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The microwave electron gun which is the focus of this project has been successfully operated, producing beam current of 0.5 A in a five microsecond pulse at pulse repetition rates up to 30 Hz. Studies of the performance characteristics of the gun are proceeding. Initially it has been determined that the new deflection magnet design produces a factor of two improvement over earlier designs.

Coherent transition radiation produced when the electron bunches impact a metal screen has been observed in the microwave spectral region. Harmonics of the driving frequency have been detected to frequencies above 50 Ghz. Installation of more efficient interaction devices to extend both spectral range and power generated is in progress.

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FINAL REPORT

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Reporting Period: May 15, 1989 - Sept. 30, 1992

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ABSTRACT

The microwave electron gun which is the focus of this project has been successfully operated, producing beam current of 0.5 A in a five microsecond pulse at pulse repetition rates up to 30 Hz. Studies of the performance characteristics of the gun are proceeding. Initially it has been determined that the new deflection magnet design produces a factor of two improvement over earlier designs.

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FINAL REPORT

I. Introduction

This project has focused on the development of a stand-alone electron beam source patterned after the microwave electron gun which serves as the injector for the highly successful MK III Free Electron Laser (FEL). The resulting device is a compact, "table-top" source of a high quality electron beam which will be used as a test bed to explore techniques for generating coherent radiation from the microwave spectral region to the infrared.

II. Operation and Performance of the Electron Gun

Assembly and installation of the electron gun and all ancillary systems has been completed (See Figure 1), lacking only installation of the momentum filter (See discussion below). Electron beam turn-on was accomplished without incident, producing approximately 0.5 amperes of beam current in a 5 microsecond pulse at pulse rates to 30 Hz. Performance of vacuum and RF systems has been very satisfactory. The laser-heated cathode combined with a digital temperature control system provides excellent cathode stabilization.

Studies of the performance characteristics of the gun have begun. The first issue addressed was the effectiveness of the redesigned deflection magnet for reducing cathode heating caused by back-bombarding electrons. This is an important issue since the average heating power due to back-bombardment puts a fundamental limit on the average current which the gun can produce. The design of the "window" deflection magnet is shown in Figure 2 and the transverse magnet field it produces is shown in Figure 3. Figure 4 illustrates the effect of the deflection field on an individual macropulse. The upper pulse shows the large current ramp due to back-heating when the deflection magnet is not in use, while the lower pulse illustrates the reduced ramp obtained when the deflection magnet is fully energized.

To evaluate the performance of the deflection magnet quantitatively, a measure of the back-heating power is needed. This cannot be obtained directly, but can be inferred by studies of the applied heater power as a function of the average beam current at fixed cathode temperature. The back-heating is proportional to the average beam current, hence as the current is increase, by increasing the pulse length or raising the repetition rate, the heater power required decreases. The slope of the heater power versus average beam current is proportional to the back-heating per ampere of current. Figure 5 (a) shows such data taken with the deflection magnet off and Figure 5 (b) shows similar data with it fully energized. Use of the deflection magnet reduces the slope by 63%. Compared to the original design used on the MK III, this is an improvement of a factor of two which allows the pulse repetition rate to be increase from a maximum of 15 Hz on the original to 30 Hz on the NCCU gun. Even greater reduction of the back-heating would be desirable and the data obtained on the NCCU gun will be used by personnel of the Duke FEL Laboratory to seek further improvements in the magnet design.

Application of the deflection magnet field necessitates the use of two dipole corrector magnets to center the beam on the axis of the quadrupole magnets which will focus the beam into the momentum filter. Using a fluorescent screen to view the beam, the proper setting of these correctors has been determined and the focusing performance of the quadrupoles has been observed. The momentum filter is in final assembly and studies of the electron energy spectrum from the gun will commence as soon as the momentum filter is installed.

