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Technical Report No. 1

DEVELOPMENT OF TRAVELING-WAVE TUBE AMPLIFIER FOR SPACE COMMUNICATION SATELLITES

Contract No. DA 36-039 SC-87480
U. S. Army Signal Research and
Development Laboratory

File No. W-J 61C-442R3

Covering the period
1 July to 30 September 1961

By

Lester A. Roberts

"The work under this contract was accomplished under the management, direction and guidance of the U. S. Army Advent Management Agency and under the technical direction of the U. S. Army Signal Research and Development Laboratory."

Watkins-Johnson Company
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Palo Alto, California

ABSTRACT

This report covers the work accomplished during the first quarter on a 35 watt, long-life, reliable traveling-wave tube amplifier for use in space communications satellites. Work accomplished on the mechanical details of the circuit, the matching sections, collector, and electron gun are described.

Construction details of the first beam testing structure are given.

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PART I

1.0 PURPOSE

This program is a three-year research, development, construction, and life-testing program for a long-life, reliable traveling-wave amplifier for use in space communications satellites.

2.0 GENERAL FACTUAL DATA

2.1 Related Project

Much of the work reported in this and subsequent technical reports is the result of effort expended on similar tube type contracts; 1) sponsored by the Navy, which was started in January, and 2) sponsored by the Air Force, which was commenced in July. Therefore, in an effort to obtain an efficient development program, all three programs are simultaneously coordinated, with a free exchange of engineers and technicians between the various projects. In this way, each project is able to benefit from the results of the other programs.

2.2 Program Organization

The first month of this program was spent in detailing the program organization for this contract. It is clearly evident that this organization is necessary for a program of this magnitude. The project performance and schedule is included in the back of this report.

2.3 Clean Facilities

A number of vendors for clean assembly booths have been contacted. We are still awaiting samples of various units for evaluation. These units should arrive very shortly.

3.0 DETAIL FACTUAL DATA

3.1 Electrical Design

3.1.1 General

The electrical design of the tube as set down in our proposal has been checked and no changes have been made. Although the beam voltage and beam power may be slightly higher than are required, no changes have been made, since the results of the first completed tube will answer a great many questions such as efficiency, gain, power output, and the various problem areas. The results of this first tube will then provide the first stepping-stone toward the programis objective.

3.1.2 Helix

Phase measurements on a 50 mil ID, 50 TPI, and 10 x 5 mil tape helix glazed to 3 beryllia wedge supports have been taken and are shown in Fig. 1. Also shown on the figure, is the dispersion curve of the same helix supported by friction in 3 unglazed alumina wedges. Above this last curve is the expected data of the helix when brazed to 3 beryllia wedges. Constructional details of the helix assembly is discussed later in this report.

