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DEVELOPMENT PROGRAM FOR A 200 kW, CW, 28 GHz GYROKLYSTRON

H. Jory, C. Conner, S. Evans, J. Moran,
W. Sayer, R. Symons, G. Thomas

Quarterly Report No. 15
October through December 1979

Prepared for:
Oak Ridge National Laboratory
Oak Ridge, Tennessee 37830

Operated by:
Union Carbide Corporation for the Department of Energy
Contract No. W-7405-eng-26

Varian Associates, Inc.
Palo Alto Microwave Tube Division
611 Hansen Way
Palo Alto, California 94303

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ABSTRACT

The objective of this program is to develop a microwave oscillator capable of producing 200 kW CW power output at 28 GHz. The use of the gyrotron or cyclotron resonance interaction is being pursued.

Testing of miter band tube 7(M) was completed and the tube shipped to Oak Ridge. Unfortunately it suffered a vacuum leak and was returned to Palo Alto where it was repaired, tested and returned to ORNL. It is now operating at 50 to 60 kW CW into the EBT-S Plasma.

Tube 5R1 was rebuilt to incorporate a new water-cooled collector seal and was operating at 122 kW peak power at a 0.006 duty cycle at the end of the quarter.

All subassemblies on tube 6 were completed except the collector seal which is due in early January.

Tube 12 M assemblies are complete except the miter, output waveguide, anode and window assemblies.

Design and the ordering of parts for the first 5" diameter axisymmetric tube has been completed except for the window spacing details.

The cause of the failure of three of the twelve magnet coils in the test station was investigated and corrective action taken.

I. INTRODUCTION

The objective of this program is to develop a microwave oscillator capable of producing 200 kW of CW power at a frequency of 28 GHz. In addition, it is intended that the program will serve as the first step toward development of a device to produce a similar power level at a frequency of 60 and 110 GHz. Feasibility for the 60 and 110 GHz designs will be demonstrated, whenever practical, in the design of the 28 GHz device. Tunability or bandwidth is not considered an important parameter in the design, but efficiency is. Mode purity in the output waveguide is not a requirement for the device, but the circular TE mode is considered desirable because of its low loss properties.

With these objectives in mind, the decision was made to pursue an approach based on a cyclotron resonance interaction between an electron beam and microwave fields. The detailed arguments leading to this choice are contained in the final report of the preceding study program[1]. The device configuration of particular interest, called a gyrotron, has been discussed in recent literature.[2,3] It typically employs a hollow electron beam interacting with cylindrical resonators of the TE_{0m1} class.

The optimum beam for the cyclotron resonance interaction is one in which the electrons have most of their energy in velocities perpendicular to the axial magnetic field. Another requirement is that the small component of axial velocity be essentially the same for all electrons. An electron which has a different axial velocity will not interact efficiently. Generation of a beam with high transverse velocity and small axial velocity spread is another important design problem.

The approach chosen to generate the beam is a magnetron type of gun like the one used in the devices described in the Russian literature. With this type of gun, the shaping of the magnetic field in the gun region becomes quite important.

As a result of the excellent performance of the pulsed oscillator, producing up to 248 kw of peak power at 28 GHz with good efficiency[4], the emphasis of the program has been shifted to stress the construction and delivery of CW oscillators.

During the period covered by this report, two tubes intended for CW operation, S/N 5, an axisymmetric output type, and S/N 7, a miter-bend output type, were operated under pulsed and CW conditions. Another pair, with the same two types of output arrangements (S/N 6 and 12) were in different stages of construction. Parts for the new 5" output tube (S/N 9) were ordered. The following observations on these tubes are reported here in the order in which they were tested or assembled.

II. TUBE S/N #7

The tube was shipped to Oak Ridge in early October where it was installed in EBT-S. Unfortunately, while being installed by Varian and ORNL personnel, it went "down to air" shortly after it was turned on as exhibited by a dramatic rise in tube pressure. Later it was established that the leak had been caused by a cracked ceramic in the loaded drift tube assembly.

