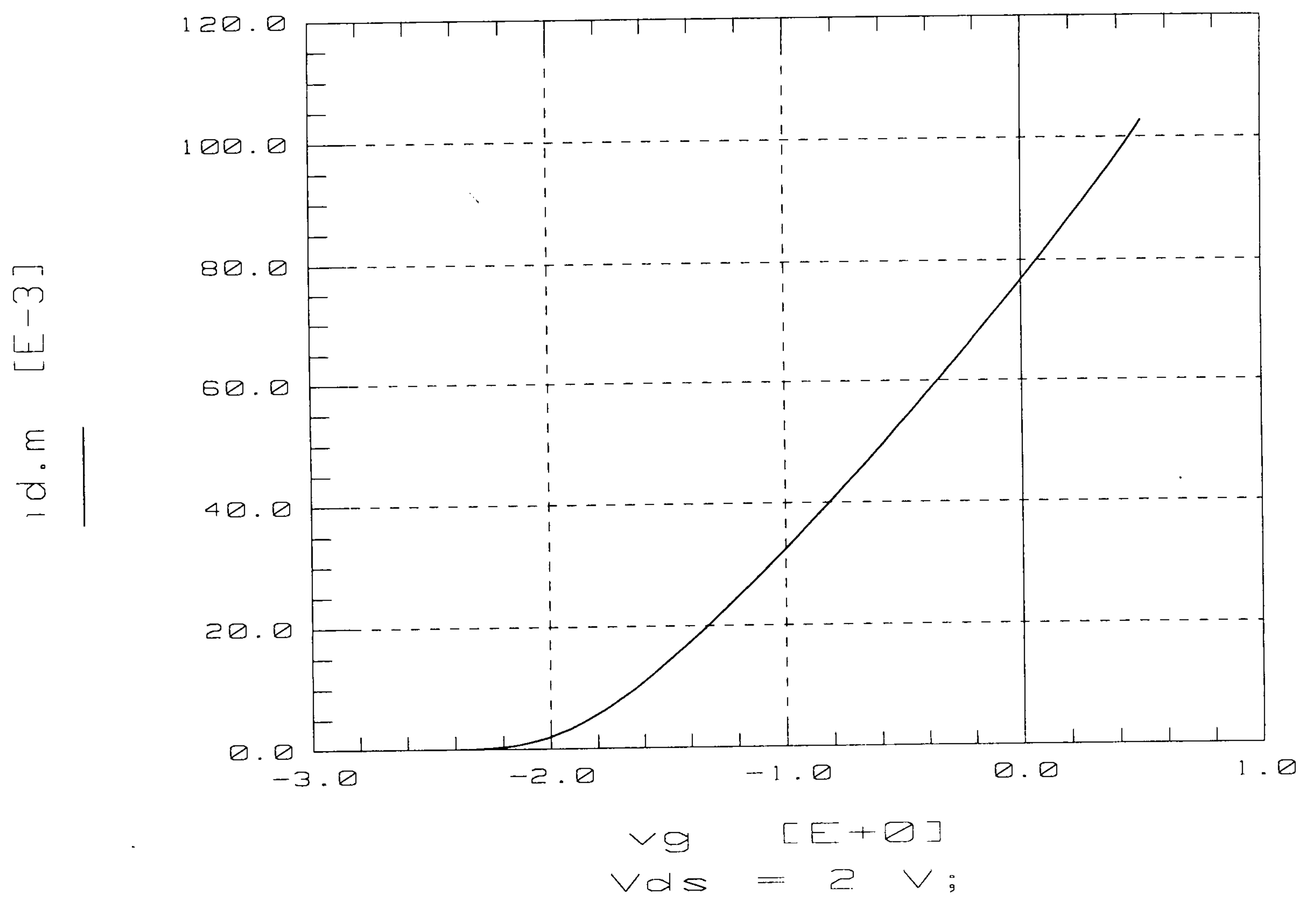
GFET 9-23-99



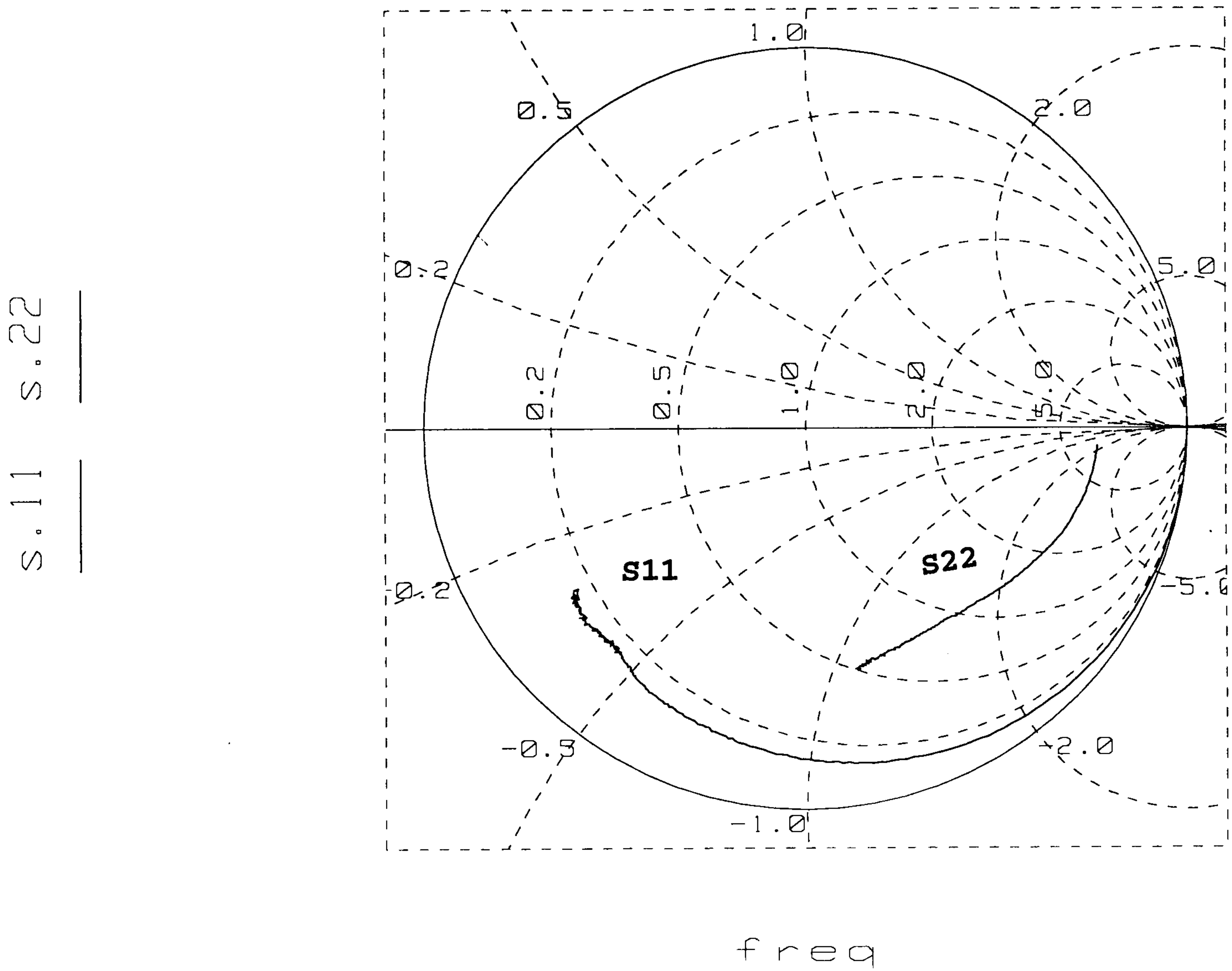
VGS=-2.5 to .5, step=.25

Plot CG_curt3/dc/idvg_vd/id_vs_vg (On)

GFET 9-23-99

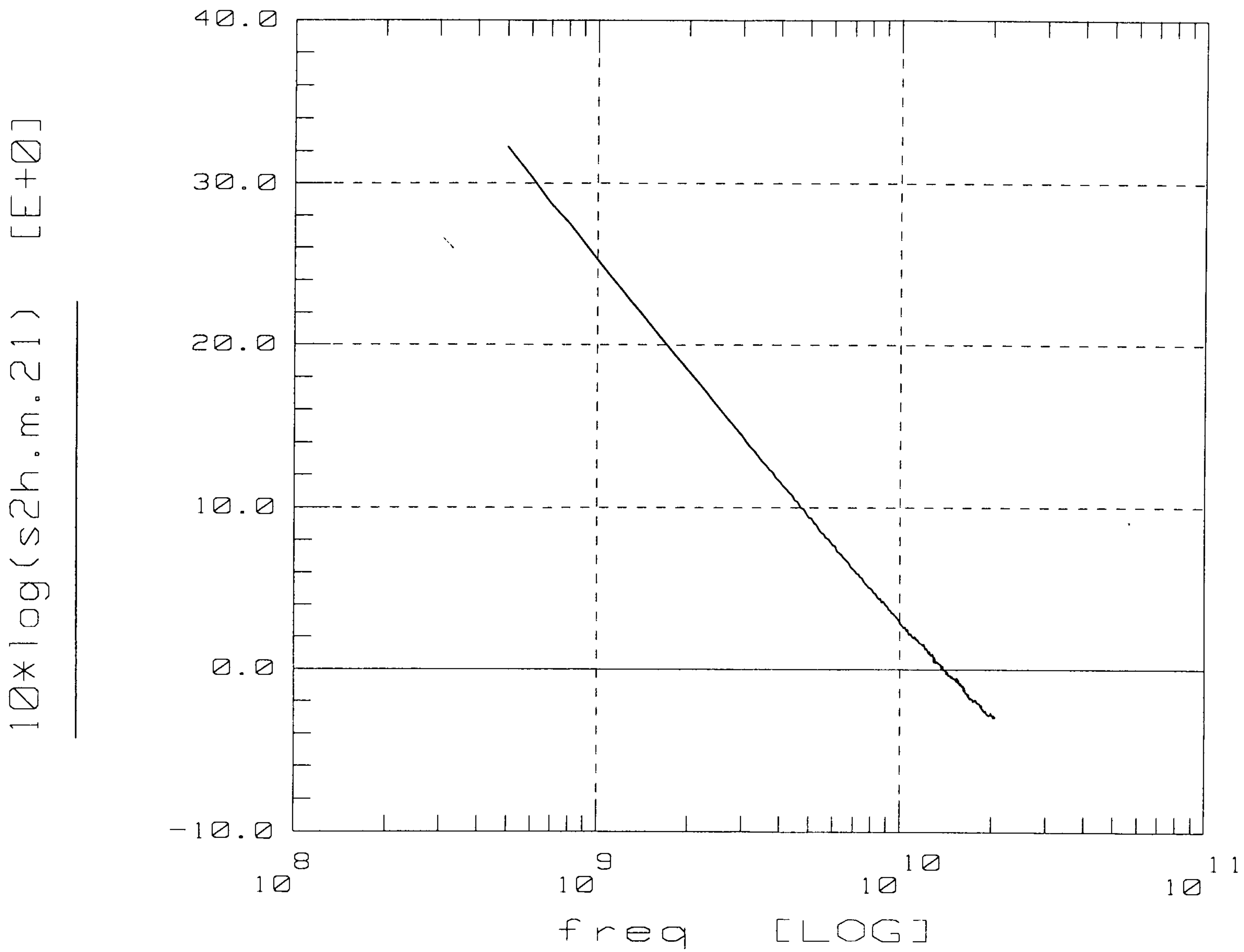


GFET 5V VDS -0.8V



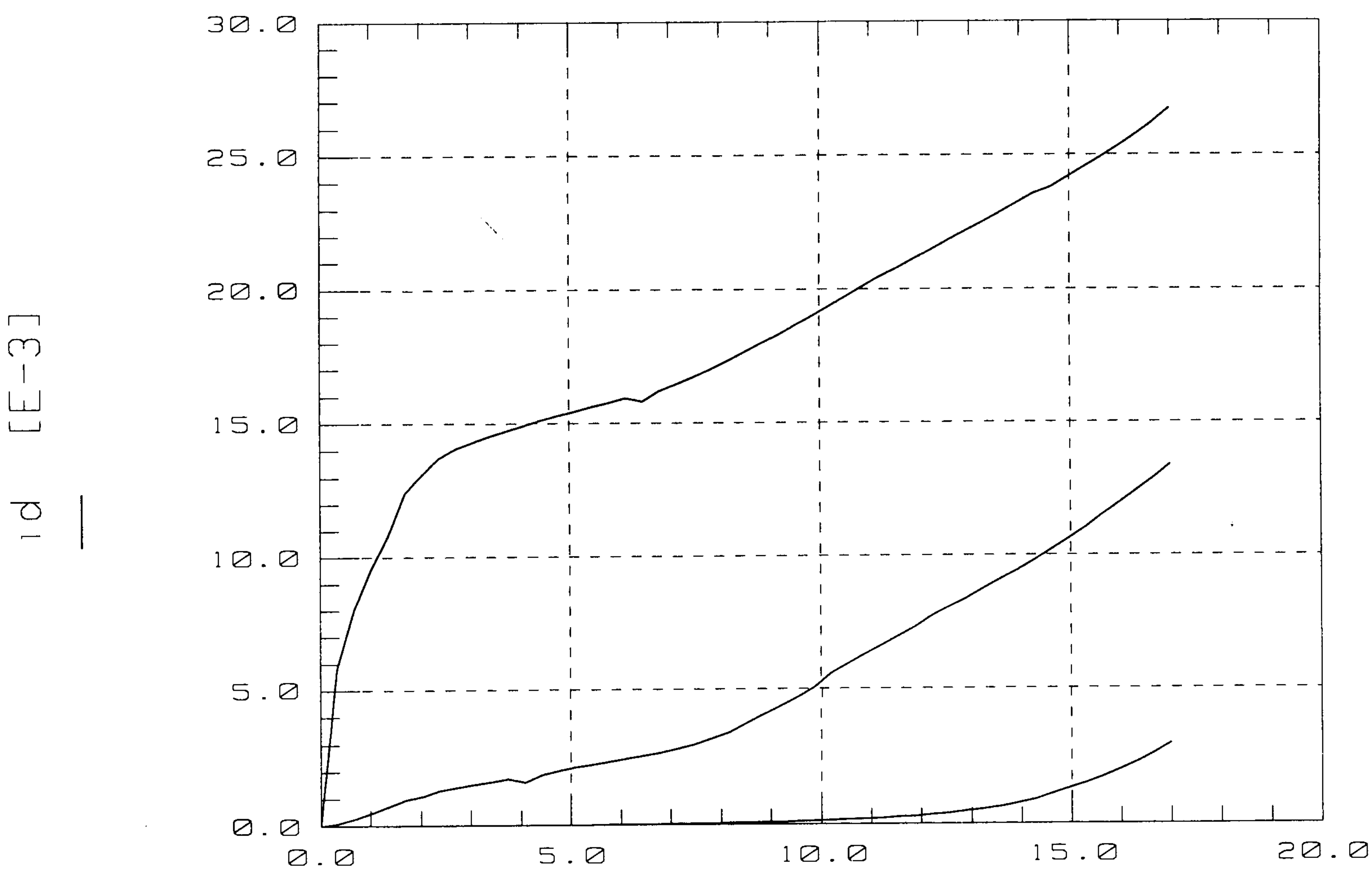
Plot CG_curt3/ac/s_vs_f/db_h21 (On)

