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Vacuum MicroElectronics

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Quarterly R&D Status Report – covering period
07/01/93 - 09/30/93

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Honeywell Technology Center
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R&D Status Report 7/01/93 - 9/30/93

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RF Vacuum Microelectronics

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D. K. Arch

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Honeywell Technology Center
10701 Lyndale Avenue South
Bloomington, Minnesota 55420

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13. ABSTRACT *(Maximum 200 words)*

We summarize our progress towards developing a thin film edge emitter vacuum transistor capable of 1 GHz modulation. The first fabrication run of these devices, using the redesigned edge emitter transistors, was completed. Several process issues identified and corrected and a second run of devices has been initiated. Verification of our ability to measure high frequency performance in our high vacuum test station was shown.

14. SUBJECT TERMS
Vacuum microelectronics, edge emitter, thin film technology, high frequency devices, triodes

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R&D Status Report
RF Vacuum Microelectronics
Quarterly Progress Report #8
(7/1/93 - 9/30/93)

Sponsored by:

Dr. Bertram Hui
ARPA/DSO
3701 N. Fairfax Drive
Arlington, Virginia 22203
Tel: 703/696-2239

Contractor: Honeywell Technology Center
10701 Lyndale Avenue South
Bloomington, MN 55420

Effective Date of Contract:	September 30, 1991
Contract Expiration Date:	May 31, 1993 (Baseline)
Option Expiration Date:	November 30, 1993
Contract Amount: Baseline	$1,315,650
Option:	$ 465,000

Principal Investigator:	Tayo Akinwande 612/887-4481
Program Manager:	David K. Arch 612/887-4404

Title of Work: **RF Vacuum Microelectronics**

I. Executive Summary

Technical Approach: Our technical approach is to utilize thin film technology and surface micromachining techniques to demonstrate an edge emitter based vacuum triode. An array of vacuum transitors are connected in parallel to achieve microwave performance. The edge emitter triode approach offers several potential advantages to achieving high frequency device operation (compared to cone emitters or wedge emitters):

- Thin film processes for the films used in the triode process are well controlled and reproducible. Control of film thicknesses to within 5% for the emitter film thickness is easily attainable resulting in a well-controlled edge emitter.
- Device capacitance for the edge emitter is less than that achievable for cones or wedges resulting in potentially higher frequency operation.
- The fabrication process is a planar process, compatible with most silicon IC manufacturing.

Program Objective: **Demonstrate an edge emitter based microwave vacuum transistor with gain at 1 GHz continuously for 1 hour.**

Key Achievements (this reporting period)

- Started fabrication of a mirowave vacuum transistor run
- Modified the microwave vacuum transistor process to improve yield.

II. Milestone Status

	Completion Date		
	Planned	**Actual**	**Comments**
Task 1. Field Emitter Development			
Test Structure Design Complete	12/91	1/91	complete
Determine Workable Emitter Structure	3/92	12/92	complete
Demonstrate Emission Current of 10 μA/μm	11/92	11/92	complete
Deliver 10 Field Emitting Diodes	12/92	10/92	delivered
Task 2. Process Development			
High Resistivity Thin Film Resistor	4/92	9/92	complete
Complete Dielectric Studies	5/92	6/92	complete
Mechanical and Electrical FEM Analysis	5/92	8/92	complete
Task 3. Triode Development			
Triode Design Complete	4/92	5/92	complete
Demonstrate Reliable/Uniform Current Emission	7/92	10/92	complete
Demonstrate Modulated/Edge Emitter Triode	8/92	12/92	complete
Demonstrate 1 GHz Modulation of Triode	2/93	12/92	behind plan
Deliver 2 Triodes	3/93	8/93	complete
Task 4. Final Report (Baseline)	4/93	4/93	complete
Task 5. High Frequency Demo			
Design Microwave Vacuum Transistor	6/93	6/93	complete
Complete Process Development	6/93	6/93	complete
Complete High Frequency Probe Assembly	6/93	6/03	complete
Demonstrate Vacuum Transistor with High Current	10/93	10/93	on plan
Demonstrate 1 GHz Modulation with Gain	10/93	10/93	on plan

III. Technical Progress

Microwave Vacuum Transistor Fabrication

We started the fabrication of the microwave vacuum transistor. We have completed 90 % of the process steps for the run. We discovered, however, that we require further process development and some mask modifications to yield the microwave vacuum transistor.