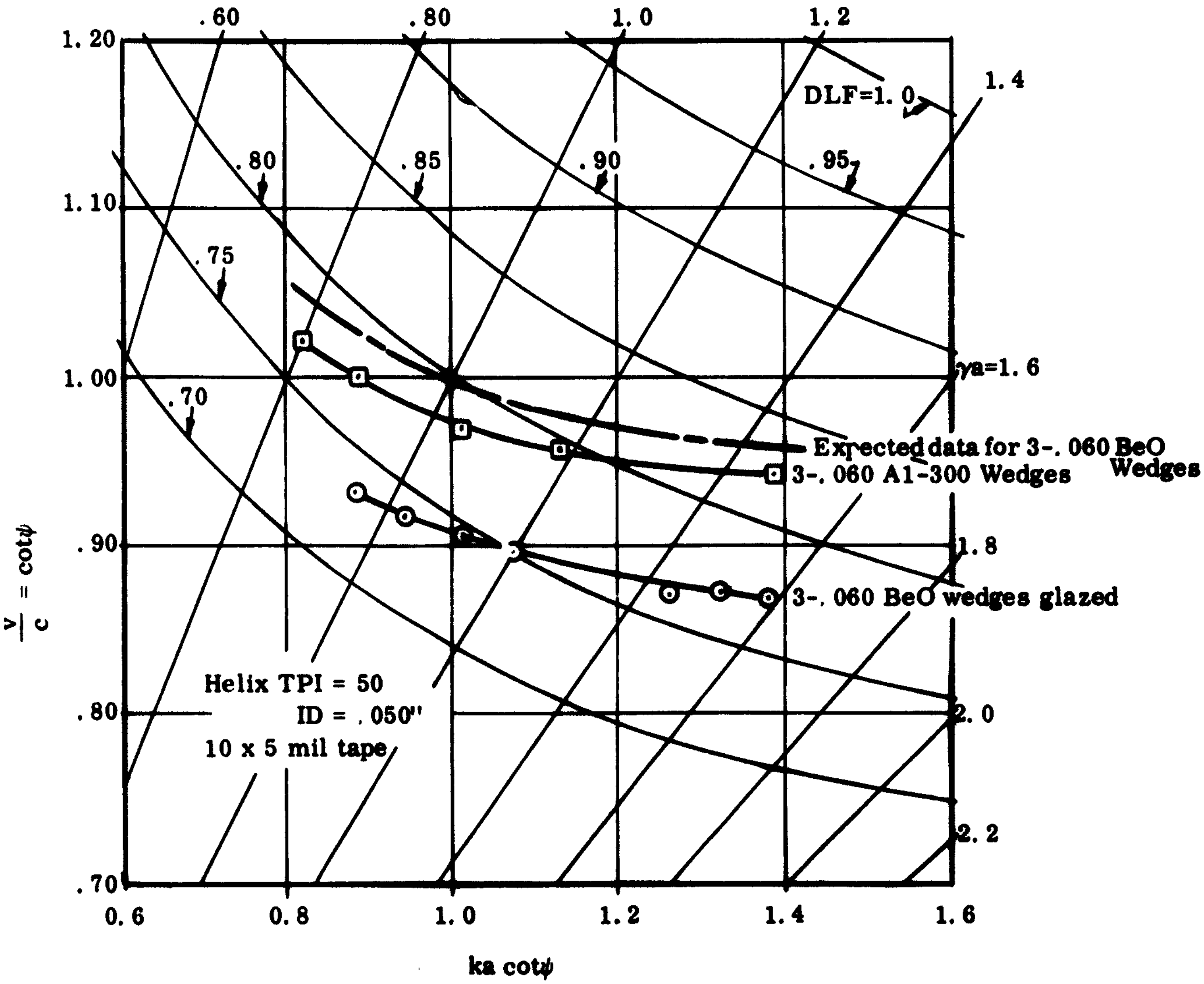

Fig. 1 - Dispersion curves of a 50 TPI, 50 mil ID, 10 x 5 mil tape helix supported in various manners. The lower curve shows the results when the helix is glazed to three BeO wedges and the middle curve is when the helix is held by friction by three alumina wedges. The top curve represents the expected dispersion curve if the helix is brazed to three BeO wedges.

3.1.3 Couplers

Much effort was expended in the design of a suitable coupler. Three courses were initially investigated and are: (1) waveguide coupler using an antenna to exchange energy between the waveguide and helix, with a cylindrical ceramic window concentric with the beam and helix; (2) the same type of coupler as the first method but with the window in the waveguide; and (3) coaxial line match with a direct pin connection to the helix with the window in the coax.

The third method of approach has been partially investigated and offers a simpler electrical design but does require a more difficult mechanical design problem, which has not been solved. The other disadvantage of this match is that coax to waveguide adapters will have to be used thus further complicating the design and adding to the total VSWR. The advantage of this type of match allows the helix to run at a different potential than the outside body. This potential difference will allow operation of the anode above helix potential to provide an ion barrier for the cathode. In the first two methods, the antenna must be securely fastened to the body thus requiring the helix and body to operate at the same voltage. This means that with the first two methods, a modulating anode is mandatory. As described in the gun section, it appears that there is a gun design which will allow the anode to be separated from the pole piece. Therefore, the antenna match is currently being pursued with the first method receiving the highest priority.

The initial antenna match used silver paint to establish electrical contact between the various cold test components. It was discovered that the silver paint was very lossy at the operating frequency hence all parts were remade and were brazed or soldered together. The ceramic window is of the high alumina type with a wall thickness of .020 inches and its fragility will in no way weaken the entire tube design. This is because the window will be encased by the waveguide thus providing strength and support.

The coupler program was slightly delayed by the lack of helix structures, the reasons for this are given in a later section of this report. Commencing at the beginning of the next quarter, sufficient helix assemblies will be available so that the coupler design should progress satisfactorily.

3.1.4 Attenuators

The initial tube is planned with attenuators made by spraying aquadag onto the helix and beryllia wedges. The fixtures for mounting the helix assembly in the spray facilities have been made and also provisions are taken to have a monitor rod in which continuous ohmic readings of the carbon deposition will be made. The necessary electronic equipment for the measurements have been assembled and are currently being checked.

As mentioned in the coupler section, preliminary work was done on the coaxial match. The results of that work is being used in the attenuator program during the phase that the loss is measured. The method here is that the center conductor of the coax will extend into a semi-circular trough. Into this trough the helix with the loss is placed and the measurements will be made. This technique has not been experimentally verified but the results are expected in the very near future.

3.1.5 Collector

The first two-stage collector design has been completed. An assembly drawing of this collector is shown in Fig. 2. All parts and tooling for this collector have been made and are awaiting technician time for assembly to a beam tester.