The consensus is that the ceramic had been subjected to an abnormal amount of microwave power during operation. This was very likely caused by a strong oscillation in the drift tube region between the gun and the cavity caused by the cyclotron resonance at the reduced magnetic field strength at the time of failure. Henceforth, it will be recommended that only normal operating magnetic field strength be used under all operating conditions.

The tube was returned to Varian, Palo Alto where the drift tube load assembly was replaced. It was then reassembled, reprocessed and made ready for high voltage testing by October 24. The tube is now known as S/N 7R1 (M); the (M) signifies that it has "miter-bend" type output.

Tube S/N 7R1 (M)

Testing of this tube proceeded through November, first in the pulse mode and then CW. Approximately six hours of CW operation at 61 kW had been logged by November 21. On this date a gas burst and crowbar turnoff occurred which coincided with a low value of Gun 1 magnet current (7.2 A). The emission of the cathode also increased significantly following this event. The heater voltage required for 8 A of beam current decreased from 12.8 volts to 11.4 volts. Heater impedance increased from 1.73 to 1.84 ohms and heater power decreased from 95 to 71 watts. Both sets of values are within the range of heater power and impedance encountered in other gyrotron guns to date. VacIon pump current indicated the tube was outgassing for several hours after the event. The tube appears unchanged otherwise. The cause of this change is believed to be interception of the beam by the modulation anode due to low gun coil current or an rf oscillation in the gun region. The resultant gas burst conbined with arcing or rf oscillation is believed to have caused increased cathode emission and erosion of the heater wire thereby increasing its impedance.

Testing of this tube was completed on November 28. Approximately 12 hours of CW operation between 50 and 60 kW had been logged by this time. The tube was shipped to Oak Ridge National Laboratories on November 30.

The tube was installed in the EBT-S system and processing begun on December 3. Full beam current and voltage were reached by December 7. By December 10, difficulty was encountered in trying to achieve more than 5 kW or rf output. The symptons were: the body current would increase and the crowbar would fire when gun anode voltage was increased to increase power output.

The problem was diagnosed as a high sensitivity to transverse magnetic field components in this tube. X and Y axis correction coils were added along the body of the tube (i.e., two sets of orthogonal coils, their axes perpendicular to each other and to the central axis of the tube).

When direct currents in these coils were set between 2 and 5 A, giving approximately 8 to 20 gauss of transverse field, the body current was reduced to a constant level of 19 mA and rf output was increased to 30 kW CW within a few hours. It appears that the beam had been intercepted slightly inside the tube and that the correction of transverse magnetic field components successfully recentered the beam. Before further increase in output power could be obtained, a failure occurred in the beam power supply. After this was repaired, tube processing continued and had reached 54 kW CW as of November 18. Difficulty was being encountered with the frequent firing of the crowbar, with no indication of tube pressure change. It was recommended that a strip-chart recorder be installed to measure tube pressure. Toward the end of the quarter investigations were still in progress to determine if the turn-offs were caused by a tube fault or a power supply fault.

During the processing of this tube, the collector seal temperature rose rapidly on occasion and it was noted that this correlated with the rf level at the collector load. By carefully adjusting the main magnet coil current, the rf at the collector could be minimized which in turn reduced the collector seal temperature to an acceptable value. Table 1 is a summary of the principle operating parameters of tube 7 measured while tested with a matched rf waterload.

Table 1
VGA-8000
Serial Number: 7

OPERATING PARAMETERS

Collector Water Flow		350	gpm
Body Water Flow		4	gpm
Window Water Flow (both)		1	gpm
FC-75 Flow		2.5	gpm
Magnet Water Flow		16	gpm
Upper Water Load		2	gpm
Magnet Coil Currents:	Main 1 =	552	A
	2 =	512	A
	3 =	480	A
	4 =	480	A
	Gun 1 =	10	A
	2 =	10	A
Beam Voltage		77.5	kV
Gun Anode Voltage		30.6	kV
Cathode Current		8.2	A
Body Current		18	mA
Power Output		67	kW
Frequency		27.86	GHz

At the end of the quarter the tube was operating at 50 kW CW into the EBT-S plasma.

