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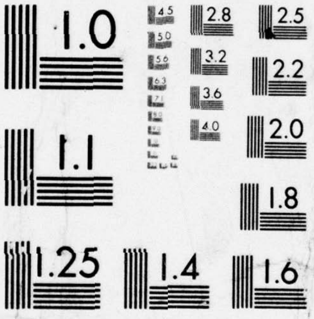
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EIGHTH QUARTERLY PROGRESS REPORT
PRODUCTION ENGINEERING MEASURES
SOLID STATE MICROWAVE OSCILLATORS FOR FUZES

CONTRACT NO. DAAB05-73-C-2070

1 FEBRUARY 1975 TO 1 MAY 1975

Prepared for

UNITED STATES ARMY ELECTRONICS COMMAND
PHILADELPHIA, PENNSYLVANIA 19103

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PRODUCTION ENGINEERING MEASURES
SOLID STATE MICROWAVE OCILLATORS FOR FUZES

⑭ Report No. EDD-W-40376-8

⑨ EIGHTH QUARTERLY PROGRESS REPORT. no. 8,

1 FEBRUARY 1975 TO 1 MAY 1975.

OBJECT OF PROGRAM

The objective of the work performed under this contract is to establish a production capability for narrow pulse TRAPATT oscillators to operate at 800 MHz and 4 GHz.

⑮ CONTRACT NO. DAAB05-73-C-2070

Prepared by

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E. Benko, C. O. G. Obah
H. C. Bowers, R. D. Regier
W. R. Lane

⑪ Oct 75

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SECURITY CLASSIFICATION OF THIS PAGE *(When Data Entered)*

REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER W-40376 ✓	2. GOVT ACCESSION NO.	3. RECIPIENT'S CATALOG NUMBER
4. TITLE *(and Subtitle)* EIGHTH QUARTERLY PROGRESS REPORT ✓ PRODUCTION ENGINEERING MEASURES SOLID STATE MICROWAVE OSCILLATORS FOR FUZES		5. TYPE OF REPORT & PERIOD COVERED Quarterly 1 Feb. to 1 May, 1975
		6. PERFORMING ORG. REPORT NUMBER W-40376
7. AUTHOR(s) H. C. Bowers W. R. Lane	C. O. G. Obah R. D. Regier	8. CONTRACT OR GRANT NUMBER(s) DAAB05-73-C-2070 ✓
9. PERFORMING ORGANIZATION NAME AND ADDRESS HUGHES AIRCRAFT COMPANY, ELECTRON DYNAMICS DIV. 3100 WEST LOMITA BOULEVARD ✓ TORRANCE, CALIFORNIA 90509		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS
11. CONTROLLING OFFICE NAME AND ADDRESS UNITED STATES ARMY ELECTRONICS COMMAND PHILADELPHIA, PENNSYLVANIA 19103		12. REPORT DATE October 1975
		13. NUMBER OF PAGES 16
14. MONITORING AGENCY NAME & ADDRESS *(if different from Controlling Office)*		15. SECURITY CLASS. *(of this report)* UNCLASSIFIED
		15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT *(of this Report)*

Distribution unlimited. Approved for public release.

17. DISTRIBUTION STATEMENT *(of the abstract entered in Block 20, if different from Report)*

18. SUPPLEMENTARY NOTES

19. KEY WORDS *(Continue on reverse side if necessary and identify by block number)*

TRAPATT diodes; TRAPATT oscillators

20. ABSTRACT *(Continue on reverse side if necessary and identify by block number)*

Work performed during the eighth quarter toward establishing a manufacturing capability for TRAPATT oscillators at 800 MHz and 4 GHz is described in this document. Continued efforts to optimize the deeply diffused TRAPATT diode are reported. The results of additional testing are summarized for the new microstrip circuit designed for operation at 0.8 GHz. Further improvements of the 4 GHz coaxial circuit are described.

