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FOURTH

INTERIM DEVELOPMENT REPORT

FOR

CATHODE-DRIVEN, HIGH GAIN,

CROSSED-FIELD AMPLIFIER

This report covers the period from 1 March to 31 May 1973

RAYTHEON COMPANY
Microwave and Power Tube Division
Waltham, Massachusetts

UNITED STATES NAVY
Naval Electronic Systems Command
Washington, D.C.

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ABSTRACT

To achieve very high gain in a crossed-field amplifier, the rf drive power is being fed into a cathode slow-wave circuit. The traveling-wave on the cathode will control the space charge and induce current into the anode circuit. The cathode structure used to introduce the rf drive signal will provide a high degree of isolation between the amplified output signal and the rf drive energy.

During this report period, the first cathode-driven hot test model was sealed in and performance data were obtained. Initial results show that the cathode-driven CFA is a workable device. With an rf drive power of 750 watts, space-charge control was obtained with an rf gain of 20 dB. The present power supply is limiting the applied voltage to 39 kV. To obtain the required 50 kV anode voltage, the power supply will be modified. Testing of model No. 1 will then be continued.

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1.0 INTRODUCTION

A cathode-driven CFA was sealed in for hot test evaluation. Model No.1 was matched over the frequency range from 2.9 to 3.1 GHz. RF drive energy to the cathode circuit was supplied by a TWT. The normal input port on the anode circuit was terminated in a matched load.

2.0 TECHNICAL DISCUSSION

Cathode-driven CFA model No. 1 consists of a 16-vaned platinum cathode slow-wave structure. The cathode circuit phase shift was set to match the phase shift characteristics of the anode circuit. Figure 1 shows the match of the phase velocity of the anode to the cathode slow-wave structure. Although these phase shift characteristics were adequate for the first model, they will be made equal over a wider bandwidth in the next tube.

The 16-vaned platinum cathode circuit was brazed into the pole-bushing assembly, and the coaxial rf input window was attached. The input and output impedance matching transformers were adjusted to give a good impedance match over a wide bandwidth. The internal rf load was attached, and further impedance matching produced a desirable match over the operating band (2.9 to 3.1 GHz) and a good match from 2.6 to over 3.2 GHz, as shown in Figure 2.

The anode circuit is a QKS 622 type that utilizes 17 vanes. This anode was matched over the frequency range from 2.9 to 3.1 GHz. A matched load is used on the normal input port to this circuit since the rf drive energy is to be applied to the cathode circuit. The electromagnetic coupling between the cathode and anode circuits was measured to be less than -40 dB from 2900 to 3050 MHz. This increased to -33 dB at the upper end of the operating band (3100 MHz), as shown in Figure 3.

