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Third Quarterly Progress Report

1 November - 1 February 1963

Report No. III

Contract No. DA36-039 SC-89163

Department of the Army
Project No. DA3A99-21-001

DISTRIBUTED JUNCTION TUNNEL

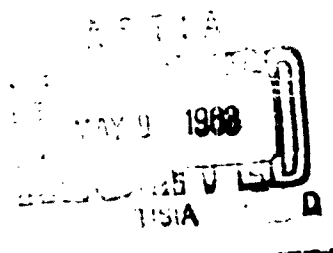
DIODE OSCILLATOR

PHASE II

U.S. Army Signal Research
& Development Laboratory

Fort Monmouth, New Jersey

MICROWAVE
ASSOCIATES,
INC.



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DISTRIBUTED JUNCTION TUNNEL DIODE OSCILLATOR

PHASE II

U.S. Army Signal Research & Development Laboratory

Fort Monmouth, New Jersey

Prepared by:

C. Howell

Approved by:

H. Ellowitz

Research Objective

To determine the feasibility of constructing a 10 mW 10 kMc tunnel diode oscillator and to examine the circuit and diode requirements for this oscillator.

MICROWAVE ASSOCIATES, INC.

Burlington, Massachusetts

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III - PURPOSE

The purpose of this contract is to conduct a theoretical and experimental feasibility study for higher frequency high power tunnel diode oscillators. In particular, the design principles and criteria will lead to the design of a distributed junction tunnel diode oscillator capable of giving power outputs in excess of 10 mW at 10 kMc. Included as part of the study shall be the consideration of appropriate microwave circuit environments for maximum oscillator efficiency and stability.

IV - ABSTRACT

Efforts to determine the feasibility of constructing 10 mW 10 kMc tunnel diode oscillators have been continued and diode requirements for these oscillators determined. Various diode fabrication techniques and oscillator circuit techniques have been investigated to determine the best combinations of these to potentially meet the frequency and power requirements.

Four packaged and two distributed junction tunnel diode oscillators have been designed and built. The present oscillator study has been concentrated on the packaged X-band oscillators. Using the packaged single diode oscillators, power outputs of more than 100 microwatts have been obtained in X-band. Tuning problems seriously hamper the use of larger peak current, larger capacity packaged diodes. Some circuit changes have been made which partially alleviate this problem. The use of a resistive shunt across the ceramic of the diode package has improved the high-frequency or power output characteristics of these oscillators. The reduced-size stripline package oscillator is the most successful.

Low peak current to capacitance ratios have been a difficulty for the distributed tunnel diode; so far no power output has been obtained in X-band from a distributed tunnel diode oscillator.

V - PUBLICATIONS, LECTURES, REPORTS AND CONFERENCES

During this quarter there were no conferences, lectures or publications due to this contract.

VI - FACTUAL DATA

A. INTRODUCTION

The purpose of this contract is to determine the theoretical and experimental feasibility of building a tunnel diode oscillator that will operate at 10 kMc delivering 10 or more milliwatts of power output with a 20% tuning range.

Oscillations occur in tunnel diodes in the negative resistance portion of the curve. The power obtainable from a tunnel diode during oscillation depends on the magnitude of the voltage swing in the negative resistance region and the magnitude of the current change. Available power from an oscillating tunnel diode (P) then depends on the $(V_V - V_P) \times (I_P - I_V)$. For high peak to valley ratio tunnel diodes this value becomes approximately $(V_V - V_P) \times (I_P)$. The amount of this power that is available from the tunnel diode depends on the cutoff frequency (f_c) of the diode and the operating frequency (f_o) as follows:

$$P_a = P \times \left(1 - \frac{f_o}{f_c}\right)^2$$

Therefore, to make a high power, high frequency tunnel diode oscillator, two things are necessary. First, a large peak current tunnel diode must be employed and secondly, the resistive cutoff frequency of this diode must be well in excess of the frequency of operation so that the available power is not diminished too severely.