3.1.6 Electron Gun

An electron gun tester was built with multi-electrodes to act as the focus electrode and tested in the electron beam analyzer. Separate leads were attached to the various electrodes so that the potential in the cathode to anode region could be varied. While the potentials are varied, the beam profile is examined in terms of beam size, profile, and laminarity. The variables in this type of gun design are the cathode convergence angle and the anode configuration. Three different cathode convergence angles of 50°, 45°, and 40° have been tried. The beam convergence varied from 200 to 120. In the 40° cathode, the perveance was 1.1 and for a 30 mil beam, the beam minimum occurred at 0.175 inch away from the anode side that faces the cathode. With this beam minimum position, it will be possible to insulate the anode from the magnet pole-piece. This gun will be tried in a dc beam tester for beam transmission.

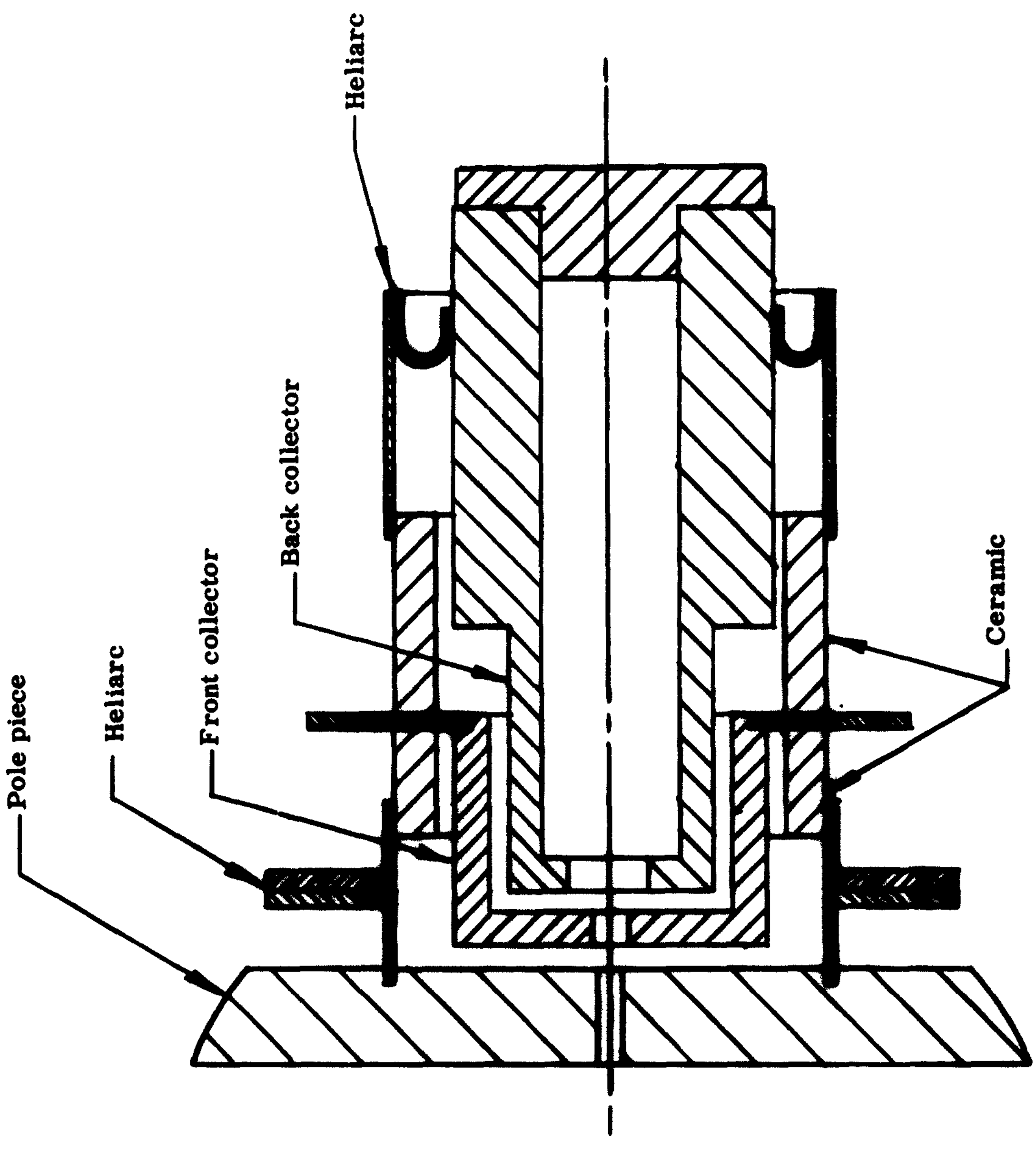

Fig. 2 - Assembly drawing of the first, two-stage, depressed collector design. All parts for this design have been made and are awaiting assembly.

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Before the gun can be made, an enlarged version of the multi-electrode gun is placed in a tank. Identical voltages as those used in the gun test are then placed on the various electrodes and the potential along the beam boundary is plotted. The multi-electrodes are then replaced by a suitable focus electrode geometry that will produce the same potential along the beam boundary. A second gun with this new single focus-electrode is constructed and tested to see if the same beam is produced.