III. TUBE S/N 5R1

This tube was returned to test in early October. After about one week of operation in the pulsed mode, it was removed in order to work on the magnet system. During the time it was in operation, it was successfully operated at a 0.009 duty cycle with 176 kw peak power output.

A miter bend was installed between the tube output and waterload. A conduction cooled carberlox ring mode filter was then inserted between the miter bend and tube output. The tube was operated at 160 kw peak at 0.6% duty in each instance. Power output remained within approximately 5% for the waterload connected directly to the tube and for the two instances described above.

Significant heating of the mode filter was noted. A new mode filter, using flowing water as an rf load, is being designed and constructed for pulse and CW operation. It will permit calorimetric measurement of rf absorption.

The behavior of the tube had led us to be suspicious of the field shape of the main magnet assembly. When approximately 150 A of 60 cycle ac was applied to each of the magnet coils, erratic current was noticed in coil number 3. The magnet system was taken apart and each section measured for resistance.

Ultimately three of the twelve sections were found to be defective and were then replaced. The field was plotted and found to be normal. The magnet was returned to the test station socket in time to test #7. (See Figure 1).

Tube S/N 5R2

In accordance with the September 27 technical proposal, 5R1 was rebuilt as S/N 5R2. It incorporates a new collector seal design which has direct water cooling and rf loading on the ceramic insulator. Difficulty was experienced in assembling the new version as evidenced by cracking of the