III. Generation of Microwave Radiation by the Electron Beam

Prior to installation of the momentum filter, the electron bunches produced by the gun are relatively long. Nevertheless it is possible to observe microwaves produced by transition radiation when the electron bunches impact upon a screen. Figure 6 shows the output from an X-band microwave detector during a current macropulse. Although no provisions have been made to efficiently transport the radiation from screen to the detector (the microwaves are extracted from the optical viewport), the signal level is on the order of 0.1 mW and readily detected. Figure 7 shows the observed RF power as a function of the beam current. The quadratic dependence is strong evidence of coherent emission by the electron bunches. Harmonics of the RF driving frequency have been observed up to the limit of the available microwave spectrum analyzer; i.e. the sixth harmonic (17.1 GHz) and signals have been seen on microwave detectors sensitive to frequencies above 50 GHz. Further diagnostic techniques are being assembled in preparation for the installation of an interaction device designed to efficiently generate and transport microwave/millimeter radiation. In addition to its usefulness for spectroscopic studies, the spectrum of radiation generated will provide insight into the temporal structure of the gun micropulses.

IV. Publications and Interactions

Papers on this work have been presented at the following conferences:

17th International Conference on Infrared and Millimeter Waves, December, 1992, Los Angeles, CA.

Annual Meeting of the Southeastern Section of the APS, November, 1991, Durham, NC.

16th International Conference on Infrared and Millimeter Waves, August, 1991, Lausanne, Swz.

A publication entitled; "A Compact Relativistic Electron Beam Source for Generation of Far-Infrared Radiation" is in preparation for submission to the International Journal of Infrared and Millimeter Waves.

