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DEVELOPMENT WORK ON TWO SIGNAL GENERATORS FOR THE RANGE OF 3650 TO 10,900 MC

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ABSTRACT

An experimental model of a signal generator for the frequency range of 3650 to 7300 megacycles has been developed. The 2K-48 Klystron tube employed for the variable oscillator displayed various undesirable characteristics, although it operates throughout the specified frequency range. This tube has now been superseded by the QK-205 (RK-5721) for signal generator application, but this oscillator is inadequate to power a signal generator of one milliwatt maximum output.

A second coaxial cavity utilizing the QK-205 tube was developed to cover the range of 6800 to 10,900 megacycles. The range was adequately covered, but the desired rf output power of one milliwatt probably cannot be achieved in a signal generator incorporating the necessary output impedance-matching system.

PROBLEM STATUS

This is an interim report on the problem; work is continuing on other phases.

AUTHORIZATION

NRL Problem R10-04D
NL 490-021

DEVELOPMENT WORK ON TWO SIGNAL GENERATORS FOR
THE RANGE OF 3650 TO 10,900 MC

INTRODUCTION

With the discontinuance of NDRC, the Bureau of Aeronautics requested this Laboratory to continue development of the Q-1205 test oscillator, which had been started at RRL, Cambridge, Massachusetts, covering the range of 2800 to 5600 megacycles. It was also requested that the development of the Q-1210 plug-in tuning unit be continued for the purpose of extending the frequency range to 10,000 megacycles. The following equipment was received at NRL from Division 15 of NDRC.

| <u>Number of Units</u> | <u>Description</u> | <u>Type or Group No.</u> |
|------------------------|--------------------|--------------------------|
| Two | Modulator Units | YQ-1205 |
| One | S-Band Tuning Unit | Q-1227 |
| One | X-Band Tuning Unit | Q-1210 |
| Two | Reflex-Klystron | 2K-48 |
| Two | Reflex-Klystron | 2K-49 |
| One | Reflex-Klystron | 1429-CT |

It was recommended by NRL that this development be confined to signal generators covering these frequency ranges rather than to test oscillators. In support of this recommendation, representatives of the signal-generator and receiver fields attended a conference at the Airborne Instrument Laboratory, Long Island, in November 1944, for the purpose of initiating the development of new oscillator tubes. The specific interest of this conference was in tubes which would be applicable to the requirements of signal generators and local oscillators in receivers. Four tubes having nominal frequency ranges of 900 to 2100 megacycles, 2000 to 4000 megacycles, 4000 to 8000 megacycles, and 8000 to 13,000 megacycles were approved for development. The first three tubes were developed and designated as QK-201, QK-202, and QK-205; the fourth tube development project failed. Tubes for signal generator application require freedom from mode interference when operating in the 2-3/4 repeller mode and a power output of at least 30, but preferably 100 milliwatts over the entire frequency range.

The TS-403 Signal Generator, covering a nominal frequency range of 2000 to 4000 megacycles, was under development at this time and was later placed on a production

basis. Therefore, any signal generator developed for extended spectrum coverage was expected to overlap the upper frequency limit of the TS-403 and cover approximately a 2 to 1 frequency range. On the basis of this and the mode and power characteristics of the 2K-48 reflex klystron a tentative frequency range of 3650 to 7300 megacycles was considered to be desirable. The nomenclature TS-621 was received for this equipment from BuAer, and TS-622 for equipment operating over a frequency range of 6800 to 10,900 megacycles.

Although a development program was under way to provide a suitable oscillator tube for the TS-622 Signal Generator, the outcome was indefinite, and certainly would require time. Therefore presently available tubes were considered for this application, with some thought given to substitution of a new tube at a later date. The only suitable tube available was the 2K-48. This tube required high repeller voltage or lower power modes, but its frequency range was limited to a ratio of less than 2 to 1 and difficulties in power output and mode interference were present. The necessary mechanism was designed and fabricated simultaneously with that of the TS-621 Signal Generator. However, further work on the TS-622 was delayed until the completion of the TS-621 Signal Generator, since both equipments were considered to be quite similar except for some differences in the coaxial cavities and their respective frequency ranges. This dictated that the work on the TS-622 project be confined to the development of a suitable coaxial cavity section only. However, at the completion of the TS-621 Signal Generator, the QK-205 tube, designed to replace the 2K-48, became available and further work on the TS-622 was based upon the characteristics of this tube.

The QK-205, a reflex-klystron, now identified as RK-5721, was developed for the Services by the Raytheon Manufacturing Company. It was specifically developed to cover the nominal frequency range of 4000 to 8000 megacycles and differs physically from the 2K-48 in that a separate modulation grid has been incorporated and the extended resonator grid that serves as the center-conductor of the coaxial cavity has been eliminated. Some modification of the original TS-622 cavity was necessary to adapt the new tube, and the construction of a suitable center-conductor and tube clamp was required. It was also evident that some modification of the pulser unit would be required since the method of pulse-modulating the QK-205 differed from that of the 2K-48 tube. The modifications were considered to be minor. The principal objective appeared to be the development of a suitable resonator section, such that continuous oscillation and adequate rf power would be available over the desired frequency range.

Thus new developments were required over and beyond the original request. A contract (NOa(s) - 9156) was awarded to the Polytechnic Research and Development Company by the Bureau of Aeronautics for the purpose of providing prototype models of the TS-621 and TS-622 Signal Generators. The Laboratory's relation to the project was changed to include consultant service to the contractor and the Bureau of Aeronautics. The contractor delayed active prosecution of the project until samples of the QK-205 tube became available. An experimental model of the TS-621 has been submitted to the Laboratory for acceptance tests.¹ It has been determined that further development work on the TS-621 or TS-622 will not be required by the Laboratory at this time, but considerable work will be required by the contractor before satisfactory production equipment is available. Other developmental models from the contractor are to be evaluated and reported on to BuAer including recommendations for their improvement. The current report presents a general survey of the results obtained by the Laboratory in its investigation of the TS-621 and TS-622 Signal Generator project as developed from the initial requests of the Bureau of Aeronautics.²

¹NRL ltr report 3920-31A/50 to Chief, BuAer, dated 28 Feb. 1950

²BuAer ltr Aer-E-3163RBP from Chief, BuAer, dated 26 Sept. 1945

DEVELOPMENT OF A SIGNAL GENERATOR FOR THE FREQUENCY RANGE OF 3650 TO 7300 MEGACYCLES (TS-621)

Preliminary Work

The preliminary work on this model was projected on a broad scale. General planning of chassis lay-out requirements was organized for the power supplies and pulsing circuitry necessary for any signal generator using a 2K-48 type of reflex-klystron with a calibrated voltage output and controlled frequency accuracy. Included were considerations of size, weight, and design of cabinet. The ultimate aim of this development was to produce a working model to demonstrate the feasibility of producing a signal generator in the frequency range of 3650 to 7300 megacycles. This work was begun in 1946 by William R. Long and continued, with some revision of plan, by George A. Gimber and Paul A. Young in January 1947. Original plans for the circuitry of the generator were compiled from circuits of existing pulsed rf signal generators. Cavity dimensioning was patterned in accordance with the findings of NDRC Division 15 (RRL, Cambridge) in connection with the Q-1205 and Q-1210 test oscillator units.³ Later, modifications were made in accordance with the design figures of W. H. Huggins.^{4,5,6}

Two reflex-klystrons were available for use as oscillators in the desired frequency range of the TS-621. These were the 2K-48 and 2K-49. Transient time characteristics of the 2K-49 are slightly less than for the 2K-48. Serious mode-interference characteristics and low power output of the 2K-49 had been experienced when used as a local oscillator in receiver designs, and therefore a decision was made to use the 2K-48 tube. This reported behavior was also confirmed by tests conducted at this Laboratory.

Preliminary tests were conducted on the 2K-48 tube to collect general performance data, under operating conditions with the cavities of the Q-1210 tuning units as received from RRL, Cambridge. Satisfactory tube operation for the desired frequency range was obtained on the 2-3/4 and 3-3/4 repeller modes. Some reservations in design were considered so that the QK-205 tube, when available, could be employed with a minimum of alteration to the generator unit.

Design and Development of Basic Units

Resonator. The design of the coaxial cavity was predicated upon the establishment of modes (2, 2) and (2, 3) as the useful ones, thus establishing the displacement required

³ Kirkman, R. A., and Kline, M., "The Transverse Electric Modes in Coaxial Cavities," Proc. IRE, Vol. 34, pp. 14-17, January 1946

⁴ Huggins, W. H., "Broad-Band Noncontacting Short Circuits for Coaxial Lines, Part I," Proc. IRE, Vol. 35, pp. 906-913, September 1947, also discussed by W. H. Huggins pp. 931-935

⁵ Huggins, W. H., "Broad-Band Noncontacting Short Circuits for Coaxial Lines, Part II," Proc. IRE, Vol. 35, pp. 1085-1091, October 1947

⁶ Huggins, W. H., "Broad-Band Noncontacting Short Circuits for Coaxial Lines, Part III," Proc. IRE, Vol. 35, pp. 1324-1328, November 1947

for full-range tuning. The output and monitor coupling loops must be placed close together, at the tube-end or the shorted-end of the cavity to insure uniform and equal pickup by both. Any compromise in this requirement creates greater variations in loop coupling with change in frequency or plunger position. Of these two choices, placement of the loops at the tube-end was selected as a matter of convenience. To place pickup loops at the shorted-end, or most desirable position for output power versus frequency, means that they must be mounted in the face of the plunger and travel with it. A somewhat difficult mechanical design would be required to accomplish this. If an extremely high-impedance type broadband pickup were available and if this type of pickup were not responsive to spurious modes, the tube-end or maximum voltage position would be more efficient. Even with these drawbacks the tube-end position appeared to present the least difficulty.

A cavity shorting plunger of the noncontacting type (the "S" type or the inverted "Z") was preferred on the basis of greater reliability and longer life.^{4,5,6}

The resonator section was developed with dimensions similar to those of the Q-1205 and Q-1210 oscillator units built at the NDRC Division of RRL, Cambridge. Lateral dimension of the cavity was based upon the required tuning distances for the $n = 2$ and $n = 3$ repeller modes and appropriate stubs were provided for the Attenuator and Power Monitor systems (see Figure 1). The noncontacting capacitor plunger system employed was based upon the design figures of W. H. Huggins.^{4,5,6} Figures 2 and 3 show the dimensions and proper alignment of the plunger and associated carriage assembly which was used for transporting the plunger cavity tuning. The length and diameters of the stubs for the monitor and attenuator coupling loops were based upon the waveguide below cutoff principle, and sufficient length was allowed to provide coupling in the cavity from zero to -120 db. The bore of these stubs must be precisely the same for each unit and of a known dimension if the attenuation rate of each is to be identical and of a known amount (see Figure 1). Independent indicator dials with front panel knobs control the Attenuator and Output Monitor stubs through identical gear trains. The attenuation dial indicates from zero to -120 db. The fiducial mark for the attenuator control is engraved upon the dial terminating the output monitor control, which is concentric with the attenuator dial (see Figure 2).

After construction and assembly of the cavity unit and associated controls, test runs were made using the 2K-48 reflex-klystron and external power supplies. Some difficulty was first experienced with the 2K-48 tubes of low emission; however, results were quite favorable when replaced by better tubes of the same type. The results of the first test runs are shown in Figures 4 and 5. The hiatus shown in the (2,3) mode between wavelengths of 4 and 5 centimeters was found to be a function of tube orientation within the cavity. On rotating the tube by trial and error, this gap could be eliminated. Though the basic cause of this phenomenon has never been satisfactorily explained, the viewpoint expressed by the tube manufacturer was that some nonuniformity of field existed within the cavity. This may be a discontinuity of the coaxial line or perhaps a discontinuity within the tube itself. Nevertheless, the fact remains that when a tube is inserted into the cavity it must be oriented to the best position. Performance must be considered on the basis of frequency continuity as well as maximum strength of oscillation or power output.

Pulse Modulator

A pulse-modulator unit capable of pulsing the rf oscillator was required, and in view of contemplated later production an attempt was made to comply with Bureau of Ships

^{4,5,6}Huggins, loc. cit.

specification CS-639 and Bureau of Aeronautics specification XEL-2. The modulation requirements were as follows:

Pulse duration of $1/2$ to $10 \mu\text{s}$ continuously variable.

Pulse rise and decay times equal to or less than $1/2 \mu\text{s}$.

Pulse rate of 40 to 4000 cycles continuously variable.

Pulse delay of 3 to $300 \mu\text{s}$ continuously variable.

The preliminary modulator unit employed circuitry similar to the pulse modulator for the TS-403 Signal Generator as shown in Figure 6.