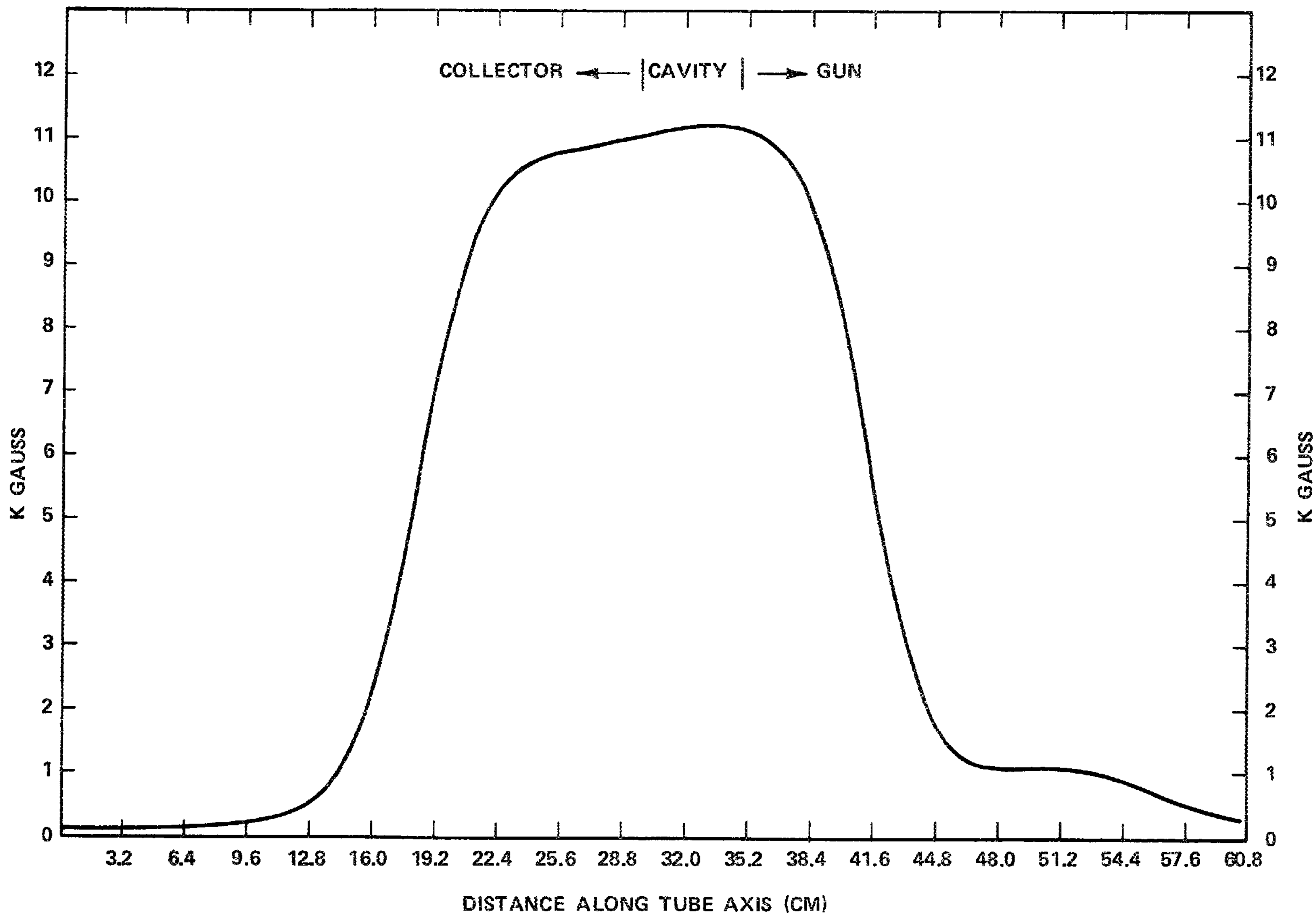


FIGURE 1. VYM-8000 MAIN MAGNET FIELD ALONG TUBE AXIS
MAGNET COIL CURRENT = 480 A PER SECTION

ceramic during brazing. The brazing tooling was extensively modified and the brazing furnace temperature program lengthened to minimize temperature gradients. In addition, a lower temperature brazing alloy was used to reduce the maximum temperature. This effort resulted in a successful collector seal.

The tube was assembled and leak tested. Following this, it went through the bake-out process and subsequent cathode heater conditioning. The water fittings, thermocouples, lead shielding, shrouds etc., were installed and the tube was ready for test on December 14.

High-potting has been completed and the tube has been tested in the pulse mode to 145 kW at 0.6% duty.

IV. TUBE S/N 6

All subassemblies of this 2.5" axisymmetric tube are on hand with the exception of the collector seal which is scheduled for completion on January 10.

A double-disc BeO window will be used. BeO discs 0.101" thick will be used compared to the 0.086" Al_2O_3 discs used in tube #5. Also the frame structure surrounding the window enclosure will be increased in thickness to avoid the distortion problems encountered in the tube #5 window. Optimum disc spacing will be determined by cold test prior to final assembly of the tube.

A set of metal parts to eliminate the ceramic collector seal is in process. These were initiated at the request of the Gyrotron Committee during the December 19 review. It will be available for possible use and evaluation on tube S/N 6.

All parts are on hand to incorporate an rf waterlead on the tube. This will give us the option of a "windowless" tube which will permit us to continue toward our 200 kW goal under more ideal conditions. A decision as to whether or not to do this experiment will depend on the results of S/N 5.

V. TUBE S/N 12M

This tube, originally scheduled for completion in September 1980, was moved up to the present in order to provide a backup for tube S/N 7, presently operating at Oak Ridge. It is a miter-bend tube, similar to S/N 7 except that its Q will be reduced to approximately 500 to improve power output efficiency at higher beam current.

All assemblies are complete except the miter, output waveguide, anode and window assemblies.

VI. TUBE S/N 9

Design and parts procurement for this first 5" window axisymmetric tube has been completed except for the window spacing details. Two sets of 5" BeO discs and six 5" waterload ceramic cones are on hand.

The window ceramics and fixture are on hand for cold test.

No "standard" 5" waveguide flange appears to be available and one has been designed after consultation with Oak Ridge.

