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OAK RIDGE NATIONAL LABORATORY

MARTIN MARIETTA

CRADA Final Report
for
CRADA Number ORNL94-0259

INVESTIGATION OF HETERODYNE PERFORMANCE OF QUANTUM-WELL DETECTORS

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Oak Ridge National Laboratory

Joe Calabretta MMEM

MANAGED BY
MARTIN MARIETTA ENERGY SYSTEMS, INC.
FOR THE UNITED STATES
DEPARTMENT OF ENERGY

DISCLAIMER

C/ORNL-94-0259

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POST OFFICE BOX 2009
OAK RIDGE, TENNESSEE 37831

November 28, 1994

Mr. Peter D. Dayton
Director, Procurement and Contracts
Department of Energy, Oak Ridge Operations
Post Office Box 2001
Oak Ridge, Tennessee 37831-2001

Dear Mr. Dayton:

Final Report for CRADA No. ORNL94-0259 with Martin Marietta Electronics and Missiles

The subject CRADA has been completed and enclosed is the Final Report for this project.

This report does not contain proprietary information or Protected CRADA Information. Neither Energy Systems nor the participant object to public distribution of this report.

If you have any questions, please feel free to contact me.

Very truly yours,

C. A. Valentine

for Brian Bovee
Business Manager
Office of Technology Transfer

BBB:cav

Enclosure - As Stated.

cc: File - RC

MARTIN MARIETTA

Internal Correspondence

MARTIN MARIETTA ENERGY SYSTEMS, INC.

Date: November 16, 1994

To: B. B. Bovee

From: W. P. Painter, 6026E, MS-6396 (6-6938) (RC)

Subject: **Final report for CRADA No. ORNL92-0259 Martin Marietta Electronics and Missiles**

Enclose are two copies of the final report and a memo of certification for the subject CRADA.

WPP

Enclosures (2)

MARTIN MARIETTA

Internal Correspondence

SEP 30 1994

MARTIN MARIETTA ENERGY SYSTEMS, INC.

Date: September 28, 1994

To: W. P. Painter, 6026E, MS-6396 (6-6938)

From: M. L. Simpson, 3500, MS-6006 (4-4171)

Subject: **Final report for CRADA No. ORNL94-0259**

Attached is the final report for CRADA No. ORNL94-0259 entitled "Investigation of Heterodyne Performance of Quantum-Well Detectors" between Martin Marietta Energy Systems (MMES) and Martin Marietta Electronics and Missiles. Neither Energy Systems nor the Participant asserts any claim to information contained in the final report as qualifying as "Protected CRADA Information." Energy Systems and the Participant have no objection to public distribution of the final report. The final report contains no Proprietary Information.

If you need additional information concerning this report, please contact me.

Investigation of Heterodyne Performance of Quantum-Well Detectors

<u>Final Report:</u> CRADA No. ORNL94-0259 between Martin Marietta Energy Systems (MMES) and Martin Marietta Electronic Missles (MMEM)

Marc L. Simpson, Don P. Hutchinson, and Roger K. Richards (MMES)
Joe Calabretta (MMEM)

September 23, 1994

Abstract: The purpose of this Cooperative Research and Development Agreement (CRADA) between Martin Marietta Energy Systems Inc., (Contractor) and Martin Marietta Electronic Missles (Participant) is the determination of the heterodyne characteristics of quantum-well detectors. The Participant has developed a quantum-well infrared imaging video detector with very low light level characteristics. A further improvement in low-level infrared detection could be achieved if this device can be operated in the coherent or heterodyne mode. A major program in the Physics Division of Oak Ridge National Laboratory (ORNL) presently uses individual heterodyne infrared detectors in a system under developement for fusion diagnostics. An imaging infrared heterodyne detector would represent a major breakthrough in this area and would have major implications for other plasma diagnostic programs. The Participant is also studying the application of this device in the area of laser radar.

Experiment Overview

MMEM provided a multiple quantum-well array mounted in a liquid nitrogen dewar. The assembly was received on 7/19/94 and was returned to MMEM on 9/14/94. The assembly was

