ESFK 20-100 WATT S-BAND AMPLIFIER

QUARTERLY REPORT NO. 3

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OCTOBER, 1967

JPL CONTRACT NO. 951105

"This work was performed for the Jet Propulsion Laboratory, California Institute of Technology, sponsored by the National Aeronautics and Space Administration under Contract NAS7-100."

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<u>ABSTRACT</u>

One of the tubes described in this report is a five-resonator electrostatically focused klystron designated tube No. 3SR. The modifications incorporated into this tube included an output resonator with a smaller tunnel diameter, an improved suppressor lens and a collector with an enlarged entrance diameter. These modifications were made to improve the overall efficiency.

Because the gun and buncher resonators in this tube had been used previously in two different experiments -- in the five resonator tube No. 3S and in the beam-analyzer chamber experiment -- by the time it had been modified for the third time and pumped as tube No. 3SR, a deposit having significant loss had formed on the inside surface of the body. This deposit caused a reduction in the buncher resonator Q values, a reduction in small-signal gain from 40 to 32 db and thermal fading of the output power. Rather than to rework this tube, it was decided to rebuild the output resonator, suppressor lens and collector into the next tube in the series, tube No. 3L, an eight-resonator broadband klystron. This decision was based on previous experience with both narrow band (5 resonator) and broadband (8 resonator) klystrons. A comparison of data between these two tubes showed that the increase in beam degradation which results when the beam traverses a larger number of lenses (as in the eight-resonator tube), does not significantly affect the overall efficiency. Also, information on both efficiency and bandwidth can be obtained from an eight-resonator tube; whereas, only efficiency data can be obtained from a five-resonator tube.

The development of a brazed helical resonator for use in tube No. 3L is discussed. In this assembly, consisting of a single beryllia rod and two quartz rods, the helix is brazed to the beryllia rod which in turn is brazed to the resonator shell. The quartz rods remain unbrazed.

Also described is the result from an investigation into the use of boron nitride as helix support rods.

(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 interplanetary 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 five-resonator, narrow band klystron, fabricated primarily to investigate the various efficiency improvement schemes. Presented in graphical form were the operating characteristics of this klystron.

The second quarterly report detailed the second major milestone, the testing of the buncher section of the short klystron, tube No. 3S, in the beam-analyzer chamber. The redesign of the output resonator, suppressor lens and collector for tube No. 3SR was also described in detail.

This third quarterly report describes the test results for tube No. 3SR. It also covers the development and fabrication of the next klystron, tube No. 3L.

I. TUBE NO. 3SR (5 Resonator ESFK)

A. Description

Tube No. 3SR is tube No. 3S repumped with several design modifications. These modifications were based on data obtained from tube No. 3S and from operation of the tube in the beam-analyzer chamber (without the output resonator).

The collector and secondary electron suppressor lens (located between the collector and output resonator) from tube No. 3S were both modified before they were used in tube No. 3SR. The modification consisted of enlarging the suppressor lens diameter and collector entrance diameter. Also, a major change in output resonator design was made by reducing the tunnel diameter. Since the output resonator from tube No. 3S could not be modified, it was replaced with a completely new assembly having a smaller tunnel diameter. The purpose of the change was to more closely match the resonator tunnel geometry to the beam profile for a well focused beam. The rest of tube No. 3S, consisting of the electron gun and four buncher resonators, remained unchanged and were used in tube No. 3SR.

The design and development of the above subassemblies were described in detail in the previous quarterly reports.

B. Lens Ceramic DC Resistance

Because this tube had been pumped and tested once before (as tube No. 3S), followed by extensive testing in the beam-analyzer chamber, the internal surfaces of the klystron had become coated with a layer of evaporated material. This coating was first noticed as a leakage resistance across the lens feed ceramics just prior to pinch-off from the exhaust station. By applying short bursts of high voltage across the lens-feed ceramics, the leakage resistance was removed satisfactorily.

C. Buncher Resonator Q Value

The same coating which appeared across the lens-feed ceramics also deposited on the helical resonators. However, the coating could not be removed from the resonators and was responsible for a large reduction in the buncher resonator Q values. The table below compares the Q values measured when the tube was first assembled as tube No. 3S to the values measured as tube No. 3SR several months later. In the latter case, the Q values were measured in hot test under small-signal conditions using a swept input drive signal while observing the resonance curve of each cavity on an oscilloscope.