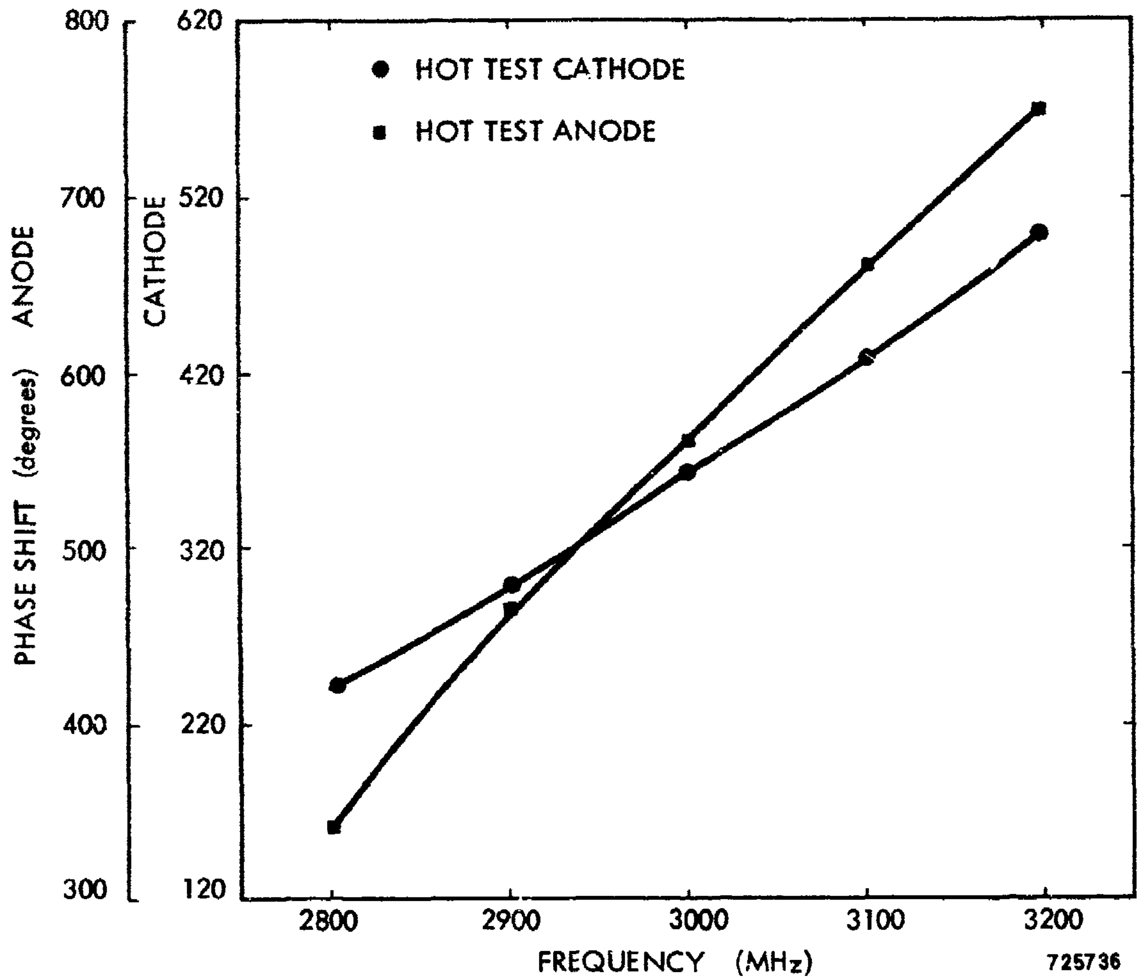

Figure 1. Phase Shift Around Network at Sealin of Model No. 1 Cathode-Driven CFA

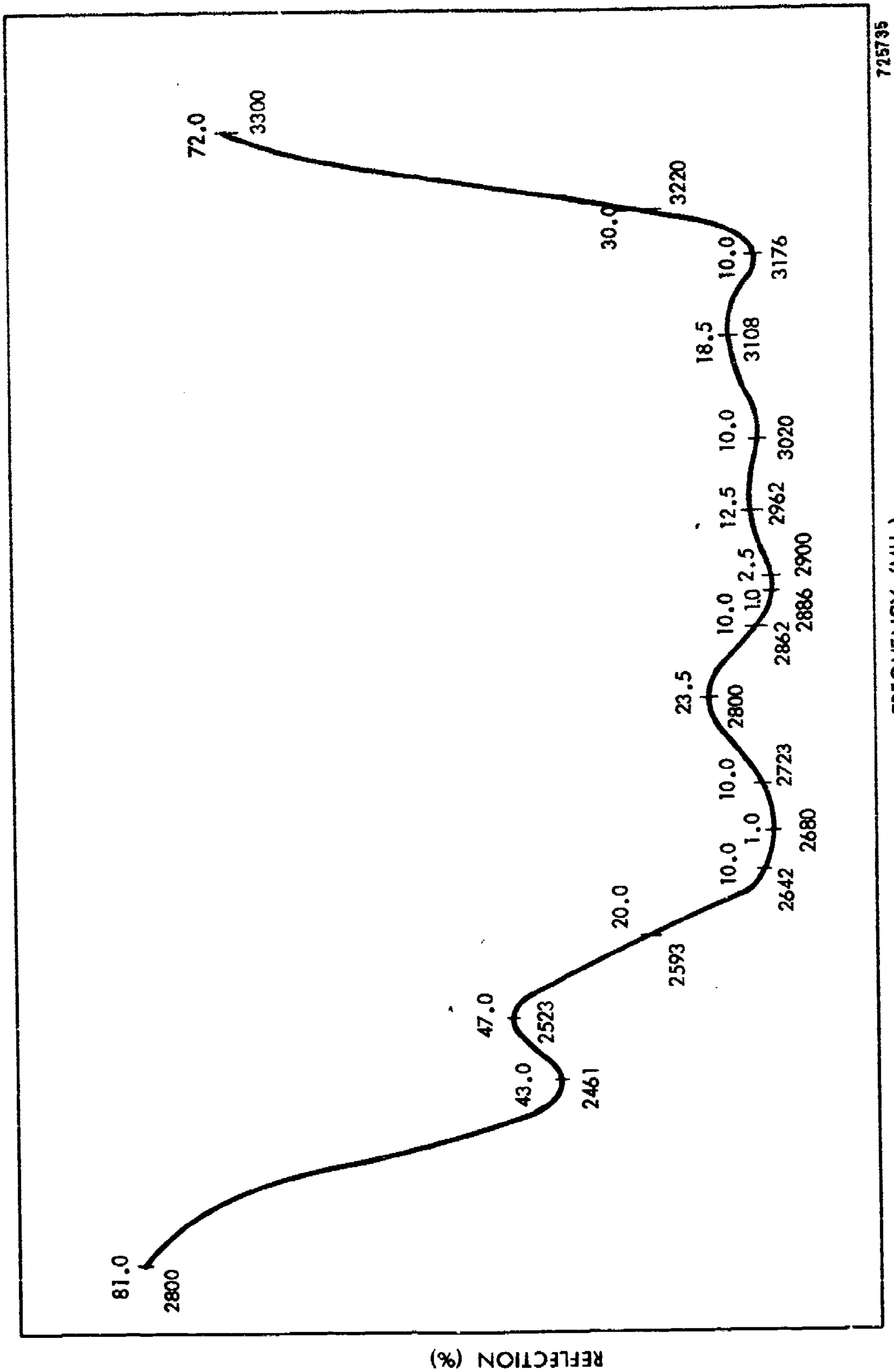

Figure 2. Impedance Match of Hot Test Cathode

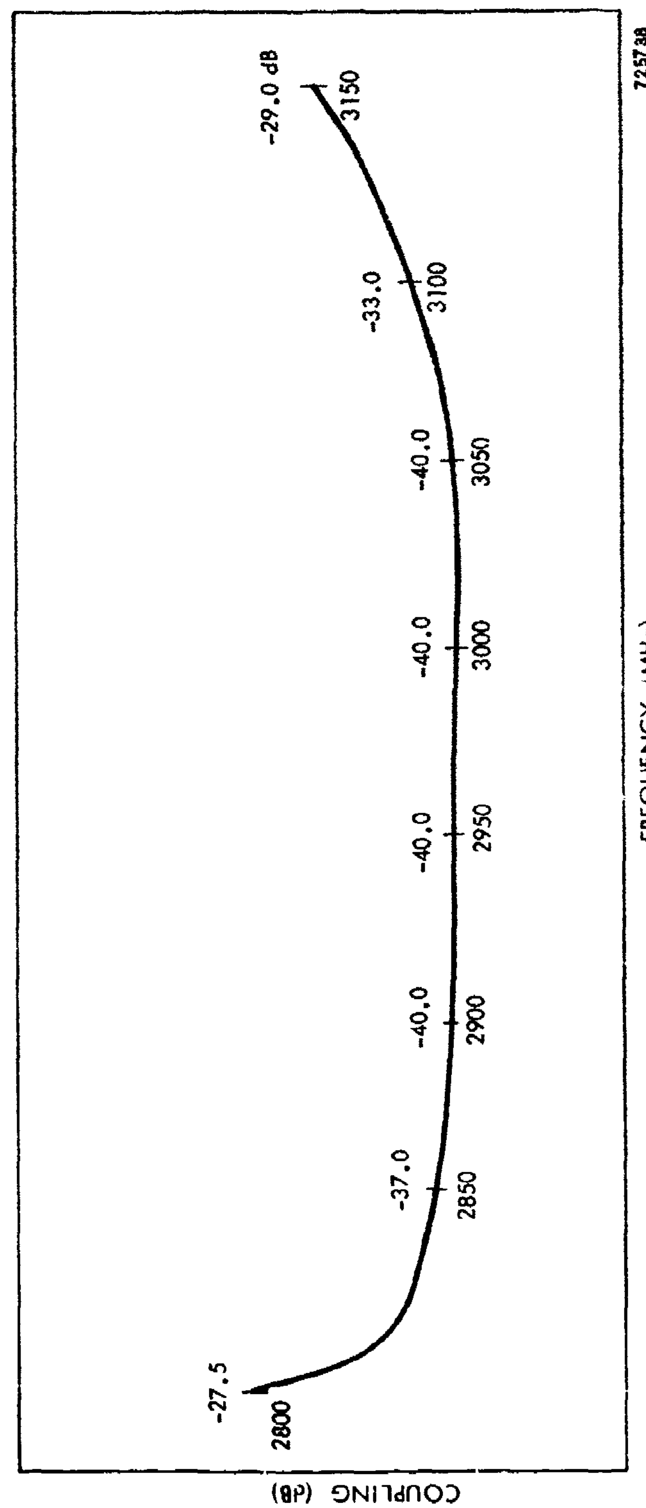

Figure 3. Coupling Between Hot Test Anode and Platinum Cathode at Seal-in

This first cathode-driven, hot-test model has an internal rf coaxial load for termination of the cathode circuit. Since this coaxial load was not water cooled, a limitation was placed on the average power in the cathode circuit (see appendix A). However, this load will collect essentially only the rf drive power; the spoke formation formed at the cathode will contribute only a small amount of energy to the cathode structure. Since the only coupling between the anode circuit and the cathode circuit is through the space charge, the cathode load will not collect a large amount of reverse-directed power. The second cathode-driven CFA will include a water-cooled cathode circuit and load.

The input rf signal was coupled into the cathode circuit through a dc block since both conductors of the input coaxial line are at cathode potential. The coaxial dc block was made of borosilicate glass and included dielectrically loaded quarter-wave chokes.

3.0 HOT TEST PERFORMANCE