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FOREWORD

This project was initiated by the U.S. Army Electronics Command. The work described herein was carried out at the Hughes Aircraft Company, 3100 West Lomita Boulevard, Torrance, California 90509. This report summarizes the development program carried out during the period 1 February 1975 through 1 May 1975.

ABSTRACT

Work performed during the eighth quarter toward establishing a manufacturing capability for TRAPATT oscillators at 800 MHz and 4 GHz is described in this document. Continued efforts to optimize the deeply diffused TRAPATT diode are reported. The results of additional testing are summarized for the new microstrip circuit designed for operation at 0.8 GHz. Further improvements of the 4 GHz coaxial circuit are described.

1.0 INTRODUCTION AND SUMMARY

The objective of work performed under this contract is to establish a production capability for narrow pulse TRAPATT oscillators to operate at 800 MHz and 4 GHz. Diodes, oscillators, and bias modulators are all to be investigated.

Several refinements in our diode manufacturing processes were accomplished during the past quarter. The quality of epitaxially grown layers has been improved by the installation of a new vertical epitaxial reactor. Our understanding of TRAPATT device design has been increased by a new computer program which analyzes the electric field and doping profiles of TRAPATT diodes. The bond between the TRAPATT device and its heat sink was found to have a high thermal impedance. Development of a new bonding process was inititated which employs the plating of silver directly onto the silicon wafer.

The relationship between performance of the UHF microstrip circuit and the orientation of the diode was explored. Substantial variations in output power and efficiency were observed due to the different mounting inductances associated with different orientations.

Several modifications were made to improve the electrical and mechanical characteristics of the 4 GHz coaxial circuit. The performance of this osciallator as a function of duty cycle was investigated extensively. These experiments indicated that chip temperature increases in excess of 70°C were causing substantial reductions in power and efficiency as the duty cycle was increased from 0.1 to 2 percent. Development of the plated silver heat sink mentioned above was initiated to reduce this temperature increase.

2.0 DIODE FABRICATION

2.1 SUMMARY

During the past quarter, in addition to the usual processing of diodes, several significant accomplishments were realized. To begin with a new epitaxial reactor was installed. The characteristics of this reactor are described in Section 2.2. Because of its characteristics, the material grown in this reactor will be substantially more uniform and reproducible as compared to material grown on the previous reactor. A computer program was set up to analyze the fields in the TRAPATT devices that are fabricated. This has increased our insight into the critical design factors affecting performance of TRAPATT devices. Finally, techniques for incorporating silver plated heat sinks onto the TRAPATT devices as a routine part of device processing were established.

Twenty-three epitaxial runs were made during the past three months yielding a total of 155 wafers. Of these 23 runs, 11 were on the old horizontal reactor and 12 on the new vertical reactor, which will be described in a subsequent section. Five of these runs were intended for UHF devices and 18 of the runs for S-band devices. A total of 44 wafers were started into the remainder of the processing cycle. Of these 44 wafers, 20 were for UHF devices and 24 for S-band devices. Ten of these wafers utilize material from the new reactor.

Aside from the addition of the new reactor and some minor changes in the diffusion process, the processing followed standard procedures previously described in earlier reports.

2.2 EPITAXIAL GROWTH

A new AMT 8" vertical reactor, along with associated instrumentation and gas control system, was installed at the beginning of the past quarter. It is anticipated that this reactor will provide yields substantially higher than those of the horizontal reactor previously used on this program. The vertical reactor has several features not found in a horizontal reactor. Specifically, it has a revolving susceptor, automatic infrared temperature control, and programmable flow controls. These features will lead to better control of epi thickness and resistivity, better uniformity of wafers within a run, and better repeatability from one run to another.

After completing installation of this new reactor, calibration runs for n-type epitaxial films using both silane and dichlorosilane were conducted. These calibration runs did in fact indicate that the anticipated better control and uniformity were accomplished. The calibration was taken to the point that several runs were made to grow material for use in TRAPATT device fabrication. At this time an insufficient number of devices have been fabricated to the point of being able to make a final judgment on the quality of the material.

