Mi

ESFK 20-100 WATT S-BAND AMPLIFIER
QUARTERLY REPORT No. 2

JPL CONTRACT No. 951105

JULY, 1967

"This work was performed for the Jet Propulsion Laboratory, California Institute of [illegible]
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DIVISION OF VARIAN
301 Industrial Way
San Carlos, California

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ERLING L. LIEN

ALBERT MIZUHARA

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by

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NOTICE

A B S T R A C T

A beam-analyzer chamber experiment is described in which beam diameter measurements were made on the rf bunched beam of the X-3064 number 3S klystron. This klystron, when placed in the chamber, was complete except for the output resonator and collector. A pin-hole target was used to measure the beam size by scanning across the beam in the region normally occupied by the output cavity. The results show conclusively that most of the beam interception occurs in the output resonator tunnel.

A description of the suppressor lens and collector entrance modification is also given. The design changes were based both on the beam analyzer trajectory measurements and the computer solutions to the field distribution in the suppressor lens. The analysis showed that a larger suppressor lens diameter and collector entrance are necessary.

A brief discussion of the fabrication of tube number 3SR is also included, with particular emphasis on the output resonator cold test data.

(REVIEW AND APPROVAL)

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INTRODUCTION

A 20 to 100 watt, S-band, electrostatically focused klystron having a radiation-cooled depressed collector for use in inter-planetary spaceborne communication systems is presently under development. Although two klystrons have been built in the past which satisfied the power output and bandwidth (30 MHz at the -3 db points) requirements, the highest efficiency achieved was 38 percent at the 100 watt level - lower than the 45 percent required by the specifications. The 30 MHz bandwidth was achieved through the use of eight extended-interaction resonators which were stagger-tuned. In order to achieve the required 45 percent efficiency level, the existing program was redirected with new milestones.

The first quarterly report described the initial major milestone of this 14 month efficiency improvement program: the development of a 5-resonator, narrow band klystron, fabricated primarily to investigate the various efficiency improvement schemes. Presented in graphical form were the operating characteristics of this klystron.

This second quarterly report details the second major milestone, the testing of the above klystron in the beam analyzer chamber and the subsequent redesign of this klystron.

I. BEAM-ANALYZER EXPERIMENT

A. DESCRIPTION

The experimental klystron, X-3064 number 3S, was tested in the beam-analyzer chamber with the output cavity and collector removed in order to investigate the beam as it emerged from the buncher region, i.e., in the region normally occupied by the output resonator. Without the output cavity, the klystron consisted of the gun, four buncher resonators and four lenses. All assemblies going into the chamber, including the klystron itself, were thoroughly scrubbed and degreased in order to minimize outgassing. In addition, all of the brass tuner knobs were replaced with copper knobs.

The chamber contained appropriate high voltage, feed-throughs for applying cathode and lens voltages. A separate rf coaxial window and a rigid, coaxial bead-supported line were used to apply rf drive power to the klystron. The beam voltage was pulsed at 300 pps and a pulse length of 20 microseconds (duty = 0.006). In order to duplicate the original conditions under which the klystron was tested, lenses numbers 1 and 2 were connected together and operated from a single dc supply. Lenses 3 and 4 were each connected to a separate dc supply.

The Faraday cage assembly containing the pin-hole target was movable in all three dimensions by means of hand cranks. In addition, an automatic scanning and recording system allowed the measurement of the beam cross-section along any given plane transverse to the axis of the tube.

Generally speaking, the beam analyzer showed that most of the beam interception occurs downstream from the buncher section in the output resonator tunnel. The more significant test results are given below for a cathode voltage of 3 kV.