Concurrently with the new beam tester work, another cathode with a convergence angle of 38° will be tried in an effort to get a slightly lower area convergence.

3.1.7 Magnet

As calculated, the expected magnetic field for beam focusing should be about 1400 gauss. A number of magnet companies have been contacted in respect to obtaining a bowl type design with a gap spacing of about 2.5 inches. We have not received any responses to our request for quotations. These requests are being followed through and expedited by our Purchasing Department. If quotations are not received in a reasonable time, we will request help from the Advent agency in this matter. It is imperative that we get our first order out and find out what problems will be involved.

3.2. Mechanical Design

3.2.1 General

The design for the first series of tubes is complete and a majority of component subassemblies have been successfully brazed. These tubes will utilize the gun used on the Navy program and has a perveance of 1.1 with an area convergence of 60. The collector for these initial tubes are the single stage type. A Philips cathode will be used. The first tube will be a beam tester and provide us with information on the difficulty of focusing the beam. More time than had been anticipated was required to solve two of the problems associated with the circuit. One beam testing tube was completed, it contained all the elements of an operating tube with the exception of the helix structure and waveguides. This beam tester is in the process of rework because the drift tube became dislodged from the tube.

3.2.2 Helix Assembly

Helices are being attached to the BeO support wedges through the use of a high melting point glaze. Unlike the round rod supports, the wedges require orientation with respect to the axis of the helix. The centerline of the wedge cross-section must be aligned so that its extension will pass through the axis of the helix. If this is not done, the constraining forces exerted by the copper body on the wedges will have a tangential component which will cause the wedge to rotate thus breaking the glaze and destroying the structure.

The design of the holding fixture required to maintain this critical alignment while heating the jig, support wedges, and helix to over 1000°C required more time than had been anticipated. Several steps were required to evolve a completely suitable design. Each of these steps required form grinding in molybdenum to very close tolerances, thereby making the time to design, build, and evaluate each design long. Parallel effort could not be used fruitfully so delay in the program was experienced.

The final system which was developed produces very good structures with a minimum of operator skill required. A picture of one of the helix-wedge subassemblies is shown in Fig. 3. Figure 4 gives another view of the wedge-helix assembly after being inserted into a copper barrel. This copper jacket did not have formed grooves. The picture illustrates the support technique used and gives a view of the wedge cross-section.

At the same time the glazing problem was being solved, tooling to produce the copper tubing used to constrain the helix-wedge system was being developed. The copper tubing required .030" radius grooves approximately .007" deep, spaced 120° apart to provide a matching surface for the side of the BeO wedge opposite the helix. Since this intersection must transmit heat, more than a line contact was desired, and the above requirement for the inside of the copper body was established.

A variety of machining operations were tried, but none of them were capable of providing the desired surface finish and tolerances. The first suitable bodies were made by electroforming copper over mandrels made by extruding aluminum through dies of the proper cross-section. In August delivery was made on the broaches which provided the most satisfactory and economical solution to the problem.