A defect density analysis of the epitaxial material grown in this new reactor indicates that virtually no defects are introduced into the material during epitaxial growth.

2.3 DEVICE DESIGN

In an effort to obtain better insight and understanding of the design and performance of TRAPATT diodes, a computer program was established to analyze all of the devices processed. The program utilizes the detailed field equations for the devices along with experimentally measureable parameters. Based on processing conditions and the measured physical parameters of the completed devices, including breakdown voltage, the computer program calculates the doping and field profiles for each device. This enables us to obtain a much better knowledge of the field and doping profiles than was previously available. These profiles can then be analyzed in an attempt to distinguish differences between diodes with good and bad RF performance.

This program is based entirely on a program previously developed by one of the authors. The bases of the program is fully detailed in a previous publication*

Over 100 different lots of devices have been analyzed in this way. Although our understanding of the design of these devices may not be complete, such understanding has been greatly increased by use of this program. In particular, the program has been useful in establishing an optimum doping profile for both UHF and S-band devices. It has shown that there is a desirable range of p-type to n-type material thickness ratios for both of these devices. This relationship is more obvious for the S-band devices than the UHF devices, but continuing analysis should yield still better understanding for both types of devices.

2.4 DEVICE FABRICATION

Until recently, all devices have been processed in a pill process in which the devices are ultrasonically bonded to a heat sink. This has been adequate for evaluating the characteristics of the TRAPATT devices. However, it appears that the bonds are not sufficiently good to sustain the required 2% duty cycle. Measurements of the quality of this bond indicate that only a small fraction of the device area is physically bonded to the heat sink. For this reason we are developing a process in which the heat sink for the diodes will be plated silver. In this process the silver is plated directly onto the silicon wafers before individual chips are processed. It is anticipated that this will yield substantially lower thermal impedances for the TRAPATT diodes and will be adequate heatsinking for the required 2% duty factor.

At this point in time the necessary processes for carrying out the silver plating have been established. The masks required for the fabrication of both UHF and S-band devices are being designed and will be procured shortly.

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*Bowers, Harold C.,"Space-Charge-Induced Negative Resistance in Avalanche Diodes," <u>IEEE Trans. on Electron Devices, ED-15</u>, June 1968.

3.0 RF CIRCUITS

3.1 UHF OSCILLATOR CIRCUIT DEVELOPMENT

During this quarter the dependence of the microstrip circuit performance on diode mounting orientations was investigated, and the results obtained were compared with the corresponding results using our standard 1.8" x 1.8" x 0.7" box circuit.

The diode was mounted into the circuit base plate such that the diode cap was parallel to and in direct contact with the metallization on top of the substrate. It was shown that circuit performance was slightly (∿5%) greater than that of the standard box circuit. The diode was then mounted through a side wall of the circuit housing such that the diode cap was perpendicular to the substrate. In this case, a contacting copper strap connects the diode to the RF circuit, and its dimensions determine the externally introduced circuit inductance in series with the diode. By using several sizes of straps, it was found that:

i) the value of this inductance had a strong influence on both the RF jitter and output power,

ii) an optimum strap size existed as was observed earlier for the contacting strap in the box circuit. However, the optimum strap size yielded output power approximately fifteen percent less than was obtained with the standard box circuit.

The diode was also mounted in the lid of the circuit housing unit such that the diode cap contacted the metallization either directly or by means of bellows. Results from several diodes showed that with direct contact the power and efficiency were comparable to the corresponding results from the standard box circuit. Furthermore, for moderate current levels ($6A < I_{BIAS} < 9A$), the jitter performance for this case was superior to that of the box circuit. Typical RF performance ratio (MIC RF performance/box circuit RF performance) is shown in Figure 1 for both cases. As might be expected, the use of bellows degrades the diode performance since the introduction of bellows increases the series inductance in the vicinity of the diode. Figure 2 shows the jitter ratio (MIC jitter/box circuit jitter) for varying bias current. It is seen that the minimum jitter obtained in each case is at least equal to the corresponding minimum of the box circuit.