Buncher Resonator	Q_o Tube No. 3S (Before)	Q_o Tube No. 3SR (After)
1	173	128
2	460	153
3	314	168
4	373	121

D. Hot Test Results

Because of the low Q values in tube No. 3SR, the measured small-signal gain was only about 32 db, in contrast to over 40 db for tube No. 3S. The calculated small-signal gain for tube No. 3SR using the reduced Q values was 31 db, confirming the measured gain of 32 db.

Far more objectionable to the operation of tube No. 3SR than the low gain was the thermal fading of the output power. At a cathode voltage of 3 kV, the thermal fading was noticed starting at a power output of about 15 watts. The fading continued to increase with increasing drive levels and was accompanied by a substantial increase in pressure. The thermal fading was caused mostly by the frequency drift of the penultimate resonator. The frequency change was always downward toward the band center -- a direction which increased the absolute rf dissipation -- contributing further to the drift.

The fading, in all probability, was made worse by the use of a bare molybdenum helix instead of a copper plated helix in each of the buncher resonators. The copper plating used in earlier resonators served to cushion the contacting surfaces between the helix and beryllia support rod, thus forming a more intimate contact. Of secondary importance was the fact that the copper increased the Q, and thereby reduced the resonator dissipation loss. The reason for discontinuing the copper plating was over the concern that the beam might be accidentally defocused long enough to vaporize the copper off of a section of helix. As such an accident had happened once before when a lens power supply failed during test, there was strong reason for such a decision. It is evident that, without the copper plating on the helix, the margin of safety in terms of helix dissipation has been reduced.

At this point in time, no further meaningful data could be obtained from this tube under these circumstances. Yet, the modified output resonator, suppressor lens and collector still remained unproven. One possible solution was to simply rebuild tube No. 3SR by replacing the low Q buncher resonators with four new buncher resonators. However, previous experience with tube No. 2A (8 resonators) and tube No. 3S (5 resonators) have shown that increasing the length of the tube from five to eight resonators will allow broadband operation with no sacrifice in efficiency. Therefore, it was clearly more advantageous to rebuild the klystron as an eight-resonator broadband tube rather than a narrow band tube.

II. TUBE NO. 3L (8 Resonator ESFK

A. Description

This tube is an eight-resonator klystron which incorporates several improvements over the previous models. One of these improvements is in the helical resonator assemblies. The helical resonators built in the past consisted of a molybdenum tape helix supported by two quartz and one beryllia support rods mechanically clamped within a molybdenum cylinder. This scheme did not always yield reproducible results because of the variation in contact pressure and contact area between the helix, support rods and shell. From the thermal dissipation point of view, a poor contact between helix and beryllia rod could result in a runaway effect manifesting itself as power fading. Both boron nitride and beryllia were investigated as possible support rods for a brazed helix assembly.

B. Isotropic Boron Nitride Support Rods (Unmetallized)

To improve the power handling capability of the helical resonator, various types of brazed helical structures were studied. Initially, isotropic BN (boron nitride) was considered because of its excellent rf and thermal properties. As an example, its relative dielectric constant is only about 3.2 as compared to 6 for beryllia. Its coefficient of thermal conductivity is equal to that of beryllia. However, BN was found to be very difficult to process properly, since the slightest amount of moisture (in BN) would cause discoloration after hydrogren firing.

Enough sample BN material was obtained to fabricate an experimental helical resonator. The test resonator was made first with two BN rods and one quartz rod. Later on, the quartz rod was replaced with a third BN rod. The assembly was not brazed but mechanically clamped in the normal manner. The cold test data are tabulated below. For comparison, data from a typical helical resonator is also included.

	2 BN 1 Quartz	3 BN	1 Beryllia 2 Quartz
f_o	2458 MHz	2491 MHz	2315 MHz
Q_o	370 ± 10%	410 ± 10%	330 ± 10%
R/Q	225 ± 7%	215 ± 7%	210 ± 7%

Bare molybdenum helices of approximately equal lengths were used in the above assemblies. The cold test results showed that it was possible to replace the beryllia and quartz rods with three BN rods without degradation in R/Q or Q value.

Despite its very favorable properties, it became evident that to substitute BN in place of beryllia and quartz in the present resonators would require a development effort to solve such basic problems as processing, metallizing, brazing, long-term vacuum (outgassing) stability and mechanical stability. To solve even a part of these problems could take several weeks to months. In view of these unknowns, it was deemed more prudent to continue with beryllia since a satisfactory metallizing technique has already been established for this material within the company.