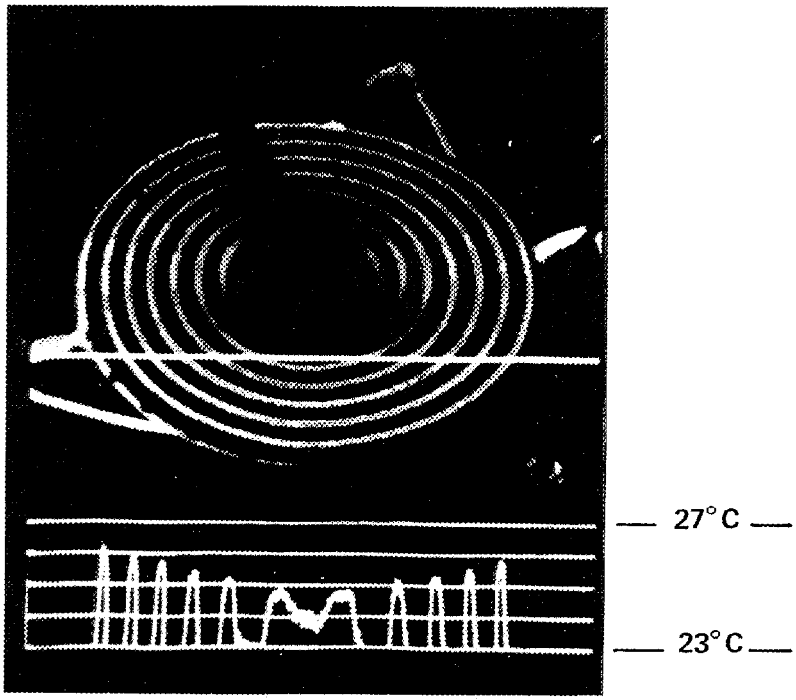
A waterload design has been completed and parts ordered.

VII. MAGNET COIL FAILURE INVESTIGATION

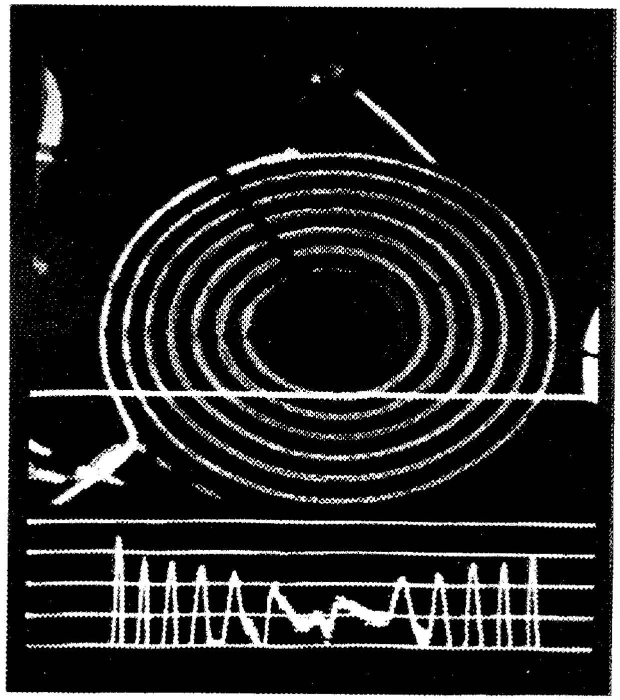
Failure of three of the twelve coils in the test station magnet assembly was mentioned in the tube S/N 5R1 report. The following investigations were made to establish the cause and to take remedial action.

One of the defective coils (displaying erratic current and severe "hot spotting") was taken to the manufacturer, Elma Engineering, for failure evaluation. He verified that it was of his manufacture but that turn-to-turn short circuits, the cause of the problem, are usually a result of inadequate reverse voltage protection. Shortly after the end of this reporting period 1N4045 reverse voltage protection diodes were installed across the output of each power supply. We recommend that users make similar installations if their power supplies are not already equipped with reverse-transient protection diodes.