The effect of bias circuit values in the microstrip circuit was also investigated. Of particular interest was the effect of the total inductance in this network on ringing in the current and voltage bias waveforms. Varying this inductance over a wide range was found to have no discernible influence on ringing. However, it was observed that reducing the inductance below a critical value caused a slight increase in voltage waveform jitter which could usually be removed by retuning the circuit.

3.2 4 GHz CIRCUIT DEVELOPMENT

The impedance measurements described in the previous quarterly report indicate that with the large-area diodes employed in this program a circuit capable of presenting a very low impedance to the diode must be used. To consistently realize such a low impedance requires a circuit having very high mechanical stability, low loss, and low parasitic impedances associated with mounting the diode. It also appears that at this impedance level it is desireable to have at least one tuning element immediately adjacent to the diode.

During this reporting period several modifications were made to the 4 GHz coaxial circuit which represent considerable progress toward the objectives described above. These modifications are summarized below.

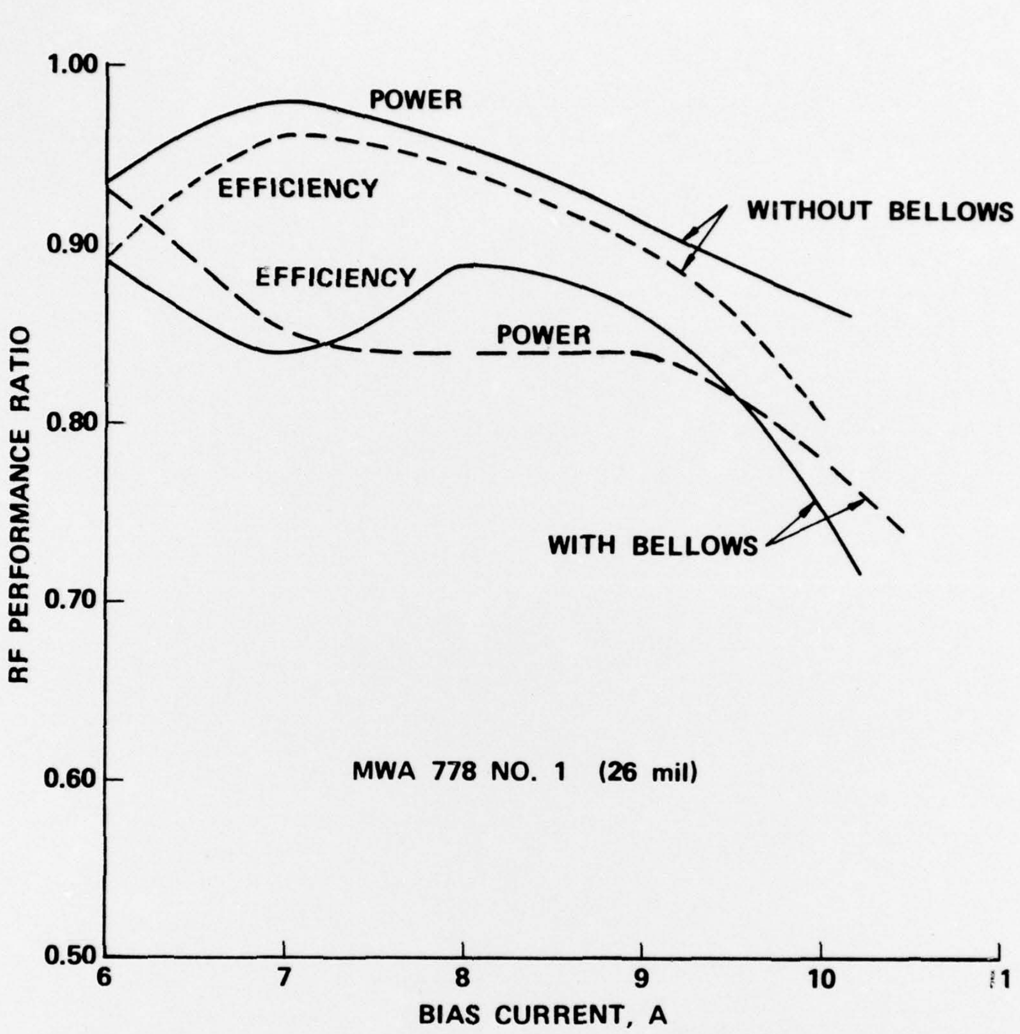

Figure 1 RF performance ratio for microstrip circuit with diode mounted in lid.