GFET 9-23-99



VDS=5 VGS=-.8; Ft=14.1GHz

Plot CG_curt3/dc/breakdown/ig_vg (On)
9-23-99

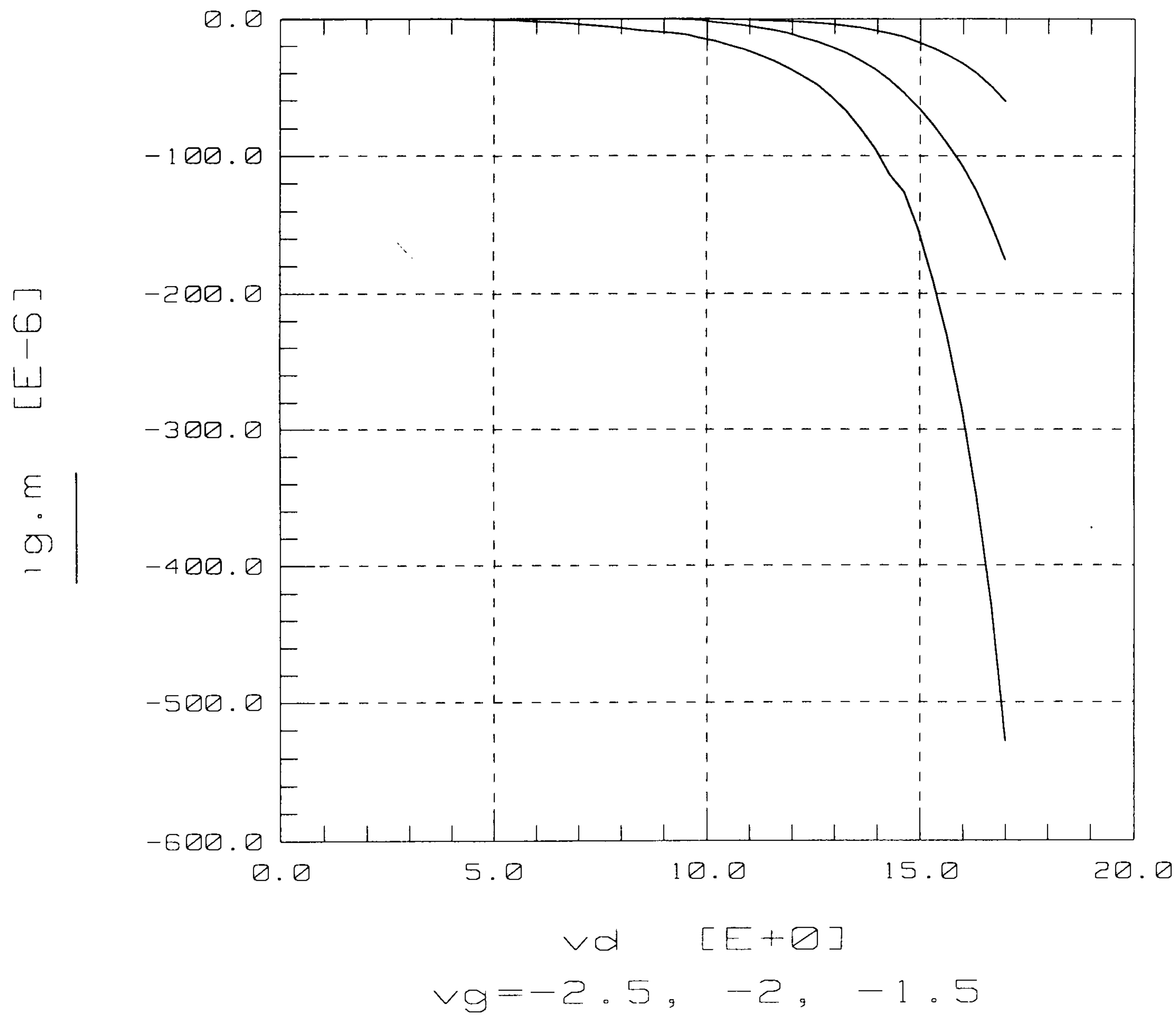


vg= -2.5 , -2, -1.5

GFET

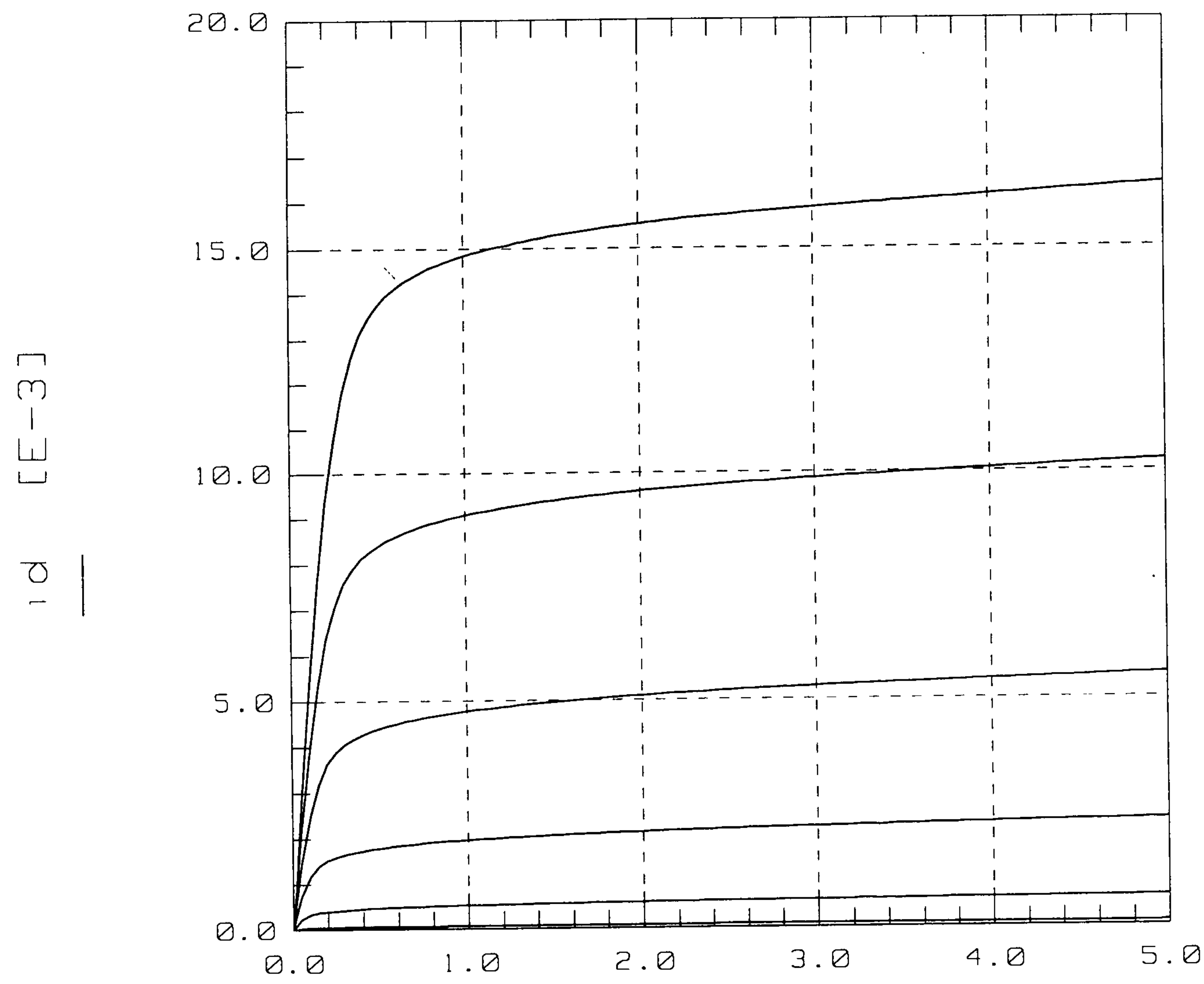
Plot CG_curt3/dc/breakdown/gate (On)

GFET 9-23-99

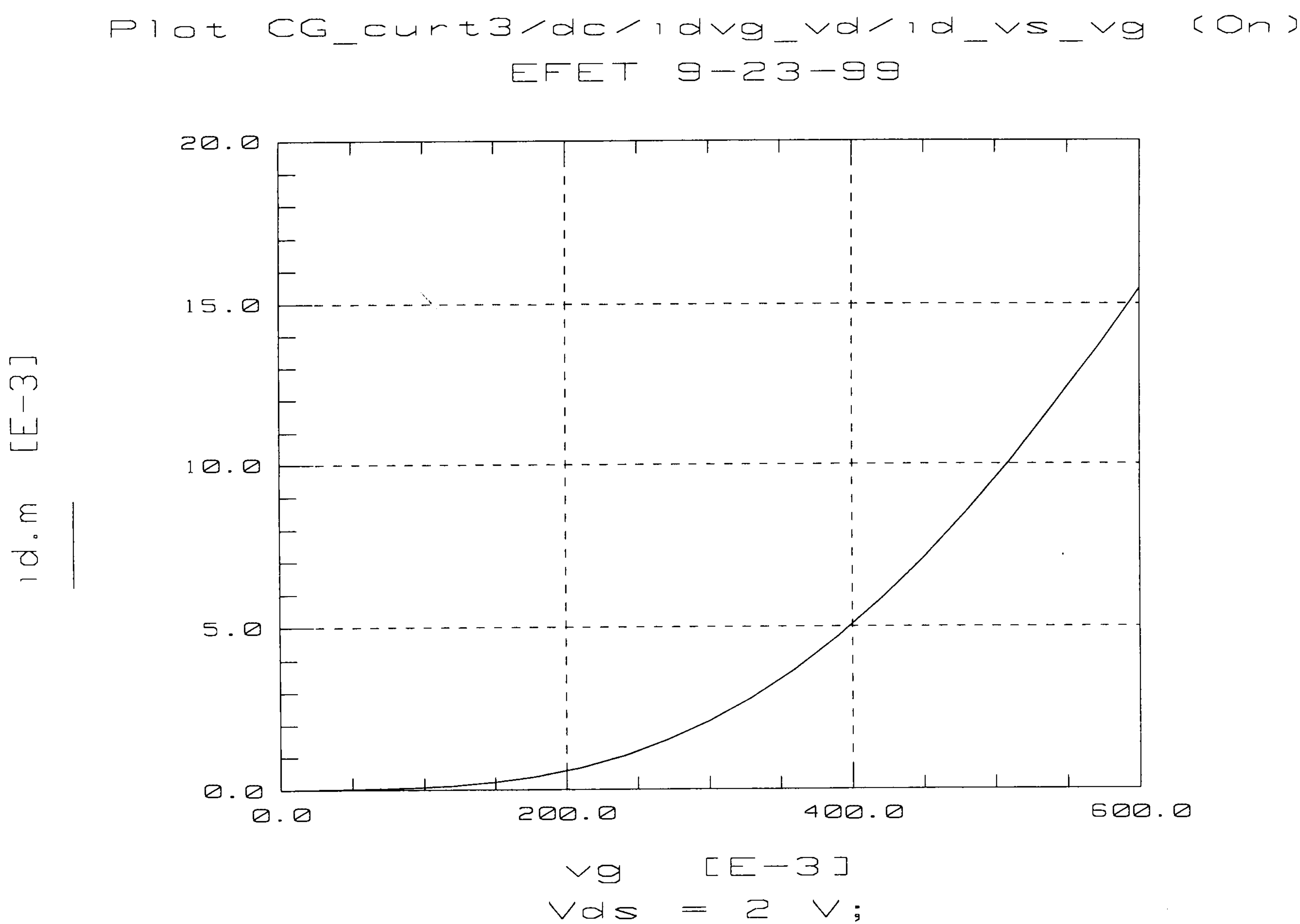


Plot CG_curt3/dc/idvd_vg/id_vs_vd (On)

