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RADC-TDR-64-465

MULTIMEGAWATT BROADBAND MICROWAVE TUBES

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TECHNICAL DOCUMENTARY REPORT NO. RADC-TDR-64-465

December 1964

Techniques Branch

Rome Air Development Center
Research and Technology Division
Air Force Systems Command
Griffiss Air Force Base, New York

Project No. 5573, Task No. 557302

(Prepared under Contract AF 30(602)-[illegible] by Microwave Laboratory, W. W. Hansen Laboratories of Physics, Stanford University, Stanford, California.)

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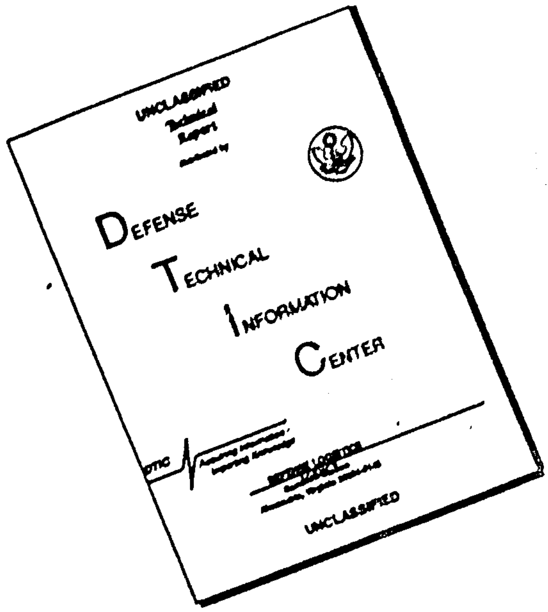

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ABSTRACTS

1. CENTIPEDE TWT

The centipede circuit has been adapted for use on the electron stick in such a manner that the amplitude and phase of the growing wave along the beam-circuit interaction length can be measured. The results of this study will be of utmost value in optimizing the many parameters affecting the beam-circuit interaction. Current results of theory and experiment are presented.

2. EXTENDED-INTERACTION KLYSTRONS

Tests on the electron stick for the suppression of parasitic oscillations have been conducted. By covering the entire stick with a thin sheet of directionally resistive mylar, oscillations were removed, up to 30 kW. Two other sources of instability have been found and removed: feedback oscillations and monotron oscillations. Work on calibration of external load and saturated-beam measurements is described.

3. TRANSVERSE-WAVE STUDIES

Studies on space-charge waves in an accelerated parallel-flow electron beam in a constant magnetic field have continued. The major emphasis this period has been on the analysis of the second-order differential system. A discussion of the solutions for certain conditions is presented.

4. BEAM-PLASMA STUDIES

Preliminary work on this new project, which constitutes an outgrowth of earlier plasma research under this contract, is described.

5. ACOUSTIC WAVE DEVICES

The objective of this new project is to investigate the properties of microwave acoustic wave transducers in order to improve their conversion efficiency and bandwidth; the status of this work is described.

PUBLICATION REVIEW

This report has been reviewed and is approved. For further technical information on this project, contact Lt Wilson, [illegible], Extension [illegible].

Approved: WILLIAM E. WILSON, 2/Lt, USAF
Project Officer
Electron Devices Section

Approved: [illegible]
Chief, Techniques Branch
Surveillance & Control Division

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INTRODUCTION

This is Quarterly Status Report No. 11, for the period of 1 May through 31 July 1964. This report describes projects active in the third year of this contract.

At the present time there are five projects, as follows:

1. Centipede TWT
2. Extended-interaction Klystrons
3. Transverse-wave Studies
4. Beam-plasma Studies
5. Acoustic Wave Devices.

The projects titled "Oscillation Suppression in TWT's" and "Nonperiodic Dielectric-lined TWT" have been completed. No work has been done on the "Periodic Circuit Studies" project during this quarter. A description of the work done on these projects during this contract year will be presented in the forthcoming Annual Report.

A technical report, "Space-charge Waves in an Accelerated Parallel-flow Electron Beam in a Constant Magnetic Field," by Rae Hooks, has been written, which describes the work on the "Transverse-wave Studies" project. It has been submitted to RADC for preparation as a Technical Documentary Report.