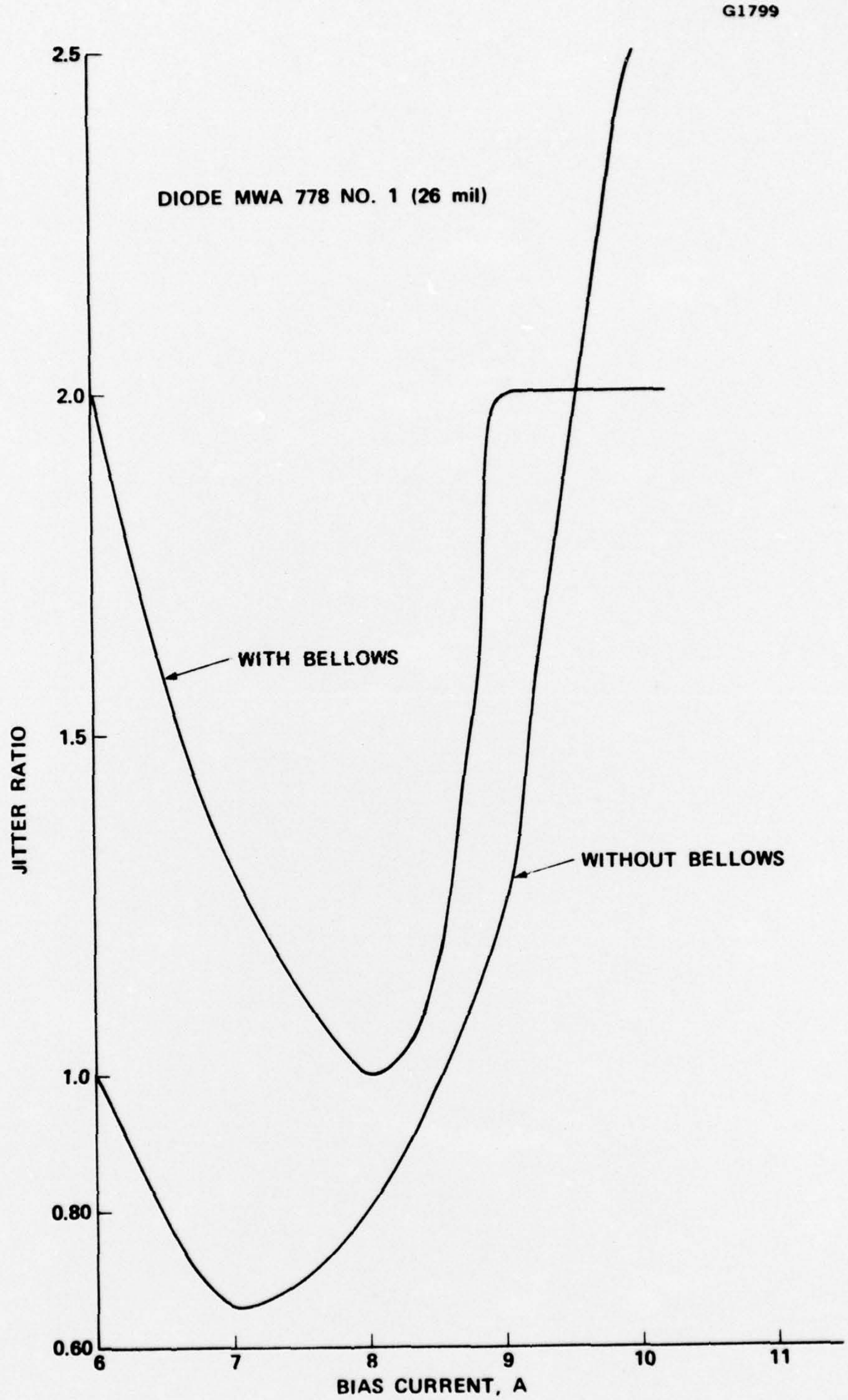

Figure 2 Jitter ratio of microstrip circuit (lid mounting).

i) The walls of the outer conductor body were thickened at key points to yield increased strength and better dimensional control and stability.

ii) Sleeves were designed to fit inside the tuning slugs to hold the center conductor precisely in the center of the slugs. Without such sleeves the center conductor moves during circuit adjustment in an unpredictable and unrepeatable manner.

iii) The plunger which contacts the diode was modified to decrease circuit loss and increase its electrical stability.

iv) A modification to the quarter-wavelength transformer next to the diode in our 4 GHz coaxial oscillator was investigated and found to yield a consistent increase in output power from all of several diodes that were tested. In the new transformer the outer diameter of the coaxial line has a step increase whereas in the old transformer the outer diameter was constant and the inner diameter had a step increase. The characteristic impedance was the same in both cases. The decreased outer diameter of the new transformer reduces the parasitic package and mounting inductance of the diode. This yields improved performance between 3.5 and 4.5 GHz where these parasitic impedances have a significant effect on output power.

The performance of the 4 GHz oscillator as a function of duty cycle was investigated extensively. When the duty cycle was increased from 0.1 to 2 percent and the circuit retuned to maximize output power, the following changes were observed:

i) The output power decreased approximately 30 percent.

ii) The operating voltage increased approximately 5 percent.

iii) Bias waveform jitter increased.

Several experiments were conducted to isolate the cause of the degradation described above. The experiments indicated that as the duty cycle increased these performance changes were accompanied by an increase of diode temperature substantially in excess of 70°C. This suggests that a reduction in thermal impedance of the diodes is desirable.

4.0 MODULATOR