FIGURE 1

Microwave Electron Gun System

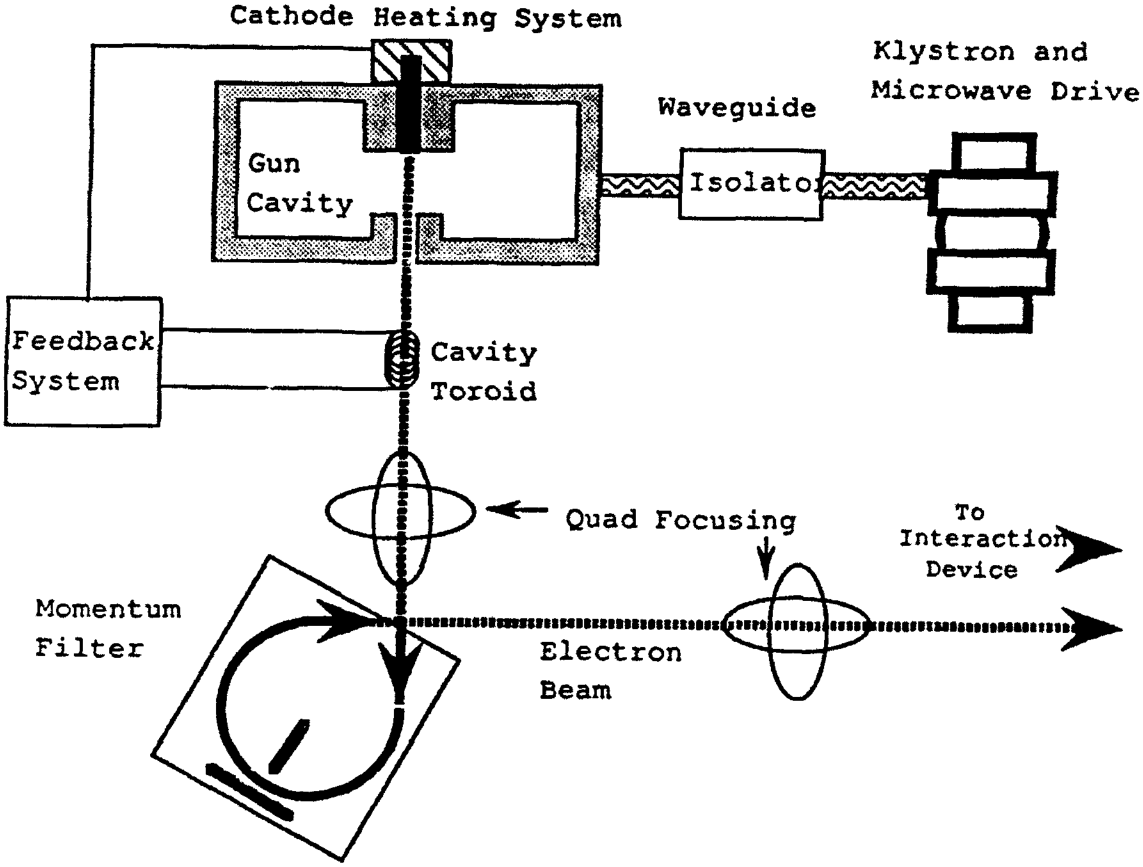


FIGURE 2

Window Deflector Magnet