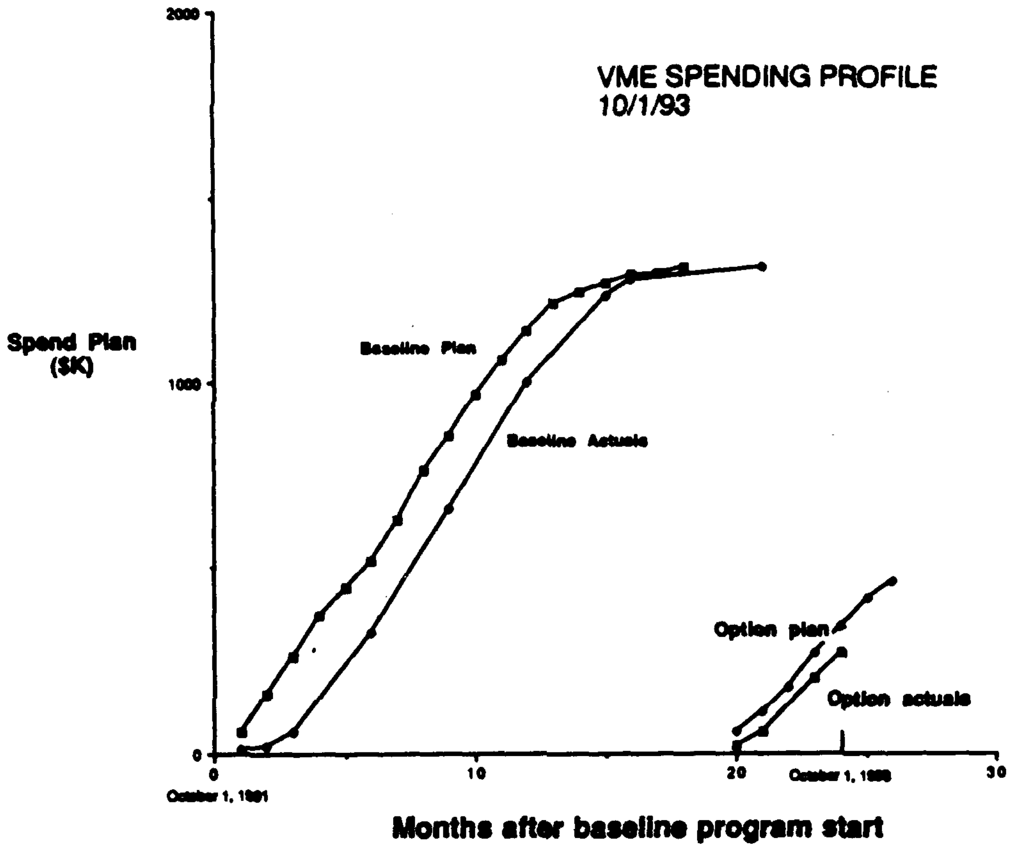
Figures 1 and 2 show SEM analysis of some of the devices. The devices are about 90 % complete. The figures show the emitting edge between the two control electrodes encapsulated by a nitride layer. The emitting edge is exposed as expected. The individual device segments look excellent as shown in the SEM. The microwave vacuum transistor is an array of these individual device segments. The device segments are are connected in parallel with metal runners such that all emitters are connected together and all control electrodes (gates) are connected together and all anodes are connected together. In order to simplify the process and reduce the number of masks and fabrication steps, we made the metal runners out of existing layers. This implied that the metal runners would have cross-overs. We found during the course of the fabrication that these metal runners that interconnect individual device segments do not cover steps very well and are not continuous over these steps.