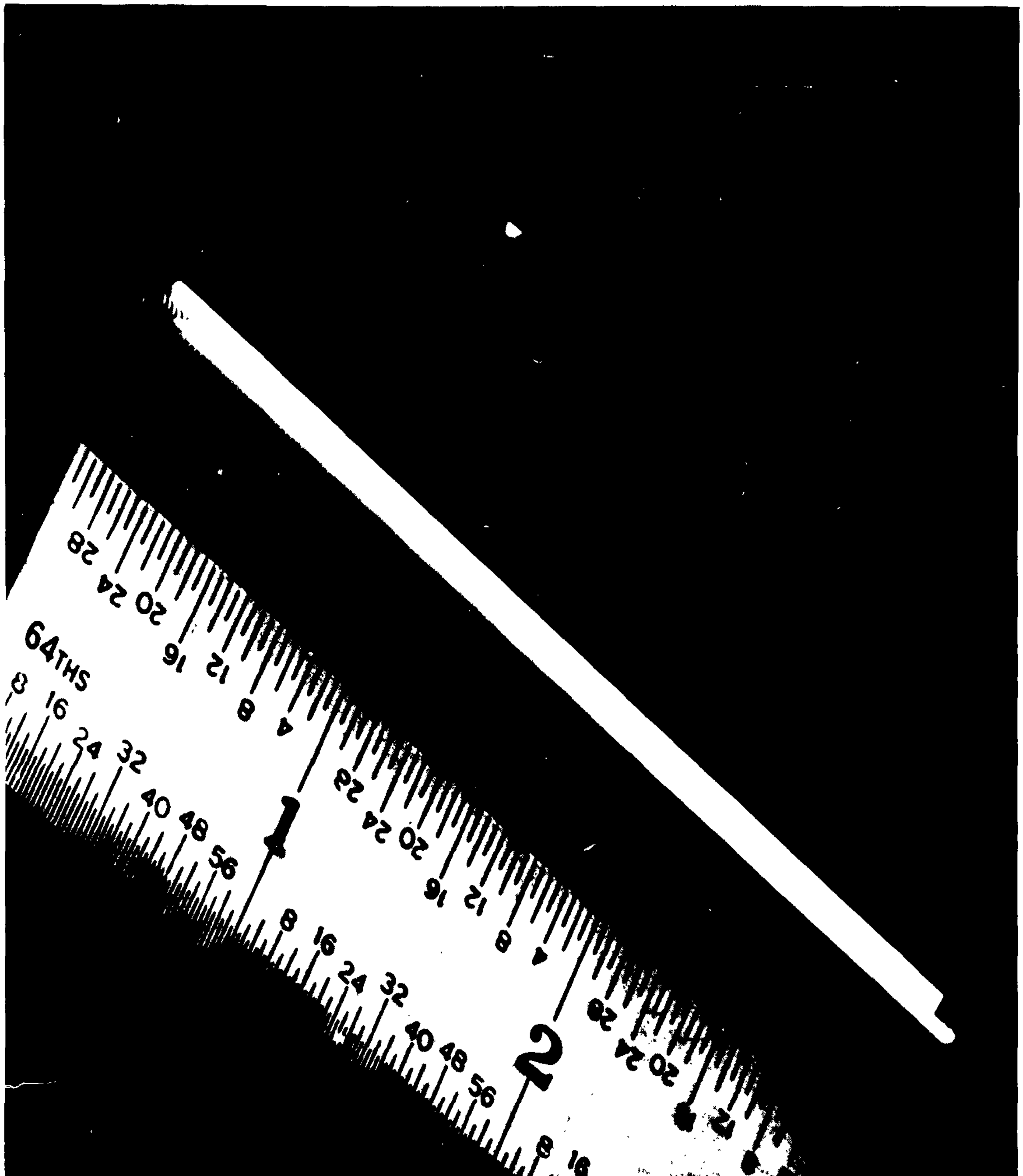

Fig. 3 - A 50 TPI tape helix with an 0.050 inch inside diameter supported by BeO wedges. The tape helix is 10 x 5 mil molybdenum and the BeO wedges are made from 60 mil diameter rods.

Fig 4 - Helix and BeO wedge assembly inserted into a copper barrel. As shown, the copper is tangent to the wedges, in final form the contact will be over the entire outer arc of the wedge.

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With the helix-wedge subassembly and properly shaped barrels available both electrical cold test and heat flow tests could be supported with suitable parts.

An evaluatory rf circuit subassembly is shown in Fig. 5. Each of the ceramic windows shown will be exposed to a gap in a waveguide to provide coupling to the helix

The picture also shows the soft copper sleeves which will be brazed into the pole pieces Through these sleeves may be seen the tunnel through which the electron beam must be focused. As shown the opening is larger than the helix inside diameter to allow sufficient clearance to allow the sleeve to be bent slightly in aligning the helix to the beam during operation without causing interception on the flexible section

3.2.3 Beam Tester

One beam tester was built late in the quarter. A picture of the beam tester is shown in Fig. 6 The copper barrel which replaces the helix has a .050" diameter hole through it to simulate the helix in-so-far as beam behavior is concerned The large central barrel contains the copper barrel and is used for alignment. The gap at the end of the barrel is bridged only by the thin copper sleeve shown in Fig. 5. Three rods bridged between the pole pieces form a cage about the simulated rf structure. In each end of the three rods adjusting screws may be seen. These will be used to move the axis of the helix to align with the beam axis by minimizing the helix current

The pin seal on the large barrel allows the simulated helix to be electrically connected to allow helix current to be measured The rf windows provide the dc isolation required since they are not bridged by an antenna as they will be in a final version of the tube.

3.2.4 Heat Flow Tests

Direct measurement of the temperature rise of the helix when supported by the BeO wedges in the copper barrel was desired Two experiments were run to develop this data.