CASE	OPTIMIZED CONDITION	LENS 4 VOLTAGE	RF DRIVE LEVEL	BEAM SIZE AT OUTPUT CAVITY UPSTREAM GAP	
				DIAMETER	FILLING FACTOR*
1	Maximum Power Output	-3.3 kV	0	0.170 inch	0.74
2	Maximum Power Output	-3.3 kV	Saturation	0.210 inch	0.91
3	Maximum Beam Transmission	-3.9 kV	0	0.136 inch	0.59
4	Maximum Beam Transmission	-3.9 kV	Saturation	0.160 inch	0.70

* Based on a tunnel diameter of 0.230 inch

In cases 1 and 2 above, the lens number 4 voltage was adjusted to -3.3 kV, a level at which the klystron produced maximum power output at the expense of reduced beam transmission. When driven to saturation, the beam diameter at the plane of the upstream gap was found to increase by 24 percent as compared to the unmodulated case, resulting in a filling factor of 0.91.

In cases 3 and 4 given in the table, the lens voltage was adjusted to -3.9 kV, a level which produced optimum beam transmission at the expense of output power. The beam diameter was measured to be 0.16 inch, resulting in a filling factor of 0.70.

Figure 1 below shows two sets of beam envelopes superimposed against the output cavity tunnel geometry used in tube number 3S (the last complete klystron built and tested). The Case 2(B) trajectory just grazes the supported drift tube tunnel. However, since the output resonator was not included in the beam-analyzer experiment, the rf radial velocity modulation produced by the upstream gap must be added to this beam trajectory to get a more realistic beam profile. The corrected beam is labeled (A) for this case in Figure 1. Now, the interception of the beam by the supported drift tube is definitely seen. Shown also on the same figure is the measured beam profile with lens number 4 adjusted for optimum beam transmission (Case 4). In the trajectory labeled (A), the rf radial velocity modulation from the upstream gap is taken into account. No interception occurs for this case.

It is now evident why there was only a minor improvement in beam transmission in this tube over that of tube 2a, even though the tunnel diameter was enlarged to create more clearance between the beam and tunnel. As shown in Figure 1, the more the tunnel diameter was increased, the more the beam was required to spread in order to maintain adequate coupling with the resonator circuit. If the beam is allowed to spread too much, however, it not only collides with the cavity nozzle, but also becomes larger than the collector entrance. Consequently, no improvement