A breadboard model of the modulator unit was built. Pulse-modulation characteristics of the 2K-48 tube and associated cavity unit described above were made with this pulser unit. As the 2K-48 does not have a pulse-modulation grid, the signal was supplied to a keyer tube. For this purpose an 807 was selected and employed between the cathode of the reflex-klystron and the negative potential lead of the accelerator power supply. The pulsing signal was applied to the grid of this keyer tube. For pulse operation, the keyer tube is biased sufficiently to prevent oscillation of the klystron and the keying pulses are applied to the grid of the 807 by the modulator section. For cw operation the 807 is biased to conduct, thereby allowing the accelerator potential to be applied to the klystron. For cw operation, the dc voltage drop occurring across the 807 tube was approximately 35 volts. During the initial tests it was necessary to operate the reflex-klystron heater with batteries. A conventional filament transformer presented far too much capacitance between primary and secondary windings to allow satisfactory passage of the video pulse (the 2K-48's cathode is connected internally with the heater). As a result of the pulsing tests it was determined that the 807 tube operated reasonably well as a keyer tube. The bias for the 807 was maintained from 20 to 60 volts negative, and the magnitude of the pulse was about 30 to 80 volts positive, depending upon the pulse repetition rate. The first rf pulsing characteristic tests were made at a few spots over the frequency band, and very little attention was paid to such characteristics as minimum width, rise time, etc. The major concern of this test was to determine the ability of the pulser unit and keyer tube to modulate the rf oscillator over the entire frequency range. As a result of this preliminary test, the circuit used was considered adequate, and provisions were made for building the pulser unit on a subchassis with one common power supply, including the repeller voltage supply for the oscillator. All units and components associated with the cathode circuitry of the rf oscillator were mounted upon this subchassis unit, which is isolated from ground. This includes a special low-capacitance filament transformer, approximately $15 \mu\mu\text{f}$, for the heater of the 2K-48. For constructional details of this transformer, see Figure 7.

Power Monitor

A conventional wheatstone-bridge circuit employing a Western Electric type D-166382 thermistor element was used. The circuit was designed to indicate a half-scale meter deflection when coupling approximately one milliwatt of power. The meter employed in the bridge requires sufficient sensitivity to indicate powers of plus 3 db and minus 8 db relative to zero db or one milliwatt at half-scale deflection.

The wheatstone-bridge circuit employed is the exact replica of those units used in measurement work by this Laboratory. A Western Electric D-166382 bead thermistor is operated in the bridge circuit at a resistance value of 200 ohms, the most ideal operating point on the thermistor sensitivity curve. Operation at this resistance level requires a flow of approximately 6 ma of dc current through the element. Previous work by this

Laboratory in the development of thermistor-type power circuits has shown the following circuit highly desirable for rf powers of the order of 1 milliwatt (Figure 8). The thermistor element should be located as close as possible to the pickup loop of the monitor stub. This loop is actually formed by the pigtail lead of the thermistor. The rf, after passing through the thermistor element, is quickly bypassed to ground by a poly-iron slug (see Figure 9). Attenuation of experimental filter units of the same diameter but of varying lengths was measured. The filter used in this circuit showed an attenuation of over 40 db, which was considered sufficient. It was found necessary to insulate the relatively low-resistance poly-iron from the wall of the power-set tube to prevent the thermistor from being shorted. Preliminary tests indicated that this circuit was adequate.

Power Supplies

Power requirements of the accelerator grid for the 2K-48 type tube, when operating on the 2-3/4 and 3-3/4 repeller modes, is approximately 20 milliamperes at 1250 volts or 25 watts power consumption. The positive is grounded and the negative connects to the cathode of the klystron, for the following reasons. It is desirable to place the accelerator at ground potential, since the physical connection of this grid with the cavity involves a large mass of material somewhat difficult to isolate from ground and thus prevent shock hazard. For good operating stability, voltage regulation to $\pm 0.3\%$ is required (see Figure 10 for the Signal Generator basic units).

A breadboard model of this 1250-volt power supply incorporating all the desired features mentioned above was designed and constructed. The circuit arrangement and component values are shown in Figure 11(a). The regulator section alone showed very good control when it was tested with an external source of high voltage. However, succeeding tests employing the regulator and the equipment power unit showed very poor regulation. The regulator test showed a fluctuation of 0.55% in the load voltage when the input voltage was varied from 1400 volts to 1950 volts and the load current was varied between 2 and 25 ma. The poor regulation revealed in the second test resulted from insufficient warm-up time for the OA2 voltage-regulator tube and an undesired ac potential which existed across the 6AQ5 series regulator tube.

The revised circuit shown in Figure 11(b) corrected this condition with a slight improvement in voltage regulation (0.4%). Further test revealed that the output voltage variation versus line voltage variation was excessive for a load current of more than 15 ma (see Figure 12). These data showed that for ac line variations down to 103 volts or below another transformer with higher secondary voltage and power rating would be necessary to permit satisfactory operation. A ripple of 0.46 volt was measured at the output terminal and considered to be sufficiently low.

An undesirable condition existed during the warm-up period of the 836 rectifier filaments. Full input voltage appeared across the series regulator tube and its ac-shunt capacitor. To correct this condition a Western Electric thermal type delay relay was used to prevent the application of voltage to the rectifier heater until the filaments of the regulator tube and the 2K-48 tube reach normal operating temperature. The final schematic of this unit is shown in Figure 11(c).

The maximum repeller supply voltage required for the $n = 2$ and $n = 3$ modes is less than 400 volts, and the current drain is so minute that for all practical purposes it can be considered zero. However, the voltage regulation must be maintained to within 1/2 volt or 0.1% to avoid excessive carrier frequency "wobulation." Plans for incorporating this negative supply with the accelerator supply were abandoned to eliminate complicated

power-supply design. Such a combination requires special high-voltage consideration for insulation breakdown, capacitor ratings, power-handling capabilities, and regulation. Simplicity of design dictates the use of separate power sources for the repeller and the accelerator. Isolation of the repeller power supply from ground is required because the cathode of the oscillator tube is at high negative potential with respect to ground.

The design of the pulse modulator employs the usual receiver tubes, and therefore the power source is conventional and capable of delivering approximately 300 volts at 60 milliamperes. Considering all possible consolidation of power units, it appeared that the repeller power supply could be modified to carry the load of the modulator section also. For this consolidation the modulator must be isolated from ground and constructed upon the same subchassis as its power supply. Since the positive of this supply is common to the 807 cathode, klystron cathode, and the negative 1250-volt accelerator supply, the modulator circuitry must also be operated above ground (see Figure 10).

The combined current requirements of the pulse modulator and repeller determine the design of the supply unit. The modulator requires a regulated supply of -300 volts at approximately 60 ma and -330 volts for fixed grid bias. During preliminary tests 400 volts was found to be adequate for the klystron repeller voltage. The circuit shown in Figure 13 was constructed and tested to determine proper functioning of the regulator tubes for all load conditions. Bias voltages for both the rf keyer tube and the rf modulator unit were made variable over limited ranges for the purpose of further experimentation in the assembled signal generator unit. With 8- μ f electrolytic filter capacitors connected as shown in the diagram, 0.175% ripple voltage was measured. By substituting 8- μ f, 600-v paper capacitors for the electrolytics, this ripple was reduced to 0.01% and by using 4- μ f, 600-v paper capacitors, the ripple was 0.10%.

The circuitry for the power monitor unit is associated with true ground, as shown in the basic unit diagram (Figure 10). A thermistor element is connected to the cavity outer-conductor through its magnetic pickup loop. Therefore, the associated 150-volts gas-tube regulated power supply for the bridge operates with one of its terminals at ground potential.

This output monitor supply, Figure 14, is of conventional grounded-negative design, regulated, and capable of supplying 12 ma. A value of output voltage sufficiently high to maintain constant current to the bridge circuit is required. Considerable first-hand knowledge of thermistor-bridge circuits and associated power units permitted a very direct approach to the requirements of this application.

In an effort to conserve both space and weight of the equipment, as many windings as practical were placed upon one transformer core. It was felt that an independent transformer for the power monitor unit was necessary to assure stable monitor operation. The transformer supplying heater power to the series-regulator tube (6AG5) of the high-voltage supply and the special transformer shown in Figure 7, which supplies heater power to the 2K-48, must be kept separate because an interwinding capacitance exceeding 15 μ f in the latter unit causes distortion of the video pulse while keying the cathode circuit of the 2K-48 klystron. Other windings were placed in one transformer unit. The complete power supply schematic is shown in Figure 25.

Microwave Filters

Poly-iron filter units of the type shown in Figure 15 were constructed and their attenuation measured at the frequencies concerned. These units showed attenuation of 57 db and were designed for insertion between all front panel "Sync" and "Mod" jacks and their

internal cables for the purpose of greatly reducing or completely eliminating the conducted leakage through these cables. To reduce the rf fields within the cabinet of the generator, similar attenuator units were mounted upon the oscillator cavity assembly between all power leads to and from the cavity enclosure (see Figure 16). All power lead connections to the front panel and monitor meter, are enclosed in shielded covers. Poly-iron filters are mounted on these shields that enclose the electrical connection within the signal generator cabinet. These filters were tested at 3500v dc and did not break down. The highest voltage to be encountered in set operation is that of the repeller lead with respect to ground. The sum of the accelerator and the repeller potentials relative to ground should never exceed 1600v dc.

Unit Assembly

The construction and composite assembly of the breadboarded units discussed in the preceding paragraphs are shown in Figures 17 to 22 inclusive. Figure 17 is a front view of the signal generator with its case. Referring to the figure the controls appear as follows:

1. The lower row of jacks and other mountings are from left to right:

- (a) RF Output
- (b) Delayed Sync. Output
- (c) Ext. Mod.
- (d) Sync. Output
- (e) Sync. Input

The power switch, pilot lamp, line fuses, and power receptacle are located on the lower right of the panel.

2. The controls in the center panel are designated from left to right:

- (a) Output Attenuator knob. This knob rotates the central disc pictured to its right. A db scale is to be engraved upon this disc indicating zero to 120 db.
- (b) Power Set knob. This control is coupled with the outer ring encircling the attenuation scale and contains the fiducial mark for indicating the position of the db scale.
- (c) The power monitor zero-set knob is located directly under the monitor meter.
- (d) The repeller voltage manual control
- (e) FM phase control
- (f) FM amplitude control

3. The controls in the upper portion of the panel are designated as follows:

- (a) Frequency Tuning Dial graduated in degrees
- (b) Output Monitor Meter (reference level at midscale)
- (c) RF-Pulse Width
- (d) Modulation Selector Switch including external modulation with either a Positive or Negative Pulse, Internal Modulation, Off, CW, and FM
- (e) Pulse Delay
- (f) Sync. Selector
- (g) Pulse Rate

Arrangement of the previously discussed subunits on a main chassis is shown in Figure 18.

A division of Figure 18 into various subunits is shown in Figures 19 and 20. To clarify these photographs all shafts connecting various controls to the front panel knobs were removed. The Accelerator Power Supply occupies the lower right-hand corner of the composite photograph. The Modulator Section and its power supply along with the repeller voltage supply, klystron filament transformer, and the klystron keyer tube are mounted upon a subchassis located directly behind the accelerator unit. The oscillator unit is located to the left of these units. The upper right-hand portion of Figure 19 displays the shield cover and poly-iron filter units that isolate the Monitor Meter from rf leakage and thus confine the rf fields within the cabinet. Directly behind and below the meter shield a portion of the monitor supply is shown.

The remainder of this circuit is located below the chassis and may be seen in Figure 21. The power transformer and choke are located in the lower right-hand section. The insulated subchassis plate, upon which the modulator and its power unit is mounted is located in the upper left-hand section of the photo. The line filters and shield cover-cans that enclose all electrical connections to the front panel appear in the lower left-hand corner, while filters for the Sync. Input, Sync. Output, and Modulation Input appear in the right-hand corner. Detailed drawings for their fabrication are shown in Figures 15 and 16.

An isolated photographic view of the oscillator section with the cover-can removed is shown in Figure 22. The rack and pinion drivers of the attenuator and power monitor stubs are clearly visible in the lower left-hand portion of this picture. The power-lead filter units, previously described, can be seen directly beneath the cavity casting. The openings in the shield lie opposite the blower unit which is located on the main chassis. The perforated holder for the klystron lies directly between the ventilation entrance and exit.