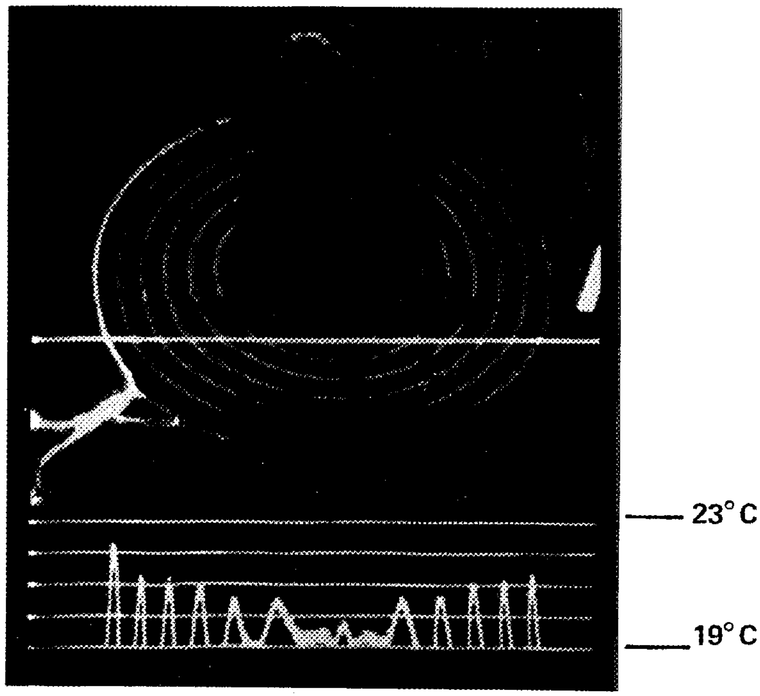
Another possible source of inter-turn breakdown has been suggested: occasional minor water leaks in coolant-line connections, hoses, etc., may soak through coil insulation and provide a conductive path which somehow might lead to permanent breakdown (even though the coolant in use is high resistivity, deionized water). To check that out a new coil was initially set up to operate at normal electrical current and coolant flow, carefully measuring stable voltage/current relationships, taking "thermograph" (scanning infra-red, electronic-camera photographs to record operating temperature gradients and color-interpreted thermal patterns). The coil was then totally immersed in deionized water overnight, without current flow, reconnected and measured, as before, with no change noted. (See Figure 2). Subsequently, the coil was operated for two day shifts with "raw" city water dripping continuously over it while repeating the original measurements No change was noted and the test was discontinued. No attempt was made to operate the coil while totally immersed as it was not considered a significant representation of normal operation.



A
BEFORE WATER IMMERSION



B
AFTER 16-HOUR WATER IMMERSION



C
AFTER 16 HOURS OF WATER DRIPPING ON COIL SECTION

FIGURE 2. VYM-8000 MAGNET COIL SECTION TEMPERATURE PROFILE, 1.5 gpm, 492A

VIII. PROGRAM SCHEDULE AND PLANS

Tube S/N 12M has been moved up in the schedule and will be available for shipment to Oak Ridge by January 25.

S/N 6, the second 2.5" axisymmetrical tube will be tested immediately following S/N 12. Final assembly will be completed following testing of S/N 5R2 to incorporate improvements indicated in testing S/N 5R2.

An updated Milestone Chart and Status Report is shown in Figure 3.

