FIELD EMITTER ARRAY RF AMPLIFIER DEVELOPMENT PROJECT
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PHASE ONE, OPTION 1

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DR. BERTRAM HUI
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MCNC ELECTRONIC TECHNOLOGIES DIVISION
POST OFFICE BOX 12889
RESEARCH TRIANGLE PARK, NC 27709-2889

GARY McGUIRE, PRINCIPAL INVESTIGATOR

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6. AUTHOR(S)
Dr. W. Devereux Palmer
Dr. Gary E. McGuire, Principal Investigator

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
MCNC Electronic Technologies Division
Post Office Box 12889
3021 Cornwallis Road
Research Triangle Park, North Carolina 27709-2889

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ARPA/DSO
3701 North Fairfax Drive
Arlington, Virginia 22203-1714

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11. SUPPLEMENTARY NOTES
Dr. Palmer (919) 248-1837, (919) 248-1455 FAX
COTR: Dr. Bertram Hui (703) 696-2239, (70[illegible] 696-2201 FAX

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13. ABSTRACT (*Maximum 200 words*)

We have demonstrated anode current modulation at 1 GHz as reported in the special technical report of 31 JAN 94. 80 μA peak of anode current modulated at 1 GHz was observed with only 2.02 V peak RF modulation on the gate electrode at a DC gate bias voltage of 118 V and DC anode emission current of 1.8 mA. The bias current is about 2 μA per tip, which is in the acceptable range for RF amplification suggested in the literature. The measured RF performance is consistent with DC current-voltage measurements shown in the report. This data was collected on a small field emitter device with 1197 tips on 4 μm columns in order to minimize the field emitter array cell capacitance. The RF input power level was 0.14 W peak. The measured input impedance of the device at 1 GHz, 28 Ω, is quite high, indeed much higher than that reported for competing device structures. We believe that this silicon-based process is easily scalable to larger arrays which should result in net RF gain. We also believe that this demonstration shows that RF modulation of field emitter devices is feasible.

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We have demonstrated anode current modulation at 1 GHz as reported in the special technical report of 31 JAN 94. 80 μA peak of modulated anode current at 1 GHz was observed with only 2.02 V peak RF modulation on the gate electrode at a DC gate bias voltage of 118 V and DC anode emission current of 1.8 mA. This emission current is about 2 μA per tip, which is in the acceptable range that was suggested by Calame *et al.* [1]. The measured RF performance is consistent with the differential DC current-voltage measurements shown in Figure 1. That data was collected on a small field emitter device with 1197 tips on 4 μm columns in order to minimize the field emitter array cell capacitance. The RF input power level was 0.14 W peak. The measured input impedance of the device at 1 GHz, 28 Ω, is quite high, indeed much higher than that reported for competing device structures. We believe that this silicon-based process is easily scalable to larger arrays which should result in net RF gain. We also believe that this demonstration shows that RF modulation of field emitter devices is feasible, and with the process improvements in progress with these devices will satisfy Phase II performance requirements.

To provide the technical background to these results, the following derivations are presented. DC performance data collected during the RF test is shown. Parameters are extracted from the DC data and used to predict RF performance, which is then compared with measurement. The conditions of the RF test documented by the oscilloscope trace in Figure 2 (and included in the last report as Figure 1) are summarized in the table below.

Modulated Anode Current (1 GHz)	80 μA_{PEAK}
Input RF Power (1 GHz)	0.1414 W_{PEAK}
Measured Input Impedance (1 GHz)	20 - j 19 Ω
Gate DC Bias Voltage	118 V
Anode DC Bias Current	1.8 mA
Anode Voltage	500 V

During the RF test, meters monitor the DC gate voltage, DC gate current, and DC anode current, and a computer records the meter readings once per second. After the test, the data is reduced to extract an I-V curve representative of the average performance of the device over the life of the test. While the measurement point of 1.8 mA at 118 V does not appear explicitly on this plot, it does appear in the data file recorded during the RF measurement. The transconductance at the anode DC emission current of 1.8 mA will be used for later calculations. This data is plotted as anode current (Ia) versus gate voltage (Vg) in Figure 1(a).