Signal-Generator Operational Tests

CW Operation - A constant accelerator potential of 1150 volts was maintained throughout the test. The klystron was oriented for the optimum power output performance and for continuous oscillation over the frequency range. Figures 23 and 24 show the frequency calibration and the mode plots obtained. At the time of this test a maximum repeller voltage of 300 controlled by the OA2 voltage-regulator tubes was available. Later the repeller voltage divider connection was changed to a maximum of 405 volts as shown in Figure 25. A slight change in frequency calibration was noted each time the klystron tube was removed and replaced. The minimum change occurred when the barrel of the tube was clamped into position before the flange clamp was fastened. With precaution, when changing the tube, a frequency calibration of plus or minus one percent was maintained. The equipment was allowed to stabilize and the rf "power-set" was corrected to the meter zero before each reading. Readings were taken at every 30 degrees rotation of the frequency dial with the "power-set" control adjusted to indicate zero DBM or half-scale meter reading of the monitor and with an attenuator setting corresponding to 1 milliwatt.

A new plunger of a more recent design by W. H. Huggins was constructed and tested in the oscillator cavity (see Figure 26). This line-plunger differs from the original in that the line section between the buckets is a tapered section and only five spurious-mode suppression slots are used instead of six. Results obtained from this test were unsatisfactory. Oscillations in the (2,2) mode were very critical. A 5/4 cavity mode-hopping occurred with very slight changes in repeller voltages and by operating the CW ON-OFF Switch. Low output power was noted in the frequency range of 7000 to 8000 Mc. Mode plots for this plunger are shown by the dotted curves in Figure 24. The original plunger was replaced at the conclusion of this test and extensive measurements were made to determine the exact requirements for a repeller voltage tracking system. A plot of these characteristics is shown

in Figure 27. The repeller maximum-voltage lead to the potentiometer connection was changed as shown in Figure 25. An external power supply was also used for the purpose of extending the curves above the 405-volt level.

The (2,2) mode of oscillation was selected for dial settings of zero degrees to 240 degrees, or 3520 to 6000 Mc. Above 240 degrees oscillation was continued by the (2,3) mode up to a frequency of 7540 Mc. Repeller voltage tracking within plus or minus 10 volts of the curve shown in Figure 27 was found to be adequate. This figure also shows that a minimum of 55 volts and a maximum of 320 volts are required for oscillation in the (2,2) mode. Limits for the (2,3) mode are approximately 75 and 165 volts. A linear potentiometer is satisfactory for repeller voltage tracking in the (2,3) mode but the voltage tracking for the (2,2) mode is more complicated. However, two systems (circuits a and b of Figure 28) have been calculated which will permit a linear potentiometer to be used, thus eliminating the necessity of winding a special potentiometer. Plots for the two systems are shown in Figure 28. Circuit b of Figure 28 was found suitable for the application. For greater flexibility in adjusting the repeller tracking curve for variations in the characteristics of replacement tubes, it is recommended that R_1 , R_3 , and KR_2 be variable. Theoretical development of the circuits is shown in detail in the Appendix of this report.

The magnitude of rf power coupled from the cavity when using tight coupling exceeds one milliwatt at all frequencies concerned. The absolute magnitude of power obtainable from the rf jack was not accurately measured, but it exceeds 2 milliwatts at all frequencies and may even approach 4 milliwatts. The strength of oscillation is indicated by referring to the "rf power monitor" calibration shown in Figure 29 and the variation in power input to the monitor as the generator is tuned over its frequency range is shown in Figure 30. The loops and plunger systems for the rf output and rf power monitor are identical in physical construction and in their positioning in the cavity chamber. It is assumed that uniformity of field within the cavity chamber exists and that for all frequencies each loop couples similar power from the cavity. (See power measurements of Figure 29.) The 2-1/2 feet of RG-58/U cable connecting the pick-up loop to the rf jack will, under load conditions, cause some change in the relationship between power variation and frequency when observed at the jack.

This development did not include the output attenuation and padding devices necessary for a complete signal generator. These have an average insertion loss totalling about 15 decibels. The maximum output power in a typical signal generator (one milliwatt maximum) is about 15 decibels below (or one-thirtieth of) the oscillator output. It is apparent, then, that the oscillator output powers (2 to 4 milliwatts) mentioned just above are entirely inadequate for a good signal generator. It is noted elsewhere in this report that the tube under study (2K-48) is now superseded by the QK-205.

Pulse Operation - A preliminary check of the pulsing characteristics indicated that the oscillator pulsed over a frequency range of approximately 3800 Mc to 7500 Mc but not above 7500 Mc or below 3800 Mc; however, pulses for a 5/4 cavity mode occurred. This is an interfering mode and has been mentioned under the discussion of cw operation. A closer check of pulsing characteristic throughout the normal frequency range revealed that at some dial settings pulses for both the dominant mode and interfering mode appeared. The dominant mode always showed the stronger pulse. Improvement of the rf pulse shape appeared with each improvement of the video pulse shape being fed into the 807 keyer tube. A fixed bias on the diode-clipper tube (V106B of Figure 25) gave the most desirable characteristic. Other minor circuit changes were also made to improve the pulsing-unit: An additional stage of amplification (V109A) was added, the bias on the delay multivibrator was changed increasing R117, and the tube types were changed. The bias applied to the grid of the 807 keyer tube had a profound effect upon the width of the rf pulses. Increasing the bias

voltage applied to this tube caused an increase in the rf pulse width. A change from -40 volts to -50 volts exactly doubled the width of the rf pulses irrespective of the position of the pulse-width control. The video pulses appearing at the grid of the keyer tube under operating conditions showed the same effect.

The circuit of Figure 31(a) was used in an attempt to isolate the keyer tube from the modulator unit. This change had little effect upon the rf pulse width, but greater stability and less jitter was noted while keying. It is believed that the positive grid swings and the flow of current in the grid circuit of the keyer tube caused shortening effects of the rf pulses. The circuit of Figure 31(a) was altered to that of Figure 31(b) so that the cathode potential could be balanced with the video pulse appearing on its grid. Under these conditions the video pulse at the grid of the keyer tube was satisfactory but the rf pulsing characteristics varied with each change in frequency and therefore the circuit was very unsatisfactory. A cathode potential change was necessary for each change in the video pulse rate and pulse width. Experimentation with the grid coupling capacitor and grid resistor of the keyer tube improved the pulsing characteristics. The best values appeared to be 1 μ f and 1000 ohms. A 0.25- μ f capacitor from the repeller to the cathode of the 2K-48 tube eliminated nearly all rf pulse fuzziness.

The final modulator was constructed mostly of miniature tubes, as shown in the schematic diagram of Figure 25. This circuit is satisfactory for positive or negative pulsing of the rf oscillator with either internal or external sync. For similar pulse modulation from an external source a square wave of plus or minus 20 volts is required.

DEVELOPMENT OF AN OSCILLATOR CAVITY FOR THE TS-622 SIGNAL GENERATOR TO COVER THE FREQUENCY RANGE OF 6800 TO 10,900 MEGACYCLES

Designs of the oscillator sections and associated mechanism for the TS-621 and TS-622 Generator were carried on simultaneously, and drawing details of the original TS-622 oscillator assembly are shown in Figure 32. Some modification of this design was necessary to accommodate the QK-205 tube. This modification consisted of building a central conductor and repeller connecting lead for the QK-205 tube. (These were integral parts of the 2K-48 type tube.) These changes in cavity design of Figure 32 are shown in Figure 33. The barrel is maintained at the same diameter as that of the 2K-48 tube; therefore the line characteristic impedance is maintained at approximately 61 ohms.

The cutoff frequency for the lowest waveguide mode is represented as having a wavelength of $\lambda_c = \pi(a + b)/2$ the mean circumference of the coaxial line. In this case λ_c is equal to 3.20 inches or 8.15 centimeters for the TE_{11} mode, the lowest waveguide mode encountered for this cavity. Spurious responses caused by the higher waveguide modes will therefore not occur below the frequency which corresponds to λ_c . In the present cavity, spurious resonances will occur within the desired frequency range (6800 - 10,900 Mc), however, there is no alternative. In general practice, it is desirable to dimension the cavity so that spurious responses occur outside and above the tuning range, but in the present case, such dimensioning is not physically feasible because the shortest wavelength is 2-3/4 centimeters. Under these conditions the TEM, TE_{11} , TE_{21} , and (possibly) TE_{31} modes can resonate. The noncontacting short-circuiting type of plunger causes further spurious resonances. These resonances are the result of waves being propagated circumferentially around the small gaps between the plunger and the outer and inner conductors of the coaxial resonator. Such resonances are discussed in detail by W. H. Huggins.⁶

⁶ Huggins, loc. cit.

Two plungers of the "Z" type were constructed and operated with this cavity. Circumferential resonances were suppressed in these plungers by means of slots in the face of the plunger, and magic-core rods were placed in the slots for suppression of multicycle resonances. The principal difference between the plungers is in the number of slots used; one contained three, the other six. Results obtained with the three-slot and six-slot plungers are shown in Figures 34 and 35, respectively. From these data it is immediately apparent that no oscillations, excluding spurious modes and parasitic oscillations, occurred within the desired wavelength of 4.4 to 2.7 cm.

The tuning curves, as plotted from the results of the above test, are shown in Figure 36. The line of the upper right-hand corner represents the $k = 1$ modes of Figure 35 and has a slope ($\lambda \div$ cavity displacement) of two. The $k = 2$ modes have a calculated slope of one, as is shown in Figure 36. The rather flat modes appearing at approximately 5 and 3 centimeters are waveguide interference modes. It appears that the cavity is operating with an inductive termination, and that oscillations are taking place on a half-wave rather than a quarter-wave cavity mode. A discussion of these effects is presented in paragraphs 32-8 through 32-15 of reference 7.⁷

All these investigations were made on the TS-621 cavity operating with a plunger designed for the frequencies of the TS-622. The plunger dimensions are shown in Figure 37 and the slotting was determined from the phase-vs.-wavelength plot shown in Figure 38. From this plot it will be noted that the three-slot plunger gives the minimum number of parasitic resonances and these are indicated at wavelengths of 3.3 cm, and 3.9 cm. Further tests of this cavity were abandoned because a cavity smaller in mean circumference appeared more desirable.

In an effort to construct a cavity resonator for the maximum impedance permitted by physical dimensions of the tube, the central conductor was reduced in diameter from 0.540 inch to 0.437 inch. If parasitic TM and TE resonances are to be avoided, the maximum diameter of the outer conductor must be limited to obtain satisfactory oscillator operation at the higher frequencies. These conditions prevent raising the cavity impedance to reduce interference from the TEM modes. By reducing the diameter of the central conductor the cavity impedance was raised from 47 to 60 ohms. This gives a mean circumference of approximately 6-1/2 cm.

The tuning chart of Figure 39 was constructed to assist in the recording and evaluation of data from the results of tests. The dashed guide curves were constructed before the commencement of tests and represent the position of the plunger within the cavity as calculated from the known rate of travel of the plunger with respect to the position of the dial as expressed in degrees of rotation. Approximately 0.65 cm was added to the physical length of the cavity to compensate for the electrical lengths of the tube, plunger, and corner. The results of previous tests indicate that this figure is approximately correct. Tests were conducted and the results were evaluated with much greater ease by using this chart. The results of these tests are plotted on this same chart and Figure 40 presents the repeller voltage mode plots as obtained from these data. The solid lines drawn across the graphs at 2.76 cm and 4.4 cm indicate the tuning limits required of this oscillator. Modes of oscillation observed outside of this frequency range, except the $k = 2$, or 3/4-wavelength cavity mode were not significant except where adversely influencing the desired modes. The shortest practical length to operate this cavity was approximately 2 cm, or 280 degrees of the dial rotation. A radial-line resonance (TM_{01}) mode was observed with shorter cavity lengths. Resonance may occur between wavelengths of 2ρ and 4ρ , and will be

⁷ Radio Research Laboratory, Vol. II, "Very High-Frequency Techniques," McGraw-Hill, 1947.

dependent upon the plunger displacement distance t . The symbol ρ is expressed as the radial distance between the center conductor, and the outer conductor. In the present instance ρ is equal to 0.96 cm. Repeller modes (2,3), (2,4), and (2,5) were killed by this TM_{01} fixed resonance point as indicated on the graph of Figure 40.

Figure 41 presents the repeller characteristics relative to the length of the resonator section in centimeters. This chart was useful in determining the various repeller modes, that is, the repeller cycles (referred to as N , where $N = n + 3/4$). Neighboring modes appearing on this chart indicate the possible interference modes. Referring once again to Figure 40, it is seen that near frequency coverage may be obtained by use of the $5/4$ cavity mode ($k = 3$), and the $4-3/4$ and $5-3/4$ repeller modes ($n = 4$ and $n = 5$). The actual frequency coverage of these two modes is from 6250 Mc to 10,400 Mc. However, the power output and frequency stability of repeller modes of the order of 4 and 5 are not sufficient to permit their use for signal generator applications.