A plasma project on this contract has been continued, although the project formerly reported (titled "Electron Beam Interaction with a Cesium Plasma") was completed and a Technical Documentary Report on the whole project has been published. The new plasma project is presently in its initial stages, and this study, which is in essence a continuation of some aspects of the earlier work, is described herein under the title of "Beam-plasma Studies."

A project titled "Acoustic Wave Devices" has been added in thin film research and is concerned with the applications of such films to microwave acoustic transducers. An objective of this project is to explore the development of device mechanisms which may be useful for variable microwave phase shifters and delay lines.

The Responsible Investigator for this contract is Professor Marvin Chodorow.

SUMMARY AND ANALYSIS OF THE WORK

1. CENTIPEDE TWT

(D. K. Winslow,* T. Reeder)

A. INTRODUCTION

The objective of this project is to study the electron beam - slow wave circuit interaction in a high-power traveling-wave tube. The centipede slow wave circuit, a coupled cavity structure, is used in this study. In particular, the centipede has been chosen because it has proven to be one of the most satisfactory slow wave structures for a high-power TWT. The method of investigation will be to measure the amplitude and phase of the fields in each centipede cavity while the centipede is mounted on the electron stick and is being operated as a TWT. Measurements over a particular region are possible, such as at a sever and in the output section of the tube. The results of this study will be of utmost value in optimizing the many parameters affecting the beam-circuit interaction.

B. DISCUSSION

The fields inside each centipede cavity are sampled by a small, movable loop probe which is coupled to the fields by small slots located between the feet of adjacent centipede loops, as shown in Fig. 1. The probe can be moved over the entire length of the centipede structure, and it can be precisely positioned over a particular cavity slot. The size of the slots was adjusted to provide about one-tenth of a milliwatt of probe output when one kilowatt is applied at the centipede input coupler. The amplitude

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*Project supervisor.