We have made adjustments in our process through a combination of changing the layout / design rules and making slight changes to some process steps. We have started a new fabrication run (Run #2) which will be completed mid-to-late October. We shall begin testing immediately upon device completion.

Microwave Vacuum Feedthrough Probes

We verified that the vacuum probes do work on GaAs wafers at 2 GHz. Figure 3 is a plot of the high frequency characteristics of the GaAs chip before probe-tip calibration. The device is a GaAs chip with a drain current of 20 mA, Vds of 3V and Vgs of -0.44V. The plot shows a 10 dB gain at 2 GHz. Figure 4 is a plot of the same chip after the calibration of the probes at the tip. It also shows 10 dB gain at 2 GHz, however the curve is much smother with a slight roll-off. Figure 5 is a plot of S parameters of the device after probe tip calibration. We shall re-do the calibration in the vacuum system prior to device testing.

IV. Fiscal Status



	Baseline Program	Option Phase
Expenditures this quarter	$ 87K	$210K
Total expenditures to date	$1,395K	268K
Projected expenditures (baseline):		
10/93 - Program Completion	0	197K
Total Projected Cost for Program	$1,315,650*	$465K

*Total cost to ARPA. The remaining funding for the baseline program (~$80K) is being cost-shared by Honeywell through a limitation of its overhead rates. In addition, as a result of the February 1, 1993 program review with ARPA, Honeywell agreed to an additional investment (internal development funds) of approximately $71K to provide further testing, testing enhancements and process enhancements to the VME effort. Of this $71K committed all has been spent.

Plans for Next Reporting Period

- Complete fabrication of run #2.
- Complete dc and ac characterization of VME devices from run #2.
- Demonstrate 1 GHz modulation on a thin film edge emitter triode device.

V. Programmatics

- Our paper entitled "Monolithic Lateral Thin-Film-Edge-Emitter Vacuum Transistor" was presented at IVMC in Newport, Rhode Island in July.