The same data is plotted as log (Ia / Vg^2) versus 1 / Vg in Figure 1(b). A straight-line fit to the data overlays the measured points. The straight-line fit is used to calculate the parameters A and B that fit the data to the Fowler-Nordheim equation relating field emission current to applied voltage. Referring again to Figure 1(a), the measured data points are represented by squares, and the thick line shows the fitted Fowler-Nordheim equation. Vertical lines are drawn at 118 and 120 V on the gate axis, representing the gate votage modulation. The projection of these lines crosses the Fowler-Nordheim curve for the device, where horizontal lines are drawn to intersect the current axis. The projected current modulation from this gate voltage modulation is on the order of 80 µA, consistent with the anode current modulation measured at 1 GHz.

By definition, the derivative of this equation with respect to gate voltage gives an expression for the device transconductance g_m. The transconductance of the device then relates the gate voltage of the device to the anode current as

$$g_m = \frac{\Delta Ia}{\Delta Vg} \qquad \text{or} \qquad \Delta Ia = g_m \Delta Vg$$

Using the derivative of the fitted Fowler-Nordheim equation, the transconductance of the device under test at a DC anode bias current of 1.8 mA is 38.9 µS. Thus, the device transconductance is experimentally determined from DC measurements on the device performed during the RF measurement.

The input modulation voltage can also be derived from measured parameters. Calculating from the generator forward using

$$V = \sqrt{W \times \Omega}$$

the peak incident voltage on the 50 Ω transmission line to the device from an RF input power of 0.1414 W_{PEAK} is 2.66 V_{PEAK}. The voltage reflection coefficient ρ resulting from the input impedance of the device (measured at 1 GHz on a vector network analyzer) terminating the 50 Ω line is

$$\rho = 0.489 \exp(-j133^\circ)$$

The voltage wave reflected from the device is the incident voltage wave multiplied by the voltage reflection coefficient. The total voltage on the 50 Ω line is the sum of the incident and reflected waves. Thus, the peak voltage at the input to the device is determined by calculating from measured parameters to be 2.02 V_{PEAK}. This represents the input modulation voltage during the test.

With this peak value of the input modulation voltage and the transconductance as calculated above, the resulting expected anode current modulation would be

$$\Delta Ia = 38.9\mu S \times 2.02V = 78.6\mu A$$

This value shows excellent agreement with the measured anode current modulation reported above. In other words, values of modulated anode current predicted from measurements of DC current versus voltage agree very closely with values measured at 1 GHz. This self-consistency demonstrates that the high-frequency measurement technique used by the program at MCNC is correct and accurate.

[1] J. P. Calame, H. F. Gray, and J. L. Shaw, "Analysis and design of microwave amplifiers employing field-emitter arrays," *J. Appl. Phys.* **73** (3), 1 February 1993, pp. 1485–1504.