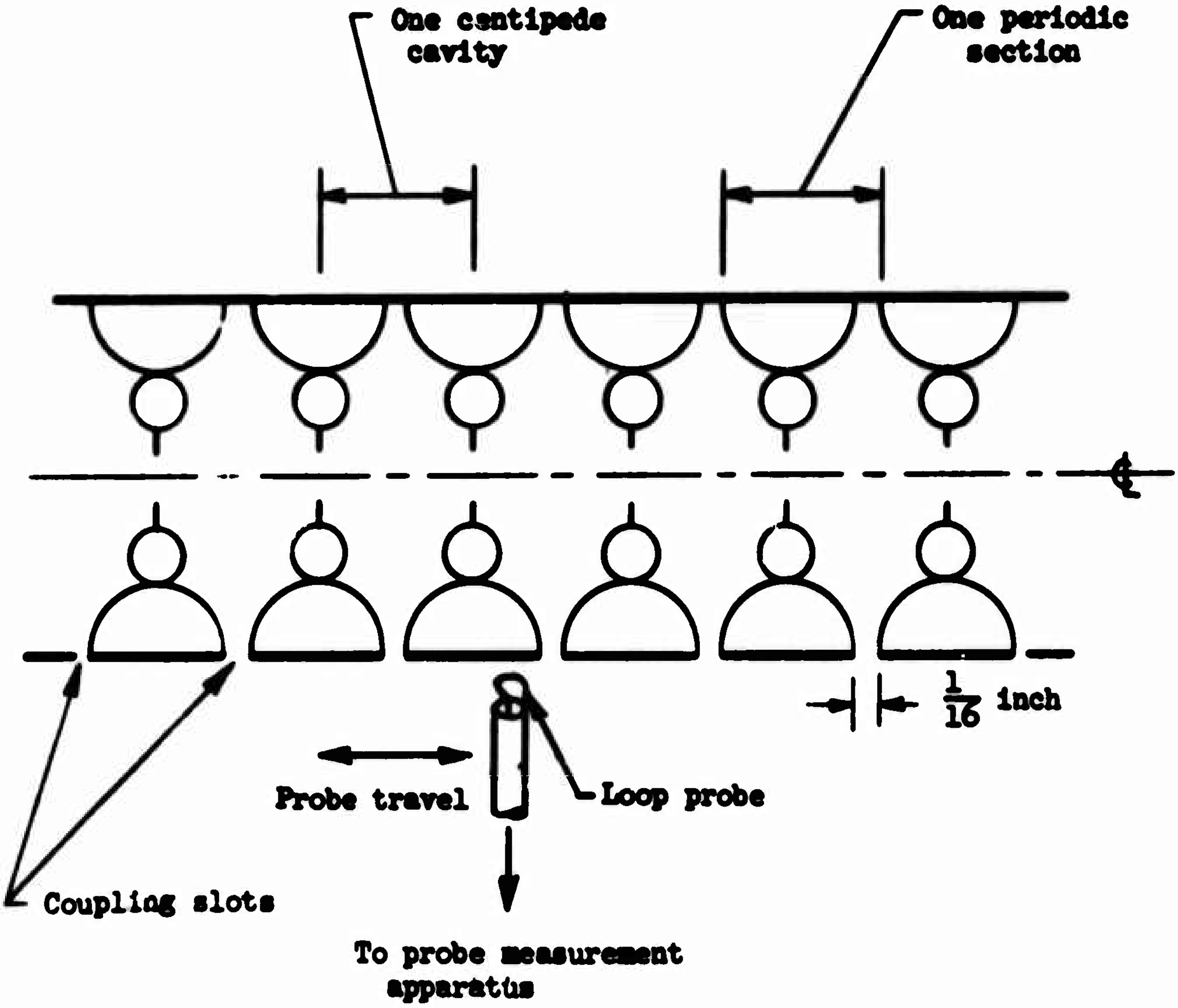


FIG. 1--Cross-sectional view of the centipede structure showing field probe and coupling slot location.

of the fields in each cavity is measured by positioning the movable probe over the coupling slot in a particular cavity, the probe output being measured by a square-law crystal detector. The detector voltage output is thus proportional to the amplitude squared of the cavity fields. The measurement of phase of one cavity to another is accomplished by mixing the movable probe output with a reference sample of the [illegible] input [illegible] in a slotted waveguide. The relative phase of the fields in each cavity is then related to the shift of the null position in the slotted waveguide as the probe is moved from cavity to cavity. This method has been described in some detail in an earlier report.[1]

The last quarterly report[2] described experimental measurements of amplitude and phase for the [illegible]. It was mentioned in that report that appreciable cold loss has been added to the [illegible] to suppress backward and other parasitic oscillations. While this added loss has made the experimental measurements practical, it has also [illegible] new problems in the theoretical calculations now in progress. The following section describes how loss may be added to the [illegible] equivalent circuit presented in Report No. [illegible].[3] The [illegible] of the equivalent circuit can be made to closely approximate the measured cold loss of the [illegible]. A comparison of calculated equivalent circuit loss with experimental measurement is included at the end of this report.

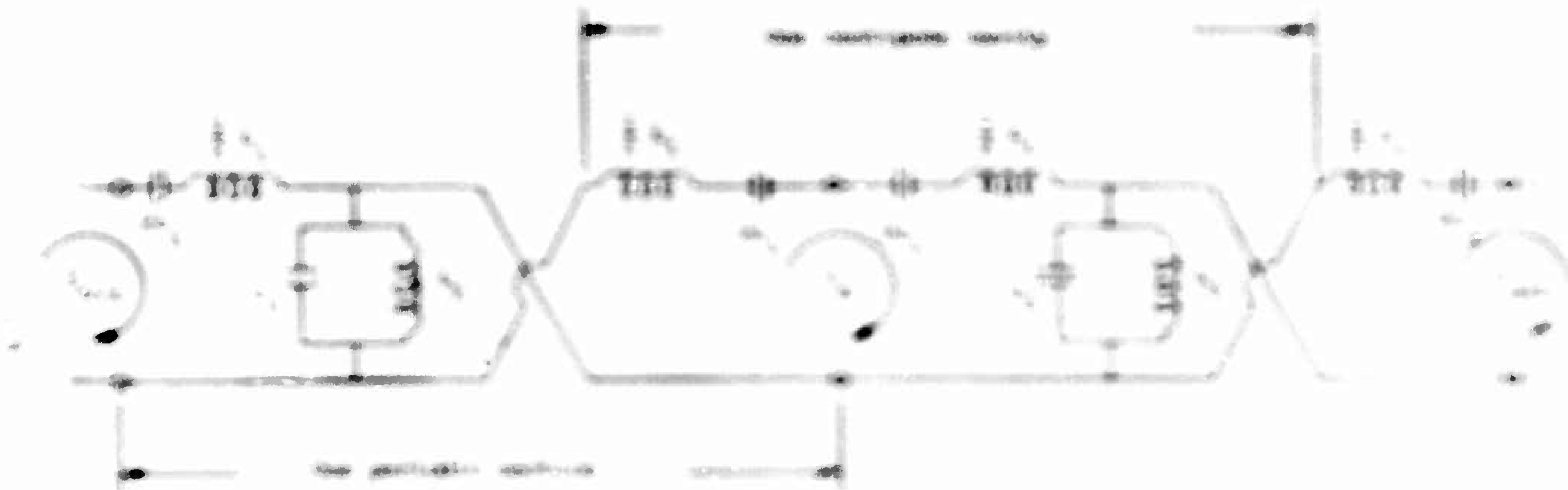
The [illegible] equivalent circuit, which was described in detail in Report No. [illegible], is shown in Fig. 1. Suppose we make the following [illegible]:

$$X_1 = [illegible]$$

[1] Quarterly Progress Report No. [illegible] [illegible]

[2] Quarterly Progress Report No. [illegible] [illegible]

[3] Quarterly Progress Report No. [illegible] [illegible]



and

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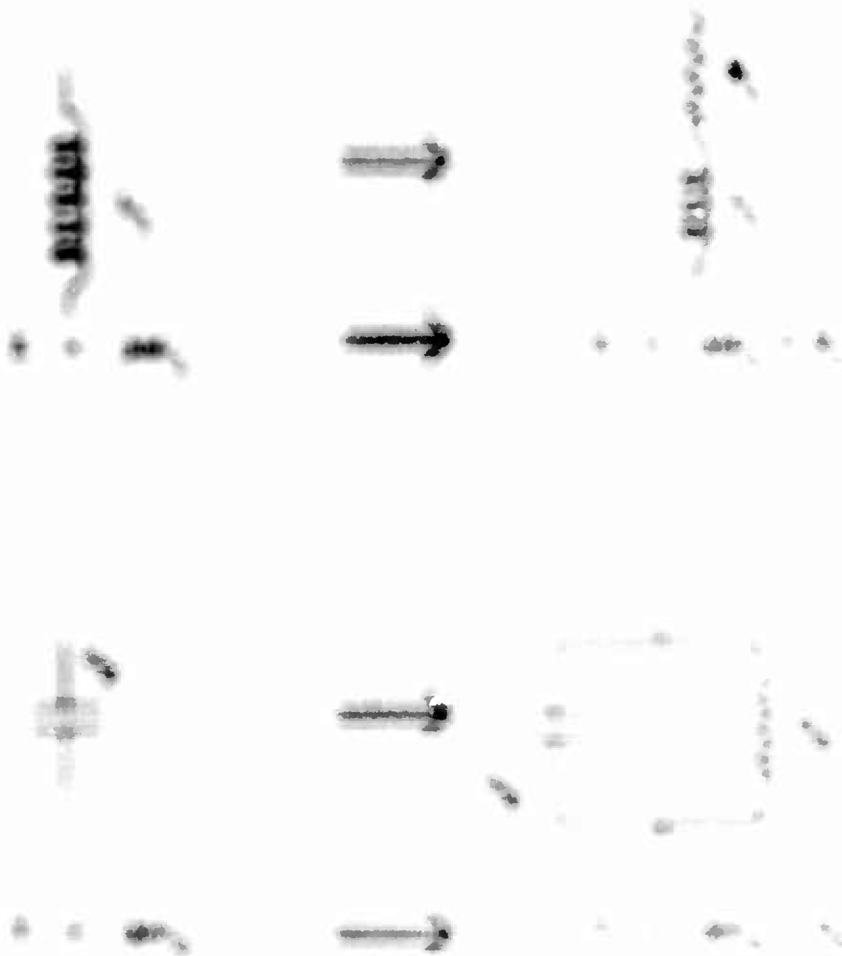