Presently Installed on the NCCU Microwave Gun

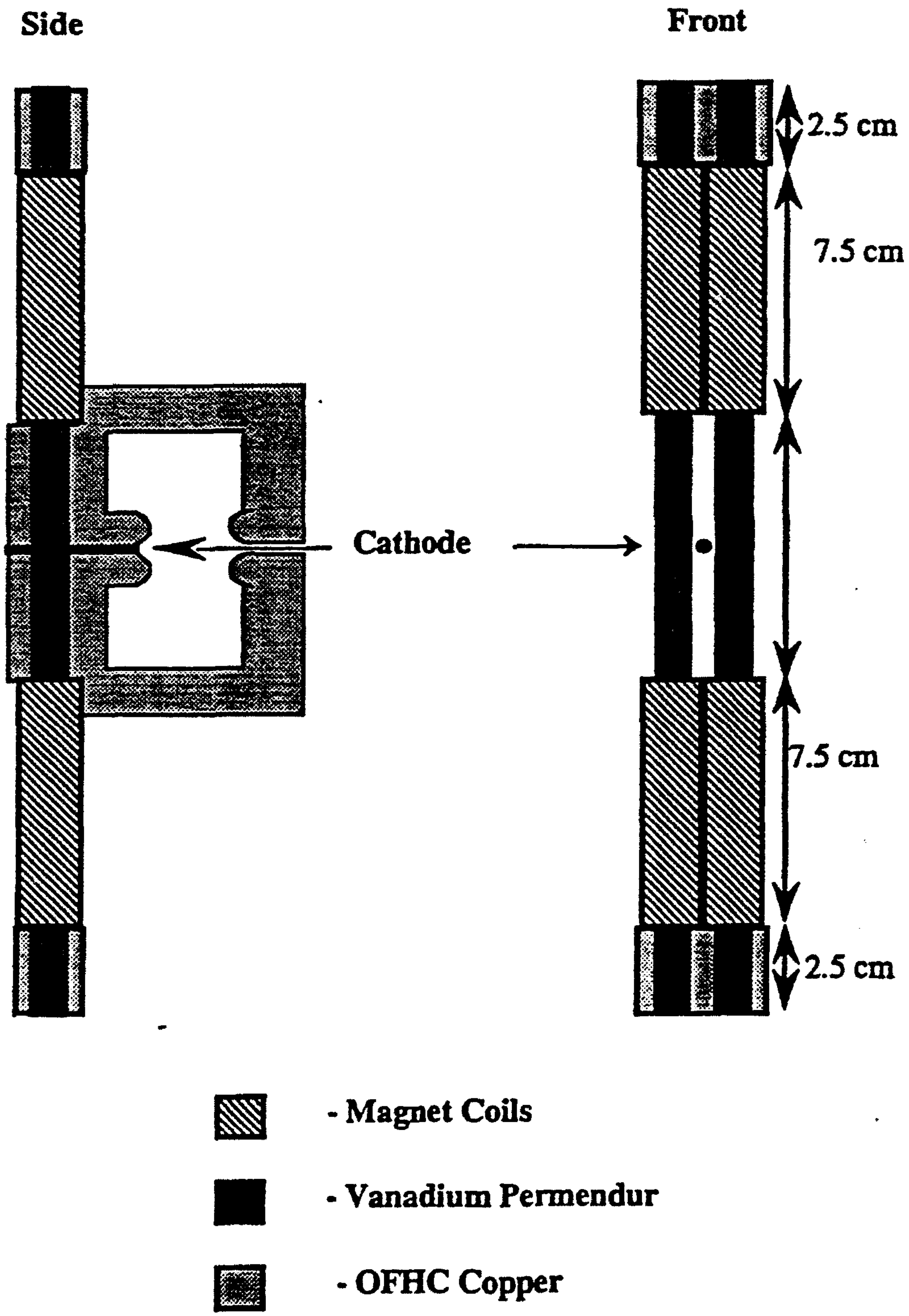
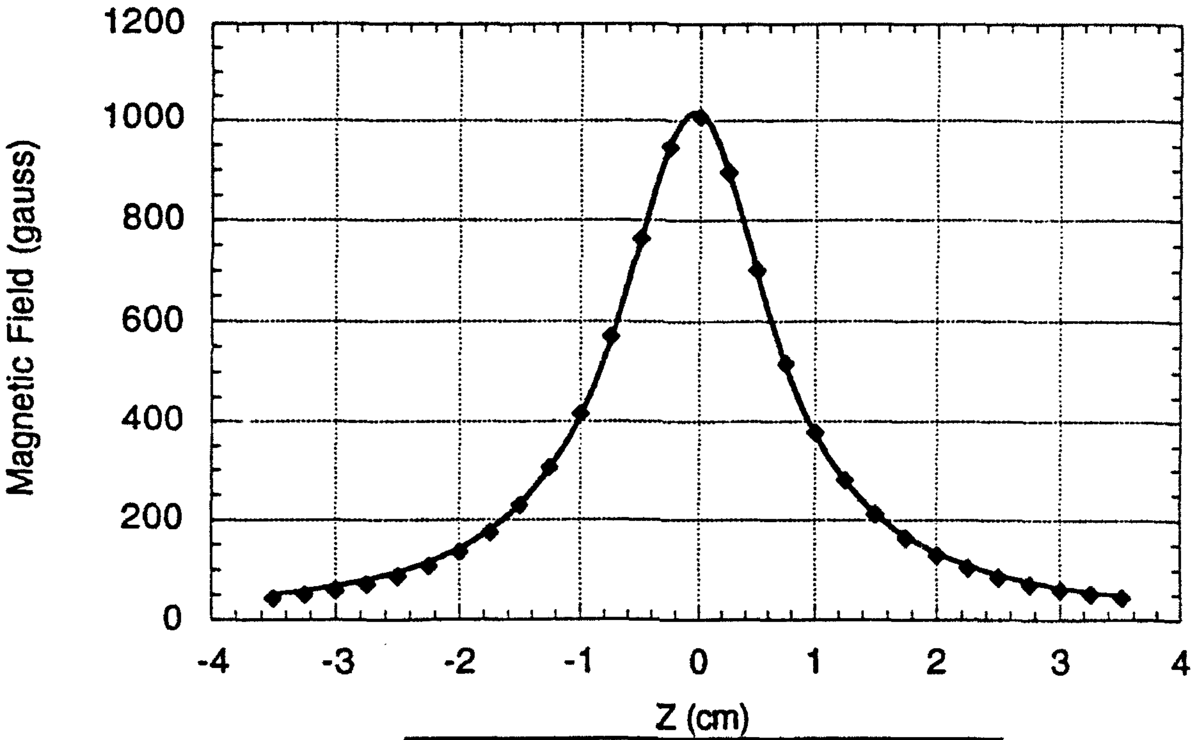