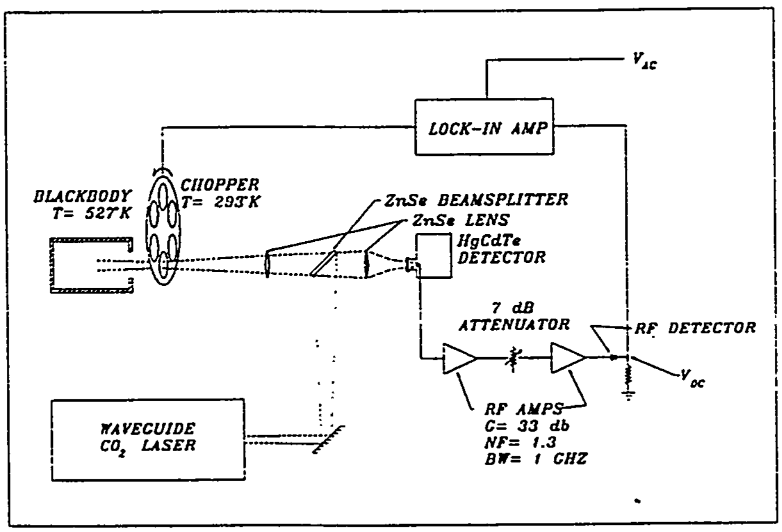

Figure 1 Heterodyne Calibration Set-up

mounted on an optical bench with the necessary components to calibrate and characterize the quantum-well detector. These components consisted of a blackbody source at 527°K, a chopper, a 10 watt CO_2 laser, a lock in amplifier, and an rf detector configured as shown in Figure 1. The basic calibration procedure is the same as that used to calibrate HgCdTe detectors for Thompson scattering experiments in the fusion energy program [1]. The detector parameters of interest included the noise equivalent power, the detector bandwidth, and the optimum local oscillator power.

Experiment Results

The major result of the experiment was that the signal level out of the MMEM quantum-well detector was too small to perform the heterodyne characterization. With 10 mWatts of laser power, measured signals were 1.36×10^{-8} amps or 1.36×10^{-6} amps/watt. This measurement can be contrasted with expected power levels out of standard diode detectors of 7.8 amps/watt for 100% video quantum efficiency at a wavelength of 9.56 microns. Measurements with the quantum well array were made at wavelengths of both 9.56 microns and 9.27 microns (closest to the optimum detector responsivity of 9.22 microns). The operation of the quantum well detector array was verified by increasing the laser power and monitoring the DC current coming out of the detector (Table 1 and Figure 2). At zero power, the current was 4.8 microamps with a 2.5 volt positive bias on the detector. Positive bias was found to produce slightly more signal than negative bias. The AC signals formed by chopping the laser beam remained linear with laser power up to approximately 0.1 watts and retained a relatively fast response (< 1 mSec) (See Table 2 and Figure 3).

An unexpected result of the experiments was that most of the laser power (>90%) was reflected from the detector and not used. The Ge window has approximately an 85% transmission and rotation of the polarization of the laser beam did not significantly alter the amount of laser light absorbed by the detector (< 10% signal changes).

Summary and Discussion

The quantum well array which MMEM sent to Oak Ridge was an early model. The Labs at Martin Marietta, Baltimore are currently producing much higher quantum efficiency devices for use in forward looking infrared (FLIR) arrays. These arrays, however, are wire bonded to a multiplexer for video detection, but are unusable for heterodyne characterization experiments. To determine the heterodyne performance of a quantum well device, the intermediate frequency (i.f.) chain must be directly wired to the detector. The quantum well array that MMEM sent to Oak Ridge was the only device available with the direct wiring to the detector.

A second issue which affected the performance of the quantum well array was the angle of incidence of the incoming light. To adequately couple energy to quantum well devices, linearly polarized light must be incident at a 45° angle with respect to the plane of the detector [2]. Due to the refractive index of the GaAs/GaAlAs (Snell's law), the maximum incidence we were able to attain was about 11°. We did note a substantial improvement in signal level at 11° incidence over normal incidence. Devices currently being produced at Martin have a diffraction grating on the back surface which is designed to couple the light into the quantum well at a 45° angle. This feature, which was absent in the detector sent to Oak Ridge, would have also helped with the signal levels.

In conclusion, the measured signal levels from the MMEM quantum well array were not adequate to perform heterodyne characterization. Higher efficiency quantum wells, available at Martin, were not suitable for the tests either since they do not provide direct wire access to the quantum well cells. Funding is not available from MMEM at the present to make the necessary modifications to a quantum well array which would have the potential for heterodyne performance. Although a stated goal in the CRADA was to perform joint testing of the detector, it did not make sense for MMEM personnel to travel to Oak Ridge given the signal levels obtained.

References

1. C.A. Bennett, R.K. Richards, and D.P. Hutchinson, "Absolute Broadband Calibration Procedure for Infrared Heterodyne Receivers," Applied Optics, Vol. 27, pp 3324-5, (1988).