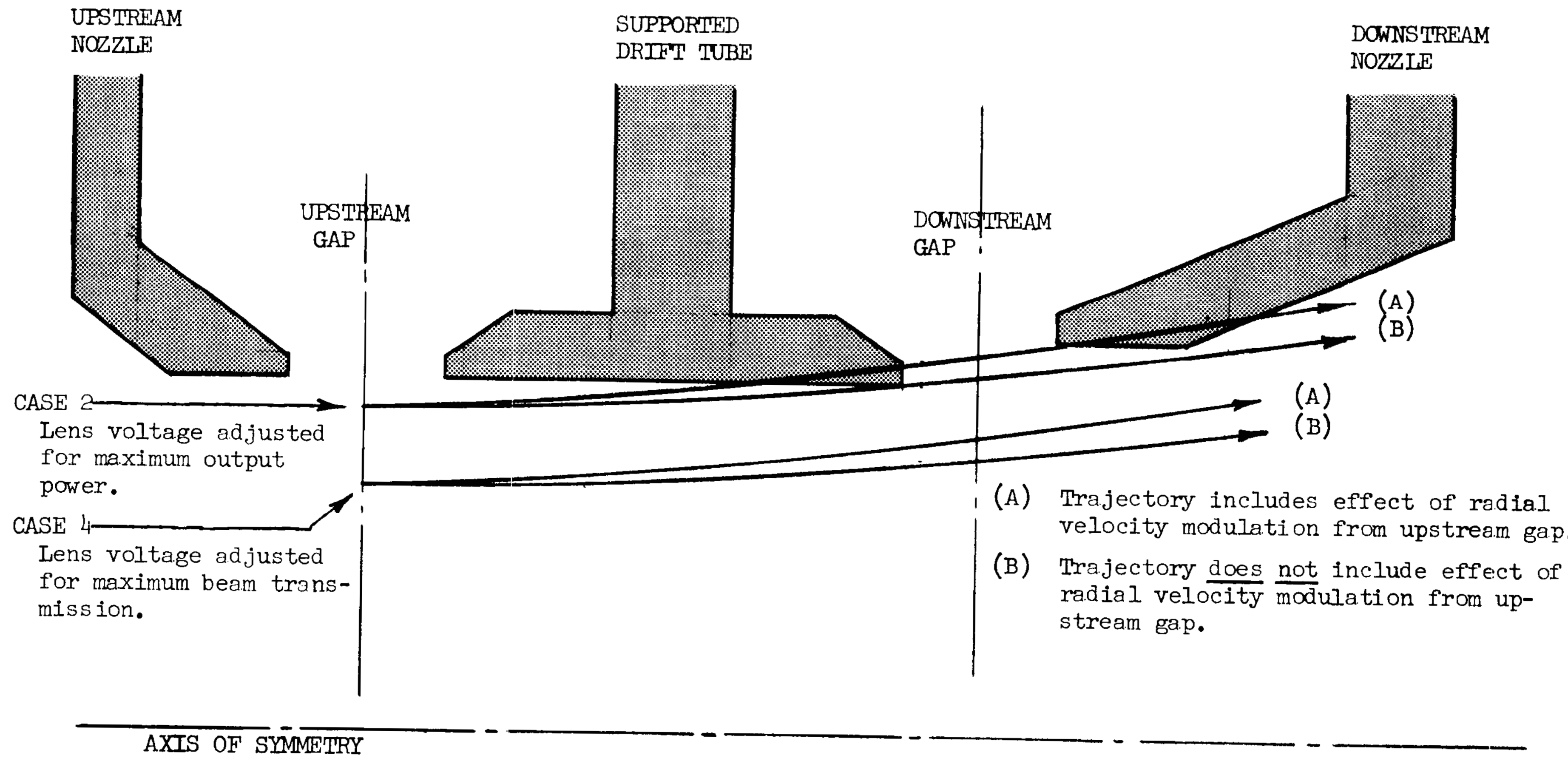

FIGURE 1 Beam envelope profiles from the X-3064 number 3S klystron. The upper trajectories clearly show beam interception beyond the upstream gap. The klystron was tested in the beam analyzer chamber with the output cavity and collector removed.

in beam transmission results and about the same output power is realized as before. In view of this finding, a smaller tunnel diameter is preferred.

The beam analyzer measurements have shown that optimum beam transmission occurs at a lens 4 voltage of -3.9 kv. (Increasing the voltage beyond this level reduces both the beam diameter and beam transmission. The latter occurs because some of the electrons are turned back within the buncher section due to the increasing potential depression generated by the lens). In order to obtain satisfactory beam coupling for this case, Case 4, it is necessary to make the cavity tunnel diameter smaller and to contour it so it will more closely follow the beam envelope. Figure 2 shows the beam trajectory superimposed against the outline of the new cavity tunnel. The old and new tunnel diameters are given below:

NOZZLE	(OLD) TUBE 3S	(NEW) TUBE 3SR
Upstream Nozzle Diameter	0.230 inch	0.180 inch
Supported Nozzle Diameter	0.230 inch	0.180 inch (Flared)
Downstream Nozzle Diameter	0.260 inch	0.230 inch

With the new nozzle geometry, both high beam transmission and efficiency should result -- the latter as a result of the increased R_{sh}/Q brought about by the smaller nozzles.