To obtain 10 or more milliwatts of useful power output at 10 kMc, the tunnel diode in the oscillator must have a peak current of approximately $\frac{1}{2}$ ampere with a cutoff frequency approaching 20 kMc. The negative resistance of a $\frac{1}{2}$ ampere tunnel diode is approximately 0.4 ohm and the junction capacity

50 picofarads or more. The extraordinarily low impedances associated with these small negative resistances and large capacitances make the circuit problems almost impossible to solve. Our approach to solving these impedance values is as follows:

1. To employ a number of small peak current tunnel diodes in one oscillator capable of producing 1 - 10 mW at X-band. This approach appears feasible for small powers (1 mW at X-band) but, to produce 10 mW or more it appears that the number of diodes required becomes prohibitive.
2. The second approach is to build a true distributed junction tunnel diode oscillator capable of producing 10 mW or more at X-band and to incorporate this distributed diode into an oscillator. The advantage of the distributed junction tunnel diode is that, although the impedance of the diode taken as itself is very small, the impedance of the finite sections of the distributed junction can be made to have reasonable values. The oscillations then occur as a growing wave moving down the distributed junction. The impedance of finite parts of the strip become reasonable and can be used in this manner to gain the large peak currents to handle within the circuit.

To build a 10 mW 10 kMc tunnel diode oscillator effort has been expanded in the following areas:

1. Tunnel diode oscillator circuitry, fabrication and characterization.
2. Fabrication of gallium arsenide tunnel diodes for use in the single and multi-diode oscillators.
3. Fabrication of distributed junction gallium arsenide tunnel diodes.
4. Microwave characterization of all these diodes and oscillators.

B. TUNNEL DIODE OSCILLATOR DESIGN, FABRICATION AND CHARACTERIZATION

During the last quarter, principle efforts were devoted to the investigation of the optimum oscillator design for packaged tunnel diodes. The designs investigated included a conical cavity oscillator with the diode centrally located within the low impedance section of the guide. This low impedance section was then transferred into a coax line with a taper. The Z_0 of the entrance of the cavity was approximately 8 ohms, but even with the use of numerous tuning screws the maximum useable junction capacitance was very small. Attempts to increase the useable junction capacity were not very successful. The best result obtained with this oscillator was approximately 100 μ W at 7.1 kMc with a diode with a junction capacitance of less than $\frac{1}{2}$ picofarad. This approach has been abandoned temporarily in favor of a stripline approach.

A stripline diode mount was built with low impedance center strips (8 - 15 ohms) and with the diode mounted between the ground plane and the center strips. The center strip was isolated from the ground plane by an RF bypass consisting of a .002 thick mica washer. Serious problems are encountered

with erratic operation of this oscillator apparently caused by leakage at the edge of the strip. This leakage was partially eliminated by shorting out the edges of the board with copper sheet stock. Using a 20 milliampere peak current gallium arsenide diode with a junction capacity of approximately 3 picofarads and a resistive cutoff frequency of 14 kMc, power outputs of approximately $\frac{1}{2}$ milliwatt were obtained at 4 kMc. Correspondingly, lower power output was obtained with diodes of 5 and 10 milliamps at up to 7 kMc. Power outputs of about 50 μ W were obtained at 7 kMc when using this board with the shorted edges. The strip line oscillator was modified, reducing the size of the package to $2\frac{1}{4} \times 7/16 \times 5/8$ " and a transformer incorporated to give an output impedance of 50 ohms. By reducing the width of this board to $1/3$ its original value, maximum frequency oscillation for a given capacity diode has been increased considerably. Power outputs of approximately 100 μ W were obtained at 8.3 kMc with diode efficiencies of 50%.

In order to partially eliminate the problems with tuning larger capacity diodes to oscillate at high frequencies, efforts were made to place a short across the ceramic of the diode; therefore, bringing the short as close as possible to the actual diode junction. These shorts are applied by evaporating a nickel strip approximately .005 wide and of such thickness as to approximately match the negative resistance of the diode. Initial efforts using diodes with these evaporated shorts across the ceramic were disappointing. On several diodes the short was broken by what appears to be a scraping off of the coating upon insertion into the holder. An epoxy resin coating was

placed over the diode to eliminate this problem. Initial measurements comparing the same diode coated and uncoated showed there was very little to be gained in frequency of oscillation or power output from the coating diodes. In both cases, the best results were obtained with diodes which had junction capacitances of 0.5 picofarad and peak currents for 5 - 10 mA. Power outputs with coated and uncoated diodes were approximately 100 μ A μ watts at 8 kMc.