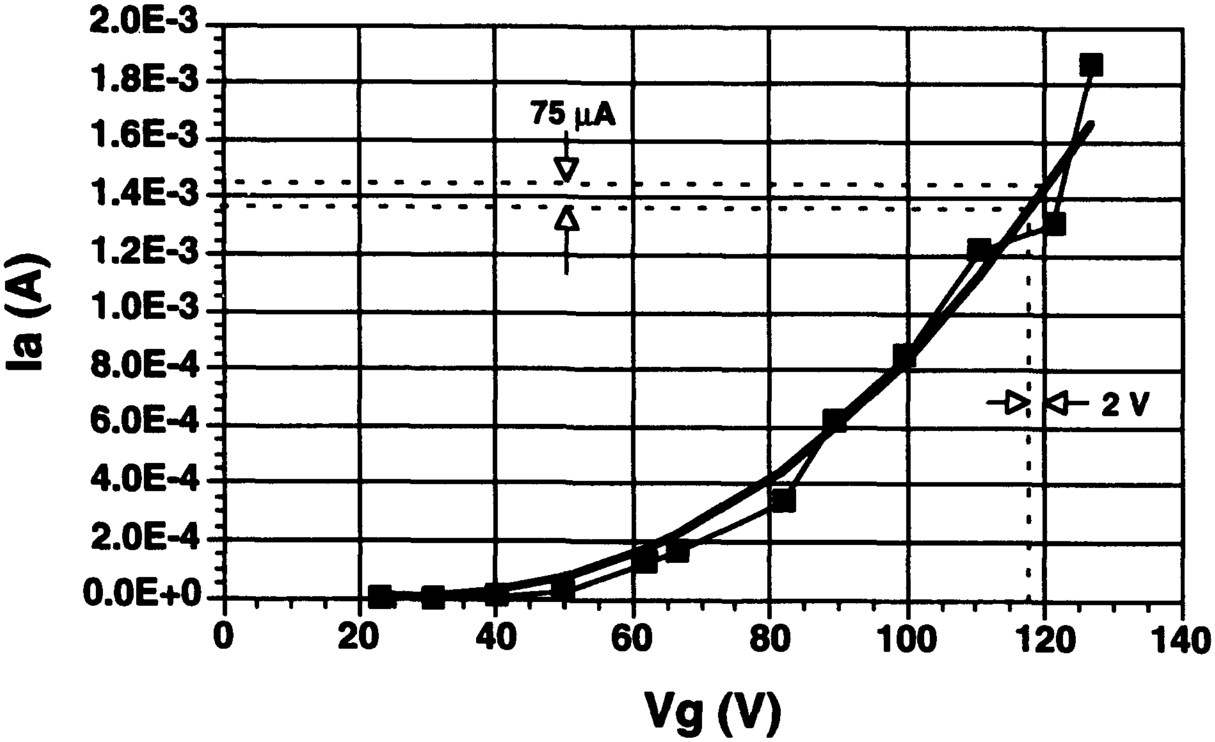

Figure 1 (a)

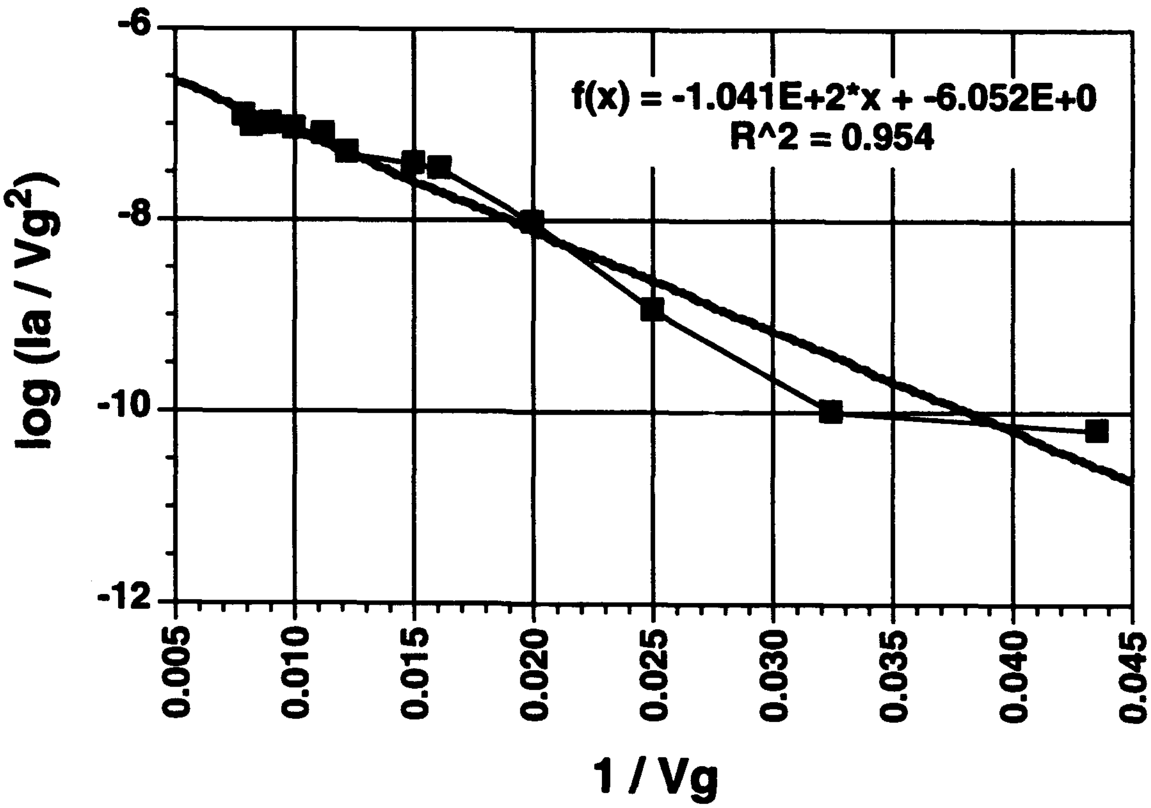

Figure 1 (b)