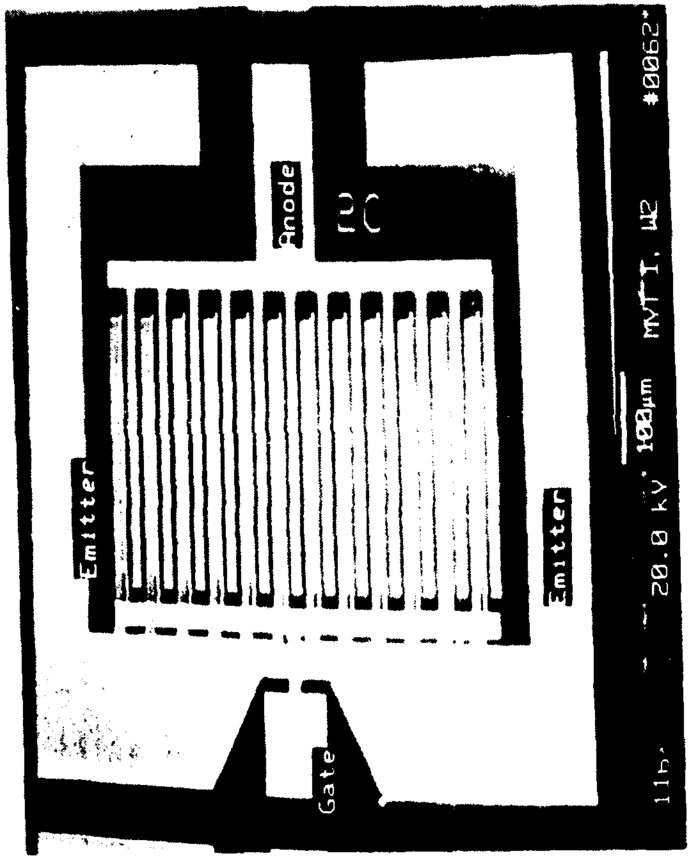
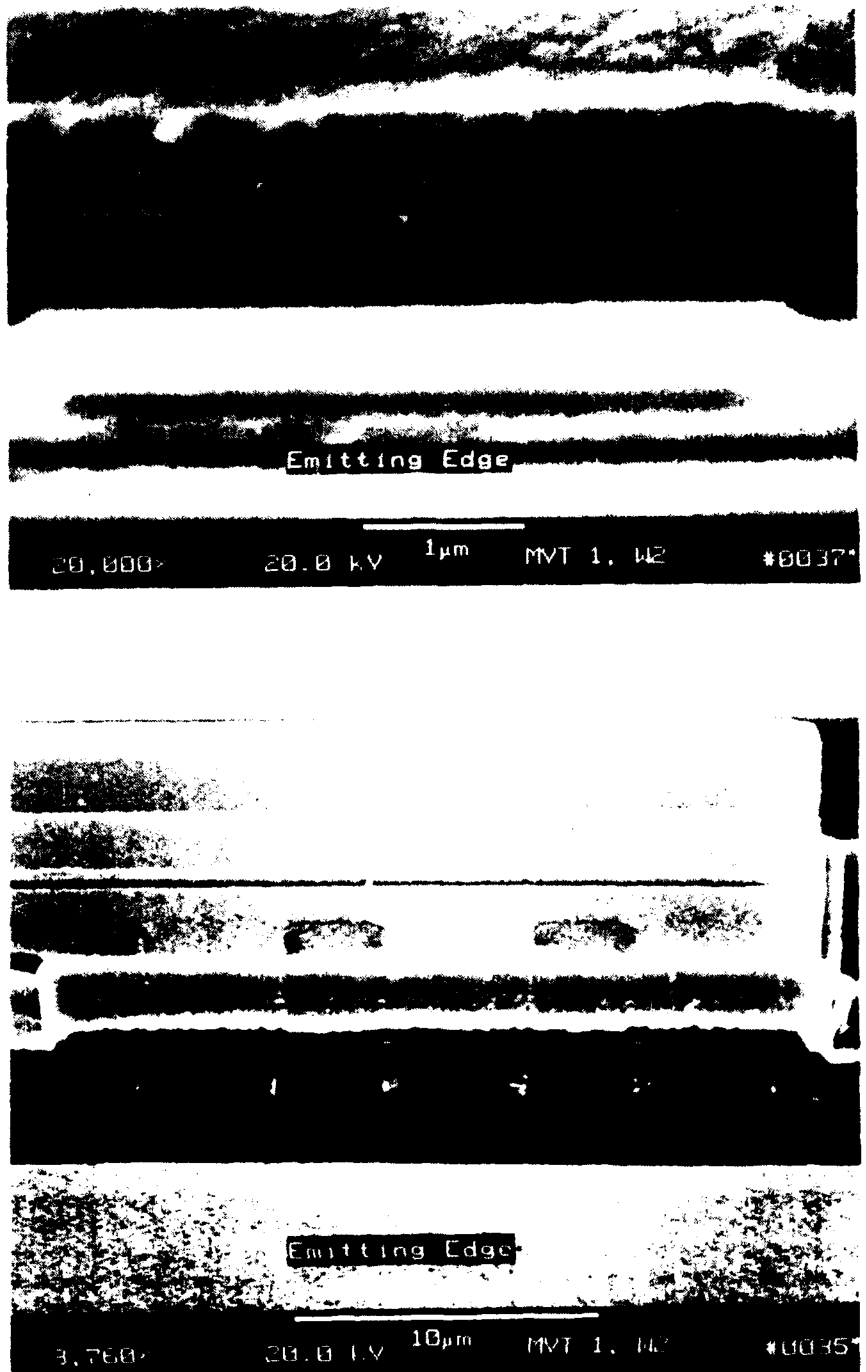


FIGURE 1. SEM of the Microwave Vacuum Transistor. It shows the individual electrodes - anode, emitter and gate.



FIGURES 2a & b.
SEM of the Microwave Vacuum Transistor showing the gates and the emitting edges.