Cathode-driven CFA model No. 1 was operated in hot test with the rf drive supplied by a TWT. The hot-test set-up consisted of the rf drive being fed into the cathode circuit of the CFA through a dc block. A matched load was connected to the normal input port of the anode circuit.

During testing of the cathode-driven CFA, no isolator was required between the CFA and the driver tube because of the greater than 30 dB of isolation existing between the cathode and anode circuit.

Platinum was used for the secondary emission material on the cathode network because of the good results obtained from it in several CFA's and because of its high secondary emission ratio. This cathode, therefore, acts as pure secondary emission cathode in the same manner as in normal tubes and also acts as a traveling-wave device which enables rf energy to be close to the source of emission.

The initial information to be determined was whether the device was workable and under what conditions it would operate. Initial hot test performance showed that the tube could be operated with an rf drive power of 750 watts with 80 kilowatts of rf power output being generated. An anode voltage of only 39 kV was being supplied, which was the limitation of the existing power supply. Additional testing will be performed with a power supply that will provide the required 50 kV to determine the range of operation. Under the present test conditions with low anode voltage, good amplifier performance was obtained at a gain of 20 dB and an efficiency of 34%. An anode current of 6 amperes was being drawn by the cathode-driven device at the highest voltage that can be supplied by the power supply.

No operating current was observed when applying the 750 watts of rf drive power to the normal input port of the CFA. This QKS622 type of anode circuit is used in applications where an rf drive power of 48 kW and 550 kW respectively are being applied to the normal input port. In the 48 kW rf drive application, the lower current mode boundary is in the order of 12 amperes. With the 550 kW drive, the tube operates in the desired mode with a few amperes. When cathode driven, the tube has a lower current mode boundary similar to the 550 kW case; however, with only 750 watts of drive power required.

4.0 INITIAL BANDWIDTH DATA

Initial bandwidth data were obtained with constant anode voltage of 39 kV because of the power supply limitation. This condition is undesirable for operating a backward-wave tube because the phase velocity and the voltage vary with frequency. In sweeping the frequency band from 2850 to 3000 MHz, therefore, the power output decreased as expected and the gain curve was as shown in Figure 4. The tube was operated with constant rf drive power of 750 watts across the frequency band.