EFET 9-23-99

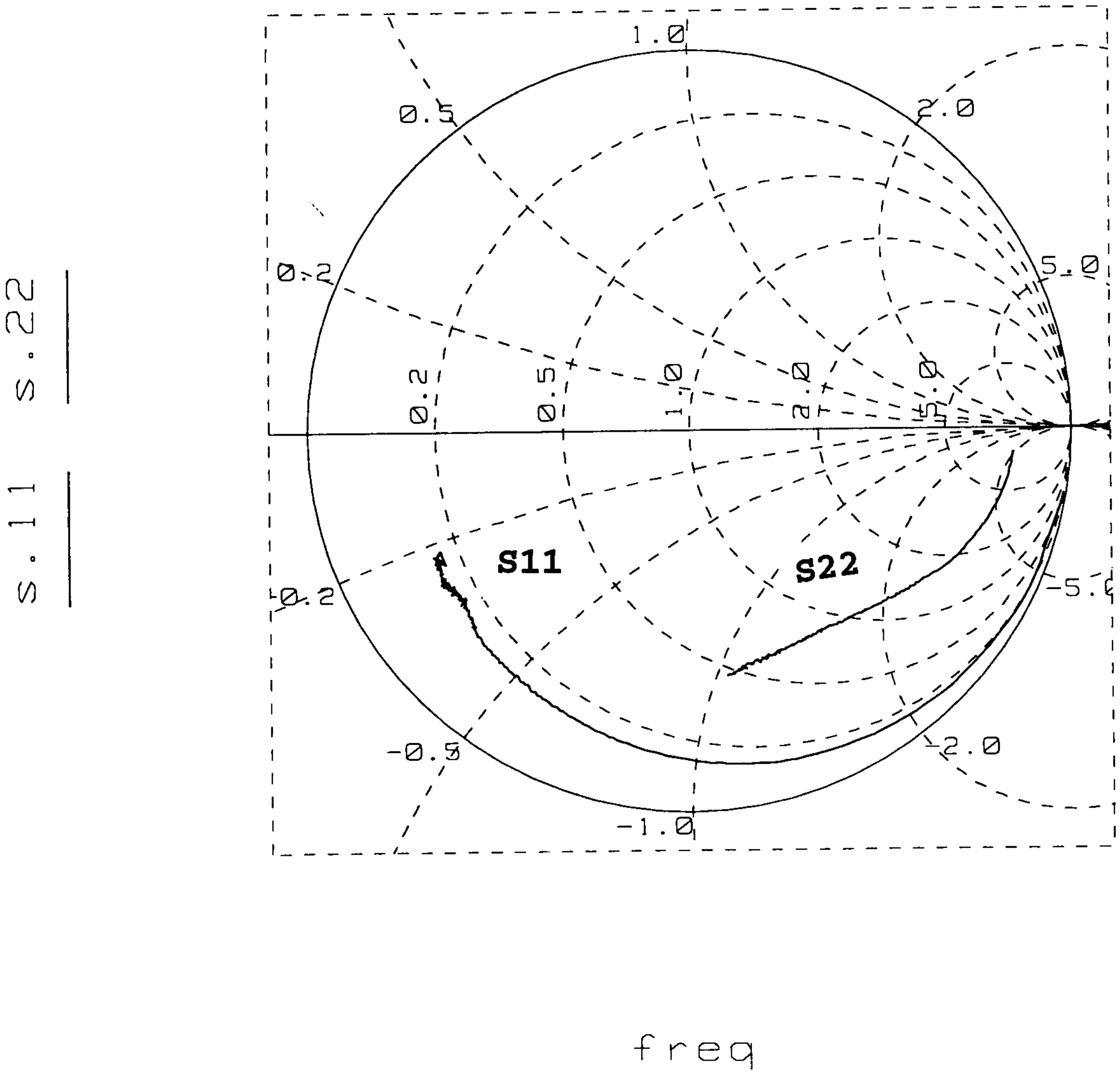


VGS=0 to 0.6V, step=.1

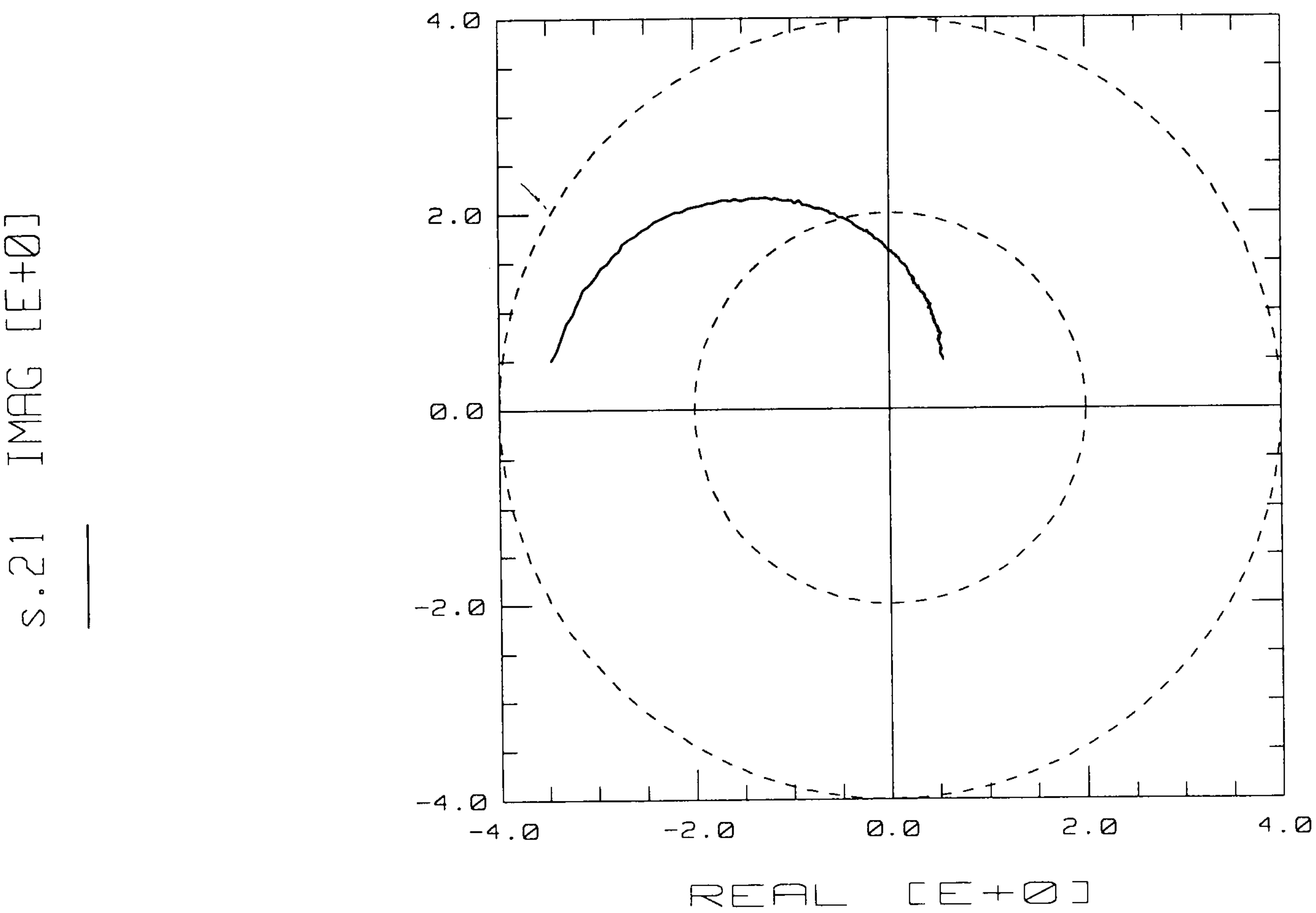

Plot CG_curt3/dc/idvg_vd/id_vs_vg (On)
EFET 9-23-99
20.0
15.0
10.0
5.0
0.0
0.0
200.0
400.0
600.0
id.m [E-3]
vg [E-3]
Vds = 2 V;

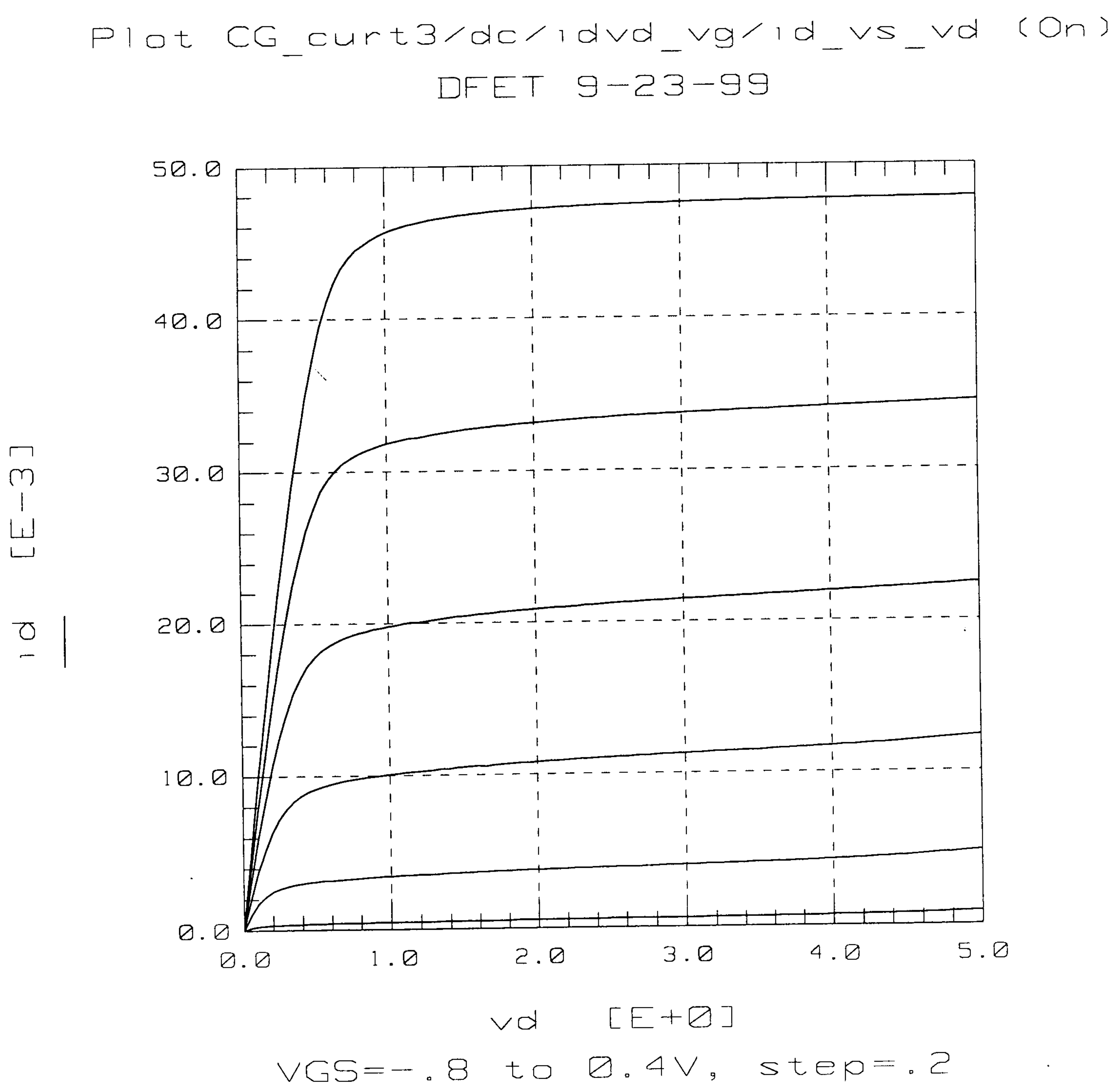
Plot CG_curt3/ac/s_vs_f/s11 (On)

EFET 3V, 0.4V 9/23/99



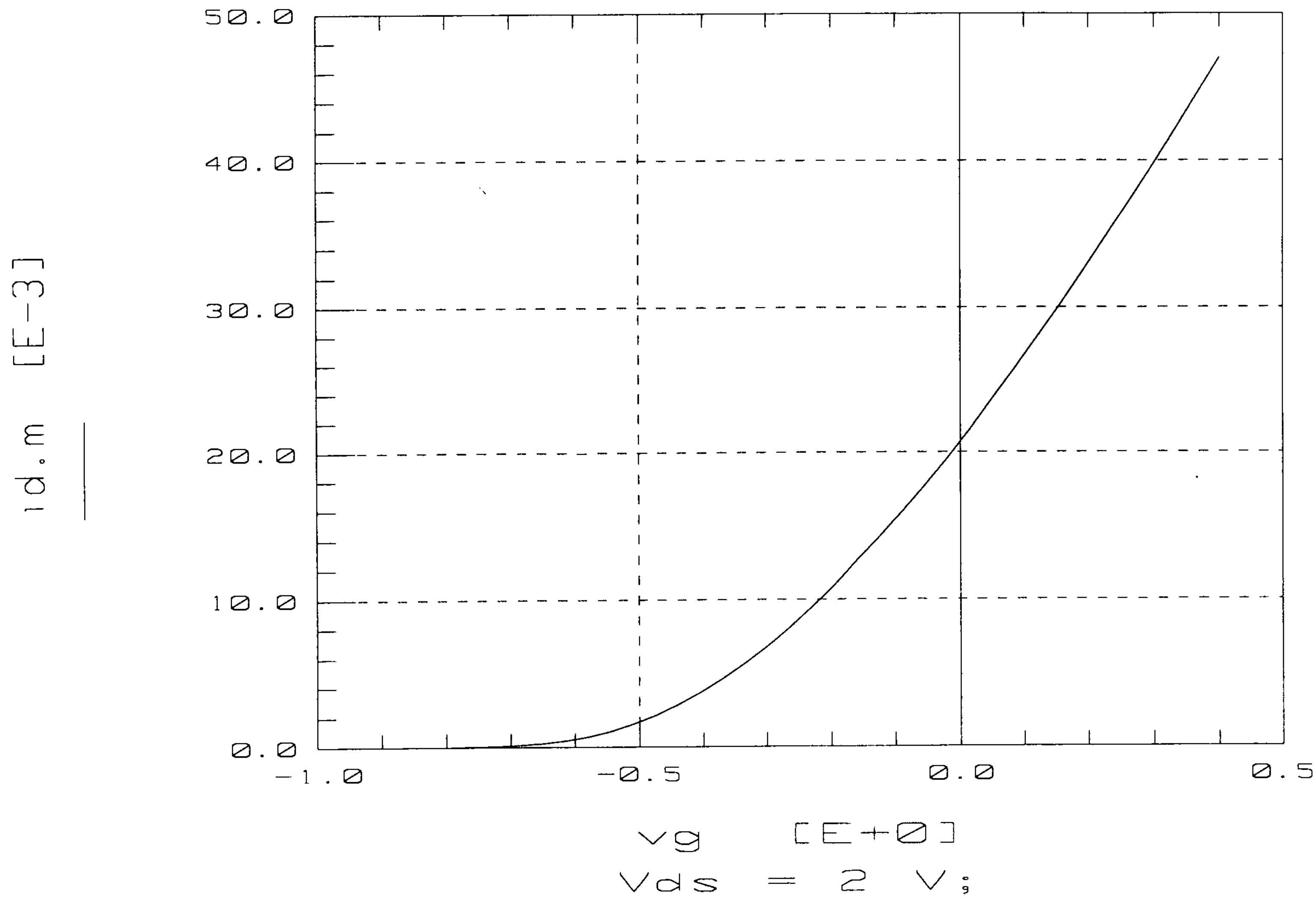
Plot CG_curt3/ac/s_vs_f/s21 (On)
EFET 3V, 0.4V 9-23-99



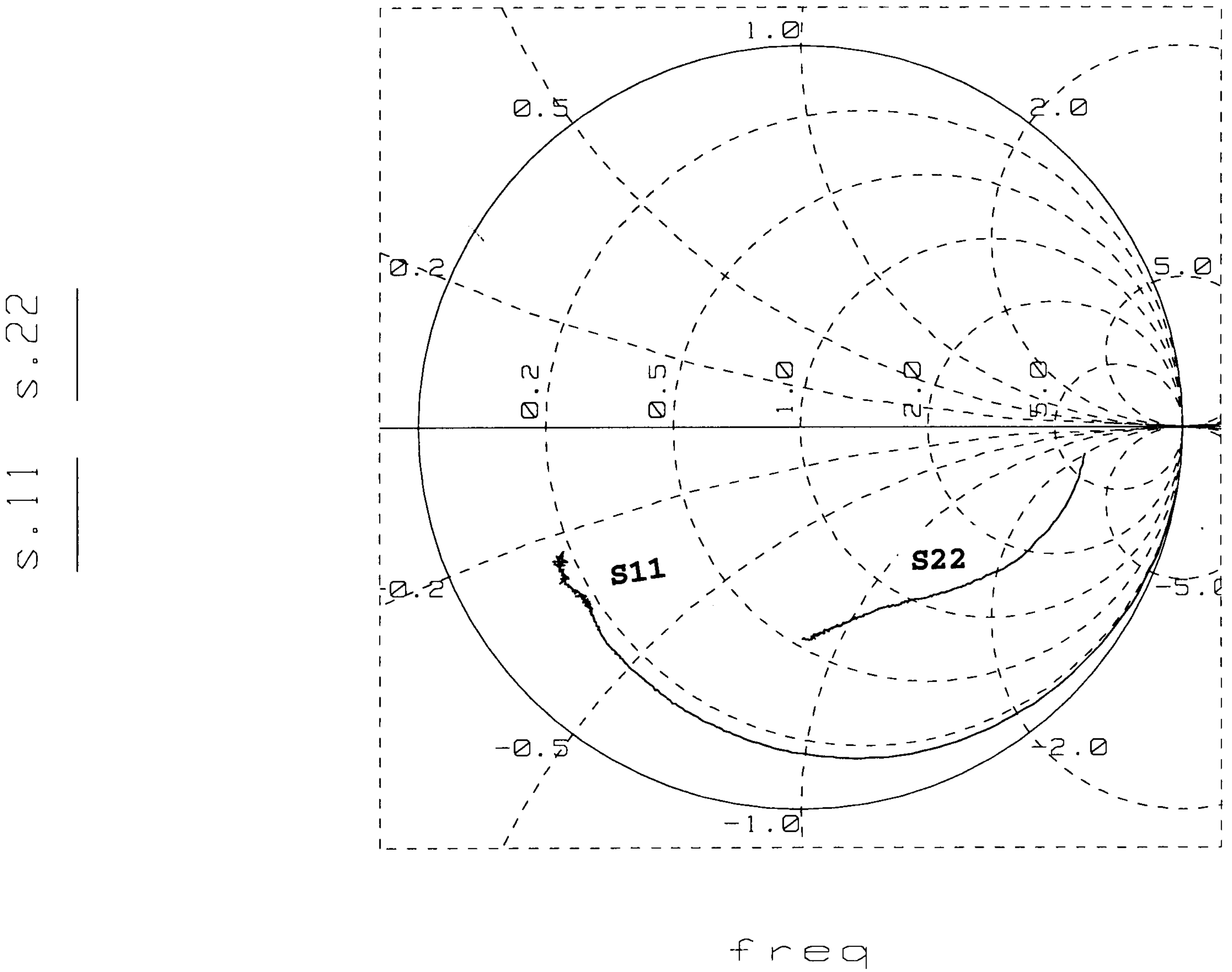

Plot CG_curt3/dc/idvd_vg/id_vs_vd (On)
DFET 9-23-99
50.0
40.0
30.0
20.0
10.0
0.0
id [E-3]
0.0
1.0
2.0
3.0
4.0
5.0
vd [E+0]
VGS=-.8 to 0.4V, step=.2

Plot CG_curt3/dc/idvg_vd/id_vs_vg (On)