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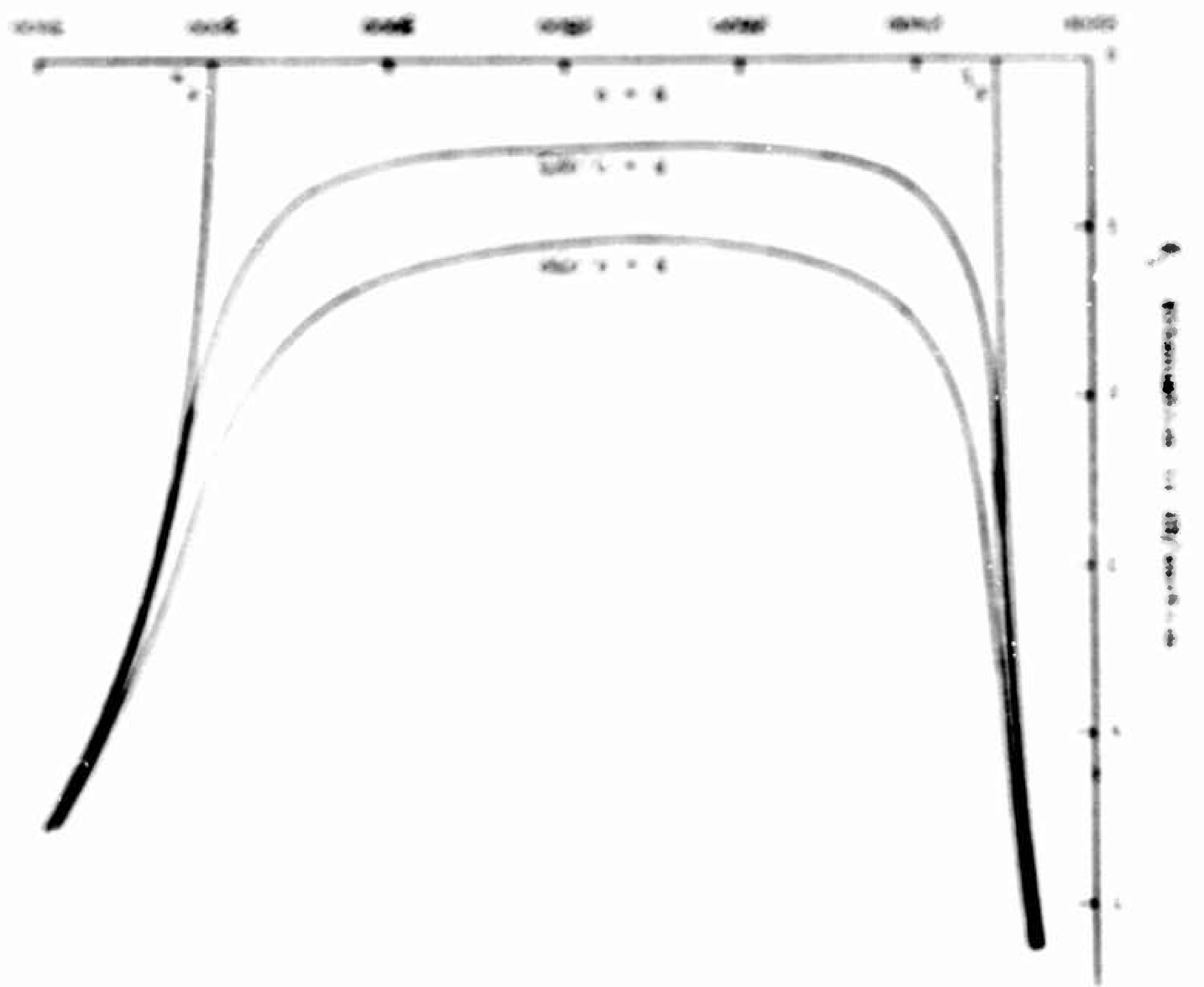