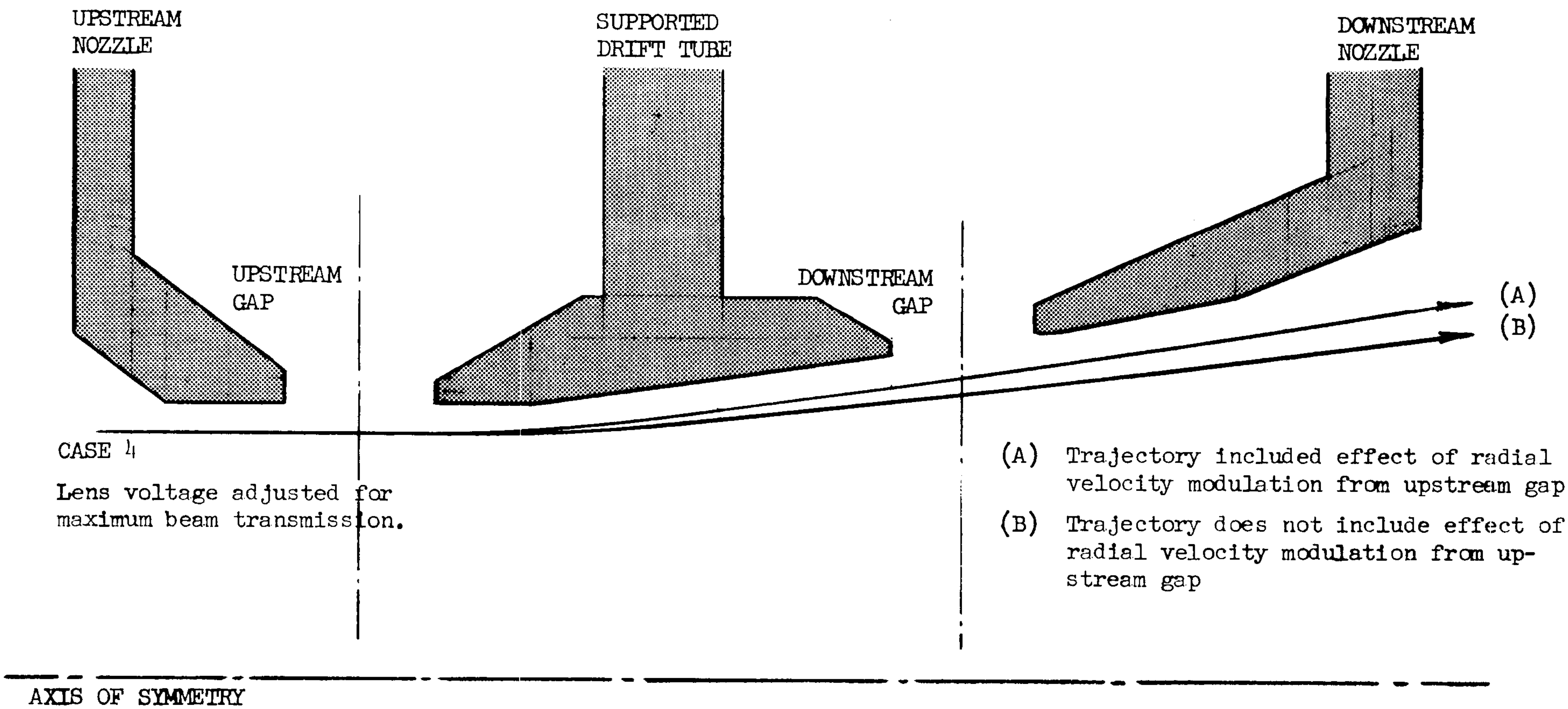

FIGURE 2 Beam envelope profile with lens voltage adjusted for maximum beam transmission superimposed against the new output cavity tunnel design. This tunnel geometry will be used in tube 3SR.

II. SUPPRESSOR LENS AND COLLECTOR

A. DESCRIPTION

The function of the suppressor lens, located between the output cavity and collector entrance, is to generate a static electric field containing an area of potential depression immediately in front of the collector entrance. The reason for doing this is to create an electron barrier -- i.e., to prevent the secondary, elastic and thermionic electrons, emanating from the collector, from reaching the output cavity. In addition, it also serves to drain away any ions generated in the area.