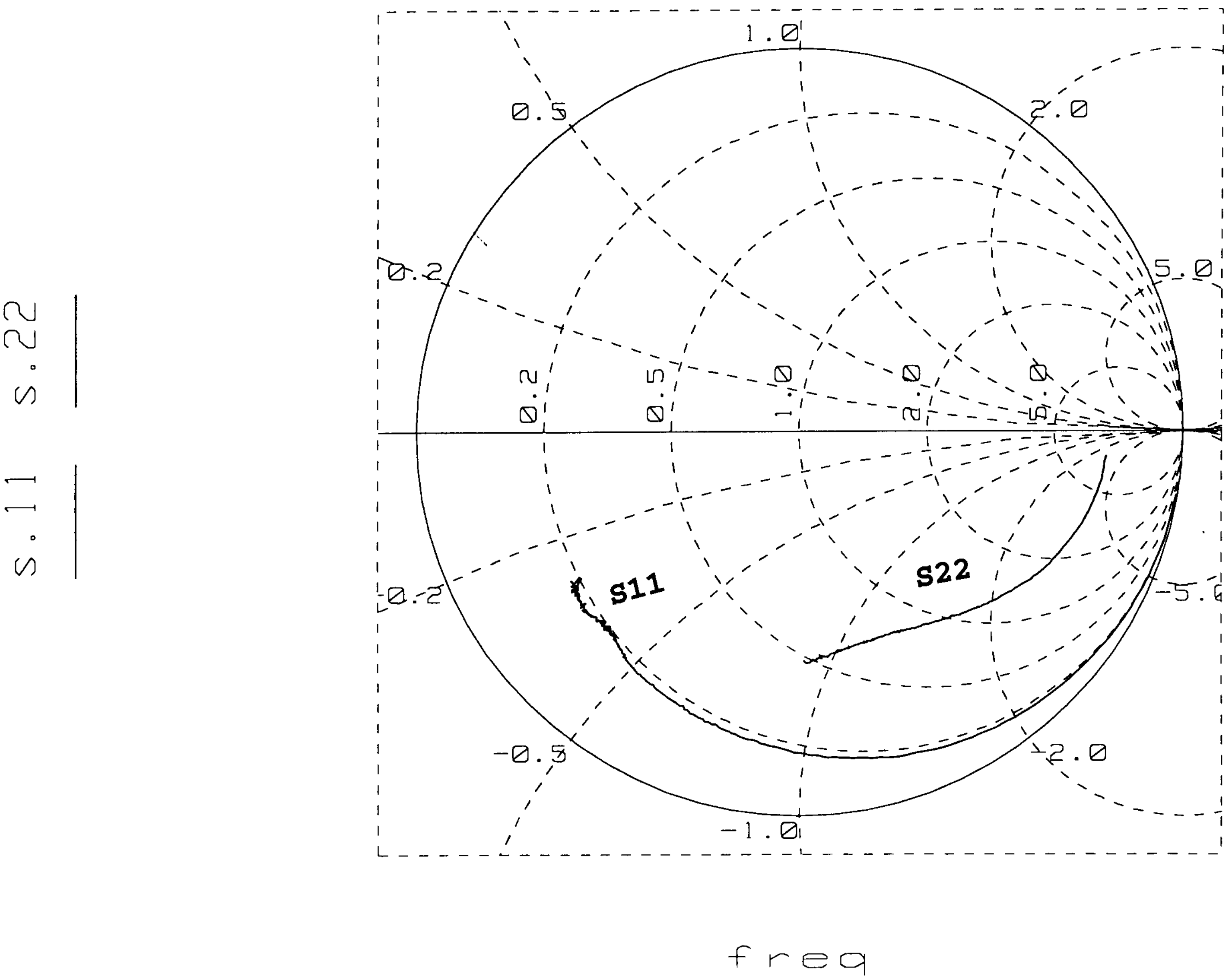
DFET 9-23-99

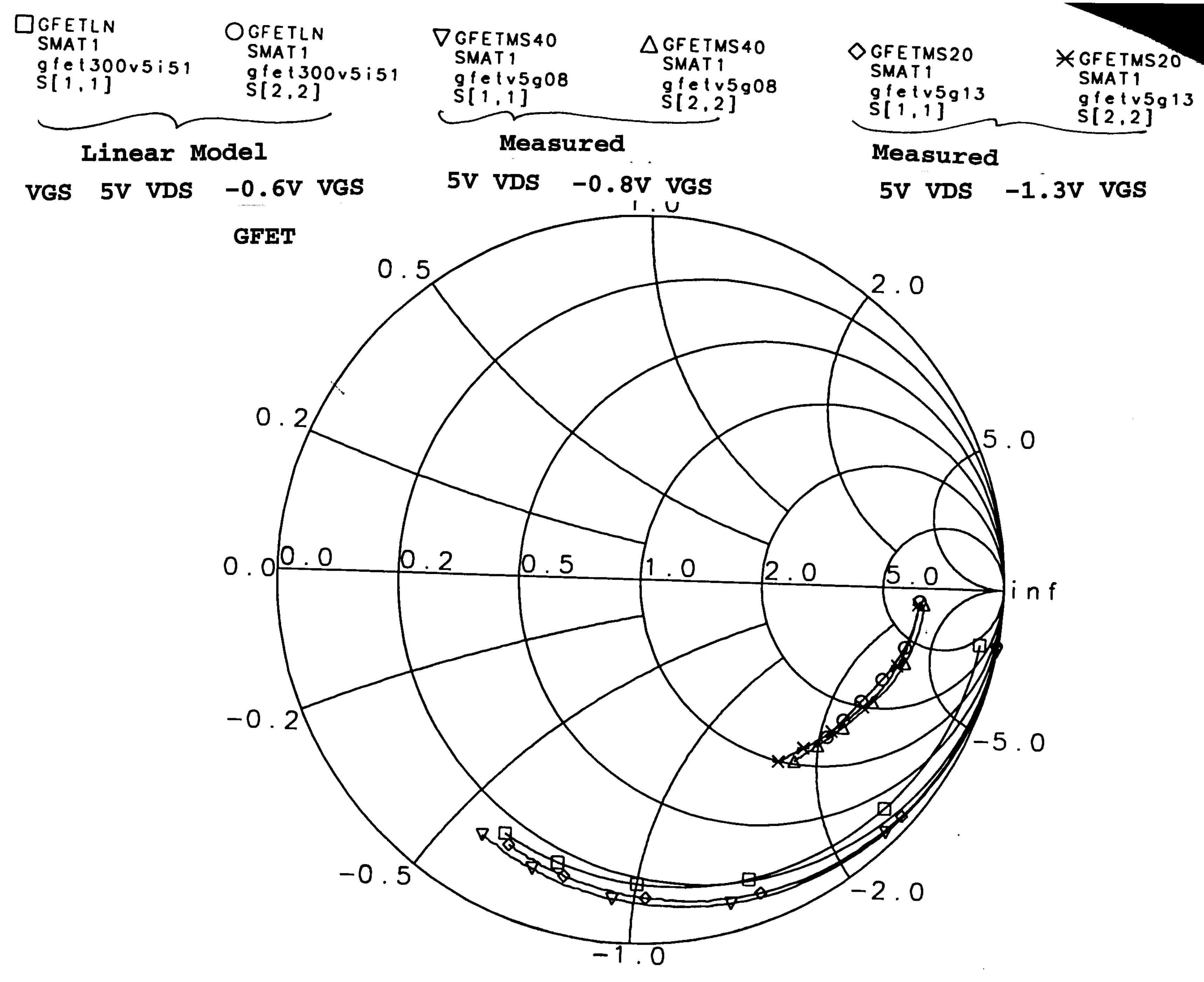


Plot CG_curt3/ac/s_vs_f/s11 (On)
DFET 9/23/99 3V, -.2 V, 7-23-97

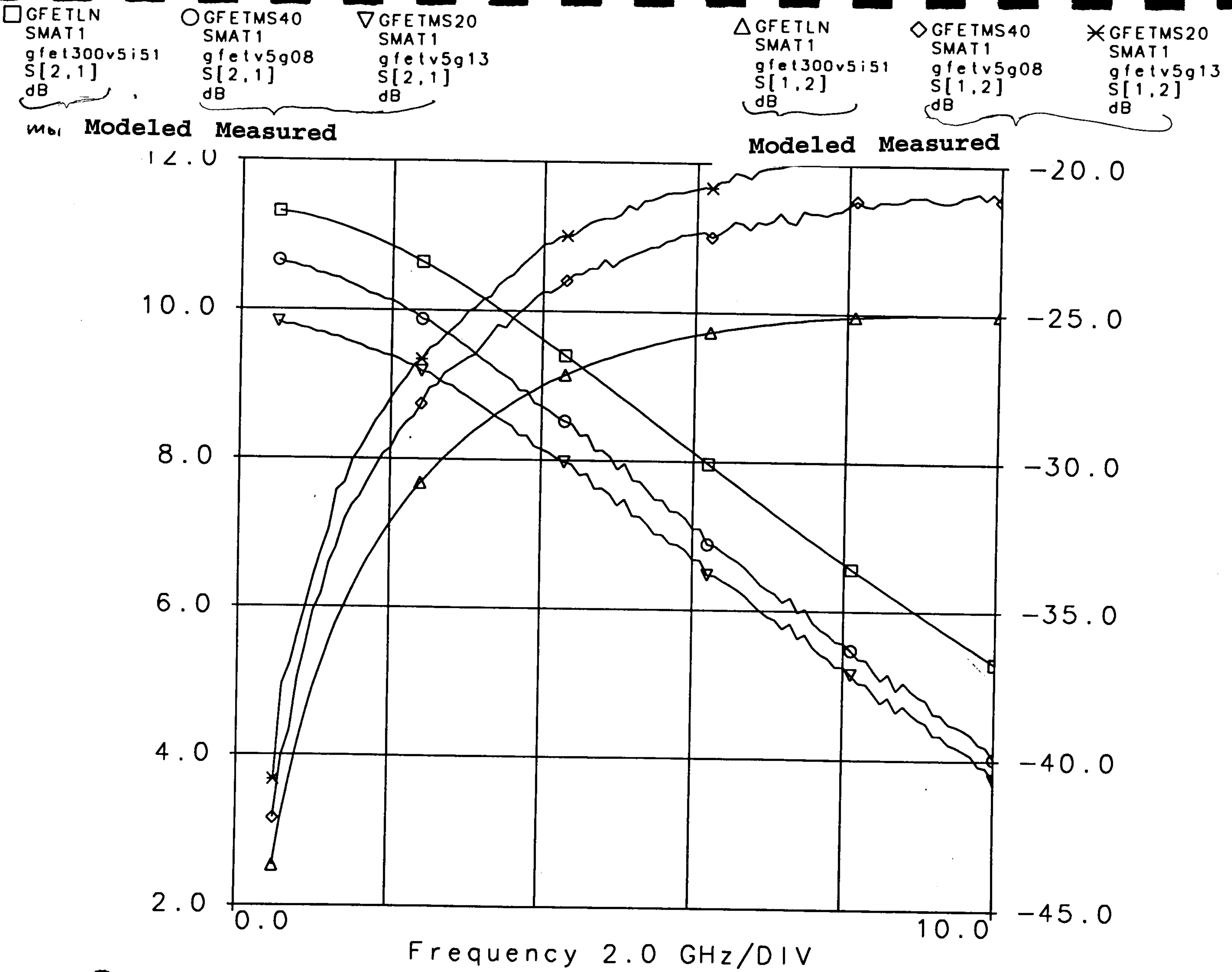


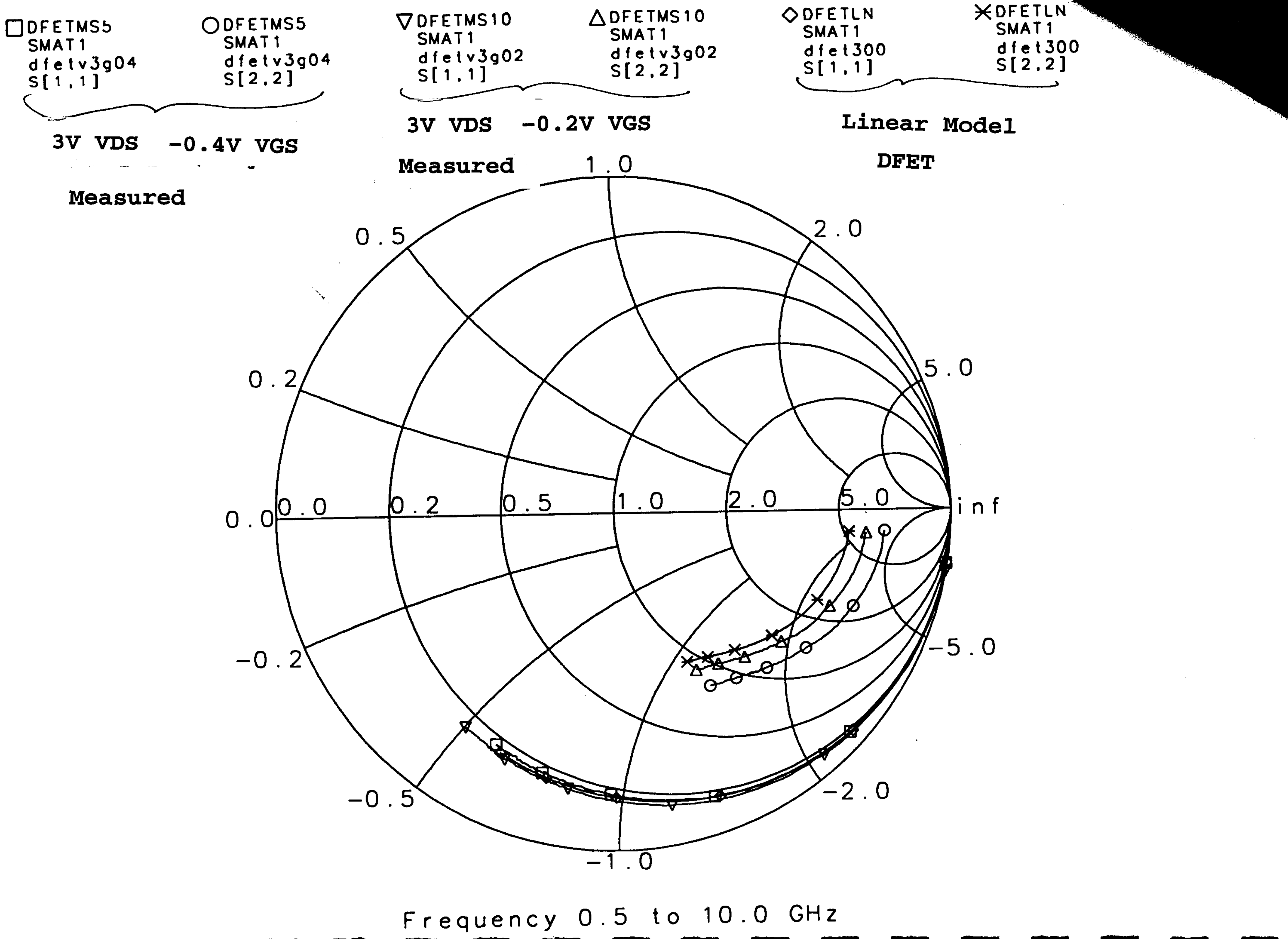
Plot CG_curt3/ac/s_vs_f/s11 (On)
DFET 9/23/99 3V, -.35 V