Assembly of the fully packaged modulator for the 4 GHz oscillator was completed. After minor rework and adjustment for optimum performance, the resulting waveforms when driving a TRAPATT oscillator exhibited a substantial damped oscillatory variation during the pulse. This variation had a periodicity of approximately 30 ns and appeared to be induced by the rapid drop in bias voltage associated with the onset of TRAPATT oscillation. When driving a resistive load the modulator produced good waveforms of constant amplitude which were free of ringing. It was decided to modify the pulse forming network so as to make it adjustable and, thereby, reduce the ringing.

5.0 CONCLUSION

During the past quarter a new vertical epitaxial reactor was installed. Initial tests support our expectation that this reactor will yield better uniformity of wafers within a run, better control of epitaxial layer thickness and resistivity, and better repeatability from one run to another. A computer program was generated which analyzes the electric field and doping profiles of TRAPATT diodes. This program has been very useful in correlating diode design with RF performance. Development of a plated silver heat sink was begun. It is anticipated that this heat sinking technique will substantially reduce the thermal impedance of TRAPATT diodes and allow us to achieve the required 2 percent duty factor.

Tests were conducted which indicate a relationship between UHF oscillator performance and diode mounting inductance. The configuration with the least mounting inductance yielded highest output power and efficiency as well as lowest leading-edge jitter. Unfortunately, this configuration is also very difficult to manufacture in large quantity. Therefore, to facilitate production, a configuration was selected which has a slightly greater mounting inductance, but which still allows us to meet performance requirements.

Several improvements on the 4 GHz coaxial circuit were implemented which improve the electrical and mechanical performance of the oscillator. Development of this circuit is now regarded as essentially complete.