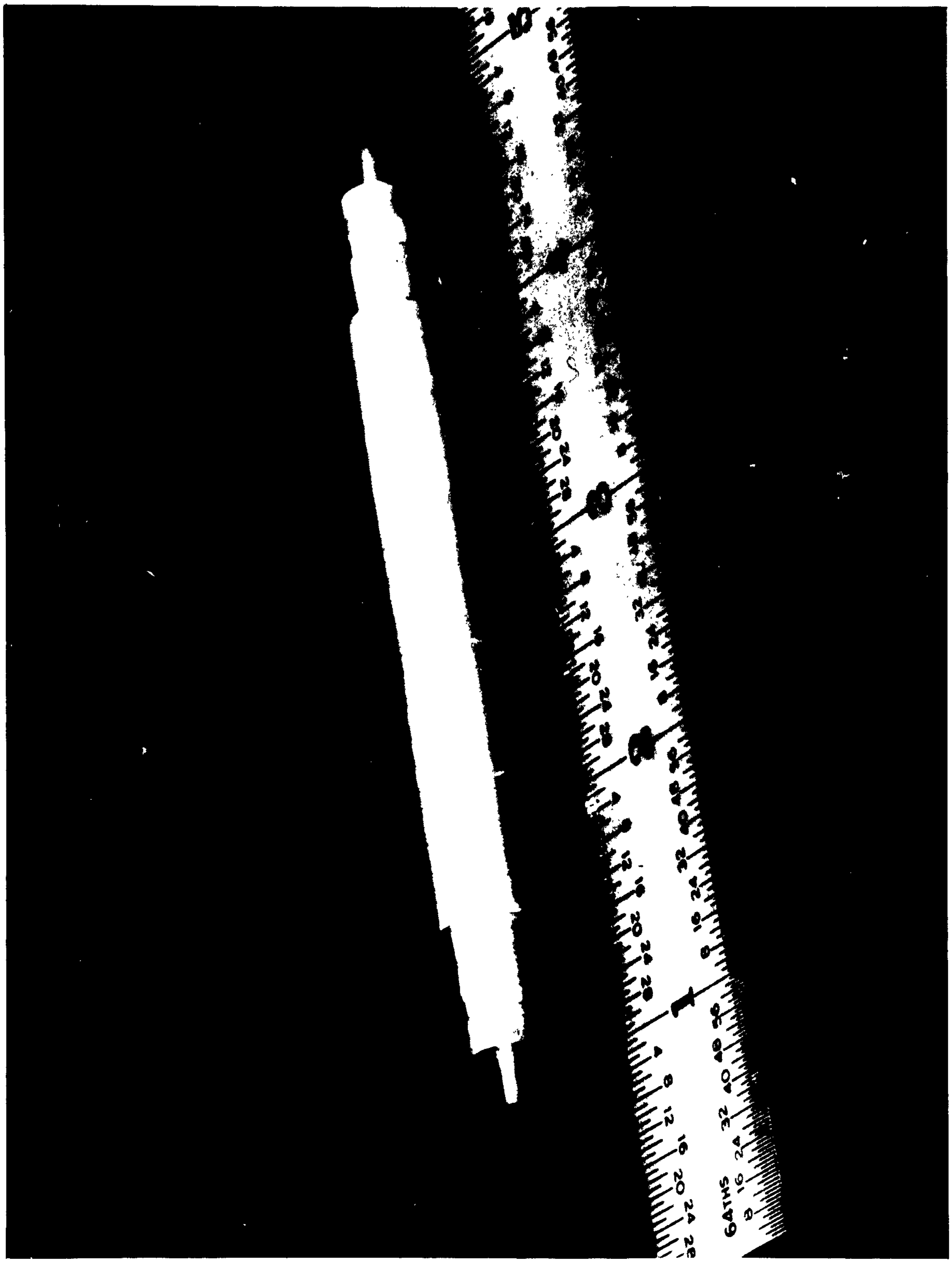


Fig. 5 - A possible complete rf circuit subassembly. The coaxial ceramic windows will be inserted into a low height waveguide. The two thin-wall sleeves will provide a flexible connection to the two pole pieces. The main body is shrunk fit to a BeO wedge supported helix subassembly.