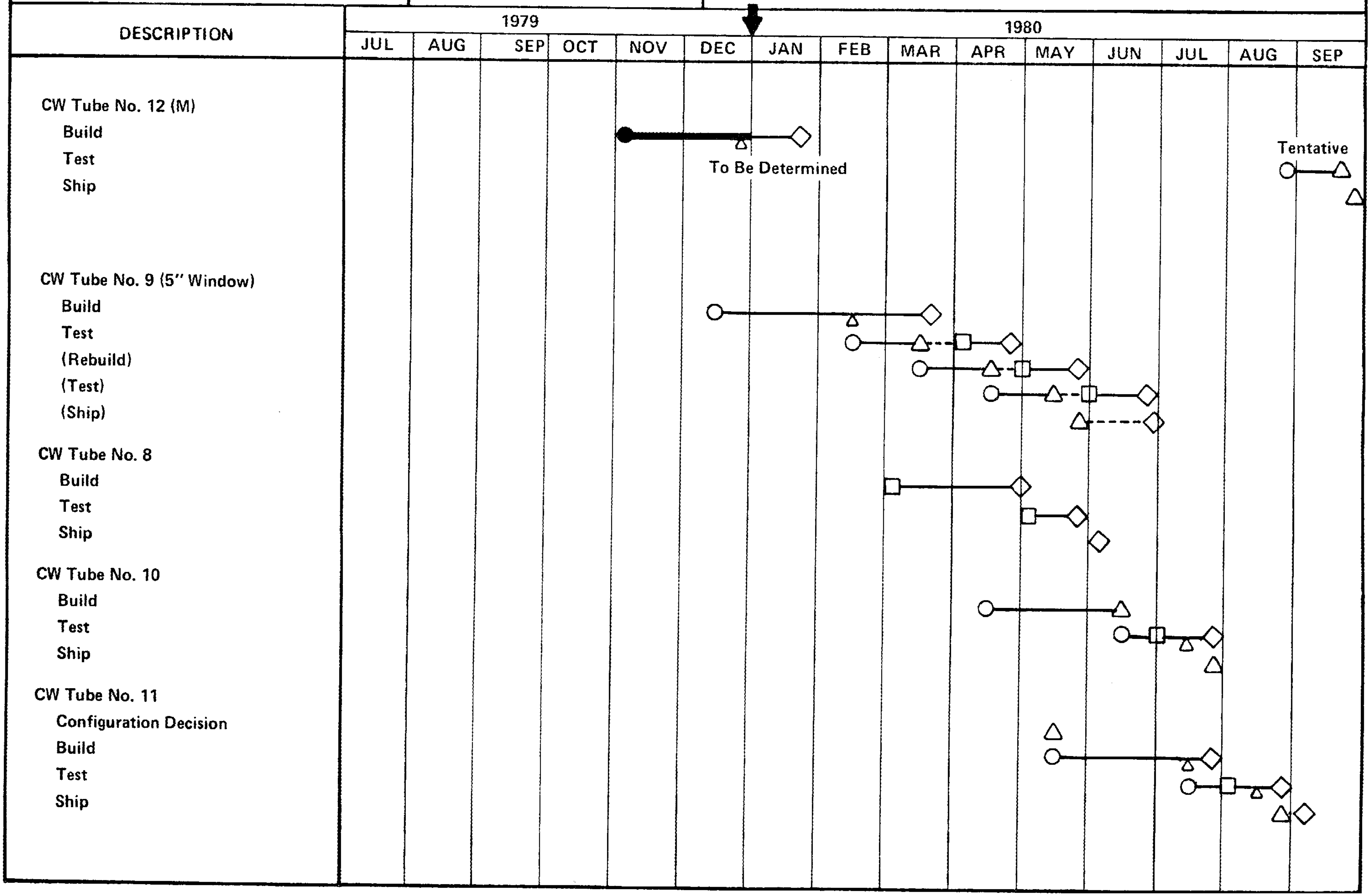
MILESTONE CHART AND STATUS REPORT

○ ORIGINAL START　□ REVISED START　△ MAJOR MILESTONE
▽ INTERMEDIATE OR DECISION POINT　◇ PROPOSED SCHEDULED DEVIATION FOR A MAJOR MILESTONE
⬇ STATUS REPORT TIME　— ACTIVITY SCHEDULED　▬ ACTIVITY COMPLETED

PROGRAM: 200 kW, CW, 28 GHz; DEVELOPMENT

JOB NO.:

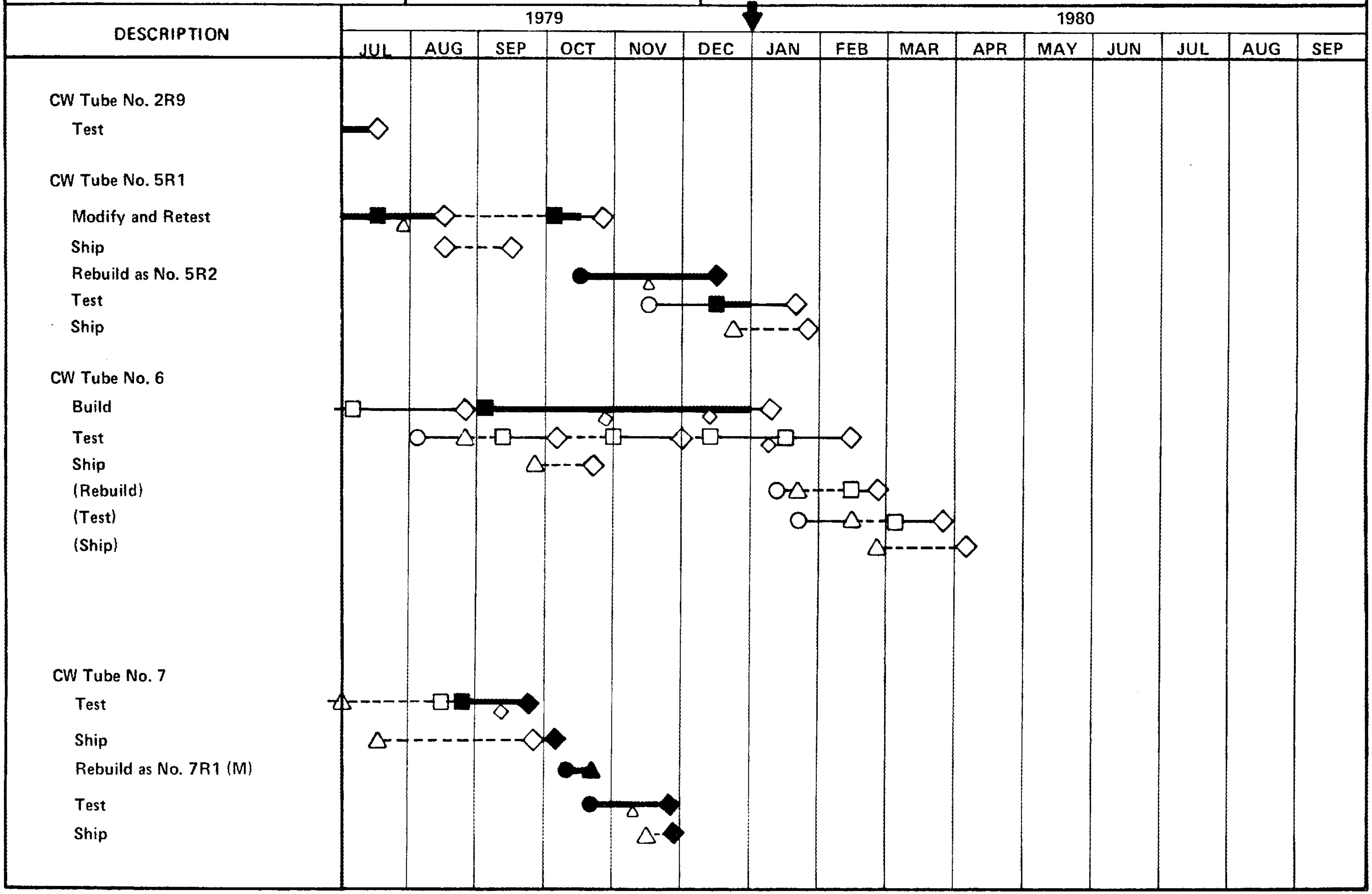
STATUS REPORT DATE: 31 December 1979



MILESTONE CHART AND STATUS REPORT

○ ORIGINAL START □ REVISED START △ MAJOR MILESTONE
▽ INTERMEDIATE OR DECISION POINT ◇ PROPOSED SCHEDULED DEVIATION FOR A MAJOR MILESTONE
STATUS REPORT TIME — ACTIVITY SCHEDULED ▬ ACTIVITY COMPLETED

PROGRAM	JOB NO.	STATUS REPORT DATE
200 kW, CW, 28 GHz; DEVELOPMENT		31 December 1979



REFERENCES

1. H.R. Jory, E.L. Lien, and R.S. Symons, "Final Report, Millimeter Wave Study Program" Oak Ridge National Library Order No. Y-12 11Y-49438V, November 1975.

2. V.A. Flyagin et al, "The Gyrotron", Trans MTT, vol 25 No. 6 pp 514 - 521, June 1977.

3. J.L. Hirshfield and V.L. Granatstein, "The Cyclotron Resonance Maser - An Historical Survey" ibid pp 522 - 527.

4. S. Hegji, et al, Quarterlyy Report No. 6, "Development Program for a 200 kW, CW, 28 GHz Gyroklystron," Union Carbide Contract No. 53X01617C, Varian Associates, Inc., pp 115-27, July through September 1977.

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