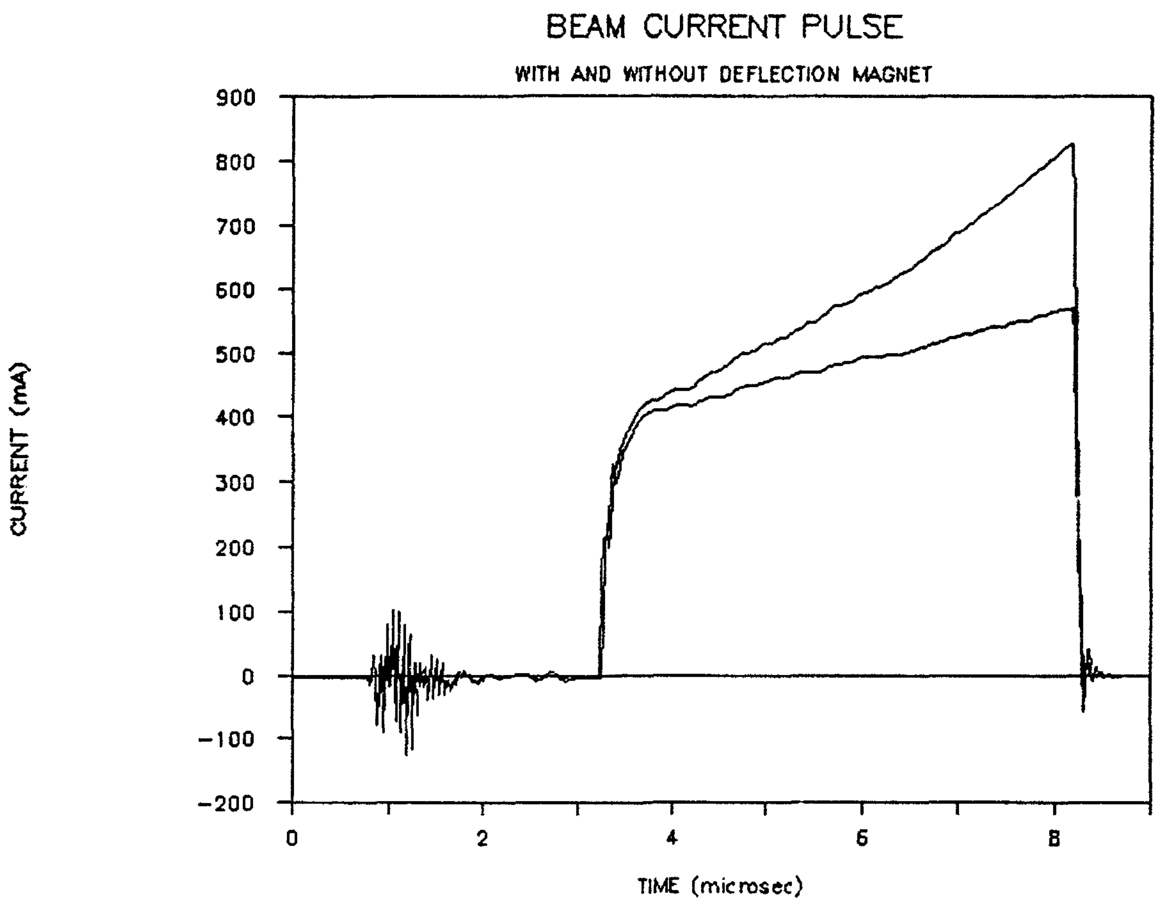
Figure 3.