A third cavity was constructed by alteration of the TS-621 oscillator assembly. The 1.188-inch outer conductor sleeve insert of the TS-621 cavity (Figure 42) was removed from the casting (Figure 43). A new cavity sleeve insert shown in Figure 44 was constructed and inserted into this casting. The diameter of the central conductor ($7/16$ inch) was not altered. This coaxial cavity had a characteristic impedance of 27 ohms, and a mean circumference of 4.49 cm. The shortest practical operational wavelength of a coaxial resonator appears to be somewhat greater than $1/2$ the mean circumference of the line. Therefore an outer conductor diameter of $11/16$ inch was chosen. This smaller diameter eliminated nearly all of the waveguide type of mode interference in the desired frequency range.

The bucket-plunger design used for this cavity is shown in Figure 45. A three-ball suspension system for maintaining concentric spacing of the plunger within the cavity is an integral part of the plunger. The carriage system for mounting the plunger required only one minor change to fasten the drive rods to the carriage drive plate.

The tuning and displacement curves for this cavity are presented in Figure 46. The dashed lines represent the theoretical $3/4$, $5/4$, and $7/4$ cavity tuning modes and function only as a guide in conducting experiments. The actual experimental tuning curves differ in slope from the theoretical, and in a direction such as to indicate an inductive termination of the coaxial line. Repeller-mode tuning curves for the $5/4$, and $7/4$ cavity modes are shown individually in Figure 47 and Figure 48. Hiatus of the (3,3) mode was indicated at a wavelength of 3.2 centimeters with oscillations then continuing to a minimum wavelength of 2.7 centimeters. Complete frequency coverage was obtained with this cavity when operating at a $5/4 \lambda$ cavity mode. This hiatus point can be corrected by proper tube orientation within the coaxial cavity, and appears to be a nonlinearity of field within the envelope of the klystron. A slight rotation of the tube will usually correct the condition.

Tube orientation greatly affects the power output of the oscillator at all frequencies. The ideal tube position appears to be the same for all frequencies but is more critical for the higher frequencies. A graph of maximum power output while operating this oscillator on the $5/4$ wavelength cavity mode is displayed in Figure 49. Allowing for the 15-decibel coupling and padding loss mentioned as average on page 10 above, it is apparent that this oscillator has inadequate power for a signal generator of one milliwatt output.

CONCLUSIONS

Performance of the experimental model of the Signal Generator to cover the frequency range of 3650 to 7300 megacycles demonstrates the feasibility of utilizing a 2K-48 klystron

oscillator tube for this purpose. However, as a consequence of low rf power output, undesirable mode interference, and the absence of a control grid, it appears more desirable to utilize the recently developed QK-205 (RK-5721) tube. Similarly the rf cavity developed for the QK-205 demonstrates the acceptability of this tube for the frequency range of 6800 to 10,900 Mc.

The desired one milliwatt of rf output power has been met by the present oscillator for most of the frequency range from 6800 to 10,900 Mc. However, additional rf power will be required to overcome the attenuator insertion loss and impedance matching device incorporated in the rf output system. An attempt to operate on the $3/4$ wavelength coaxial cavity mode has failed, possibly because of faulty cavity design and/or tube phenomena other than repeller mode interference. While repeller mode interferences did exist in some instances, they were not wholly responsible for the "dying off" of the desired modes. No serious mode interferences existed in the frequency range for normal operational modes of the third oscillator described and the complication of repeller-mode separators was not considered necessary.

The Polytechnic Research and Development Company appears to be making satisfactory progress on the development of the prototype models of these two signal generators covering the frequency range from 3650 to 10,900 Mc. Their work is being performed on Bureau of Aeronautics contract NOa(s) 9156. Therefore further developmental work at NRL will be limited, but consultative service assistance to the contractor and the Bureau of Aeronautics is still required. Prototype models will be evaluated at NRL for compliance with governing specifications upon receipt.