B. TEST RESULTS

The suppressor lens was designed to be operated at cathode potential. However, the test results from tube 3S showed that with the collector at -1.1 kV corresponding to a collector depression of 36.7 percent (cathode voltage = -3.0 kV), the optimum suppressor lens voltage was -1.5 kV. Increasing the lens voltage beyond this level resulted in an increase in body interception current and unstable operation due to the slower edge electrons being returned to the output cavity interaction region. Therefore, the suppressor lens could not be operated at cathode potential. The beam analyzer measurements made later on tube 3S showed that when the tube was adjusted to yield maximum efficiency, beam interception occured in the tunnel of the output cavity. In addition, the beam diameter at the collector entrance plane was found to be larger than the entrance diameter, resulting in interception at the collector entrance and consequently, generation of secondary electrons. The fact that the beam envelope was much larger than originally anticipated, meant that the edge of the beam was nearer the lens -- thus the edge electrons experienced a greater potential depression than expected. To compensate for this during operation, it was necessary to operate the lens at a reduced voltage. Going beyond this threshold voltage of -1.5 kV caused the beam edge electrons to be returned; whereas, going below this voltage totally eliminated the suppressor action of the lens.

Based on these recent findings, it became apparent that a modification of the suppressor lens and collector was necessary.

C. COMPUTER SOLUTION

A computer program which solves Laplace's equation was used to determine the electric field distribution contained within the boundary made up of the output cavity downstream nozzle, suppressor lens and a portion of the collector entrance cone. Figure 3 shows the solution for the first case investigation. The potential depression along the axis is given with respect to the collector. In this case, the boundary conditions were adjusted to simulate the original test conditions for tube number 3S, in which the suppressor lens was set at -1.5 kV. By inspecting the equipotentials, it is clear that under these conditions, no potential depression exists along the axis to suppress secondary electron emission. In all probability, an electron emanating from the collector will be accelerated toward the output cavity and cause the generation of spurious signals.

The figure also includes the beam envelope for reference purposes only since the calculation of the equipotentials was performed without taking the electron beam into account.