Experimental Data: NCCU Deflection Magnet Transverse Field versus Axial Distance with 0.5 Amperes



y = m1 / (1 + (m0 - m2)^ ...		
	Value	Error
m1	1016.9546205	3.6691
m2	-0.038148685247	0.00284623
m3	-0.79148136073	0.0040956
Chisq	863.19599472	NA
R	0.99982978886	NA

FIGURE 4



BEAM CURRENT PULSE
WITH AND WITHOUT DEFLECTION MAGNET
CURRENT (mA)
900
800
700
600
500
400
300
200
100
0
−100
−200
0
2
4
6
8
TIME (microsec)

FIGURE 5(a)

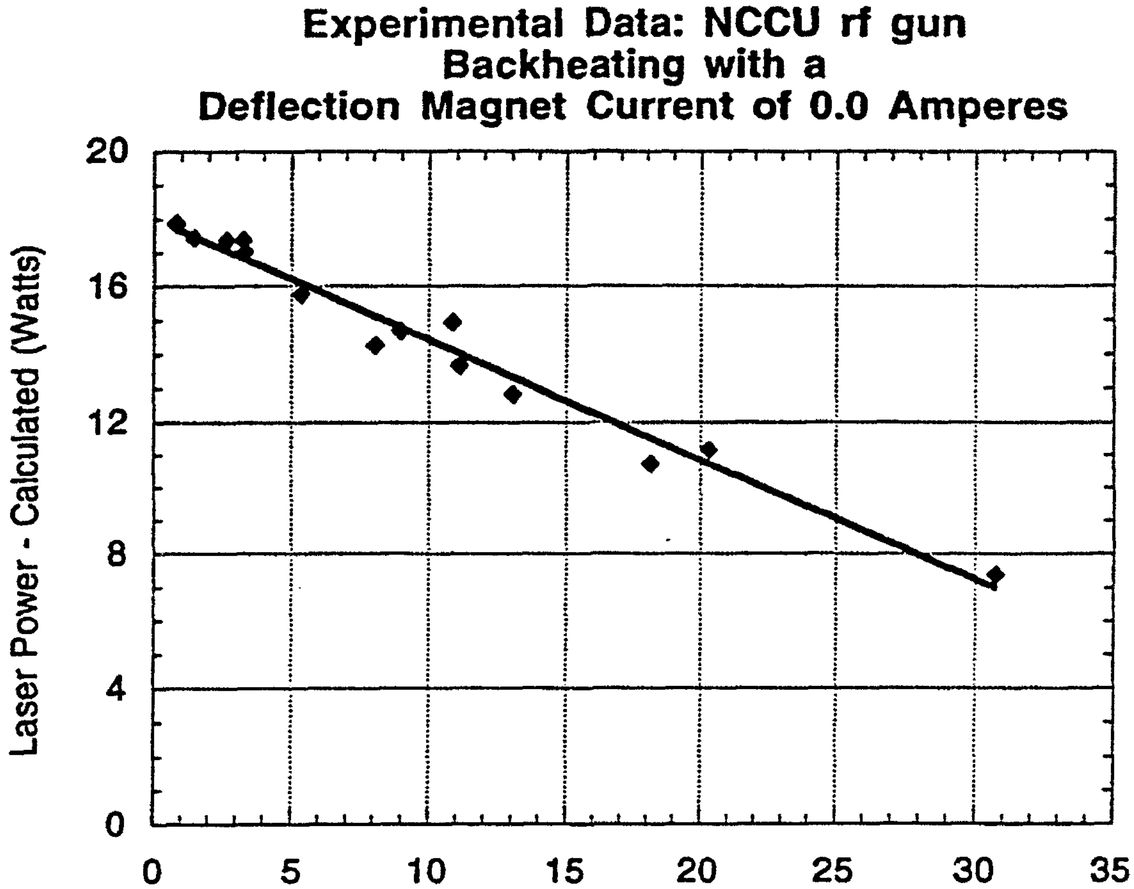


FIGURE 5(b)