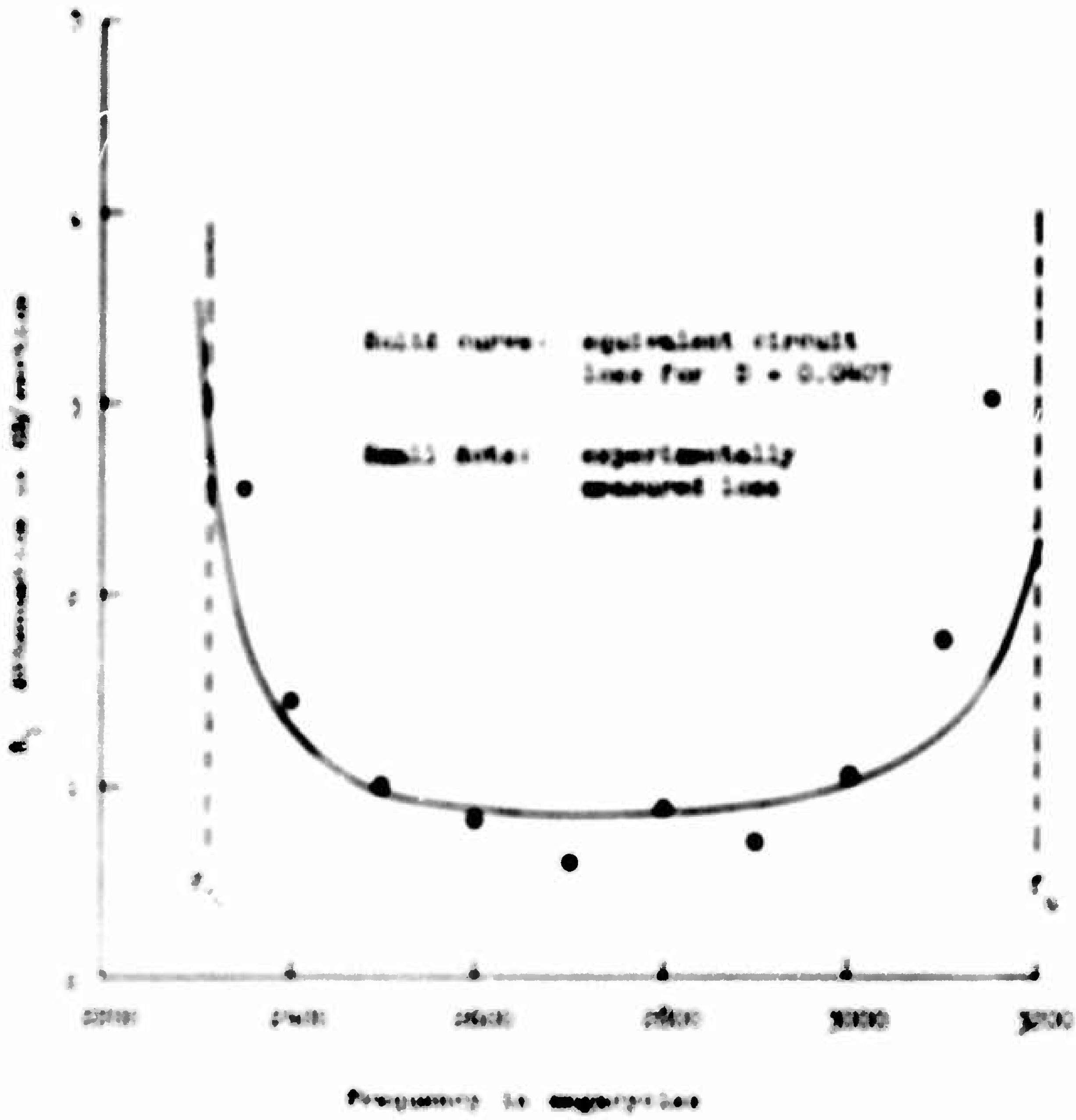

Fig. [illegible] Comparison of equivalent circuit loss with experimental data.

define

$$X = 20 \log_{10} e^{\xi} \quad \text{dB/section} \quad . \tag{28}$$

The approximate equations yield good accuracy for $X \leq 2.5$ dB/section

The above equations have been used to calculate circuit loss for several values of D . The constants have been chosen to match the fundamental and loop band dispersion of the centipede structure which has been studied experimentally. These constants are

$$f_a = 3.200 \text{ Gc}$$

$$f_b = 4.461 \text{ Gc}$$

$$k = 0.3266 \quad .$$

The frequency cutoffs of the fundamental passband are

$$f_L = 2.310 \text{ Gc}$$

$$f_u = 3.200 \text{ Gc} \quad .$$

Figure 3 shows the results of the loss calculations for $D = 0$, 0.025 and 0.050. It has been possible to show that if $D = 0.0407$, the calculated loss of the equivalent circuit is in good agreement with the experimentally measured loss of the centipede. Figure 4 compares this calculation with the experimental data.