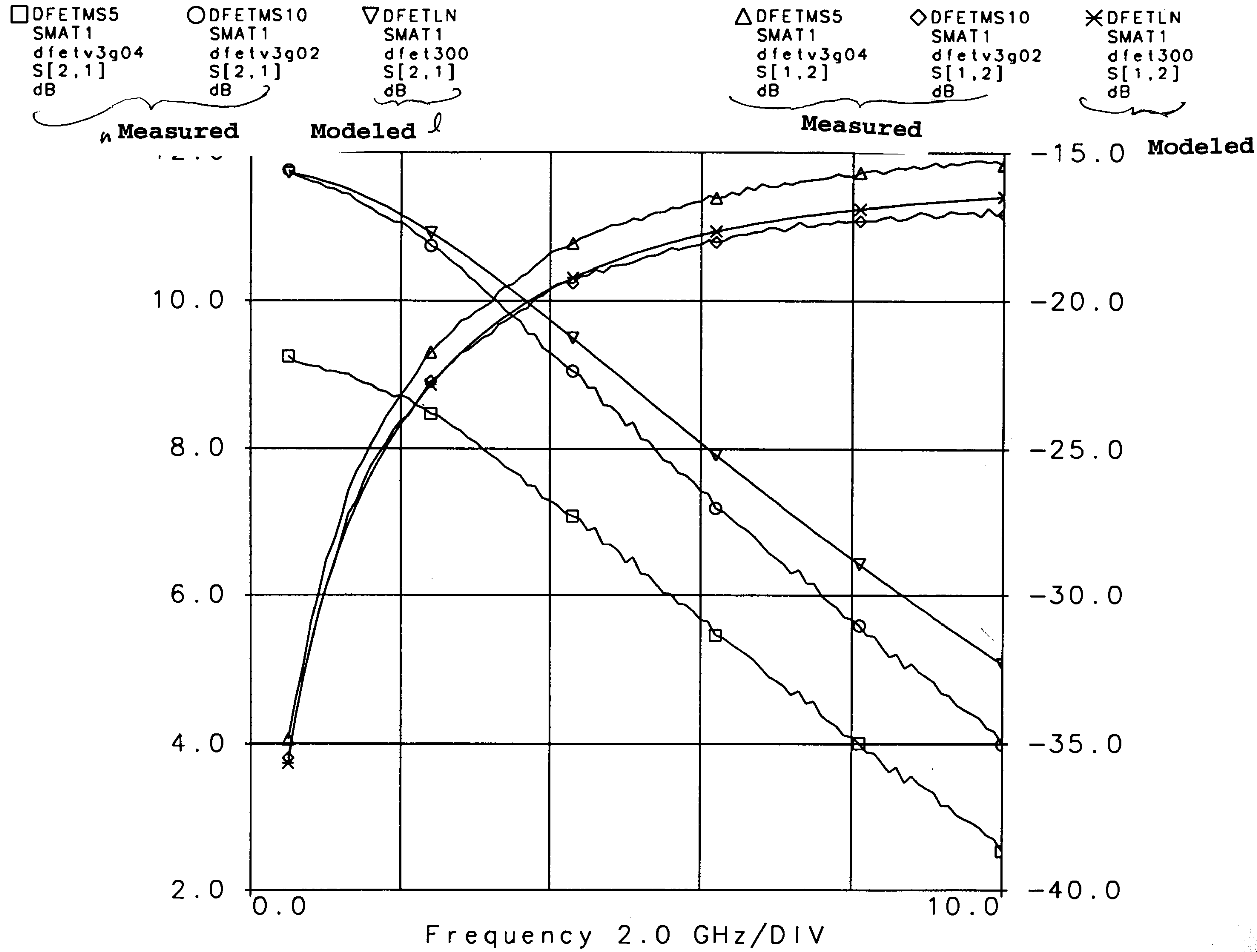




Frequency 0.5 to 10.0 GHz

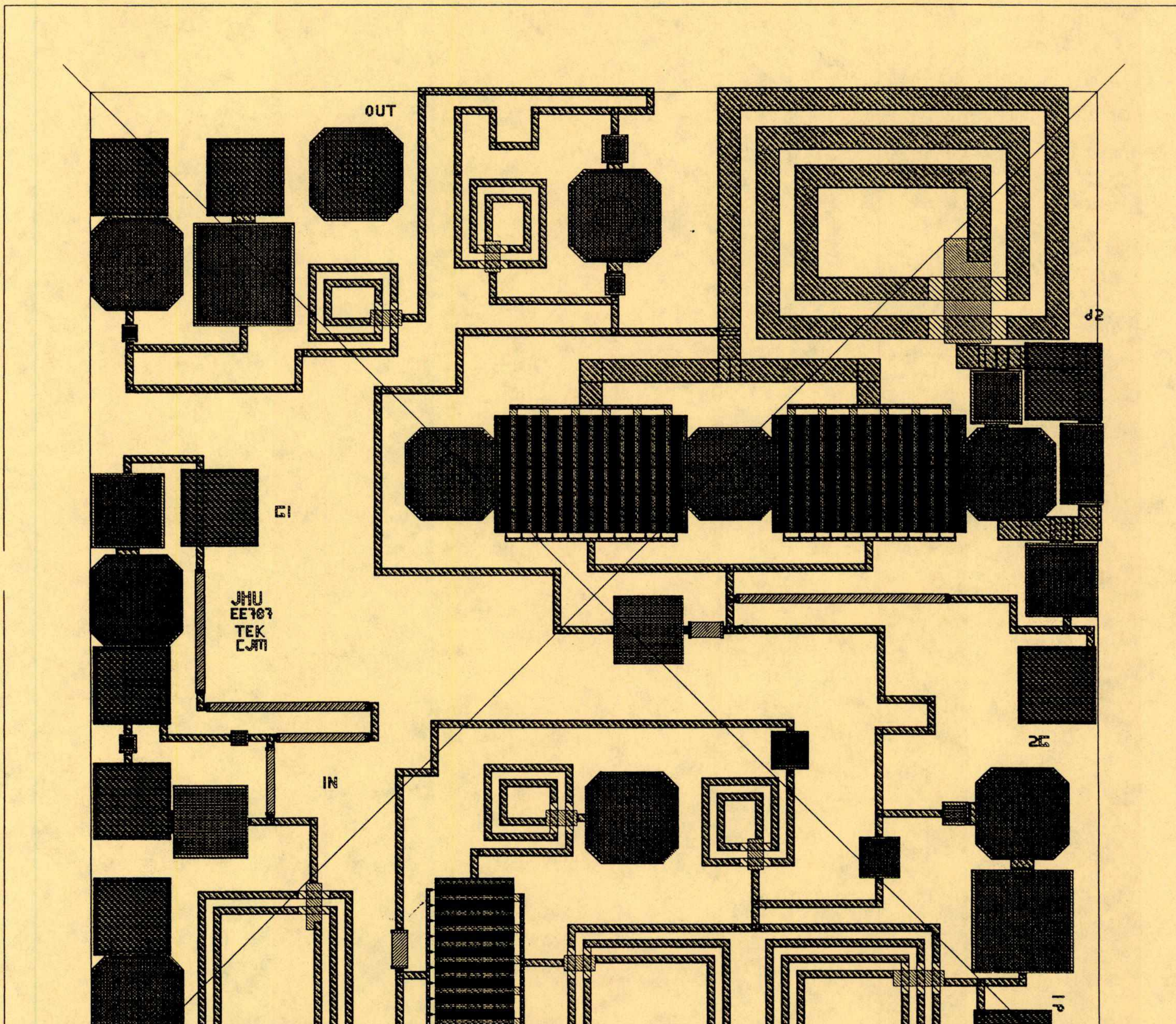

□ GFETLN SMAT1 gfet300v5i51 S[2,1] dB
○ GFETMS40 SMAT1 gfetv5g08 S[2,1] dB
▽ GFETMS20 SMAT1 gfetv5g13 S[2,1] dB
△ GFETLN SMAT1 gfet300v5i51 S[1,2] dB
◇ GFETMS40 SMAT1 gfetv5g08 S[1,2] dB
✕ GFETMS20 SMAT1 gfetv5g13 S[1,2] dB
Modeled
Measured
Modeled
Measured
12.0
10.0
8.0
6.0
4.0
2.0
-20.0
-25.0
-30.0
-35.0
-40.0
-45.0
0.0
10.0
Frequency 2.0 GHz/DIV


□DFETMS5 SMAT1 dfetv3g04 S[1,1]
○DFETMS5 SMAT1 dfetv3g04 S[2,2]
3V VDS -0.4V VGS
Measured
▽DFETMS10 SMAT1 dfetv3g02 S[1,1]
△DFETMS10 SMAT1 dfetv3g02 S[2,2]
3V VDS -0.2V VGS
Measured
◇DFETLN SMAT1 dfet300 S[1,1]
✕DFETLN SMAT1 dfet300 S[2,2]
Linear Model
DFET
1.0
0.5
2.0
0.2
5.0
0.0
0.0
0.2
0.5
1.0
2.0
5.0
inf
-0.2
-5.0
-0.5
-2.0
-1.0
Frequency 0.5 to 10.0 GHz



DFETMS5
SMAT1
dfetv3g04
S[2,1]
dB
DFETMS10
SMAT1
dfetv3g02
S[2,1]
dB
DFETLN
SMAT1
dfet300
S[2,1]
dB
DFETMS5
SMAT1
dfetv3g04
S[1,2]
dB
DFETMS10
SMAT1
dfetv3g02
S[1,2]
dB
DFETLN
SMAT1
dfet300
S[1,2]
dB
Measured
Modeled
Measured
Modeled
10.0
8.0
6.0
4.0
2.0
-15.0
-20.0
-25.0
-30.0
-35.0
-40.0
0.0
10.0
Frequency 2.0 GHz/DIV

JHU98PA1



C Band Power Amp 1 – Todd Knibbe and Chris Martin

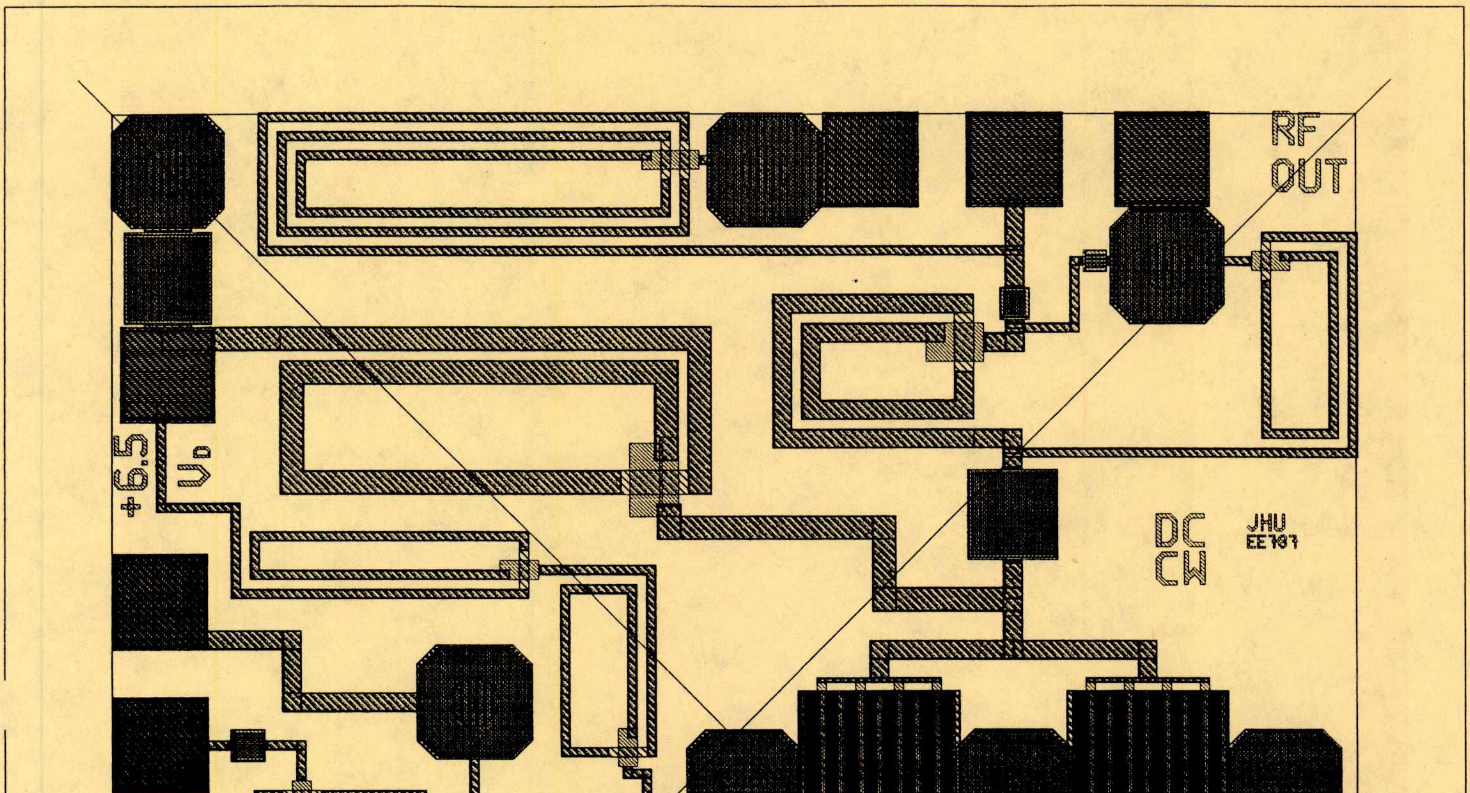
Two power C-Band Power amplifier projects were designed by two different student teams. The output power specification was greater than 0.5W with a goal of 1W. For the first amplifier team's project, power out measurements were taken on 9/27/99 and 9/29/99. Small signal network analyzer measurements were not taken. Using a signal generator and spectrum analyzer, the amplifier appeared to have good gain from about 3-5 GHz. The measurement taken on 9/27 yielding 29+ dBm output power at 4 Ghz was taken at about 1 dB compression. Power output measurements taken on 9/29 were by Chris Martin so I am not sure what the compression levels were. Our MITEQ AMP driver amp used for these measurements rolled off below 4 Ghz but was useable at 3 Ghz. However, the drive at 3 Ghz was limited such that the MMIC amp could only be driven about 1 dB into compression.

F(GHz)	Pmeas	Ploss 9/27	Pout 9/27	Ploss 9/29	Pout?
2	*	*	*	+2.66	*
3	25.50			+3.0	+28.50
4	25.33	+3.83	+29.16	+3.3	+28.63
5	23.83			+3.7	+27.53
6	19.67			+3.93	+23.6

The amplifier appears to have good output power at 3-5 Ghz. Unfortunately, we did not measure the small signal gain. It must be greater than 12 dB, and less than 20 dB. Bias was very close to the expected level, as were power output and efficiency at 4 Ghz. From the students project report, they were expecting 29 dBm best case with about 1 db compression, but were having trouble getting the simulations to converge for higher compression levels. Chris Martin measured a device Monday 9/27/99 which was delivering 29 dBm at 4 Ghz. At the measured bias of 7V VDS and ~0.45A, this would yield about 25% efficiency with 0.8W of RF output.

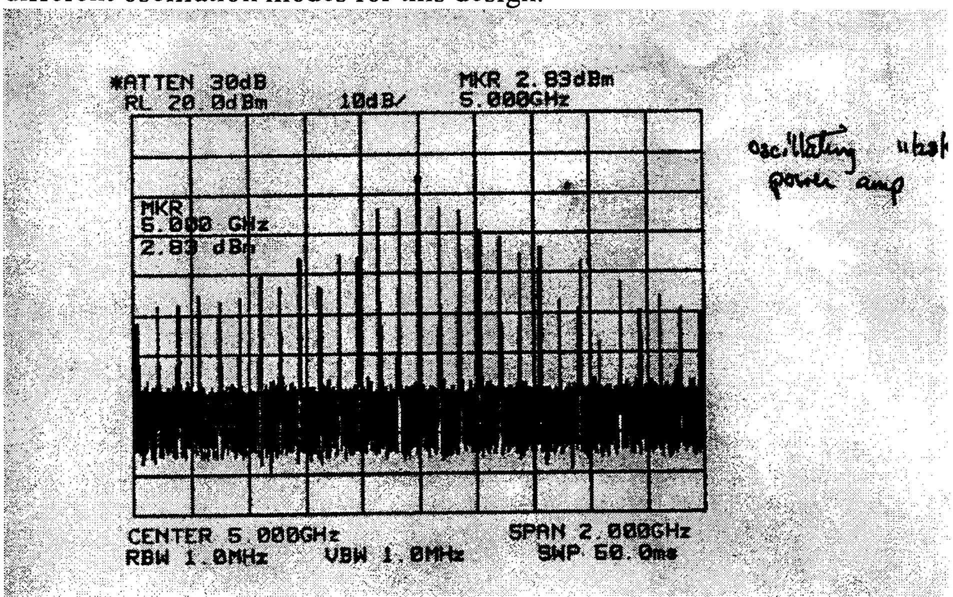
The MMIC die were solder attached to a small piece of Kovar to act as a heat sink for probing. I think the DC power supplied to this 60x60mil MMIC and RF power output achieved were probably near the limits of our current measurement capabilities at the Dorsey Center of Johns Hopkins University. We were very pleased to get this much power out of a device using the probe station. Possibly a packaged part with a good heat sink would yield even better performance than the 0.8W RF output measured for this amplifier.