TEST FET FOR VACUUM PROBES

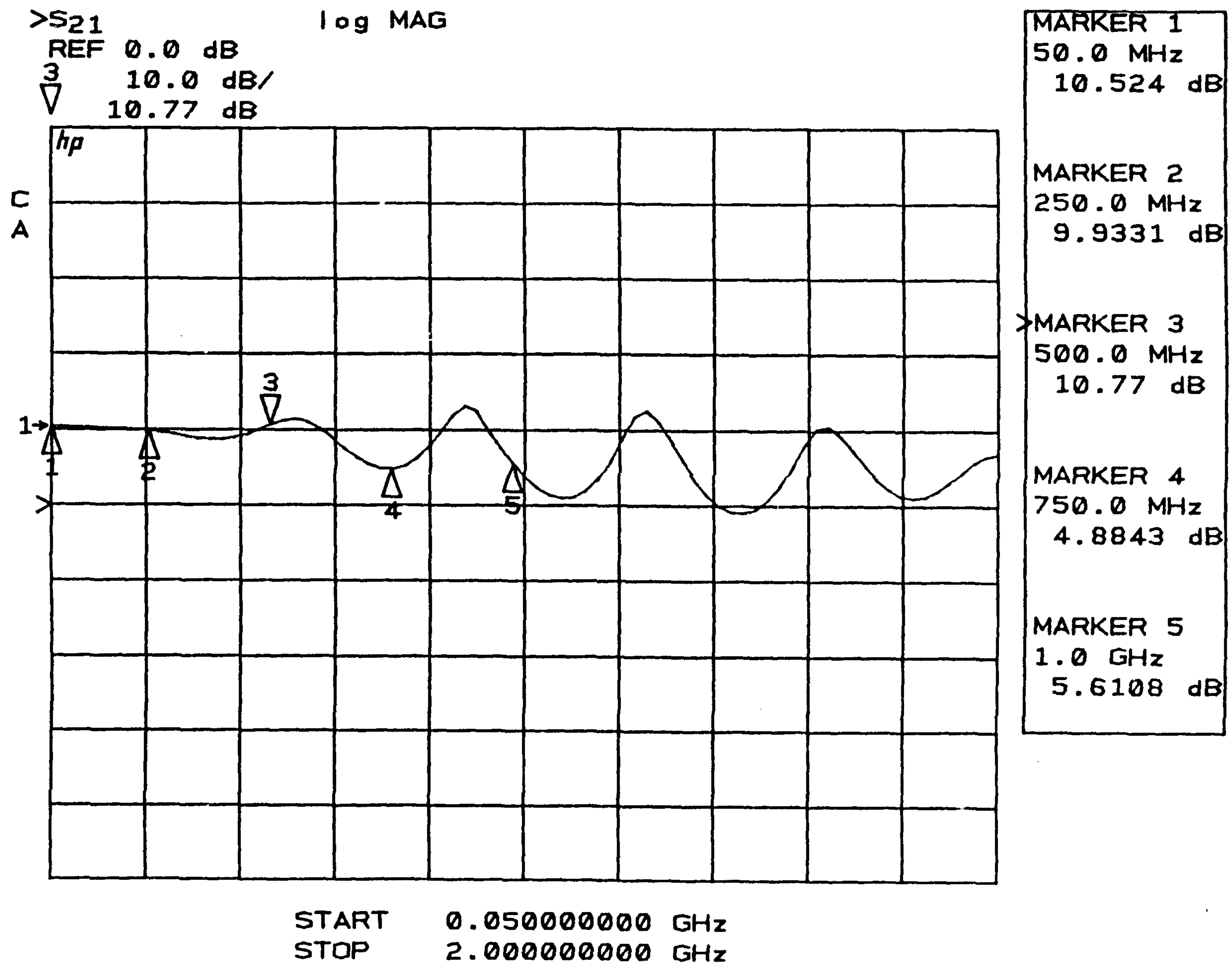


FIGURE 3. Vacuum Probe Test of a microwave GaAs FET for 0-2 GHz. The test shows that the probes have very little insertion loss and feedthrough in the frequency range of interest for the MVT.