Work is continuing on a small-signal theory for the centipede which includes the effect of two circuit waves and two beam waves. Circuit loss is included in this theory in the manner described in this report. Thus far, a computer program has been written to calculate the propagation constants of the four waves produced by the beam-circuit coupling. Another program is being devised to calculate amplitude and phase in each centipede cavity. A complete report on both the experimental and the theoretical work of this project is being written and will be available later.

2. EXTENDED-INTERACTION KLYSTRONS

(M. Chodorow,* B. Kulke)

A. INTRODUCTION

The primary purpose of this project is to investigate the maximum gain-bandwidth product and conversion efficiency which can be achieved in an extended-interaction klystron, with cavities consisting of resonated sections of a slow-wave structure. The current phase of this work is the evaluation, by means of the electron stick, of a three-cavity L-band tube. In this device, broadband modulation of the electron beam is simulated with input and intermediate cavities containing tunable resonated sections of a ring-bar structure. The length of the output cavity can be changed, in half-wavelength increments, from one to five resonant half-wavelengths of its component ring-bar structure, and the loading can be adjusted by changing the terminal conditions on the couplers attached to both ends of the output resonator.

The tube is better suited for beam-testing on the electron stick than the earlier S-band model, because the L-band device has higher interaction impedance on the beam axis and can operate at lower beam voltages, thus facilitating the suppression of parasitic oscillations on the electron stick. Beam tests of the L-band tube are in progress.

B. STABILITY CONSIDERATIONS

In Quarterly Report No. 9 (M. L. Report No. 1143), a new method was described by which one would suppress parasitic oscillations on the electron stick by covering the entire stick with a thin sheet of directionally resistive mylar. This approach has been quite satisfactory in that no stick oscillations were observed up to 30 kV, the highest beam voltage of interest. Tests at higher beam voltages will not be done until after completion of the main experiment, since, in case of breakdown, the resistive film is liable to destruction due to arcing from the glass tube. During trial

* Project supervisor.

[illegible]

1. [illegible]

[illegible]

2. [illegible]

[illegible] adjacent to the design resonance [illegible] an external impedance transformer [illegible] coupling, e.g., to obtain a [illegible] frequency. [illegible] a narrow frequency range; consequently, [illegible] resonance [illegible] to the adjacent resonance [illegible] effect, removes all external loading from the [illegible] instability in the adjacent resonances. [illegible] the adjacent resonance [illegible] product of external loading. [illegible] shown in Table I.

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[5] [illegible], "Coupling and [illegible] Systems." To be presented at [illegible] October [illegible].

ACOUSTIC WAVE DEVICES

[illegible]

1. INTRODUCTION

The objective of this project is to investigate the properties of microwave acoustic wave transducers in order to improve their conversion efficiency and bandwidth. The efficient conversion of rf energy to acoustic energy is necessary to increase the usefulness of acoustic delay lines, acoustic wave amplifiers and related devices using elastic waves in solids. The immediate objective is to improve the transducers by evaluating both the piezoelectric and magnetostrictive types, and to improve the coupling from the transducer to the crystalline solid transmission line by using appropriate acoustic impedance matching techniques. To accomplish the above objectives, thin evaporated films of metals and dielectrics are required for both the impedance transformers and transducers.

2. PRESENT STATUS

A number of thin films have been evaporated in this laboratory in the past for a variety of purposes and, to date, on this contract, equipment has been modified and acquired to evaporate films for our purpose here and to measure the coupling efficiency of these transducers. A typical nickel film transducer with rf resonator and delay line for operation at X-band is shown in Fig. 1. The immediate objective is to improve this type of transducer by the use of multilayer films between the nickel and the delay line to afford the proper acoustic impedance matching. The method is similar to that used for optical impedance matching using films of quarter-wave thickness of alternately high and low impedances.