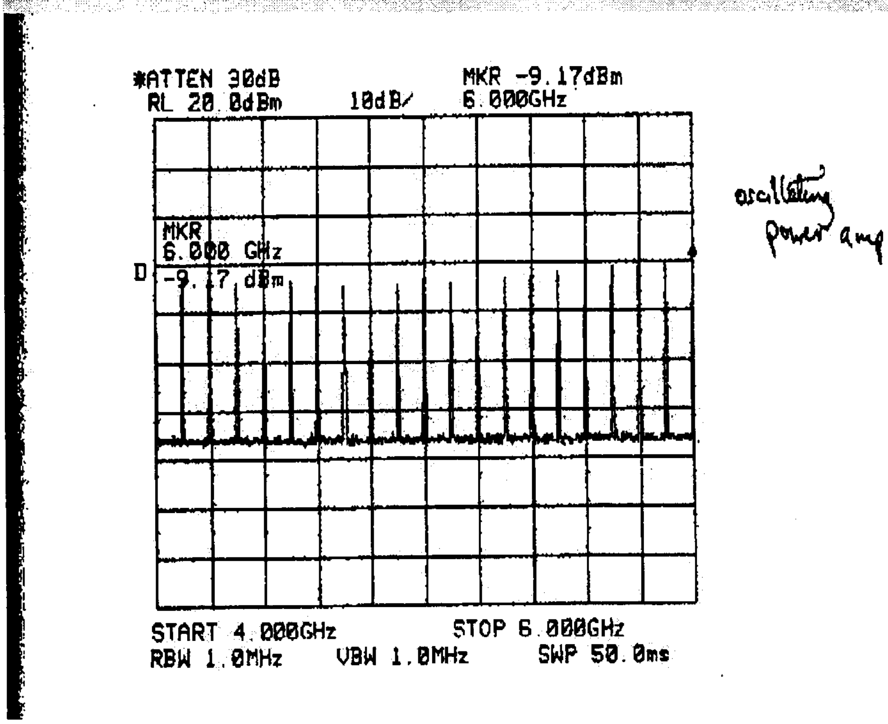
JHU98PA2



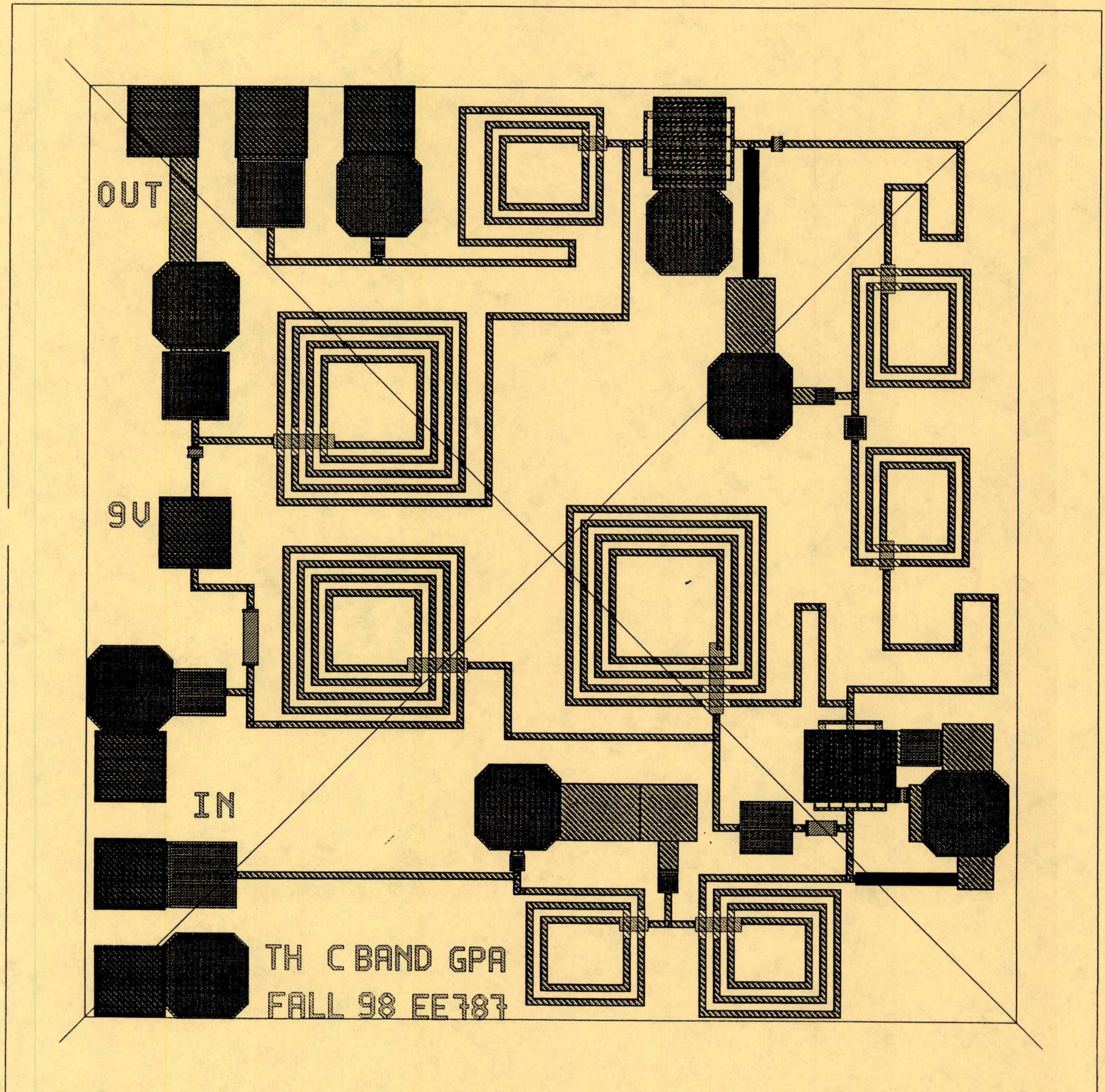
C Band Power Amp 2 – Dave Cross and Chad Wilson

The second team's power amplifier project was similar in design expectations but unfortunately was marginally unstable and could only be measured at lower bias levels. This amplifier die was solder attached to a piece of Kovar for heat-sinking and then measured on the probe station. Several attempts were made to dampen the oscillations that occurred when the bias was increased. It did seem to be "borderline" unstable and possibly packaging the MMIC with bypass capacitors would prevent these oscillations. Unfortunately, that is beyond the scope of the current course measurement/fabrication capabilities. Attached are two spectrum plots of two different oscillation modes for this design.



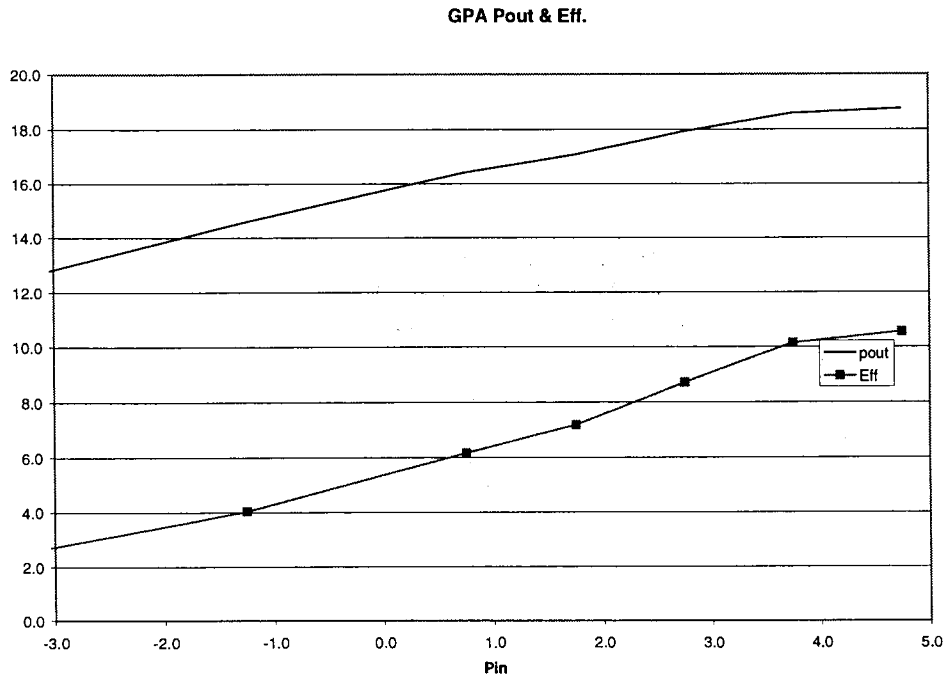


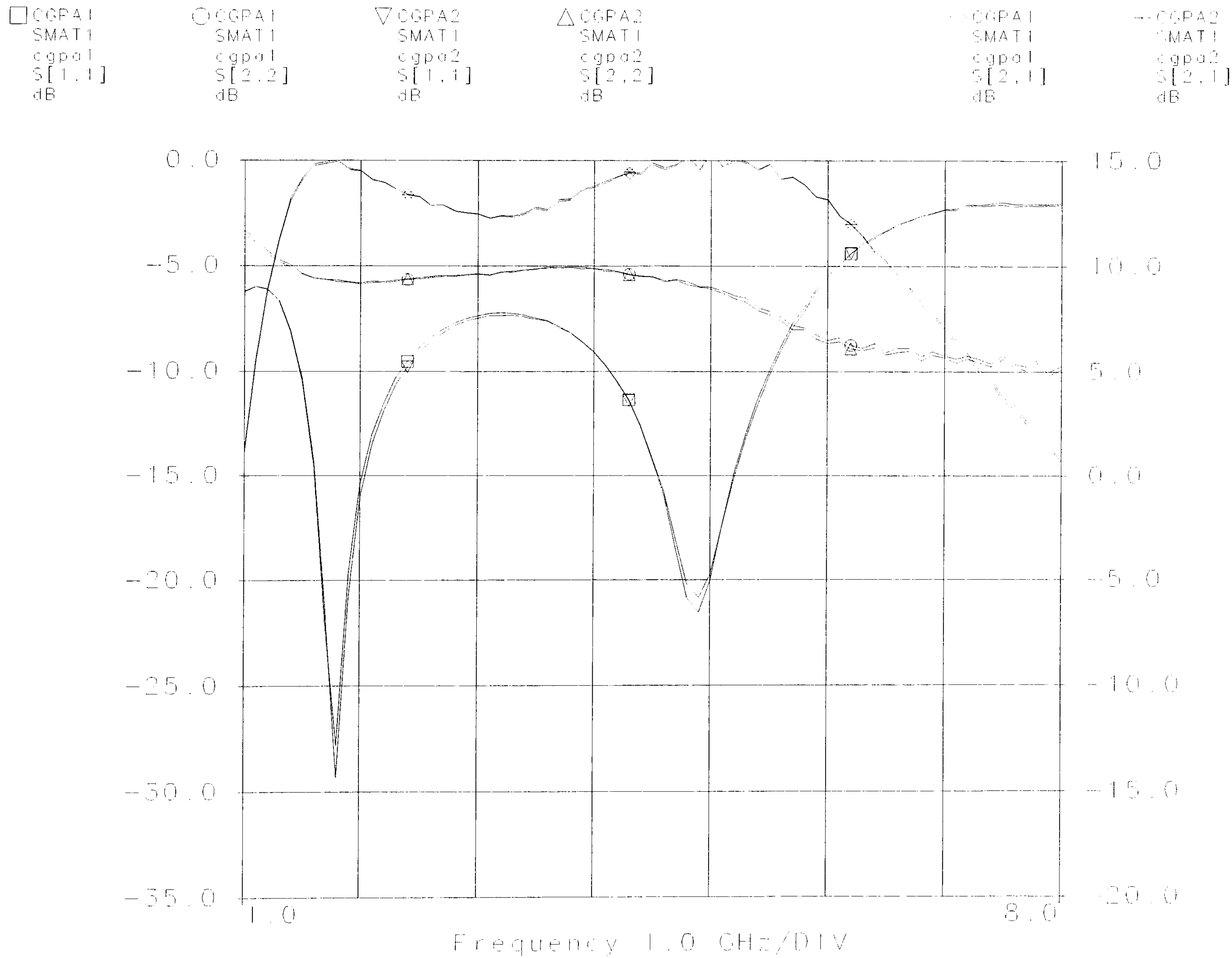
JHU98GPA



C-Band General Purpose Amp—Herb Sutcliffe and Todd Longreen

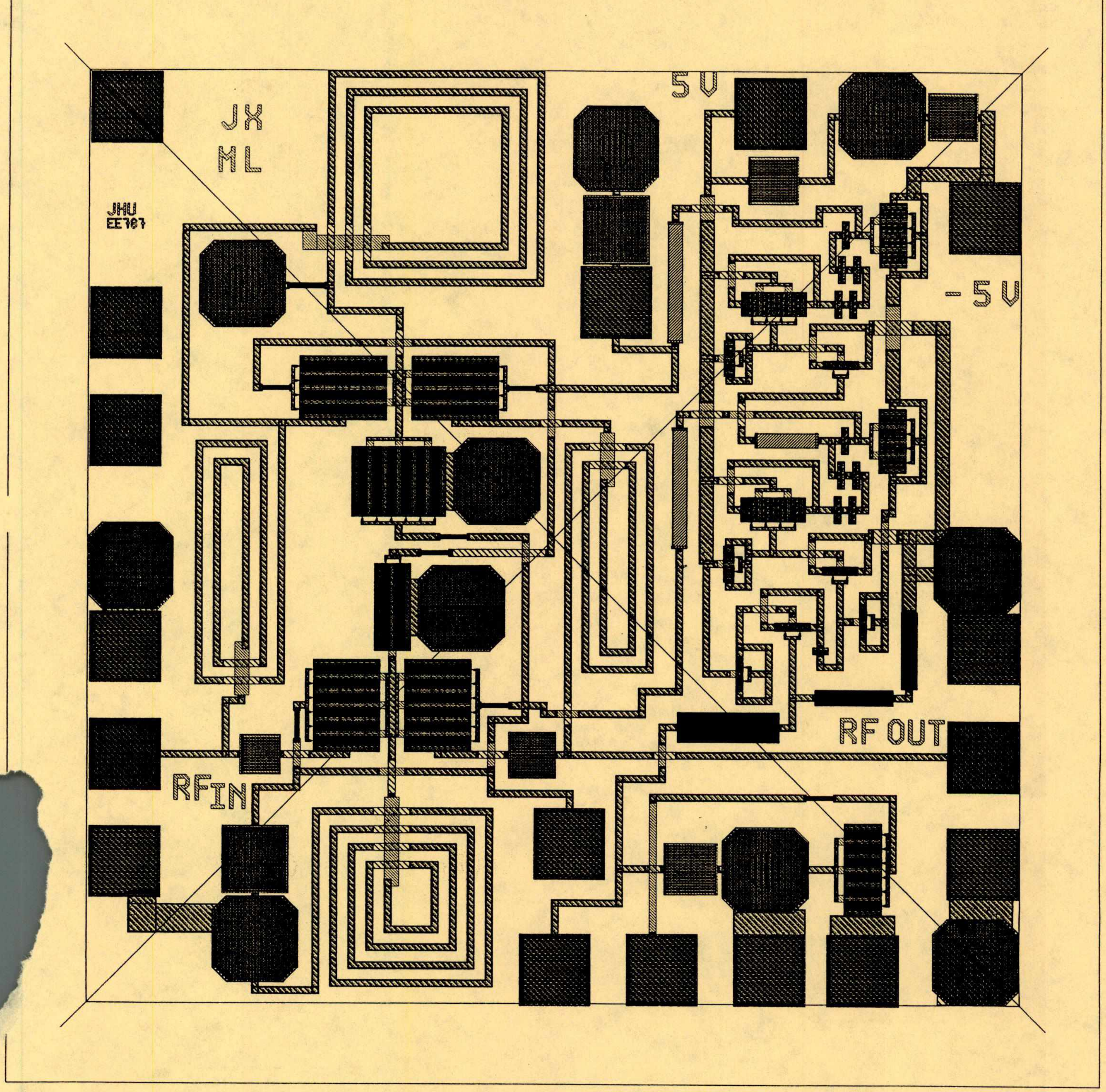
Below is a plot of Power Out and Efficiency of the C-Band amplifier with a bias of 9V at 79mA. Attached are plots of the amplifier's performance plotted on roughly the same scale as the original plots in the student's project report. The amplifier gain shifted slightly down in frequency but was broadband from 1.3 Ghz to 6.3 GHz (3 dB BW). Output match was slightly worse than expected but input match was good. Bias was very close to the predicted levels.