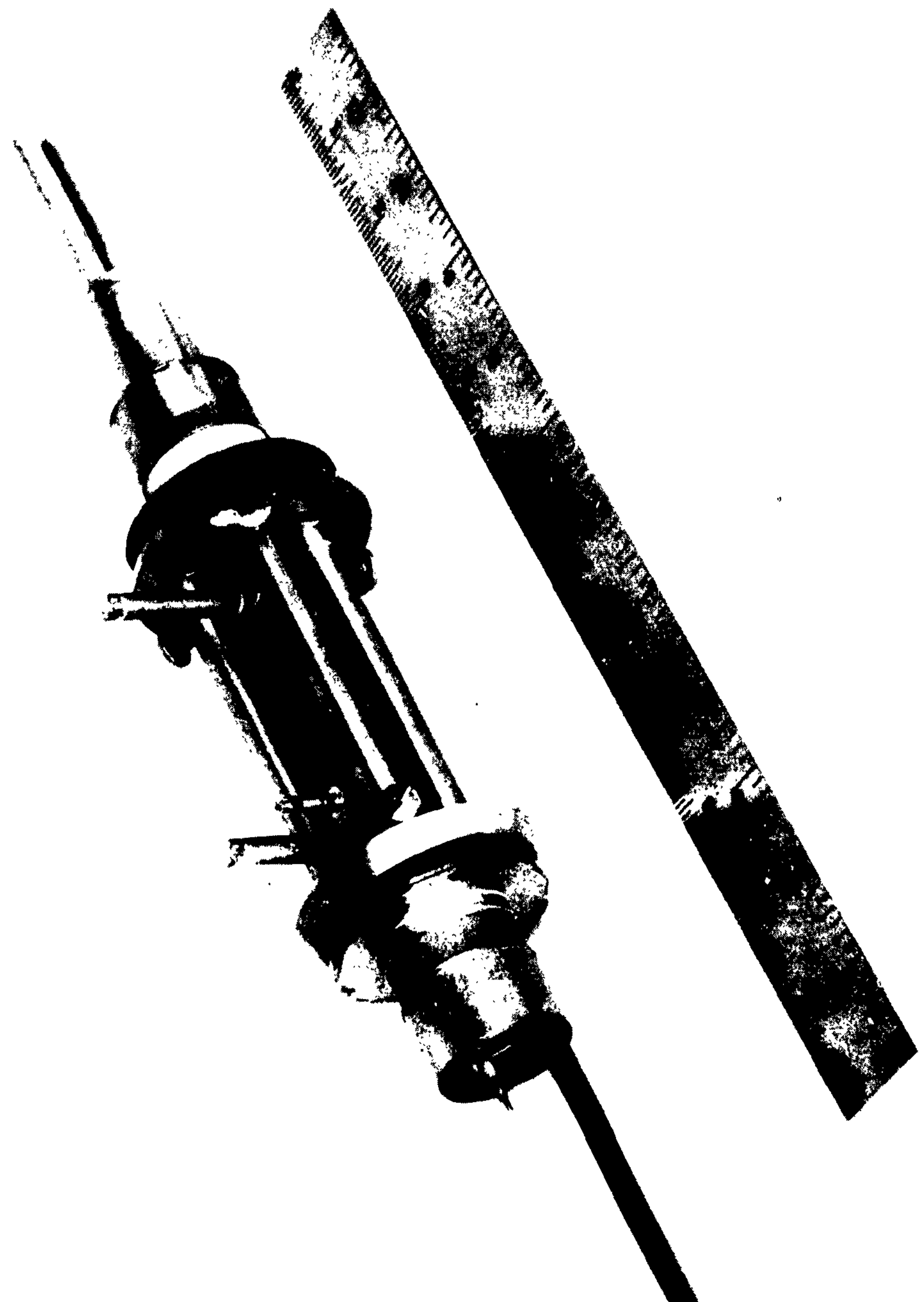


Fig. 6 - Beam tester for a perveance 1.1 gun used in conjunction with a 50 mil ID structure. The picture shows the adjusting screws which allows the helix section to be aligned with the electron beam after construction.

The first of these utilized cooled connections to each end of the helix. When heated by passing electrical current through the helix, the required data should have been developed. During the test however, some turns of the helix became visibly hot while the others remained black. The explanation lies in the non-uniformity of cooling due to minor variations in the glazing. As heating occurred certain turns would become hotter than others; due to the fast change in electrical resistivity of molybdenum with temperature, more power was applied to these poorly cooled turns further increasing the temperature. A run-away condition is thus established.

Even with this problem about 150 watts of power was dissipated in a section of helix about one and one-half inches long. Three or four hot-spots existed with temperatures about 900°C measured by optical pyrometer. The remainder of the helix was below color in temperature. This test obviously did not provide definitive results, but the results were not cause for rejection of the support system either.

The next test, which was designed to eliminate the uneven heating, utilized electrons released from a heated tungsten wire centered in the helix. By placing a dc voltage between the helix and the emitter, heating of the helix was obtained. By this means uniform heating may be assured.

The first test failed after getting about 35 watts dissipated on the helix. The emission from the tungsten emitter used was too low, and in attempting to heat it sufficiently to obtain the desired power level the emitter was lost.

A new set-up was planned which will use a larger diameter tungsten wire for the cathode. Also a thermocouple will be attached to the helix to allow the helix temperature to be monitored continuously.

This series of tests are important since the heat flow through the interfaces formed between the helix and the BeO support and between the BeO and the outer copper sleeve does not lend itself to calculation. The success of the tube program is directly related to obtaining good thermal conductivity from the helix to the outside heat sink.

4.0 CONCLUSIONS

As evident in the preceding sections, the work accomplished on a similar tube type supported by the Navy has given this program a very healthy start. Schedule progress appears satisfactory with completion of the initial phase of the various tasks aimed to coincide with the first major milestone at the end of next quarter. This milestone is the completion of the first rf tube.

PART II

5.0 PROGRAM FOR NEXT INTERVAL

The schedule for the next quarter will be to build the first rf tube. To accomplish this, the following tasks will have to be accomplished.