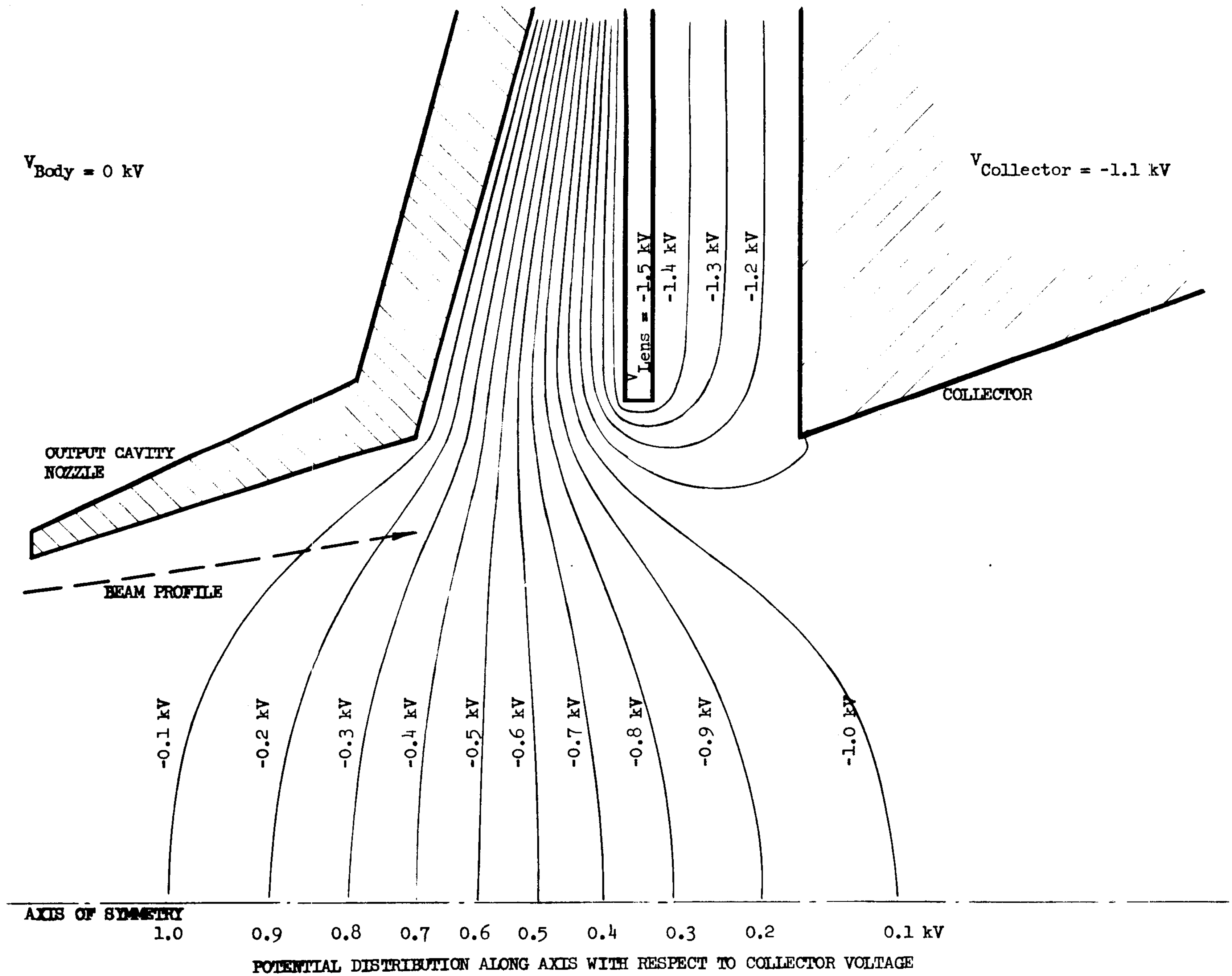

Figure 3 - Equipotential plot of the suppressor lens region for X-3064 No. 3S klystron. The collector is depressed 36.7 percent.

In the second run, Figure 4, the lens diameter was increased and set to cathode potential. The collector entrance diameter was also increased to allow capture of the total beam. The -1.2 kV equipotential line, with the collector potential at -1.1 kV, is also the -100 volt potential depression line with respect to the collector. It is seen to bulge in toward the collector entrance. The solution in this case is satisfactory and it was deemed more expedient to refine the final lens design by varying the lens potential in hot test and later transforming the desired -3 kV equipotential surface to its geometric equivalent.