* * *

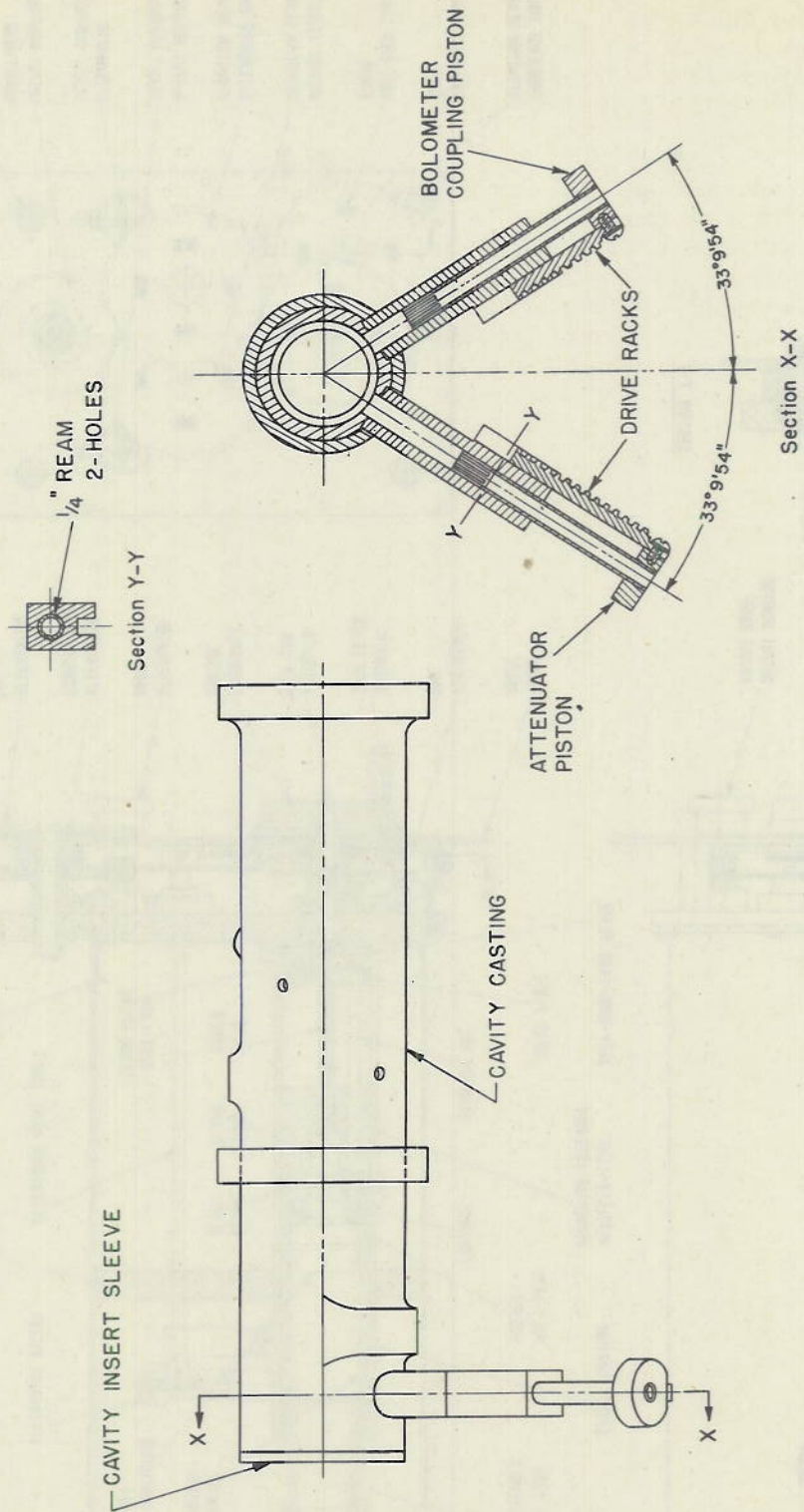


Figure 1 - TS-621 signal generator and attenuator system

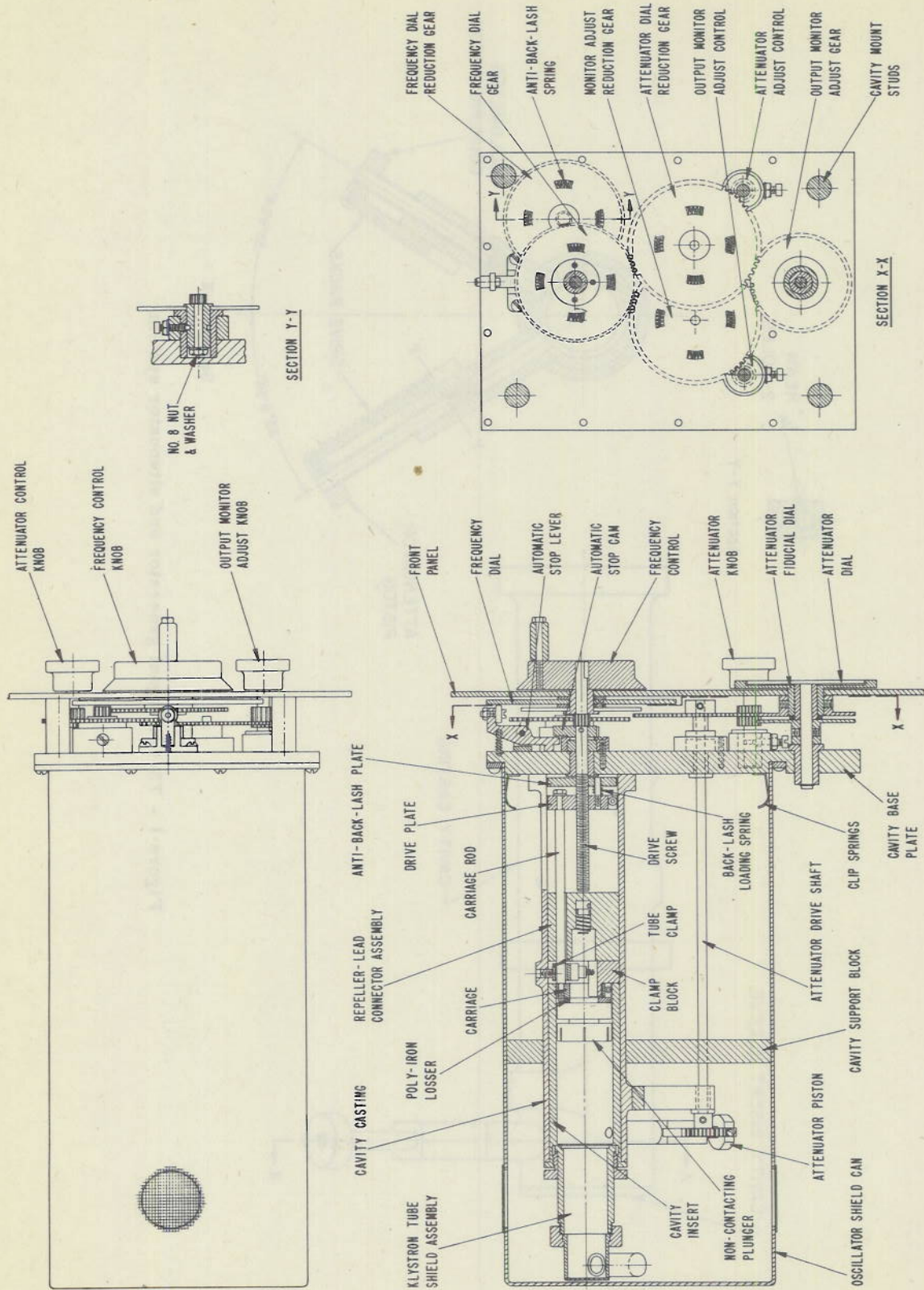


Figure 2 - TS-622 signal generator oscillator assembly

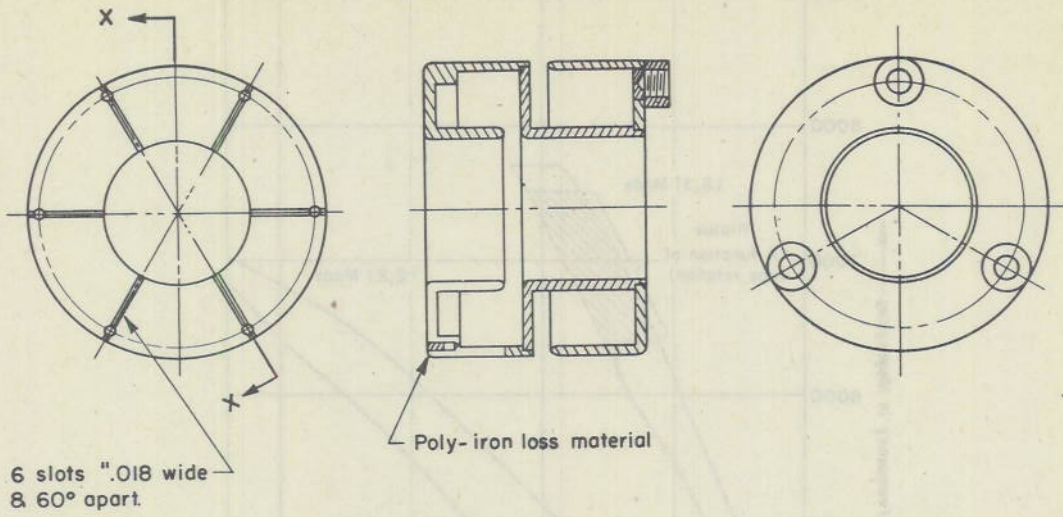


Figure 3 - TS-621 signal generator plunger subassembly

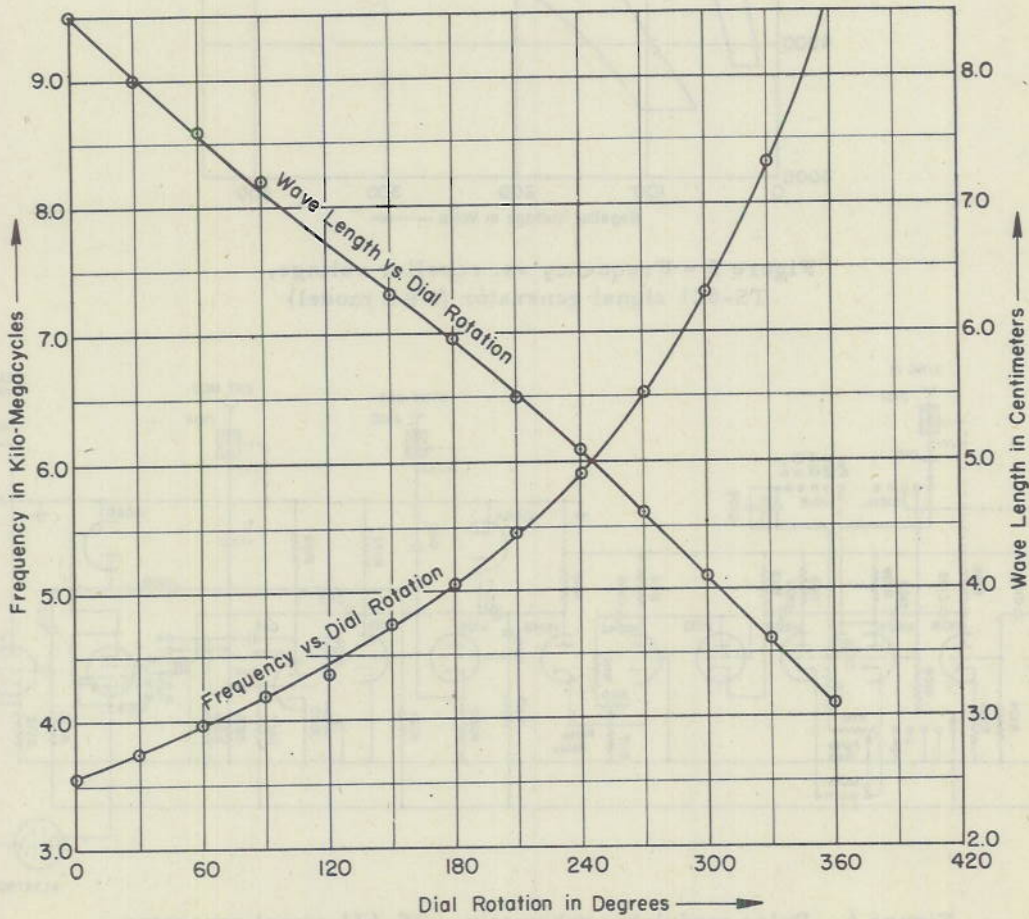


Figure 4 - TS-621 cavity resonator curves

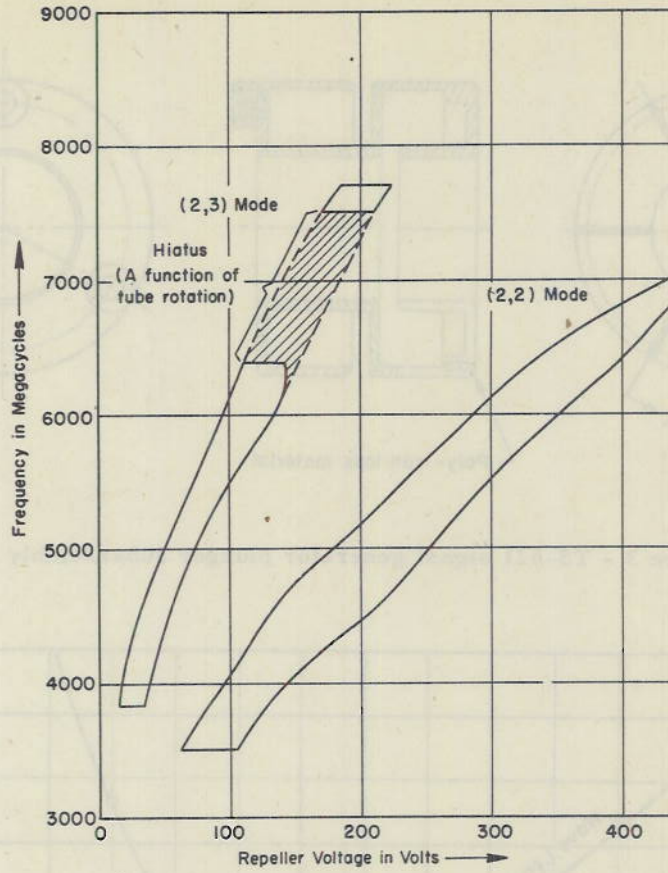


Figure 5 - Frequency vs. repeller voltage, TS-621 signal generator (NRL model)

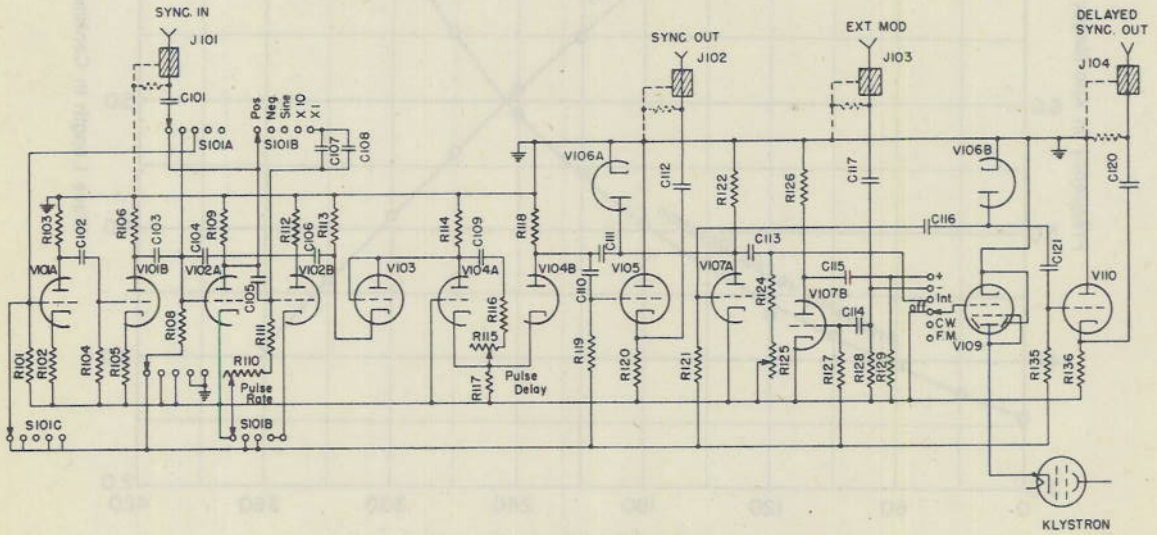


Figure 6 - Pulse modulator schematic, TS-621 signal generator

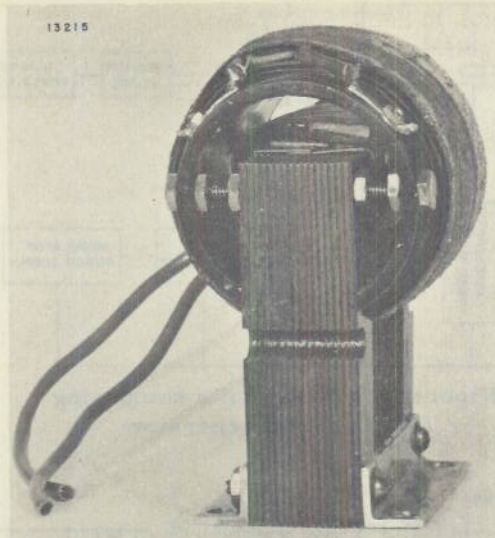


Figure 7 - TS-621 signal generator, klystron filament transformer

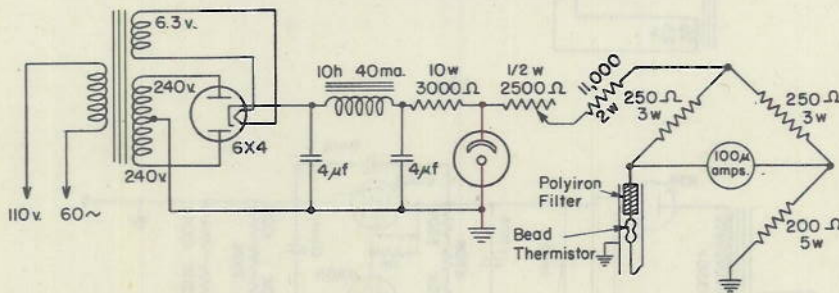


Figure 8 - TS-621 signal generator power monitor schematic

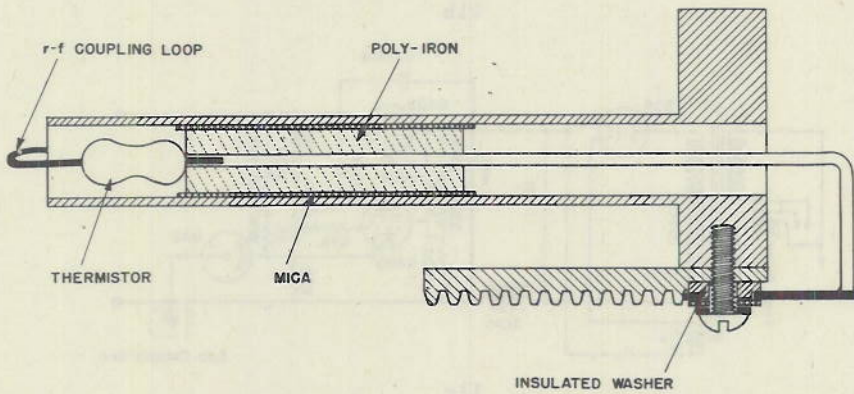


Figure 9 - TS-621 signal generator monitor probe

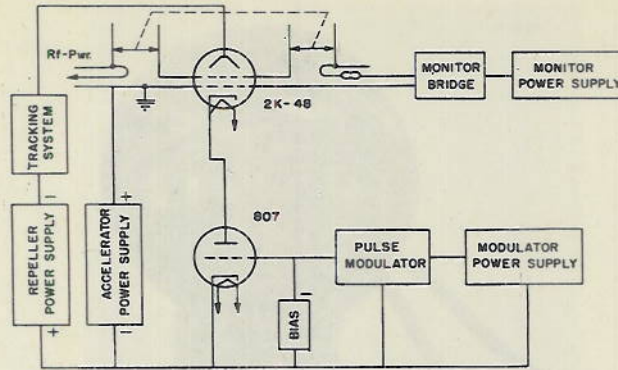
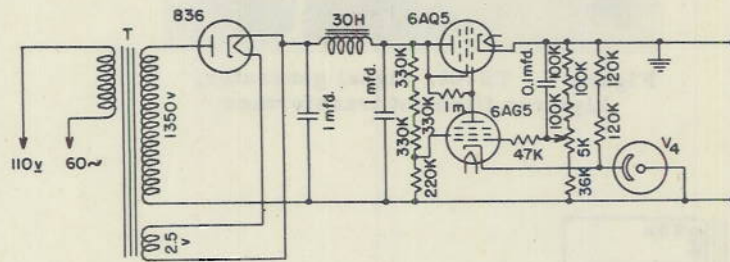
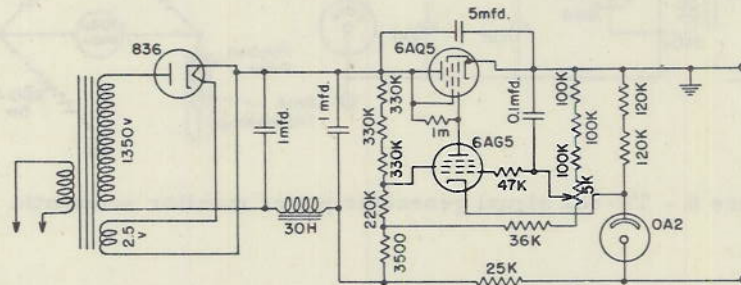