1. Complete aquadag attenuator design.
2. Complete preliminary rf coupler.
3. Test and evaluate a beam tester with an electron gun with a perveance of 1.0 with an area convergence ratio of 110 or slightly larger.

Concurrent with accomplishing the first rf tube, the depressed collector used in a beam tester will be evaluated. Also, the magnet procurement and design will have to be closely monitored so that no delays might develop.

A schedule for the second quarter is shown on the following page.

6.0 IDENTIFICATION OF PERSONNEL

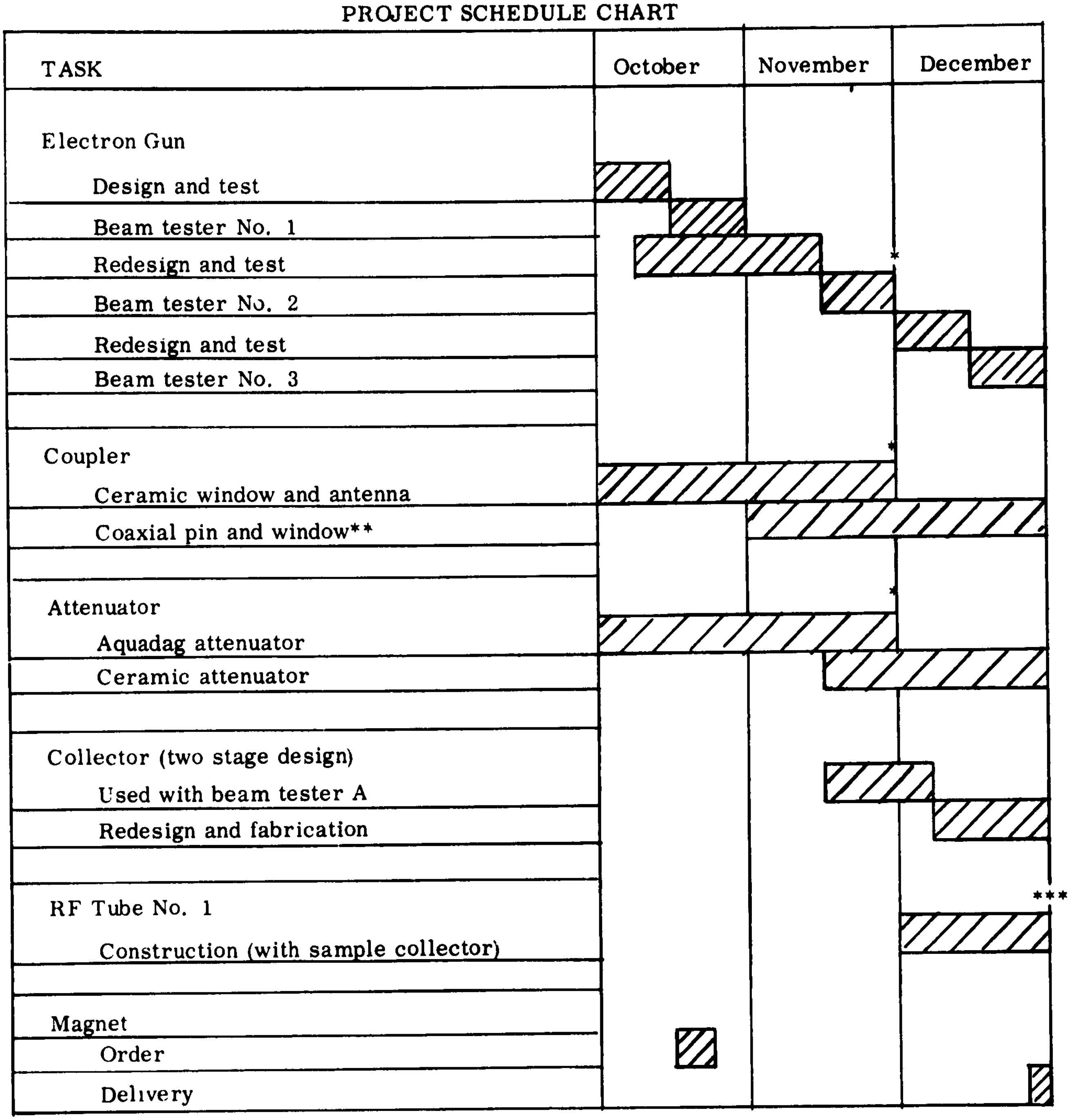
6.1 Engineers assigned

The following engineers were assigned during the period 1 July to 30 September 1961 and performed the hours of work shown.

C. A. Arnold	238 hours
Robert Frost	153 hours
James Long	92 hours
Lester A. Roberts	120 hours
George Wada	318 hours
Total	921 hours

Biographies of the above engineering personnel are included at the end of this report.

PROJECT SCHEDULE CHART



* Use best design at this point to construct the first rf tube.

** Initiation of work on this phase to depend upon the success of the other approach.

*** Completion of first rf tube.

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