C - SPOT TUNNEL DIODE FABRICATION AND RESULTS

Spot tunnel diode fabrication efforts during the past three months concentrated primarily on improving the peak current density of gallium arsenide diodes, and to supply these diodes both with the non-shortcd and with the short across the ceramic for circuit test. The target specification for the gallium arsenide package diode has been a diode with a peak current of approximately 20 milliamperes and a junction capacity less than 0.8 picofarad. Several vendors' samples of highly doped P type gallium arsenide have been examined and several different doping materials and diffusion (soaking) techniques for preparing more highly doped "P" type gallium arsenide. To date the most satisfactory results are obtained by using gallium arsenide doped in the melt with 6.5 to 7.5 10^{19} Δ tons/cc of zinc and using a tin 2% tellurium sphere with alloying temperatures of approximately 600°C for alloying times of 50 to 150 milliseconds. The center of the distribution of diodes fabricated in this manner have peak current to capacitance ratios of approximately 10 - 1 with a 5 - 10% yield of diodes having peak character capacity ratios of 15 to 20 to 1. No diodes to date have been obtained with junction capacitances of less than 0.8 pf at 20 milliamperes.

Various methods for placing a short across the ceramic of the diode have been investigated to improve oscillator results. The principal problems of producing reproducible resistive shorts is the runover of the metallizing on the 10 mil ceramic used to fabricate the package. The gap between the metallizing varies from package to package from .005 to .0085" making it very difficult to reproducibly evaporate a given width strip with a given resistance. The best results are obtained by carefully measuring the difference between the runover on the metallizing on individual diodes and calculating the thickness of the nickel required to give the desired resistance to match or the negative resistance of the diode. Even with these precautions, reproducible results within 50% were difficult to obtain.

D. FABRICATION OF THE DISTRIBUTED JUNCTION TUNNEL DIODES

During the past quarter distributed junction tunnel diodes have been fabricated in the modification of the Coupland and Hilsum structure discussed in the previous quarter. This structure consists of a p+ epitaxial layer of gallium arsenide on a semi-insulating or high resistive substrate. (See Figure No. 1.)

The p+ semi-insulating or high-resistivity gallium arsenide layer is formed by two methods.

1. High resistivity p type or gallium arsenide was obtained and doped with oxygen by sealing the gallium arsenide in a quartz ampule filled with air and heating it from 800 to 1000°C from 10 to 24 hours. This semi-insulating material was diffused with

zinc to a depth of .2 μ A to 1.0 micron in an evacuated quartz ampule at 850°C. Some degradation of the resistivity of the semi-insulating gallium arsenide was observed. Typically the resistivity dropped to 2-10 ohm centimeters. Several diodes were fabricated from the diffused p+ semi-insulating gallium arsenide and characterized. It was found that generally the current density of these diodes was unsatisfactory for operating at X-band; diodes having peak current to capacity ratios of no more than 3 to 1. Studies are underway to determine the reason for the low current density in these diodes. Secondly, grown p+ epitaxial layers on semi-insulating gallium arsenide were also investigated. The thickness of these layers varied from 1 to 3 microns. Doping of the epitaxial layers is a problem as epitaxial layers with doping densities of greater than 5×10^{19} ions/cc of zinc were not available. As in the diffused thin skin technique mentioned above, the current densities of the epitaxial diodes were insufficient to make them oscillate at X-band. More work is in process to attempt to increase the doping in the diffused thin-skinned layer and thereby increase the current density of the tunnel diodes obtained.

VII - CONCLUSIONS

A redesign of both the strip and conical X-band tunnel diode oscillators has improved their frequency capabilities. The stripline oscillator is to be the most promising. Power outputs of more than 100 μ W at 8 kMc have been obtained. The maximum junction capacitance useable at X-band appears to be less than 1 picofarad. Placing a resistive short across the ceramic of the diode appears to be doubtful assistance in decreasing this capacity limit of the oscillator. Unless a large change is made in the peak current density of tunnel diodes or in circuit capabilities, the maximum power output of a single packaged tunnel diode at X-band is approximately $\frac{1}{4}$ milliwatt.