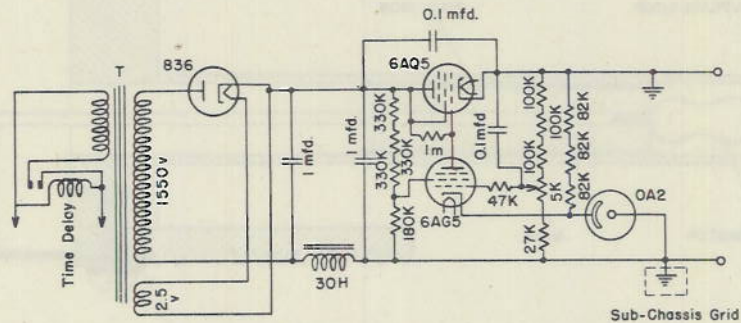
Figure 10 - Basic units composing TS-621 signal generator



11a



11b



11c

Figure 11 - TS-621 signal generator accelerator voltage supply

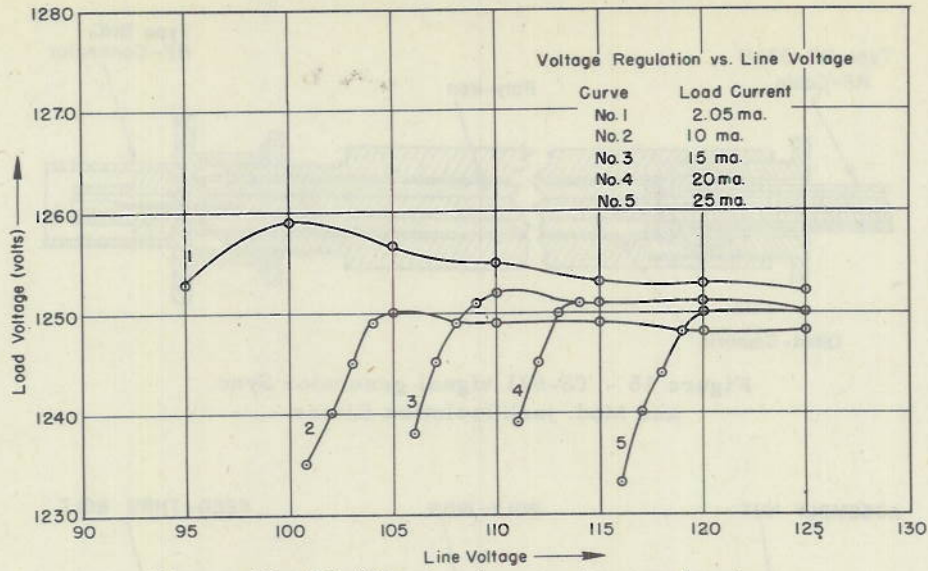


Figure 12 - TS-62' signal generator accelerator power supply regulation curve

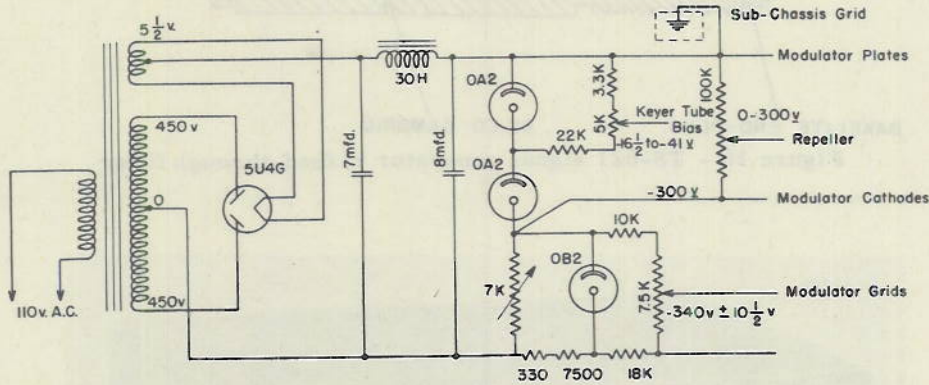


Figure 13 - TS-621 signal generator modulator and repeller power supply

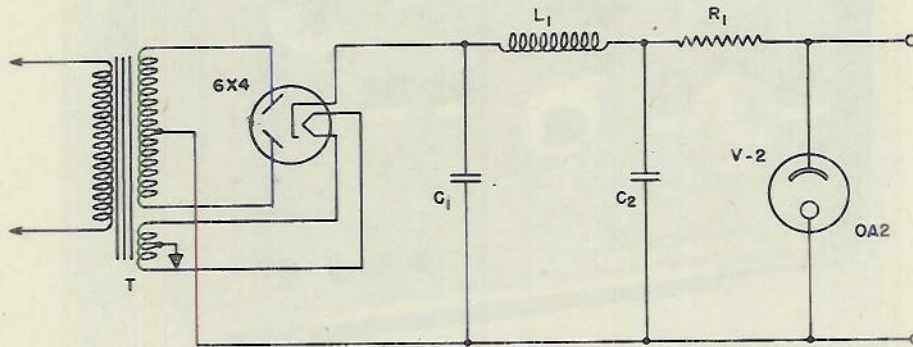


Figure 14 - TS-621 signal generator monitor power supply

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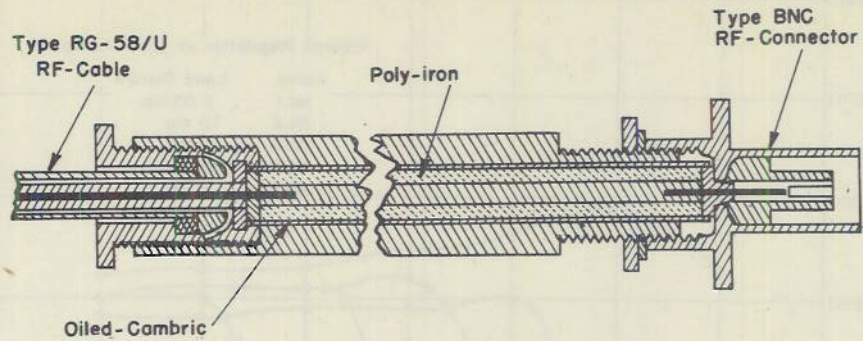


Figure 15 - TS-621 signal generator Sync. and Mod. jack isolation filters

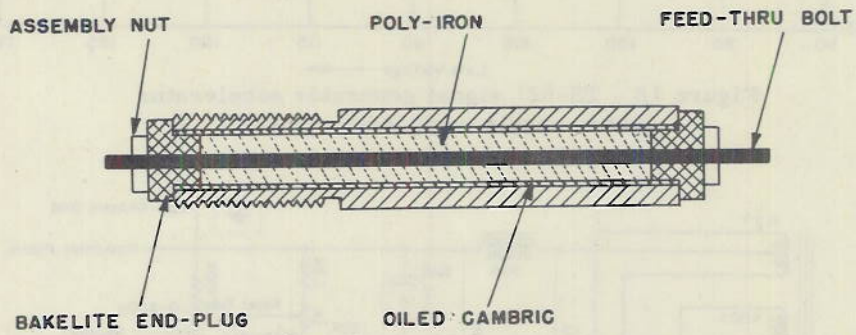


Figure 16 - TS-621 signal generator rf feed-through filter

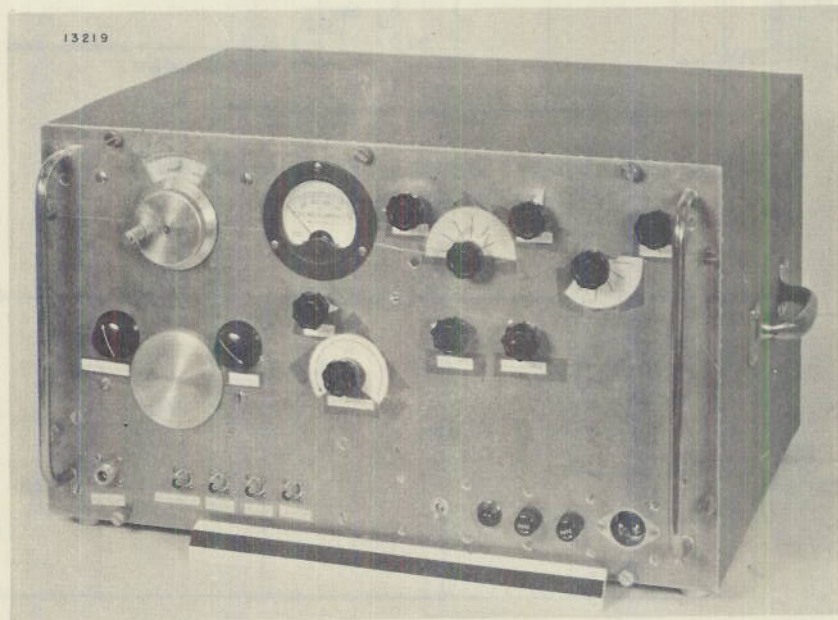


Figure 17 TS-621 signal generator (NRL model)

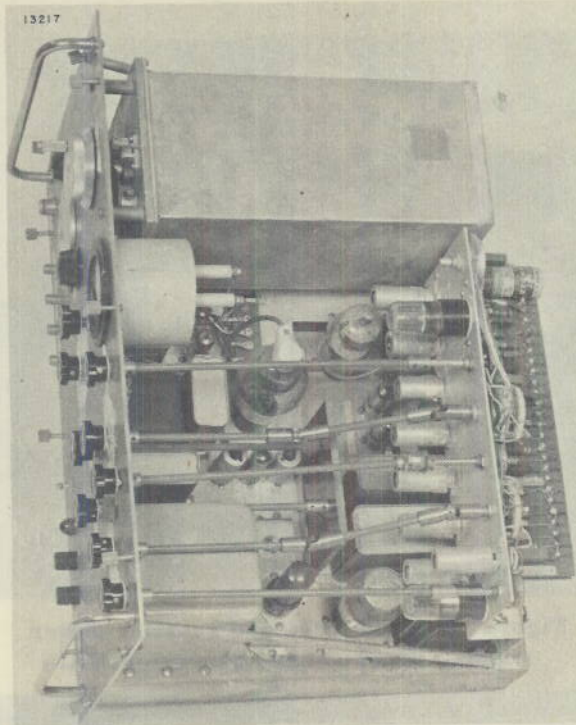


Figure 18 - TS-621 signal generator chassis (top view)