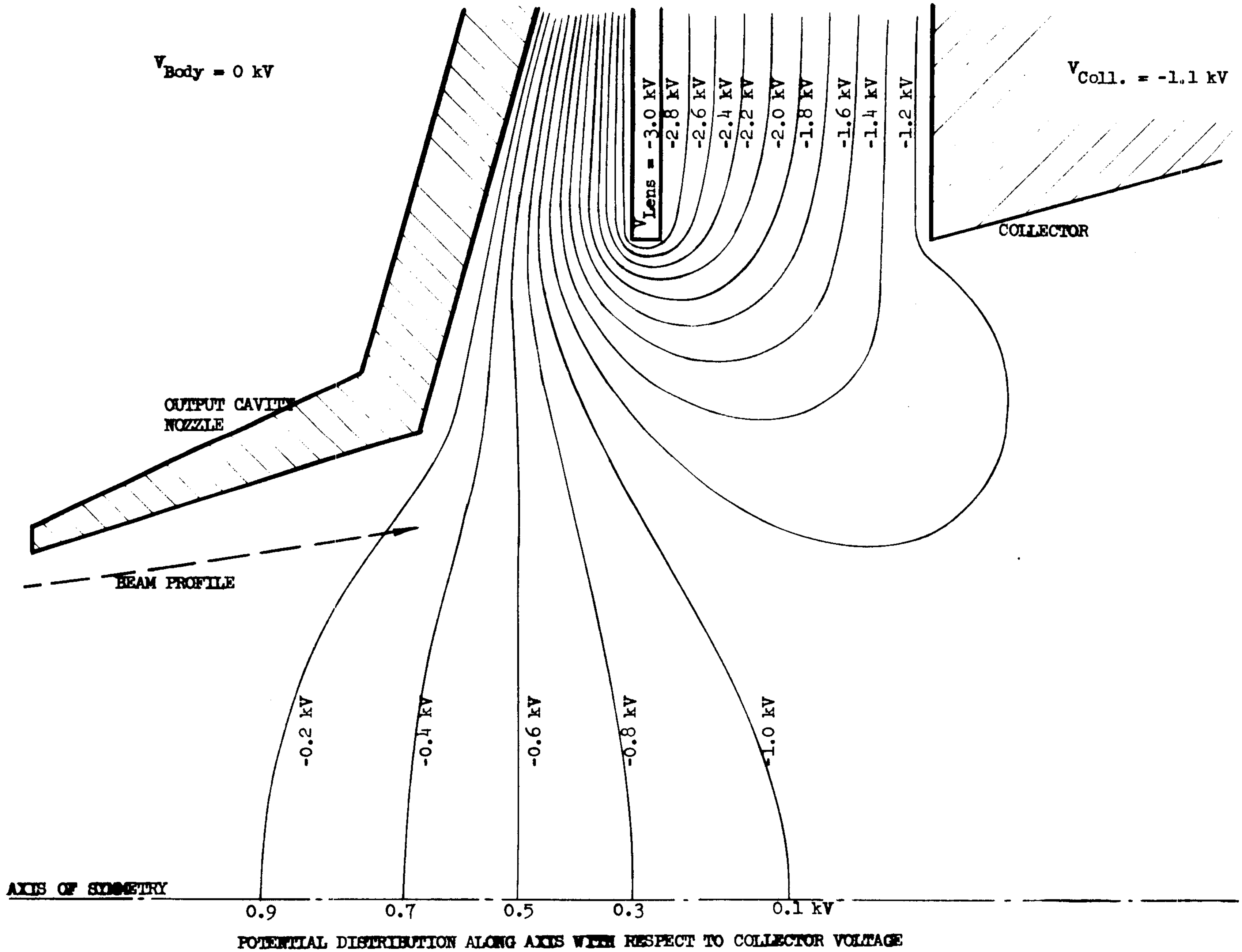

Figure 4 - Equipotential plot of the suppressor lens region for X-3064 No. 3SR klystron. The collector is depressed 36.7 percent. The lens diameter and collector entrance have been enlarged.

III. REBUILDING OF TUBE NO. 3S

A. SUPPRESSOR LENS AND COLLECTOR

The suppressor lens and collector salvaged from tube number 3S were redesigned for use in the next tube, designated tube number 3SR. The redesign was based on the computer solution discussed in the previous section.

The actual replacement of the suppressor lens in the collector assembly was straight-forward and consisted simply of removing the old lens and bolting on the new one. The collector was modified by machining-off the entrance half of the existing water-cooled collector and brazing on the new section with the larger diameter opening.

B. OUTPUT CAVITY

By changing only the resonator tunnel size, a very large increase in the shunt impedance was obtained. The resonant frequency was also increased quite significantly. The measured values are given below:

OUTPUT CAVITY TYPE	R_{sh}/Q	FREQUENCY
Tube 3S (Old)	230 ohms	2277 MHz
Tube 3SR (New)	330 ohms	2363 MHz

In order to compensate for the 86 MHz increase in frequency, it was necessary to increase the resonator inside diameter by 0.085 inch, or 1 mil per MHz. Because of the large change in inside diameter, it was necessary to design new dies to fabricate the molybdenum cavity shell. These dies are presently being fabricated.

IV. PROGRAM FOR NEXT PERIOD

The X3064 number 3S will be rebuilt with a new output cavity and a modified collector. It will be designated number 3SR and will be hot tested in the usual manner. After successful testing of this tube, it will be rebuilt into a "long" tube.