Low current density problems applied the use of distributor junction diodes at X-band. Peak current to junction capacitance ratios have generally been less than 5 to 1 and typically 3 to 1. To date, no power output has been obtained at X-band using a distributor junction diode.

VIII - PROGRAM FOR NEXT INTERVAL

The program for the next quarter will consist of the following:

1. Continued design and circuit improvements in both the single diode X-band stripline oscillators and a multiple diode oscillator.
2. Material investigations will be continued to attempt to improve the current density of present spot and distributed junction tunnel diodes. Principal efforts will be made to push up the peak current density through improved thinskin techniques on the distributed junction tunnel diodes.
3. Efforts will be made to combine several packaged X-band diodes into a series lump distributed oscillator or to obtain at least 1 milliwatt at X-band.

These diodes will be placed in a cavity which has a resonant frequency of greater than 10 kMc and the power coupled out into a 10 kMc resonant cavity. This technique gives considerable promise that the power requirements for the contract can be met using multiple diode approach, which is not junction capacity limited.

IX - IDENTIFICATION OF PERSONNEL

The following key technical personnel contributed to this study:

<u>Name</u>	<u>Title</u>	<u>Hours</u>
Dr. Kenneth E. Mortenson	Project Director	18
Charles M. Howell	Project Engineer	90
Carmen Genzabella	Semiconductor Engineer	221
Robert Galvin	Circuit Engineer	54
Robert Tennenholtz	Circuit Engineer	116

Biographies of these people have been given in previous quarterly reports during Phase I of this contract.

LIST OF ILLUSTRATIONS

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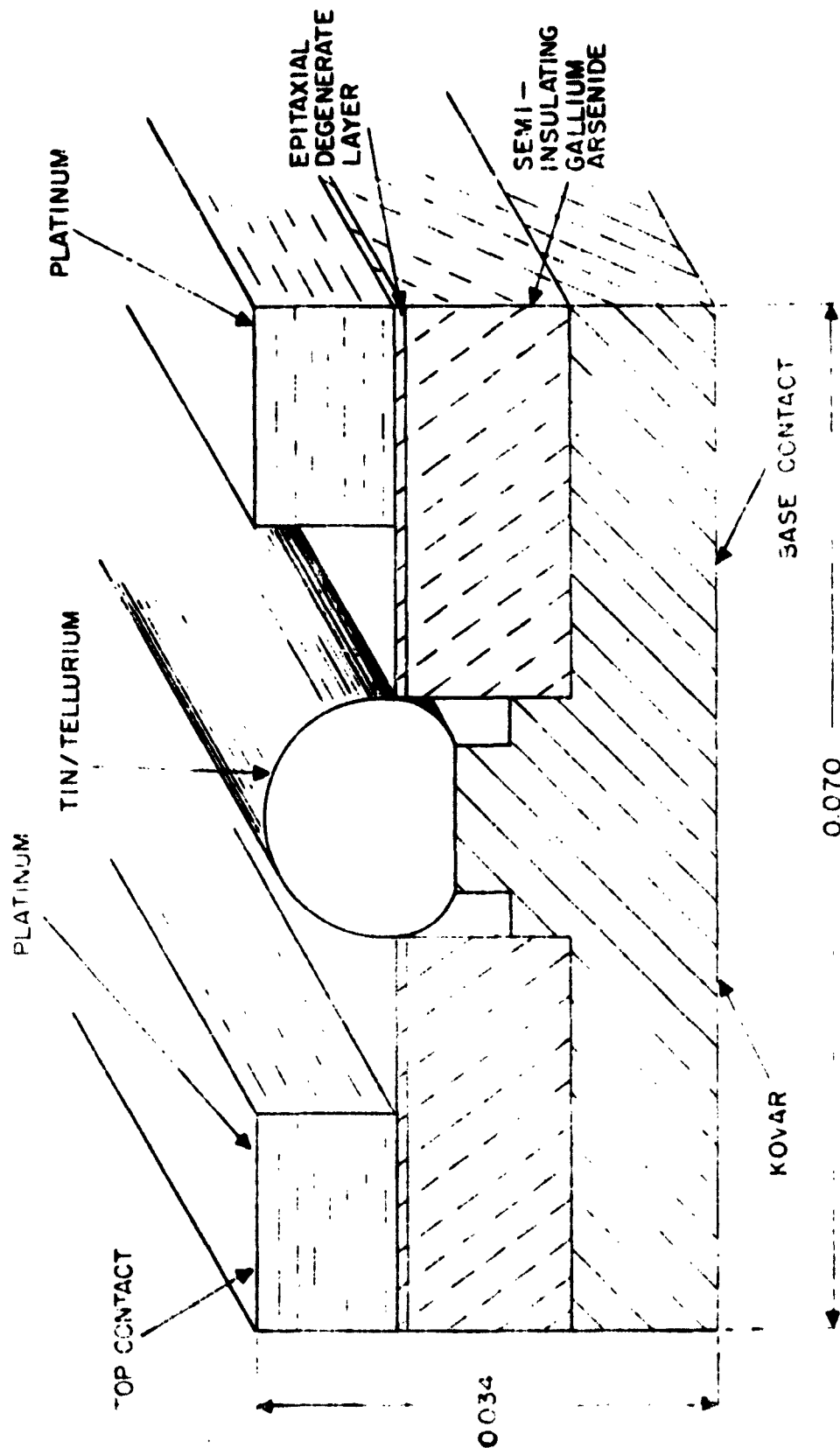