2. B.F. Levine, et. al., "Strong 8.2 μm Infrared Intersubband Absorption in Doped GaAs/AlAs Quantum Well Waveguides," Applied Physics Letters, Vol. 50, No. 5, (1987).

DC LASER POWER AT 9.56 MICRONS

Laser Power (Watts)	Detector DC Current (Microamps)
0	4.8
0.76e-2	5.44
0.32e-1	5.82
0.785e-1	6.74
1.46e-1	8.80
0.290	16.8
0.47	37.3
0.595	76.3
0.670	128
0.750	274
0.758	420

TABLE 1

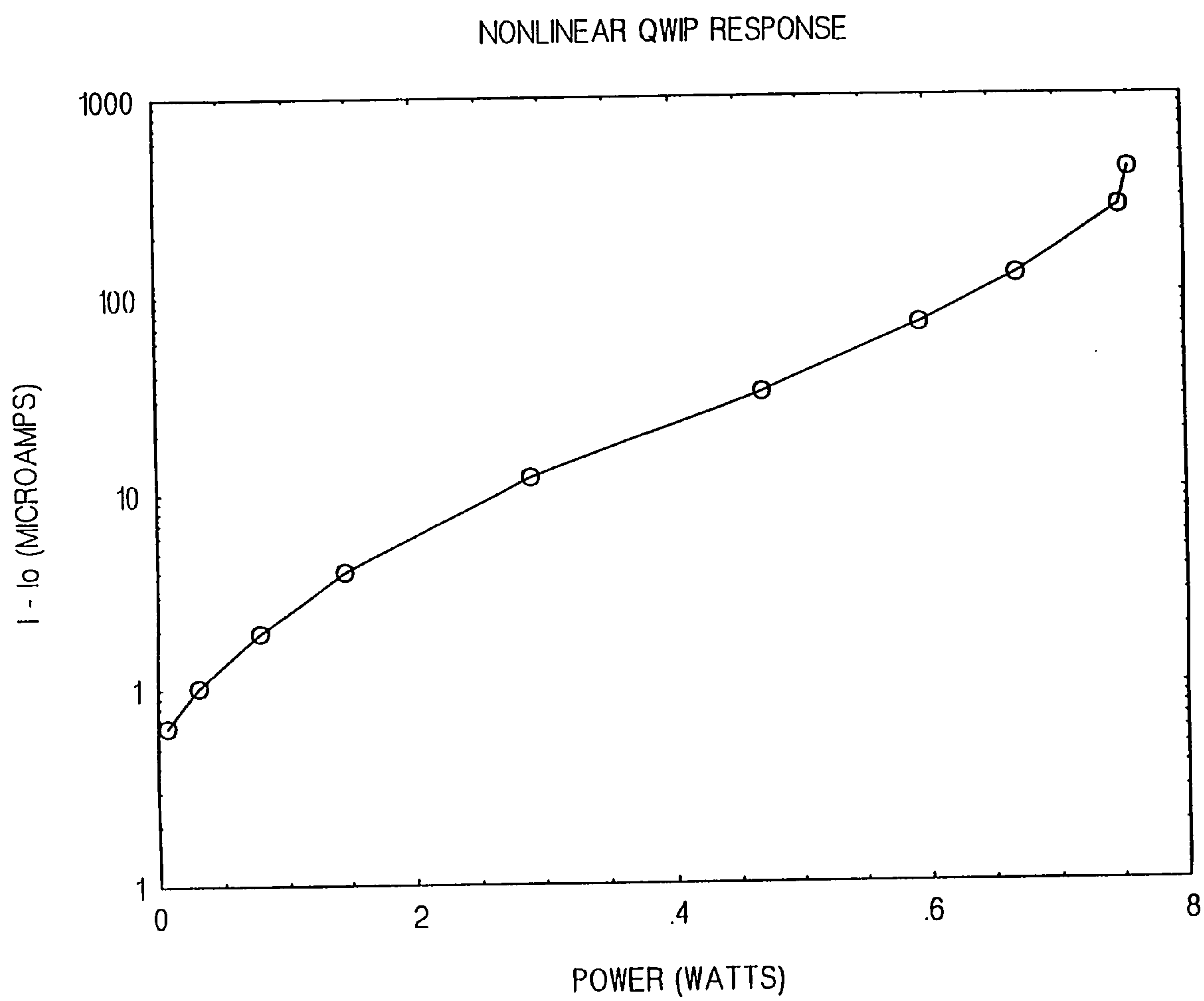
NONLINEAR QWIP RESPONSE
1000
100
10
1
1
I - Io (MICROAMPS)
0
2
.4
.6
8
POWER (WATTS)