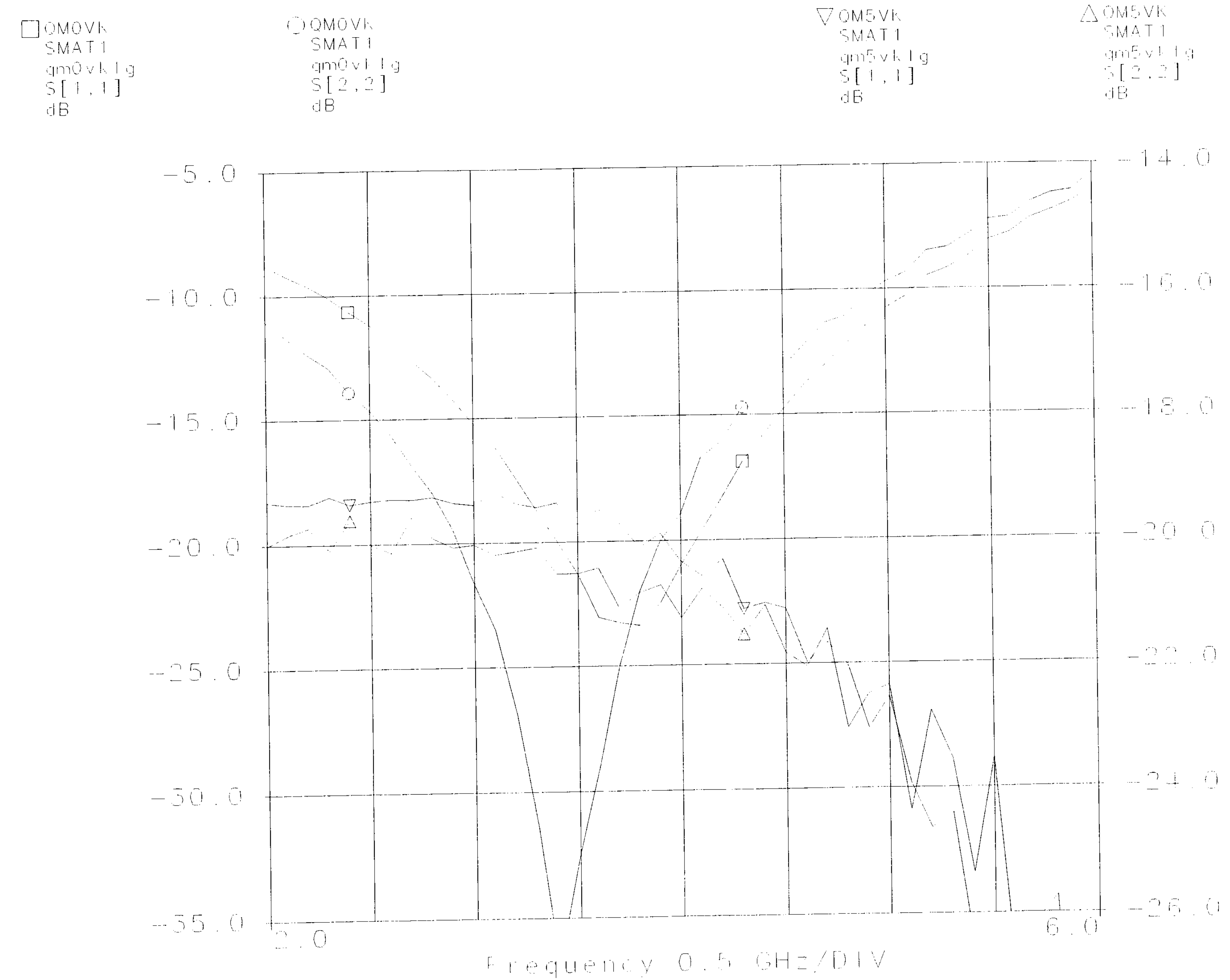
JHU98GPA Measurements 9/29/99

JHU98QM

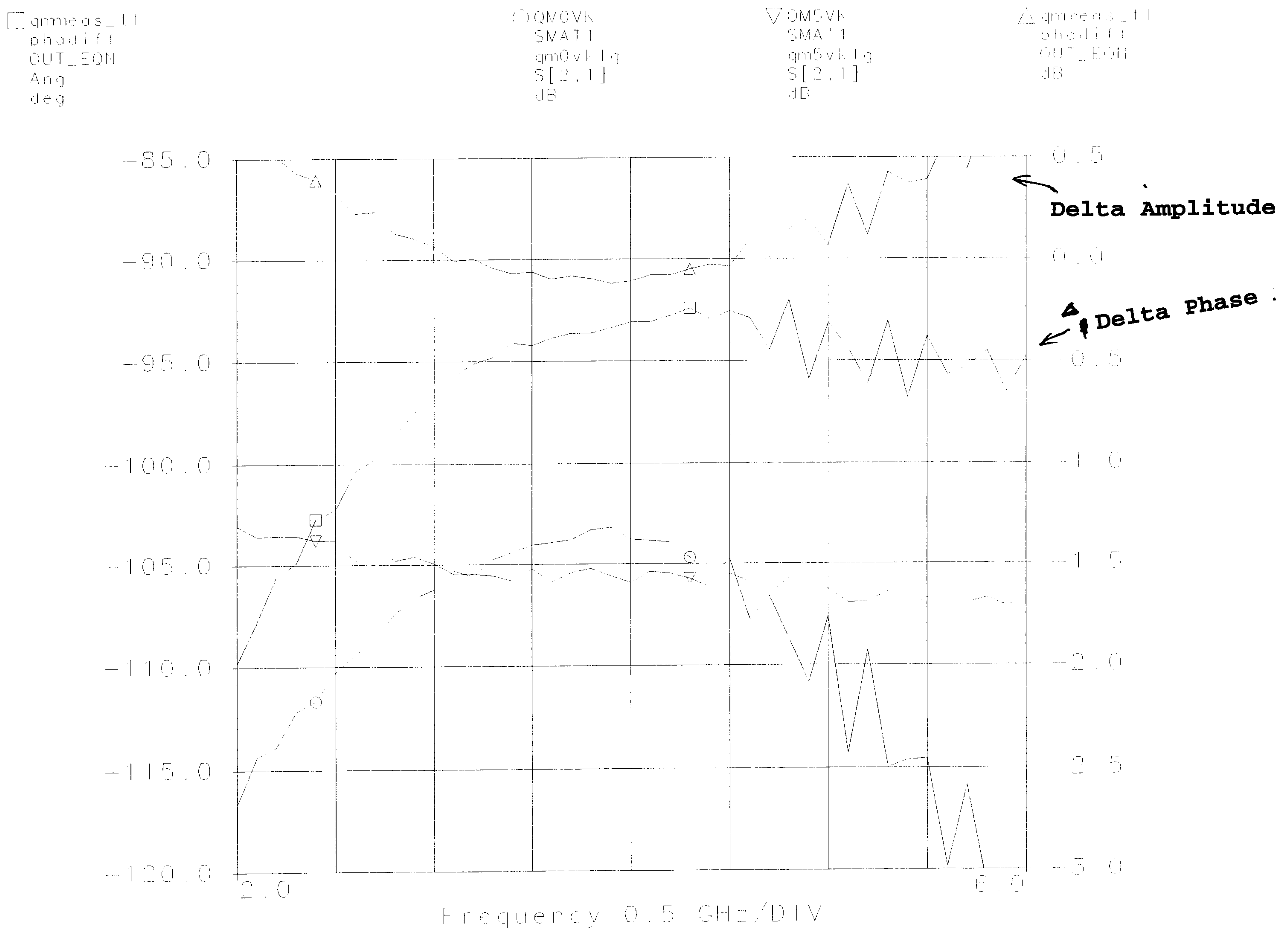


C Band Quadrature Modulator—Matt Long and Jimmy Xiang

The C-Band Quadrature Modulator consisted of a TTL to FET switch driver circuit and a 90 degree modulator. Two or three chips could be chained to provide 180, or 270 degree modulation states. Bias was about as expected, 5V at 25 mA in either phase state. Phase shift of 90 degrees was achieved with moderate bandwidth. Attached are plots of the measured results. Phase shift was about 93-96 degrees from 3 Ghz to 6 Ghz and match was better than 10 dB from 2 to 5 Ghz. Results were similar to the simulations, though shifted slightly lower in frequency.