FIGURE 1
 DISTRIBUTED TUNNEL DIODE

UNCLASSIFIED 1. Distributed Junction Tunnel Diode Oscillator - Phase II 2. Contract No. DASH-009 SC-49163	AD ACCESSION NO. MEMORANDUM ASSOCIATES, INC. BURLINGTON, MASSACHUSETTS DISTRIBUTED JUNCTION TUNNEL DIODE OSCILLATOR - PHASE II C. Howell Third Quarterly Progress Report 17 pp. - 11 illus., Signal Corps Contract DASH-009 SC-49163 Efforts to determine the feasibility of constructing 10 m 10 Mc tunnel diode oscillators have been continued and diode requirements for these oscillators determined. Various diode fabrication techniques and oscillator circuit techniques have been investigated to determine the best combinations of these to potentially meet the frequency and power requirements. Four packaged and two distributed junction tunnel diode oscillators have been designed and built. The present oscillator study has been concentrated on the packaged X-band oscillators. Using the packaged single diode oscillators, power outputs of more than 100 microwatts have been obtained in X-band. Tuning problems seriously hamper the use of larger peak current, larger capacity packaged diodes. Some circuit changes have been made which partially alleviate this problem. The use of a resistive shunt across the current of the diode package has improved the stability of the oscillators, but not materially improved the high-frequency or power output characteristics of these oscillators. The reduced-size stripline package oscillator is the most successful. Low peak current to capacitance ratios have been a difficulty for the distributed tunnel diodes so far as power output has been obtained in X-band from a distributed tunnel diode oscillator.	UNCLASSIFIED 1. Distributed Junction Tunnel Diode Oscillator - Phase II 2. Contract No. DASH-009 SC-49163	AD ACCESSION NO. MEMORANDUM ASSOCIATES, INC. BURLINGTON, MASSACHUSETTS DISTRIBUTED JUNCTION TUNNEL DIODE OSCILLATOR - PHASE II C. Howell Third Quarterly Progress Report 17 pp. - 11 illus., Signal Corps Contract DASH-009 SC-49163 Efforts to determine the feasibility of constructing 10 m 10 Mc tunnel diode oscillators have been continued and diode requirements for these oscillators determined. Various diode fabrication techniques and oscillator circuit techniques have been investigated to determine the best combinations of these to potentially meet the frequency and power requirements. Four packaged and two distributed junction tunnel diode oscillators have been designed and built. The present oscillator study has been concentrated on the packaged X-band oscillators. Using the packaged single diode oscillators, power outputs of more than 100 microwatts have been obtained in X-band. Tuning problems seriously hamper the use of larger peak current, larger capacity packaged diodes. Some circuit changes have been made which partially alleviate this problem. The use of a resistive shunt across the current of the diode package has improved the stability of the oscillators, but not materially improved the high-frequency or power output characteristics of these oscillators. The reduced-size stripline package oscillator is the most successful. Low peak current to capacitance ratios have been a difficulty for the distributed tunnel diodes so far as power output has been obtained in X-band from a distributed tunnel diode oscillator.
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