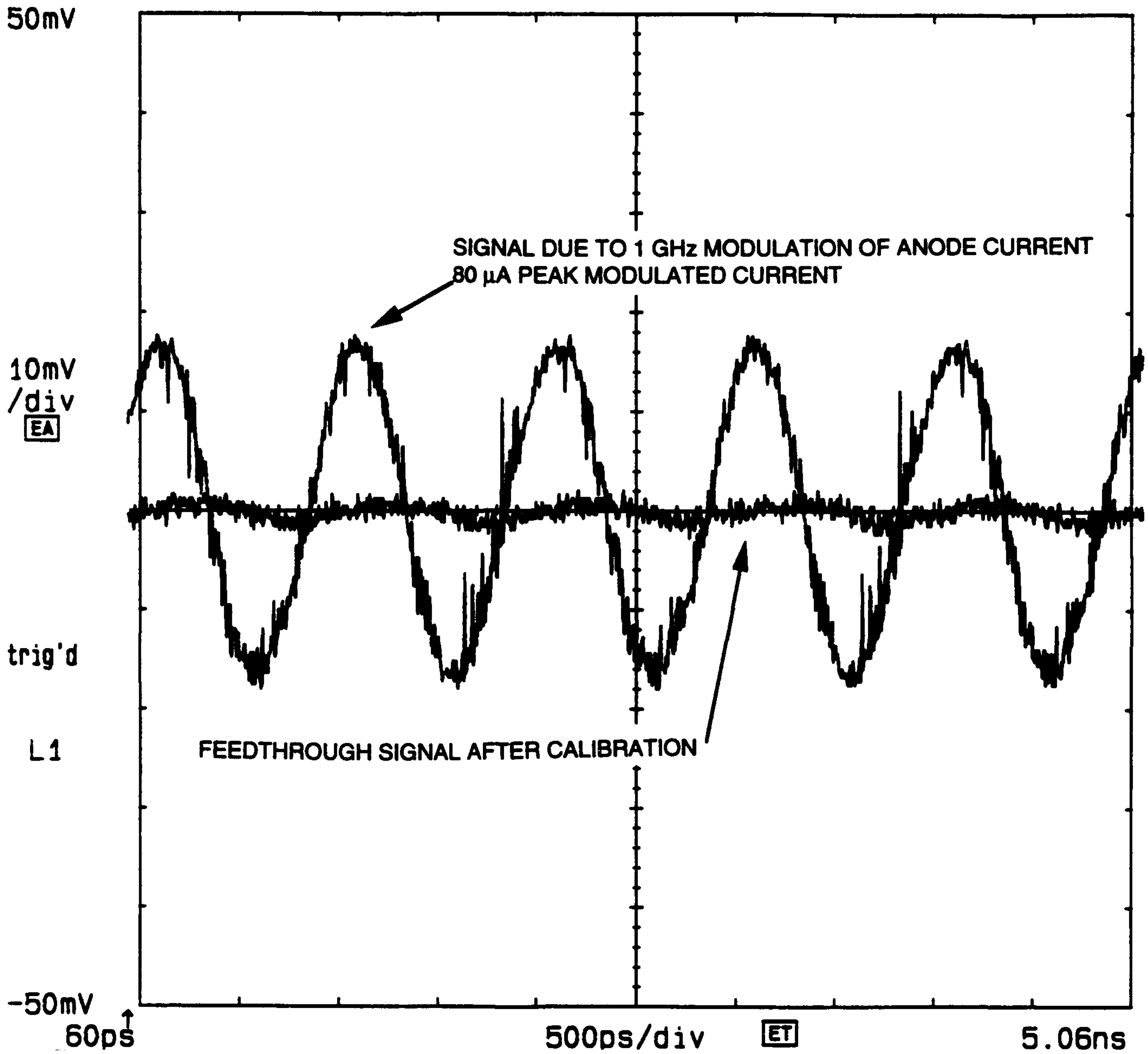

Figure 2: DSA602A oscilloscope screen image displaying the feedthrough signal with the emitter off after calibration, and the output voltage signal (16 mV peak) due to 1 GHz modulation of field emitter array anode current (81 μA peak).