The fact that beryllia was selected over BN should in no way be misconstrued to mean that the latter is less favorable. Quite the contrary is true. Based on our preliminary investigation, BN was found to have properties which make it unique and in most respects superior to any dielectric material presently in use as a helix support. Unfortunately, the application of BN in tubes is so new that little or no data is available regarding the long term behavior in vacuum. In choosing beryllia, therefore, the decision was simply based on the best material which offered the highest probability of success.

C. Metallized Beryllia Support Rods

In order to incorporate brazed beryllia support rods in tube No. 3L, the existing beryllia rods were painted lengthwise with two strips of metallizing 180 degrees apart. One strip was interrupted periodically with grooves to remove the metallizing from the areas corresponding to the spaces between turns, and also to decrease the dielectric loading. The other strip was left continuous to braze to the resonator shell. The helix in a typical assembly was supported by one brazed beryllia rod and two unbrazed quartz rods.

Despite the undercutting between turns, the dielectric loading did increase. A comparison between the brazed and unbrazed versions are given below. The same helix length was used in both structures.

	Brazed	Unbrazed
Frequency	2245 MHz	2315 MHz
Q_o	350 $\pm$ 10%	330 $\pm$ 10%
R/Q	170 ohms $\pm$ 7%	210 ohms $\pm$ 7%

The 70 MHz decrease in frequency was compensated for later by adjusting the helix length.

D. Buncher Resonators

Because the rf power dissipation of the first four resonators is relatively low, these resonators will be assembled in the conventional manner; i.e., the helix will be mechanically clamped. Resonators Nos. 5, 6 and 7 will be fabricated with brazed helices.

In the pre-prototype model (the next tube after No. 3L), present plans call for all helical resonators to be of the brazed version. In this way, a far more rugged resonator package will be realized.

E. Lens No. 7 Modification

Lens No. 7, located between the penultimate and output resonators was modified to correct its operating voltage from a high of -4000 volts to about -3400 volts. This correction, which required a 13 percent reduction in the inside diameter of the lens, was based on an early lens study. Since separate lens power supplies will be used for this tube, the lens was not completely corrected to operate at cathode voltage. Instead, it was left with a margin of about -400 volts, with respect to the cathode voltage, in order to prevent operation of the lens with a positive potential and consequent electron interception. This is a precaution taken only for experimental tubes. In the final tube, of course, the lenses will all be scaled to operate at cathode potential.

F. Output Resonator

The same output resonator as that used previously in tube No. 3SR will be used in this tube. This resonator, as discussed earlier in this report, has a smaller tunnel. Since this resonator was not successfully evaluated in tube No. 3SR, its advantage over the larger tunnel resonator remains to be experimentally confirmed.

G. Suppressor Lens and Collector

The same suppressor lens and collector combination as that used previously in tube No. 3SR will be used in this tube. As with the output resonator, no concrete test results are available regarding this latest version with the redesigned lens and enlarged collector entrance diameter. Therefore, the lens and collector assemblies will be used in tube No. 3L with no alterations.

III. CONCLUSIONS

Low gain and thermal fading due to a coating of evaporated material inside the tube prevented normal testing of tube No. 3SR. Frequency drift of the pentultimate resonator showed the need for a helix package which has improved heat dissipation and mechanical rigidity. The omission of copper plating from the helix has decreased the helix thermal dissipation.

A brazed version of the helical resonator consisting of one brazed beryllia support rod and two unbrazed quartz support rods, yielded a (R_{sh}/Q) of 170 ohms in contrast to 210 ohms for the mechanically clamped version. However, the brazed version offers greater mechanical and thermal stability.

Boron nitride was investigated as a substitute for the beryllia and quartz rods, but the effort necessary to develop a suitable BN supported helix assembly was judged to be beyond the present scope of this program.

The redesigned lens No. 7 (tube No. 3L) is expected to operate closer to cathode potential than the previous lens (tube No. 3S) which operated at -4 kV.

IV. PROGRAM FOR THE NEXT PERIOD

The program for the next period involves the completion and testing of the eight resonator tube, No. 3L. The brazed helix structure and reduced tunnel output cavity will be thoroughly evaluated in this tube. In addition, the effectiveness of the suppressor lens when used in conjunction with a depressed collector will be studied.

With the contractor's approval to start the next task, the design and fabrication of the pre-prototype tube will begin. This tube will incorporate a radiation-cooled collector and will be very close to the final version of the 100 watt ESFK.