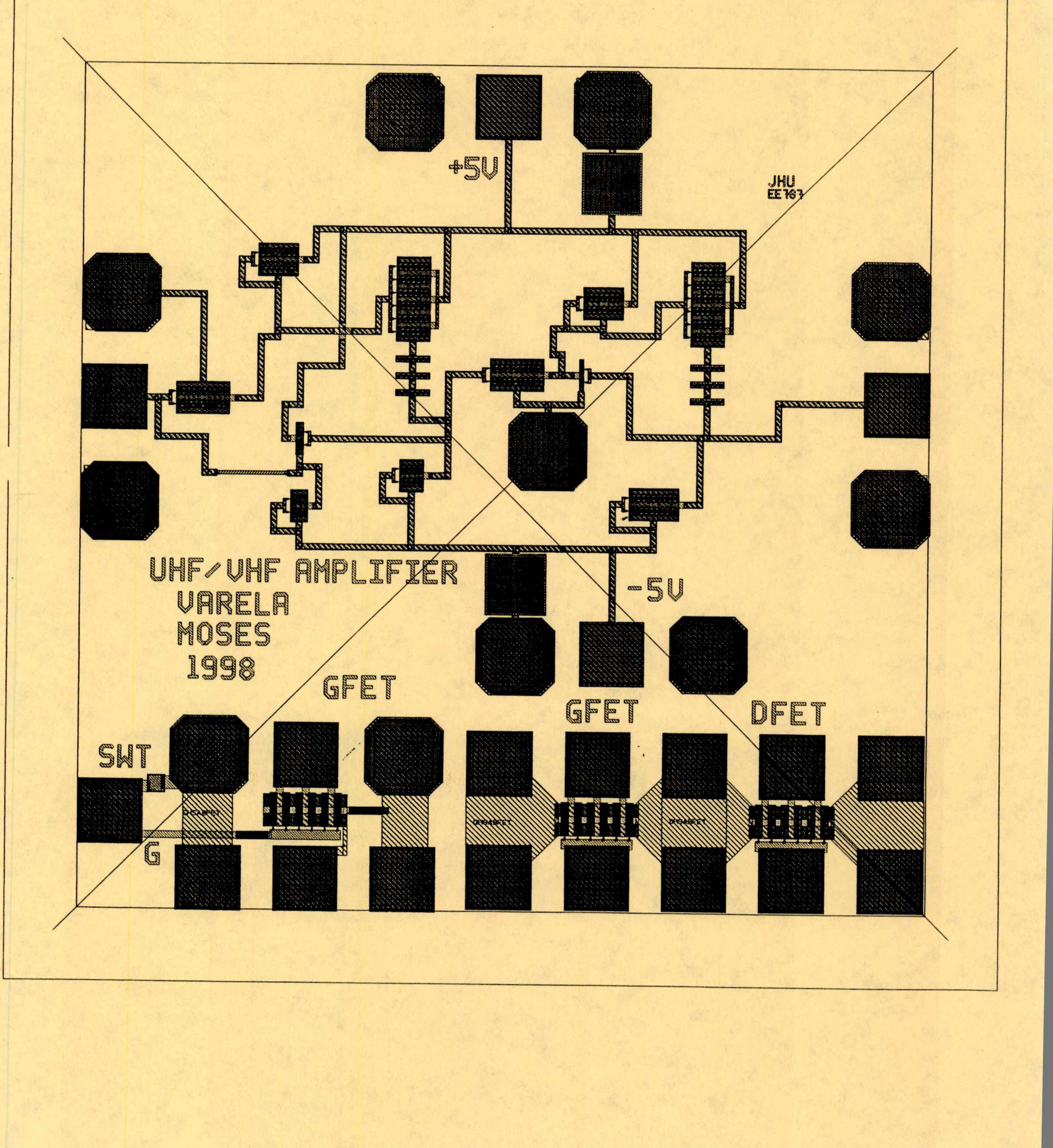


JHU980M Measurements 9 29 99



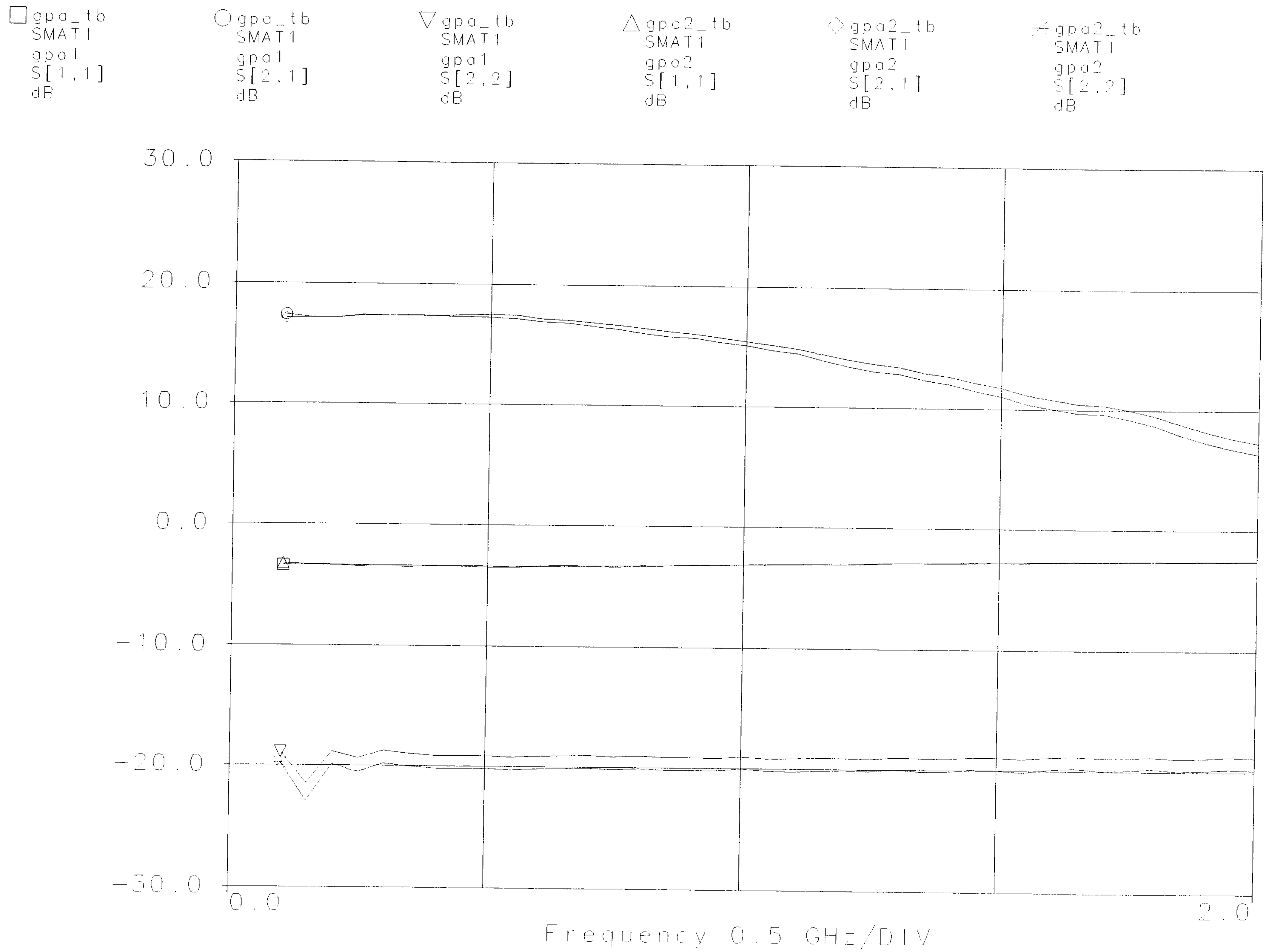
JHU980M Measurements 9/29/99

JHU981FA


+5V
JHU
EE787
UHF/VHF AMPLIFIER
VARELA
MOSES
1998
-5V
GFET
GFET
DFET
SWT
G

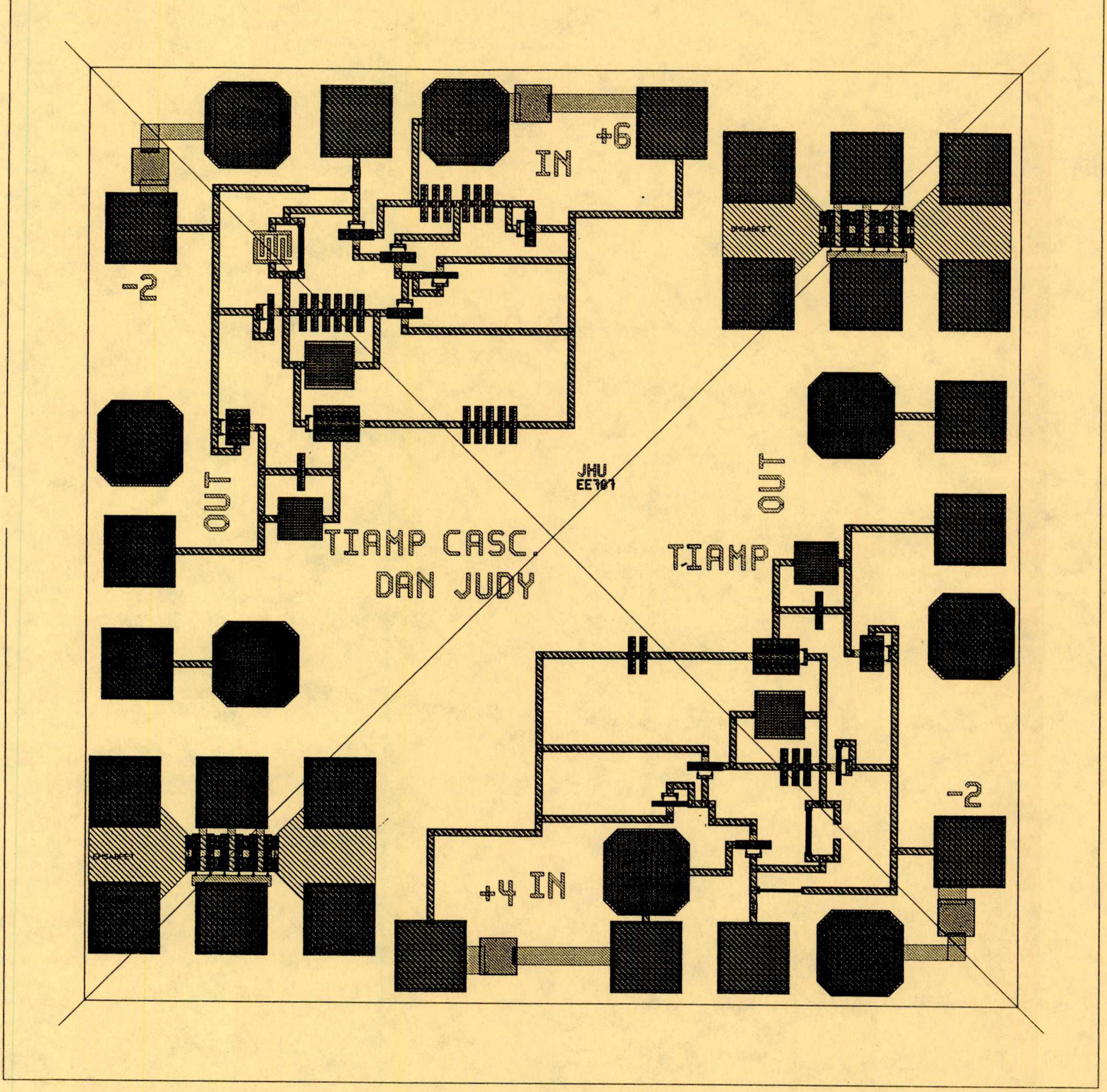
UHV/VHF Amplifier—Julio Varela and Chuck Moses

A general purpose low frequency (< 2Ghz) amplifier was designed. The bias was about as expected and the amplifier did exhibit broadband low frequency gain. However, the input match was much worse than expected and the gain was lower and had more rolloff than the student's original simulations. The GFET model used for the Fall 98 course did have some problems particularly with lower frequencies. This may explain some of the discrepancies with this lower frequency project and with the transimpedance amplifier which was a special student project by Dan Judy. Attached is a plot of match and output gain. The scale is similar to that from the original student's project report.



Measured UHF/VHF Amp JHU Fall 98 (2 MMICs)

JHU98TIA



MMIC Transimpedance Amplifier—Dan Judy

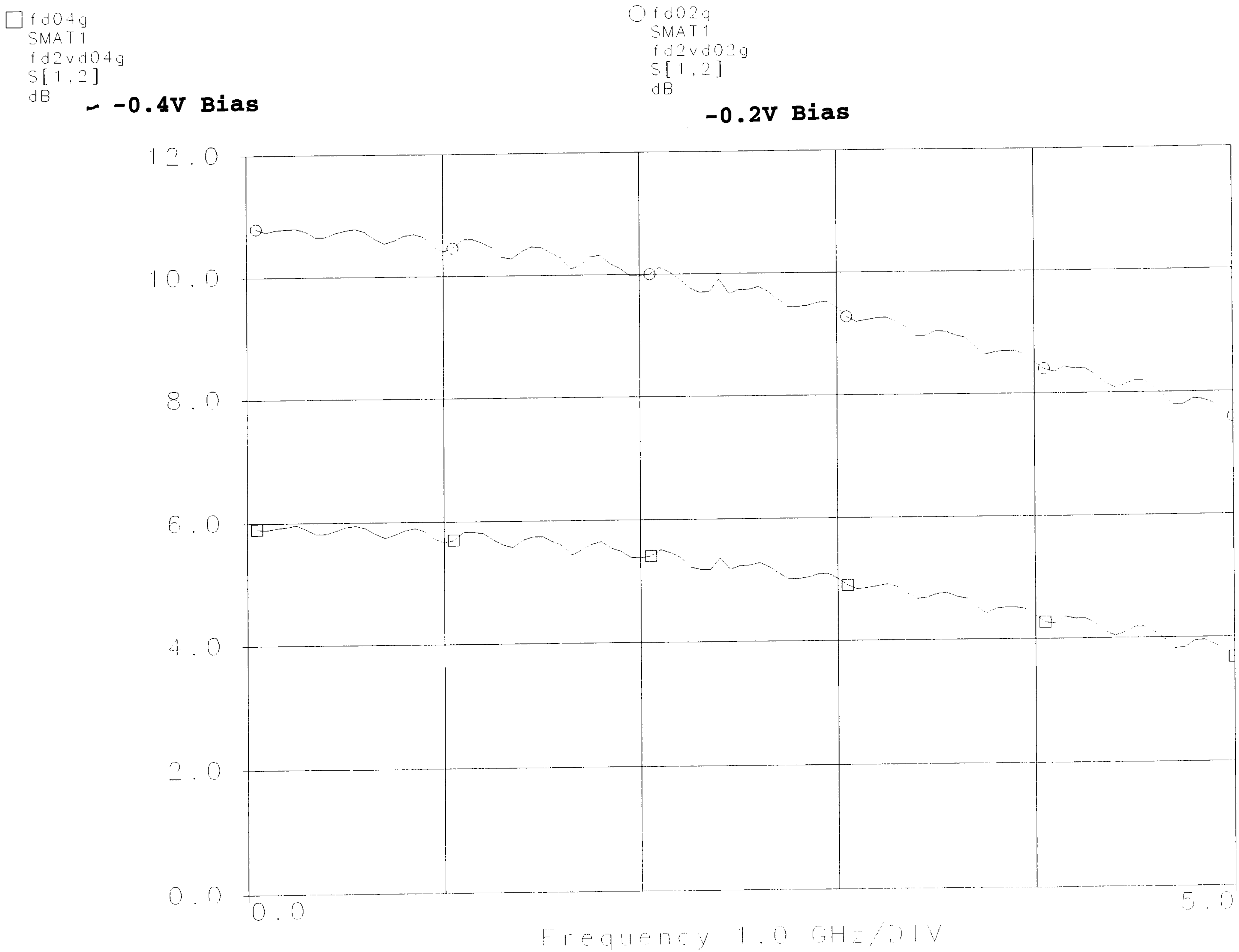
This design was a special graduate student project. Dan was a student of the previous year's JHU EE787 class. The transimpedance amplifier was intended to interface to a high impedance laser diode for use in optical high-speed communications. An impedance transform from a few K ohms at the diode to a 50-ohm output impedance is performed by the circuit. Two versions of the circuit were designed on a 60x60 mil die and there was still some room on the die for a couple of test FET structures. Attached are some plots of this design and some comments from Dan about his own measurements of the design.

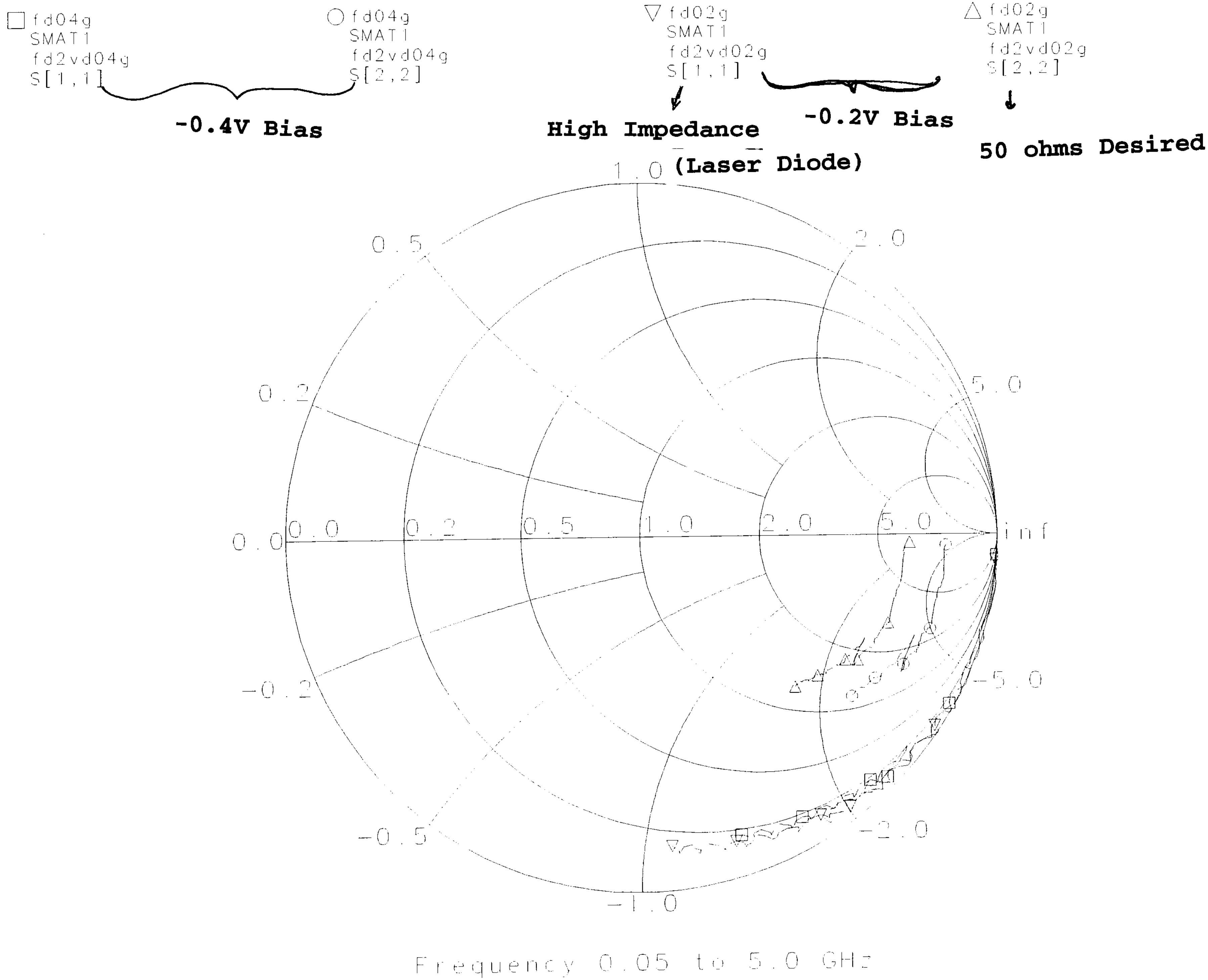
Dan's Comments:

We were unable to get the tiamp to work properly. After looking at the bias currents, we suspected that the circuit was not biased correctly. So Roger Kaul shorted out the input capacitor (he has a steadier hand than I), so that we could apply bias to the input FET. We then applied various gate bias voltages (-0.2,-0.4, and -0.6 Volts) to the input FET and made measurements. When biased at Vg=-0.2,-0.4, the amp showed positive gain with the best response at Vg=-0.2V. Even with this modification the bandwidth (1.2GHz) is well short of the modeled bandwidth of 2.7GHz. The bandwidth problem could be due to a larger feedback capacitance than expected. I used an interdigitated capacitor for the feedback capacitance, and I wonder if the larger relative cross sectional area for MMIC conductors (metal1+via2+metal2=6um+via1 thickness, trace width= 10um) is modeled well using the interdigitated capacitor in Libra. Also the input impedance is much lower than expected (this effects transimpedance Zt=-S21*50/(S11-1)) I have no idea right now what could cause this, but maybe it's a problem with the bias tee on the network analyzer.

Attached are the s2p files for the measurements we made.

fd_tia4.s2p unmodified
fd_2vd_0_2g.s2p Vg=-0.2V
fd_2vd_0_4g.s2p Vg=-0.4V
fd_2vd_0_6g.s2p Vg=-0.6V


fd04g
SMAT1
fd2vd04g
S[1,2]
dB
-0.4V Bias
fd02g
SMAT1
fd2vd02g
S[1,2]
dB
-0.2V Bias
12.0
10.0
8.0
6.0
4.0
2.0
0.0
0.0
5.0
Frequency 1.0 GHz/DIV


□ fd04g
SMAT1
fd2vd04g
S[1,1]
○ fd04g
SMAT1
fd2vd04g
S[2,2]
-0.4V Bias
▽ fd02g
SMAT1
fd2vd02g
S[1,1]
High Impedance
(Laser Diode)
-0.2V Bias
△ fd02g
SMAT1
fd2vd02g
S[2,2]
50 ohms Desired
1.0
0.5
2.0
0.2
5.0
0.0
0.0
0.2
0.5
1.0
2.0
5.0
inf
-0.2
-5.0
-0.5
-2.0
-1.0
Frequency 0.05 to 5.0 GHz