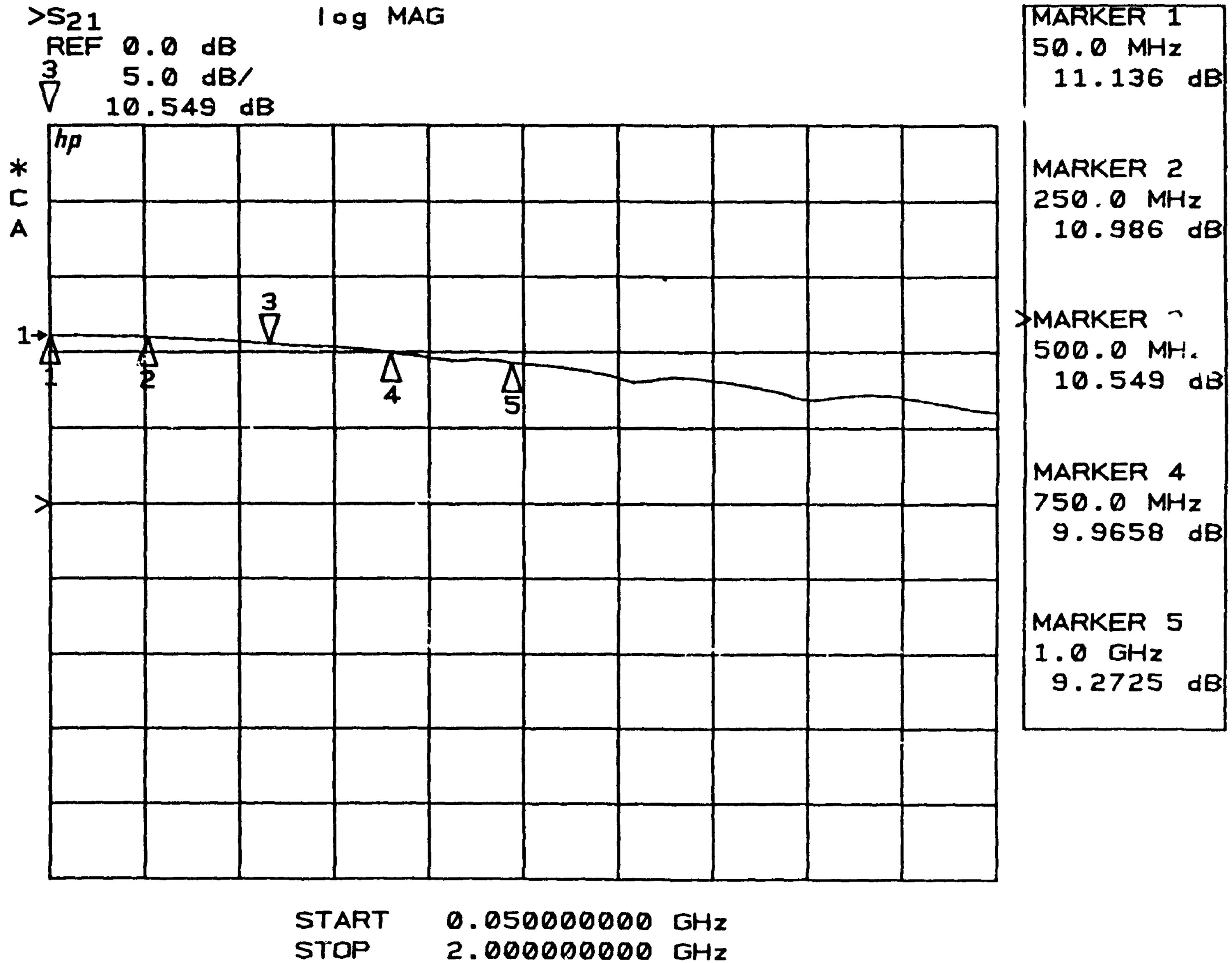


FIGURE 4. Vacuum Probe Test of a GaAs FET from 0-2 GHz. The probes have been calibrated. The test shows less than 5 dB loss over the range of interest for the MVT.