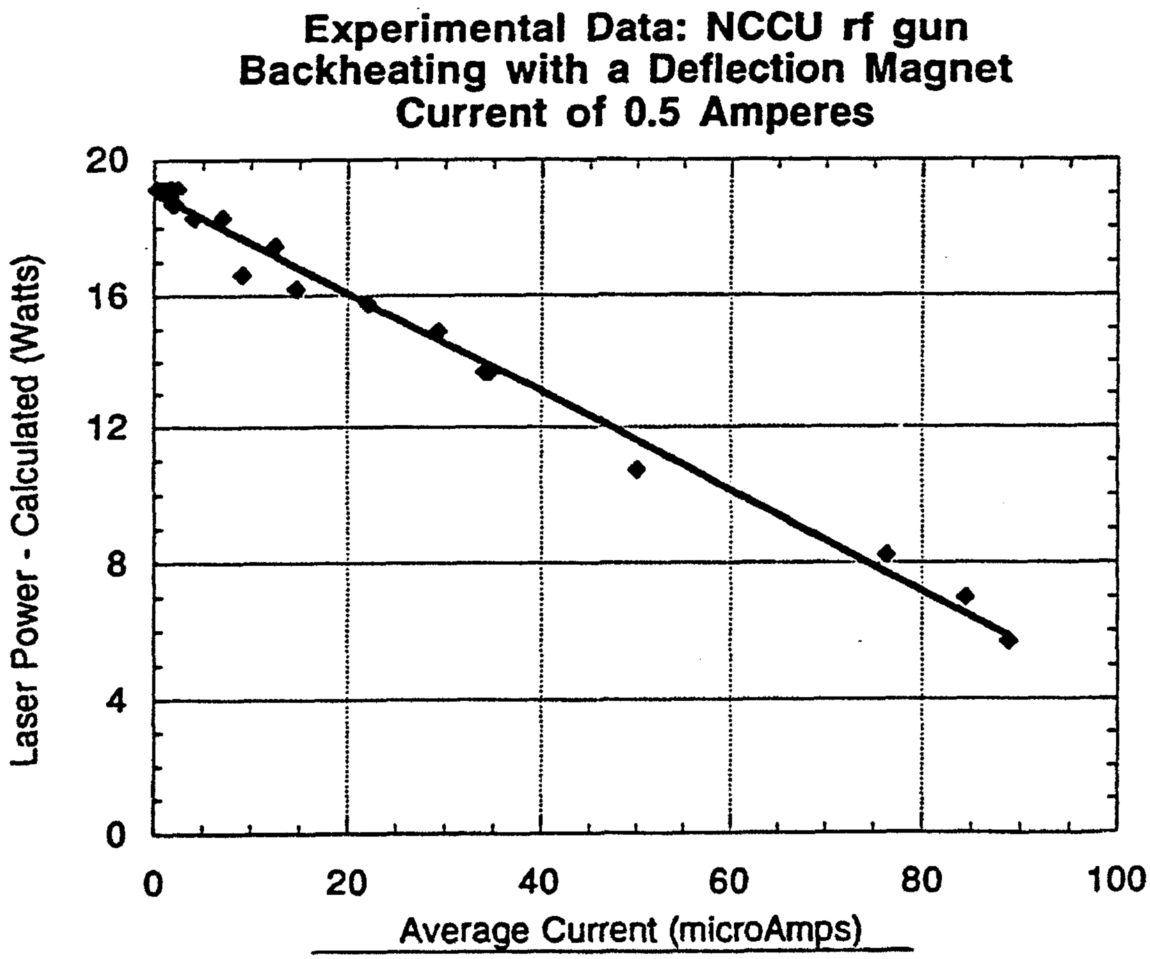


FIGURE 6

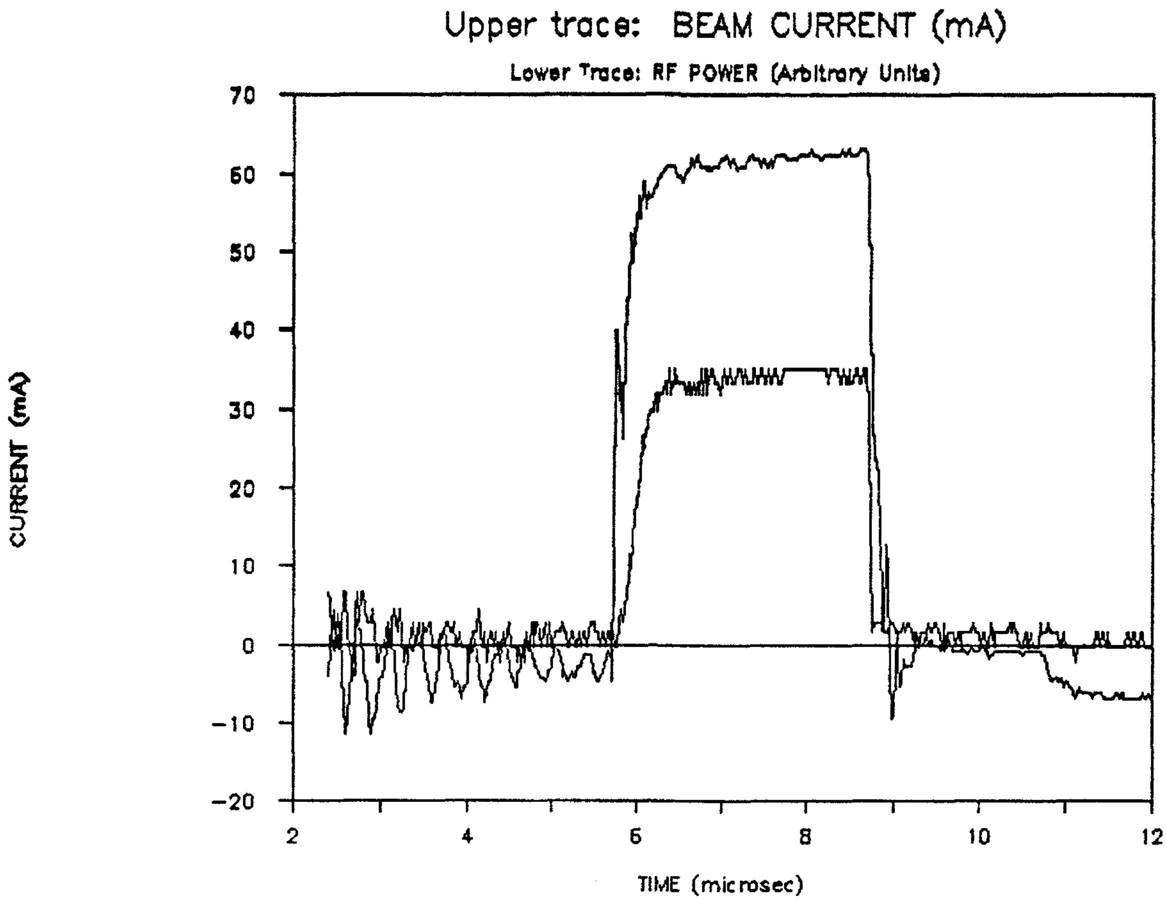
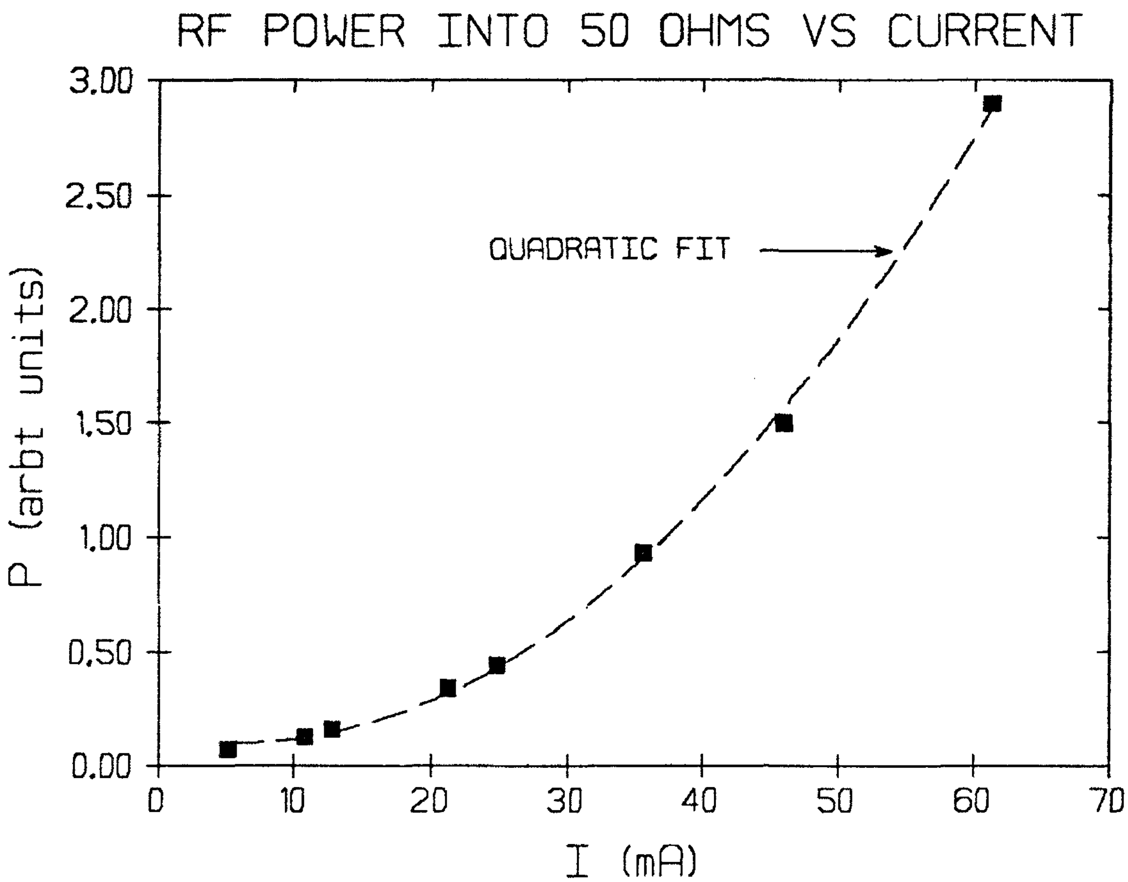

Upper trace: BEAM CURRENT (mA)
Lower Trace: RF POWER (Arbitrary Units)
CURRENT (mA)
70
60
50
40
30
20
10
0
−10
−20
2
4
6
8
10
12
TIME (microsec)

FIGURE 7



RF POWER INTO 50 OHMS VS CURRENT
QUADRATIC FIT
P (arbt units)
3.00
2.50
2.00
1.50
1.00
0.50
0.00
0
10
20
30
40
50
60
70
I (mA)