FIGURE 2

AC LASER POWER AT 9.57 MICRONS

LASER POWER (W)	DC SIGNAL (MICROAMPS)	AC SIGNAL (NANOAMPS)
0	4.8	0
0.010	5.1	13.6
0.029	5.5	24.4
0.068	5.7	56.0
0.102	8.8	130
0.195	19	400
0.255	48	700

TABLE 2

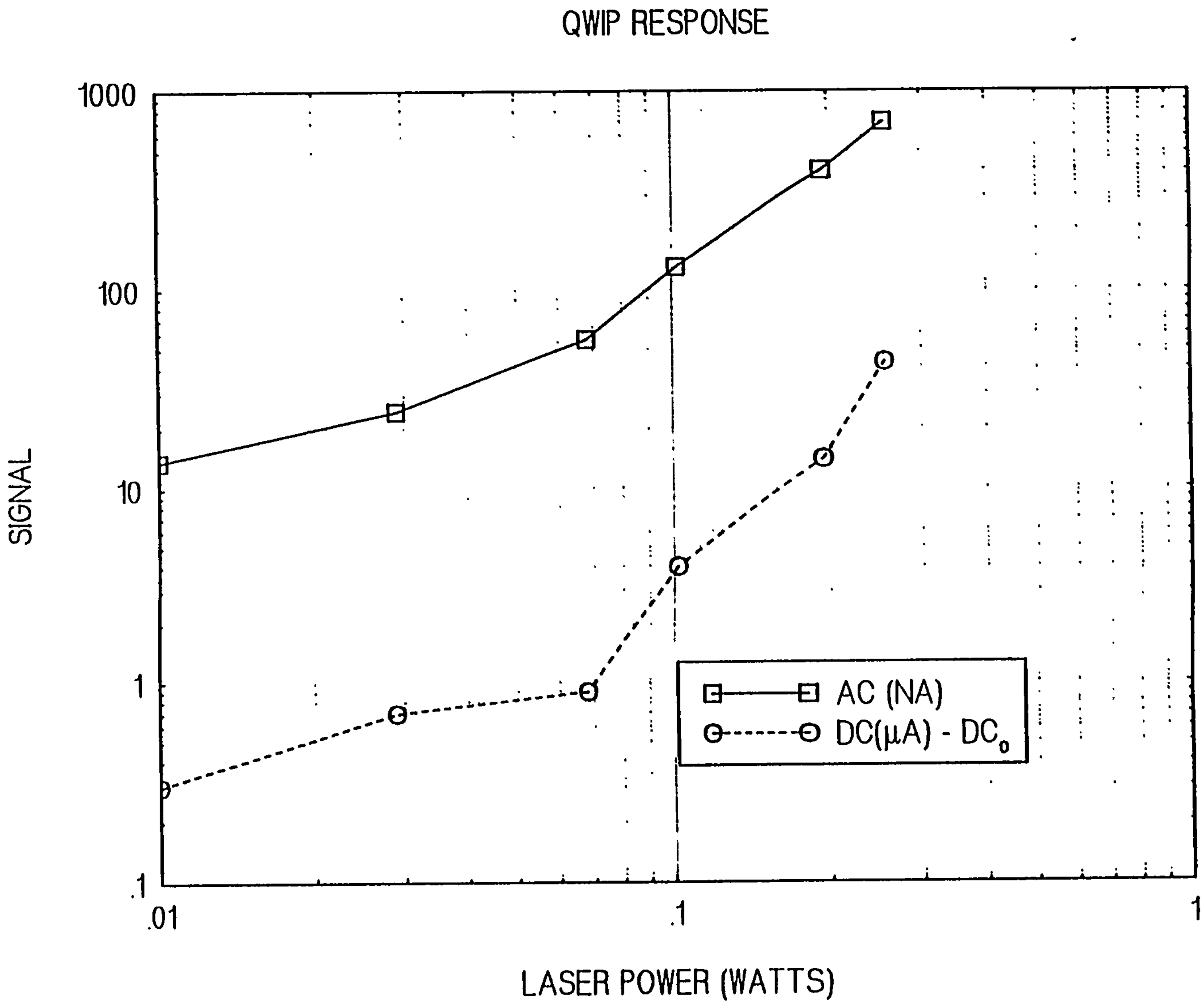
QWIP RESPONSE
SIGNAL
1000
100
10
1
.1
.01
.1
1
LASER POWER (WATTS)
AC (NA)
DC(μA) - DC0

FIGURE 3