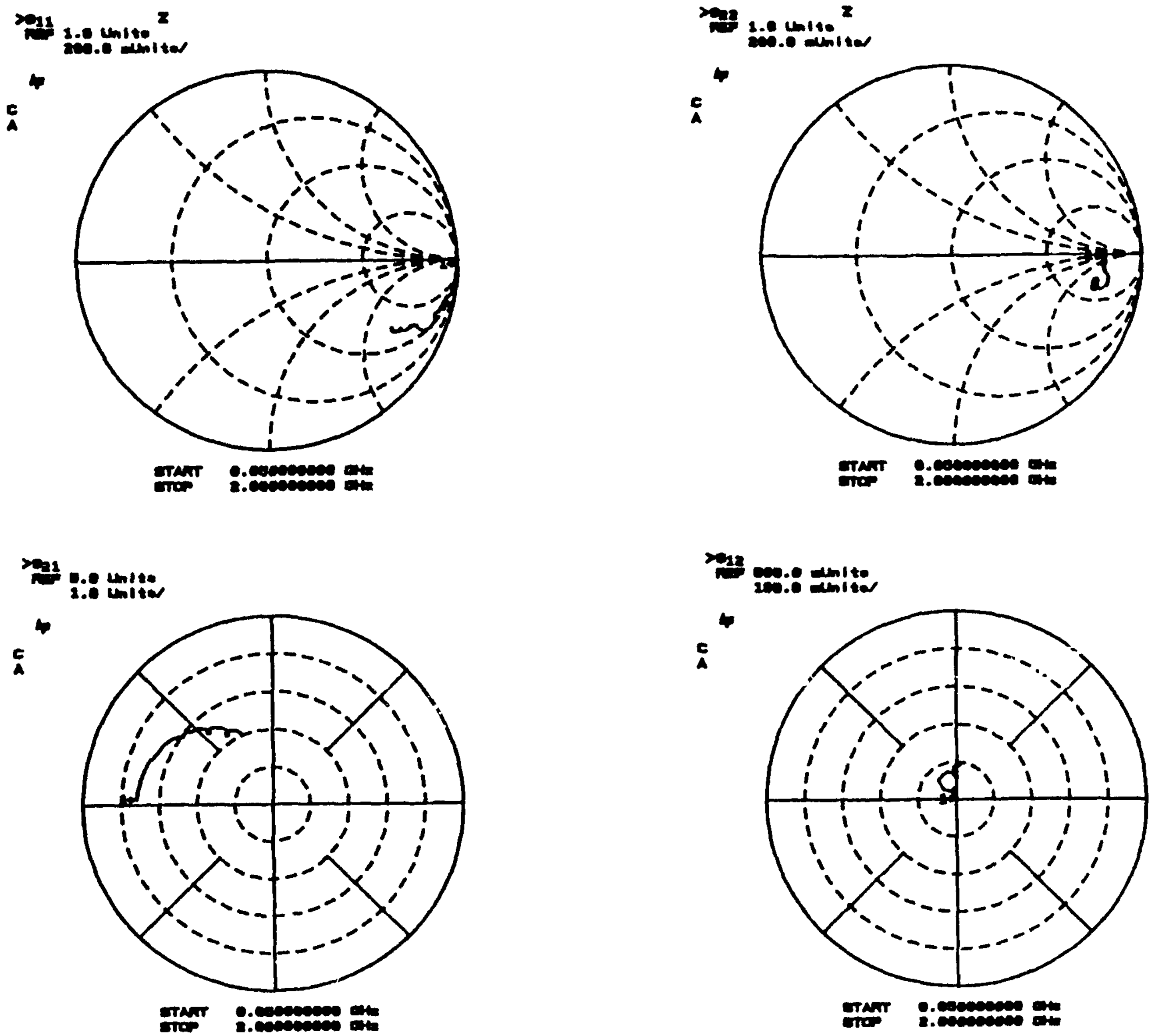


FIGURE 5. Vacuum Probe Test of a GaAs FET. S-parameters of the device are plotted in the 0-2 GHz frequency range. The test shows that the vacuum probes will be adequate for testing the MVT.