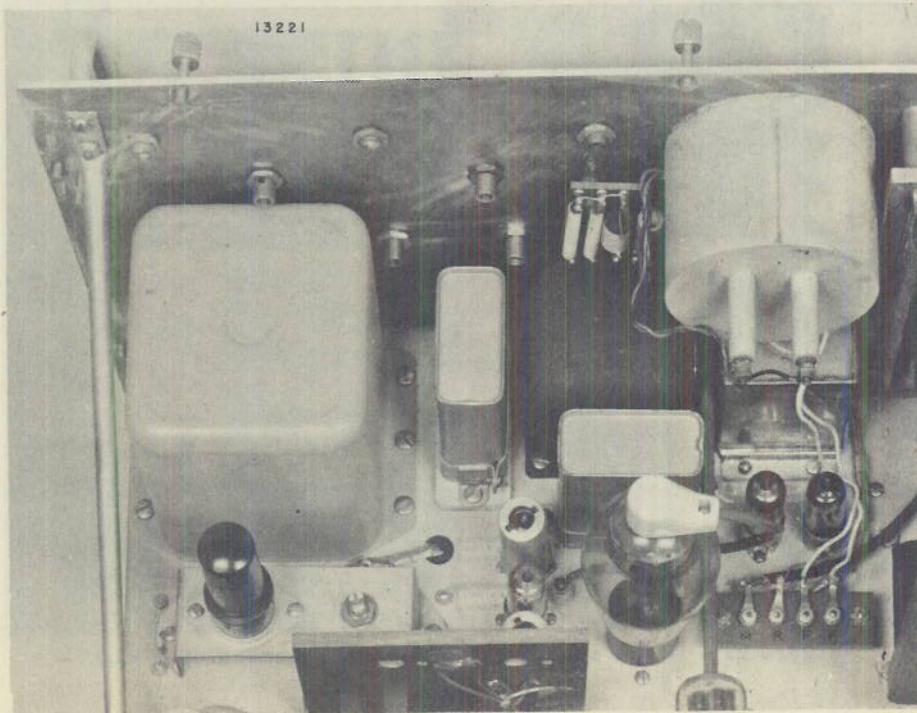


Figure 19 - TS-621 signal generator accelerator power supply

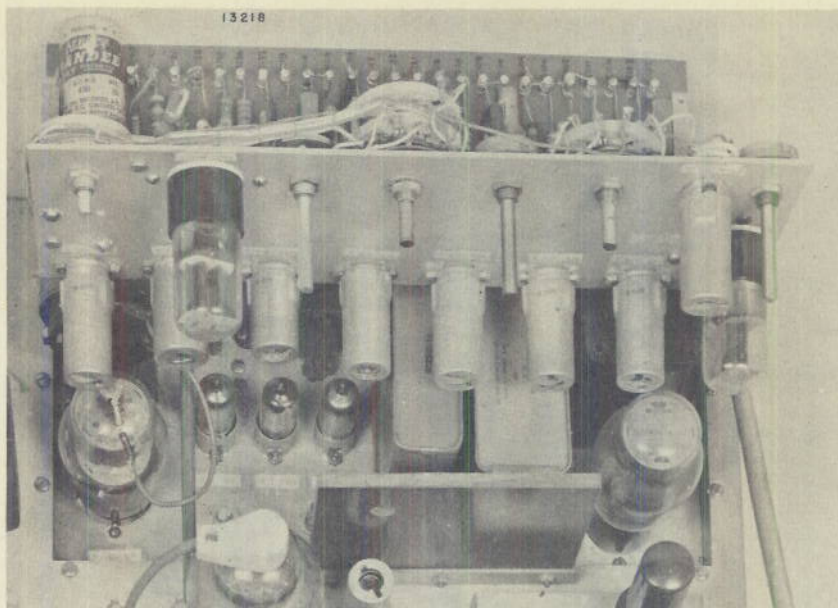


Figure 20 - Modulator and repeller power supply (TS-621 signal generator, NRL)

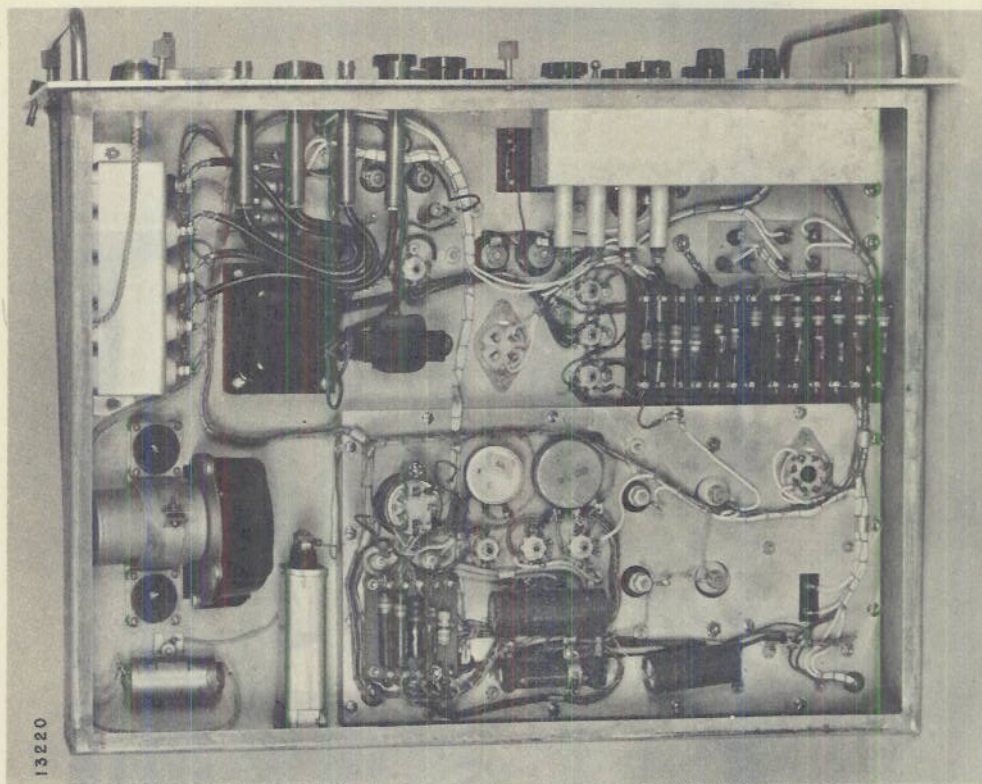


Figure 21 - Under chassis (TS-621 signal generator, NRL)

Figure 19 - TS-621 signal generator accelerator power supply

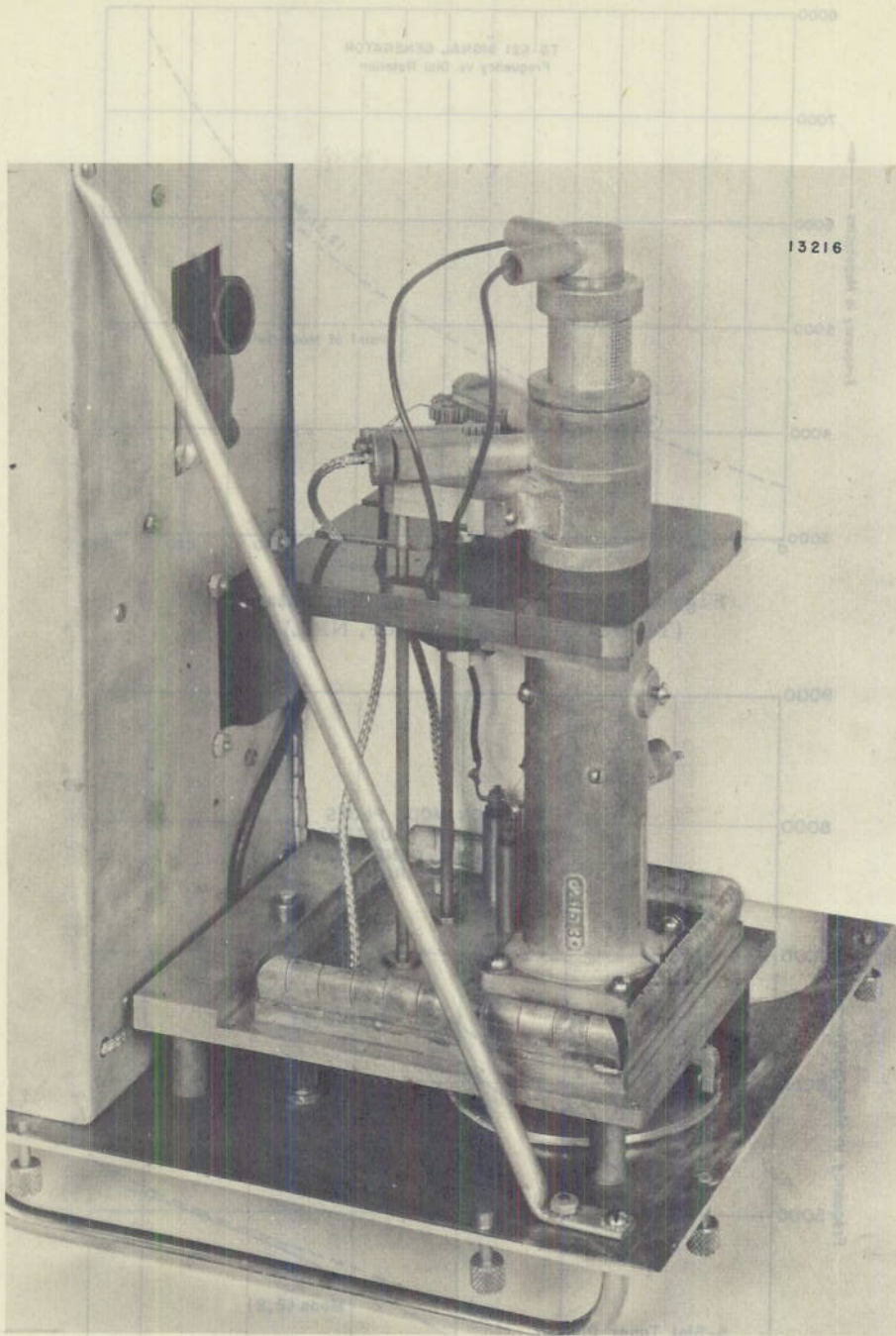


Figure 22 - TS-621 signal generator, oscillator section

Figure 24 - Comparison mode plots for 5- and 6-slot pluggers
(TS-621 signal generator development, NRL)

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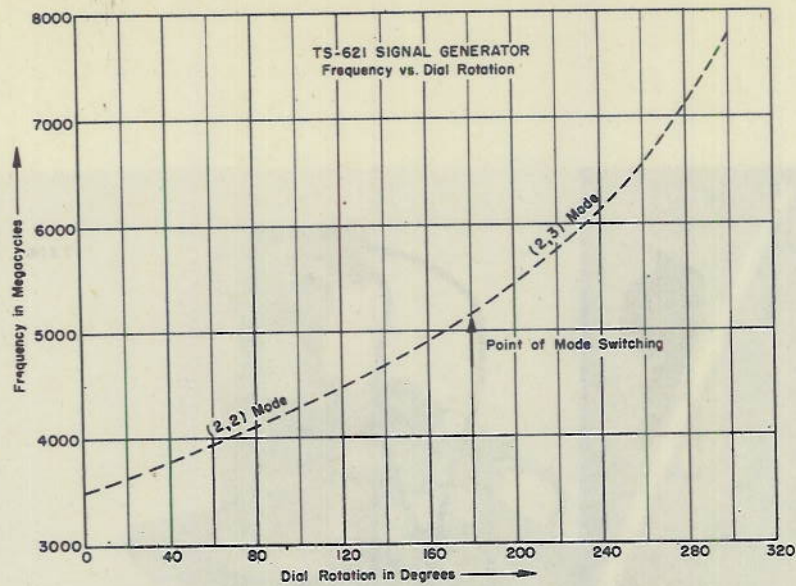


Figure 23 - Frequency vs. dial rotation
(TS-621 signal generator, NRL)

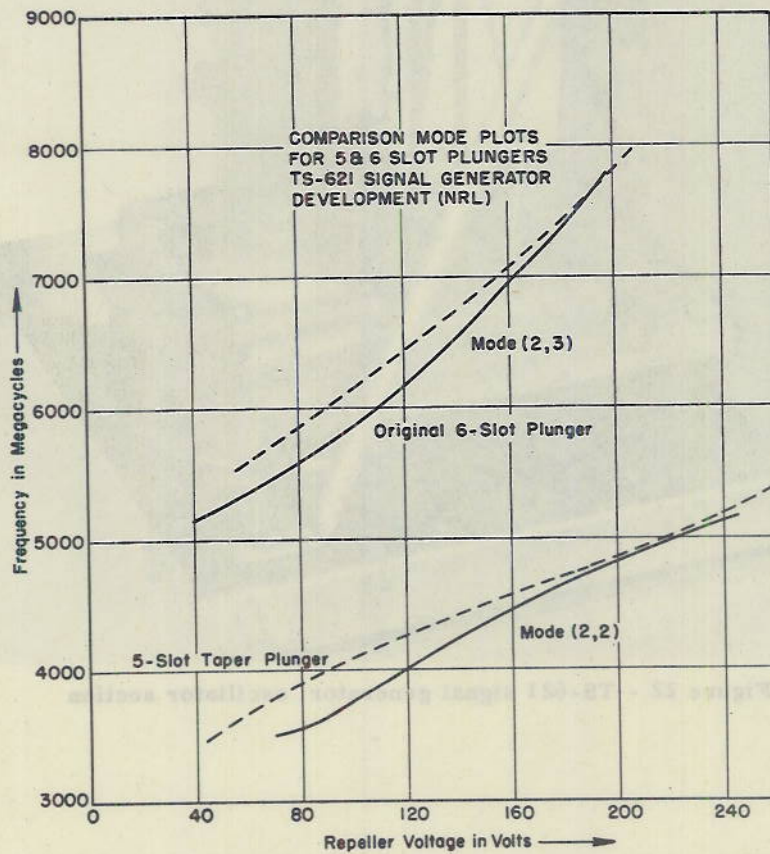


Figure 24 - Comparison mode plots for 5- and 6- slot plungers
(TS-621 signal generator development, NRL)