The equipment for the evaporation of single layer nickel films is in operation, and several nickel films have been evaporated. An electron gun is used in this equipment. Evaporators for use with dielectric materials are being designed. The facility for evaluating the completed transducer,

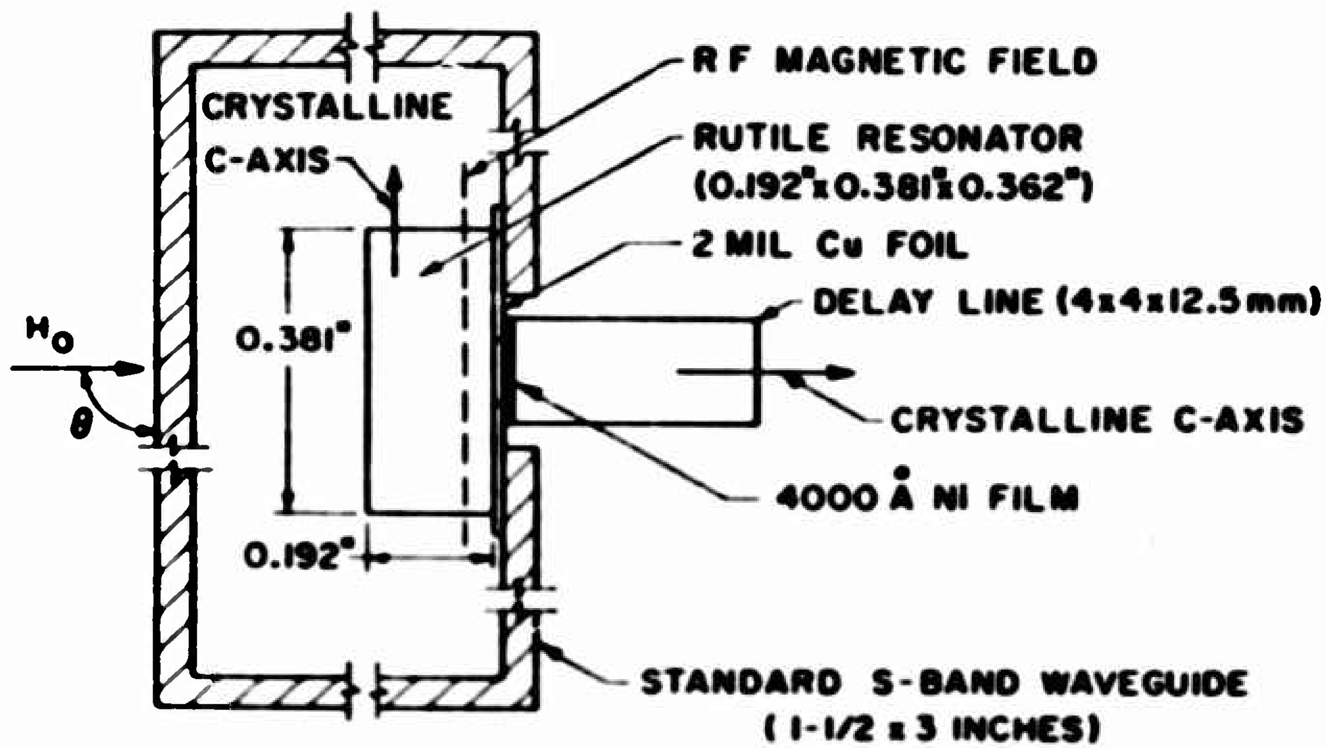

FIG. 1—Resonator and delay line (not to scale)

similar to that in Fig. 1, including the rf equipment, is also operational. This is the first report on this project and no definitive results have yet been obtained. Subsequent reports will give more detailed results of analysis and experiment.

[illegible]

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MULTIMEGAWATT BROADBAND MICROWAVE TUBES

Interim, 1 May - 31 July 64

Not given
Responsible Investigator on Contract: Chodorow, Marvin

November 1964

AF30(602)-2575

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Task No.
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M. L. Report No. 11

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Rome Air Development Center
Griffiss AFB, New York

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