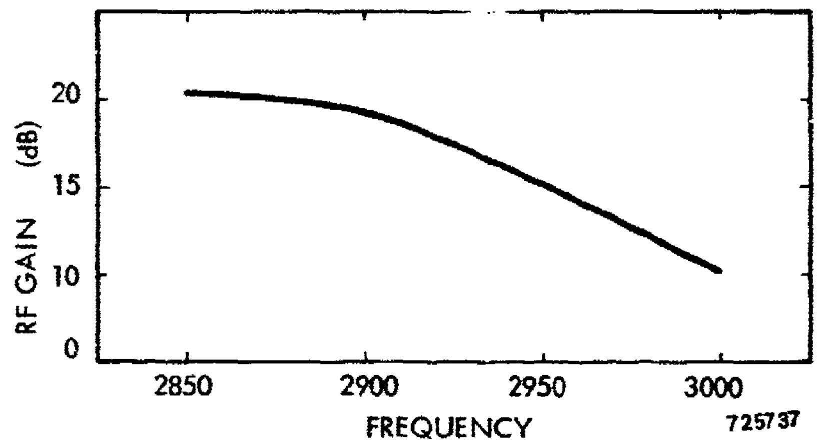

Figure 4. RF Gain of Cathode-Driven CFA at a Constant Voltage of 39 kV and 0.75 kW Drive Power

At 2850 MHz, a phase shift around to anode network is 52° less than that around the cathode, and, at 3000 MHz, it is 20° more. Tube operation over the frequency range shows that an exact phase shift match is not required.

5.0 REVERSE POWER

The amount of reverse-directed power was measured from the cathode circuit and from the normal input port of the anode circuit. The cathode driven tube was operating under the following conditions:

RF drive	=	0.75 kW
RF output	=	80 kW
RF gain	=	20.3 dB

The reverse-directed power from the normal anode input port was 0.34 kW which is -23.7 dB from the output power. This is mainly due to reflection from the output window, and anode network to waveguide transitions. Generated power coming out of cathode circuit was 0.09 kW or -29.5 dB. This small amount of reverse power (about 0.1%) shows the high degree of isolation between anode and cathode networks.

6.0 CONCLUSIONS

A cathode-driven CFA is being operated in hot test. An rf gain of 20 dB has been obtained which shows the cathode-driven CFA to be a workable device. Testing will be continued on model No. 1, and the necessary modifications will be made on the power supply to obtain the required voltage.

APPENDIX A

MAXIMUM POWER LIMITATIONS

For a high average power device, the platinum cathode and the internal load would be water cooled. The cathode consists of 15 platinum tubes which can easily accommodate water cooling.

The internal rf coaxial load consists of a tapered, lossy dielectric on the end of a coaxial line. In a vacuum bell jar test with the large end water cooled, 375 watts were dissipated in the load before the small end reached 450° C. This temperature restriction was maintained to protect the silver braze joint to the dielectric. There was no significant change in load characteristics.

For the initial experiments, it was decided that low duty cycle operation would be sufficient, so there was no need for using water cooling with its associated mechanical complications.

The load is mounted in a cylinder 0.875 inch in diameter by 0.825 inch long. With the outside at 400° C, the small end will be under 450°C and the cylinder end will radiate about 2.2 watts.

Black body radiation at 400°C $= 1.2$ watt/cm^2

Total emissivity (E) of copper at 400°C ~ 0.1

$$\text{Power} = 1.2 \times 0.1\,(\pi DL + \pi D^2/4)6.45 = 2.2 \text{ watts}$$

Since most of the rf drive will be dissipated in this load, the average drive power should be limited to about 2 watts.

The generated rf power should couple mainly to the anode circuit and not to the cathode, so its effect upon heating of the cathode load should be small.

The cathode back bombardment power is usually between 5 and 10% of the dc input power. Since this cathode is not water cooled, this power should be limited to what can be safety radiated or conducted away. The tail end shield's effective area is about 38 cm^2, and, at 450°C, it can radiate about 1.57 $watt/cm^2 \times 0.1\ (E_t) \times 38 = 5.7$ watts. The support end shield has a conduction path to a cool surface, so about 20 watts dissipated on the cathode will heat the center of the platinum vanes to about 500°C and the tail end shield to 450°C.

The cathode dissipation should be limited to about 20 watts average to keep the silver braze joints from deteriorating.

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