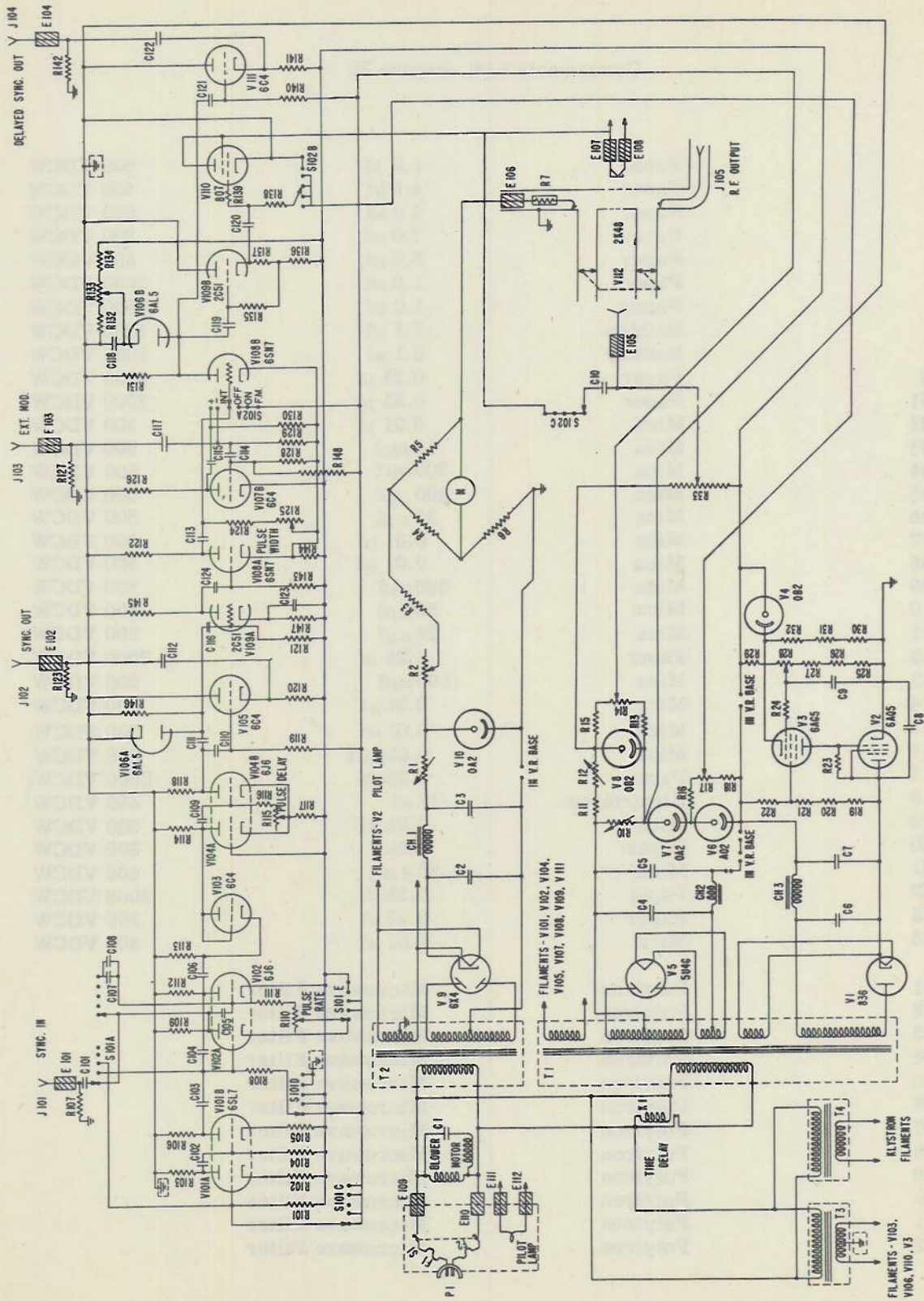


Figure 25 - Schematic diagram, TS-621 signal generator, NRL model

Components List, Figure 25

| | | | |
|------|--------------|--------------------|-----------|
| C1 | Paper | 1.0 μ f | 600 VDCW |
| C2 | Paper | 4.0 μ f | 500 VDCW |
| C3 | Paper | 4.0 μ f | 500 VDCW |
| C4 | Paper | 7.0 μ f | 800 VDCW |
| C5 | Paper | 8.0 μ f | 600 VDCW |
| C6 | Paper | 1.0 μ f | 2000 VDCW |
| C7 | Paper | 1.0 μ f | 2000 VDCW |
| C8 | Bathtub | 0.1 μ f | 1000 VDCW |
| C9 | Bathtub | 0.1 μ f | 1000 VDCW |
| C10 | Paper | 0.25 μ f | 2000 VDCW |
| C101 | Paper | 0.25 μ f | 2000 VDCW |
| C102 | Mica | 0.01 μ f | 300 VDCW |
| C103 | Mica | 15 μ μ f | 500 VDCW |
| C104 | Mica | 200 μ μ f | 500 VDCW |
| C105 | Mica | 300 μ μ f | 500 VDCW |
| C106 | Mica | 27 μ μ f | 500 VDCW |
| C107 | Mica | 0.01 μ f | 500 VDCW |
| C108 | Mica | 0.01 μ f | 500 VDCW |
| C109 | Mica | 680 μ μ f | 500 VDCW |
| C110 | Mica | 56 μ μ f | 500 VDCW |
| C111 | Mica | 25 μ μ f | 500 VDCW |
| C112 | Paper | 0.25 μ f | 2000 VDCW |
| C113 | Mica | 100 μ μ f | 500 VDCW |
| C114 | Mica | 0.01 μ f | 300 VDCW |
| C115 | Mica | 0.01 μ f | 300 VDCW |
| C116 | Mica | 0.01 μ μ f | 300 VDCW |
| C117 | Paper | 0.25 μ f | 2000 VDCW |
| C118 | Electrolytic | 16 μ f | 450 VDCW |
| C119 | Mica | 0.01 μ f | 500 VDCW |
| C120 | Paper | 1.0 μ f | 600 VDCW |
| C121 | Mica | 56 μ μ f | 400 VDCW |
| C122 | Paper | 0.25 μ f | 2000 VDCW |
| C123 | Paper | 0.25 μ f | 200 VDCW |
| C124 | Mica | 0.01 μ f | 300 VDCW |
| E101 | Polyiron | Microwave Filter | |
| E102 | Polyiron | Microwave Filter | |
| E103 | Polyiron | Microwave Filter | |
| E104 | Polyiron | Microwave Filter | |
| E105 | Polyiron | Microwave Filter | |
| E106 | Polyiron | Microwave Filter | |
| E107 | Polyiron | Microwave Filter | |
| E108 | Polyiron | Microwave Filter | |
| E109 | Polyiron | Microwave Filter | |
| E110 | Polyiron | Microwave Filter | |
| E111 | Polyiron | Microwave Filter | |
| E112 | Polyiron | Microwave Filter | |

| | | | |
|------|---------------------------|----------|--------------------|
| R113 | Composition | 33 K | $\frac{1}{2}$ watt |
| R114 | Composition | 33 K | 2 watts |
| R115 | Potentiometer Composition | 250 K | $\frac{1}{2}$ watt |
| R116 | Composition | 480 ohms | watt |
| R117 | Composition | 3.3 K | 1 watt |
| R118 | Composition | 22 K | 2 watts |
| R119 | Composition | 150 K | $\frac{1}{2}$ watt |
| R120 | Composition | 33 K | 1 watt |
| R121 | Composition | 100 K | $\frac{1}{2}$ watt |
| R122 | Composition | 100 K | 2 watts |
| R123 | Composition | 1.2 M | 1 watt |
| R124 | Composition | 2.2 K | $\frac{1}{2}$ watt |
| R125 | Potentiometer Composition | 100 K | watt |
| R126 | Composition | 4.7 K | $\frac{1}{2}$ watt |
| R127 | Composition | 1.2 M | 1 watt |
| R128 | Composition | 100 K | watt |
| R129 | Composition | 100 K | watt |
| R130 | Composition | 100 K | watt |
| R131 | Wire Wound | 47 K | 2 watts |
| R132 | Composition | 39 K | 1 watt |
| R133 | Potentiometer Composition | 50 K | 2 watts |
| R134 | Composition | 10 K | 2 watts |
| R135 | Composition | 150 K | $\frac{1}{2}$ watt |
| R136 | Composition | 33 K | 1 watt |
| R137 | Composition | 830 ohms | 1 watt |
| R138 | Composition | 1 K | watt |
| R139 | Composition | 100 ohms | watt |
| R140 | Composition | 150 K | watt |
| R141 | Composition | 30 K | 1 watt |
| R142 | Composition | 1.2 M | 1 watt |
| R143 | Composition | 100 K | $\frac{1}{2}$ watt |
| R144 | Composition | 6.8 K | $\frac{1}{2}$ watt |
| R145 | Composition | 18 K | 1 watt |
| R146 | Composition | 4.7 K | watt |
| R147 | Composition | 3.9 K | watt |
| R148 | Composition | 500 K | $\frac{1}{2}$ watt |

| | | |
|------|--------|------------------------------|
| J101 | B.N.C. | High Freq. Connector (Panel) |
| J102 | B.N.C. | High Freq. Connector (Panel) |
| J103 | B.N.C. | High Freq. Connector (Panel) |
| J104 | B.N.C. | High Freq. Connector (Panel) |
| J105 | | Type N Connector (Panel) |

| | |
|------|----------------------------|
| S101 | Rotary Switch Single Wafer |
| S102 | Rotary Switch Two Wafer |
| S1 | Double Pole Single Throw |

| | | |
|----|------|------------------------------|
| V1 | 836 | Vacuum Tube |
| V2 | 6AQ5 | Vacuum Tube Miniature |
| V3 | 6AG5 | Vacuum Tube Miniature |
| V4 | 0B2 | 105-Volt Regulator Miniature |
| V5 | 5U4G | Vacuum Tube |

| | | | |
|------|---------------------------|----------------------|--------------------|
| F1 | Fuse | 3 amp | |
| F2 | Fuse | 3 amp | |
| K1 | Time Delay Relay | 4 amp | Delay 35-45 sec |
| CH1 | Choke Thordarson T13C27 | 10H, 40 ma | |
| CH2 | Choke Kenyon T153 | 30H, 350 ohms, 90 ma | |
| CH3 | Choke Thordarson T15C52 | 30H, 675 ohms | |
| R1 | Wire Wound | 3000 ohms | 10 watts |
| R2 | Potentiometer Carbon | 2500 ohms | $\frac{1}{2}$ watt |
| R3 | Wire Wound | 11,000 ohms | 2 watts |
| R4 | Wire Wound | 250 ohms | 3 watts |
| R5 | Wire Wound | 250 ohms | 3 watts |
| R6 | Wire Wound | 200 ohms | 5 watts |
| R7 | Bead Thermistor | | |
| R10 | Wire Wound | 7 K | 25 watts |
| | | (Set at about 3.7K) | |
| R11 | Composition | 330 ohms | 1 watt |
| R12 | Wire Wound Variable | 7.5 K | 10 watts |
| R13 | Composition | 10 K | 2 watts |
| R14 | Potentiometer Wire Wound | 7.5 K | 1 watt |
| R15 | Composition | 18 K | 2 watts |
| R16 | Composition | 22 K | 2 watts |
| R17 | Potentiometer Wire Wound | 5.0 K | 1 watt |
| R18 | Composition | 3.3 K | 1 watt |
| R19 | Composition | 330 K | 1 watt |
| R20 | Composition | 330 K | 1 watt |
| R21 | Composition | 300 K | 1 watt |
| R22 | Composition | 180 K | 1 watt |
| R23 | Composition | 1 M | 1 watt |
| R24 | Composition | 47 K | $\frac{1}{2}$ watt |
| R25 | Composition | 100 K | 2 watts |
| R26 | Composition | 100 K | 2 watts |
| R27 | Composition | 100 K | 2 watts |
| R28 | Potentiometer Wire Wound | 5 K | 2 watts |
| R29 | Composition | 27 K | 1 watt |
| R30 | Composition | 82 K | 2 watts |
| R31 | Composition | 82 K | 2 watts |
| R32 | Composition | 82 K | 2 watts |
| R33 | Potentiometer Wire Wound | 100 K | 2 watts |
| R101 | Composition | 1.2 M | $\frac{1}{2}$ watt |
| R102 | Composition | 1.5 K | $\frac{1}{2}$ watt |
| R103 | Composition | 470 K | $\frac{1}{2}$ watt |
| R104 | Composition | 1.2 M | $\frac{1}{2}$ watt |
| R105 | Composition | 1.5 K | $\frac{1}{2}$ watt |
| R106 | Composition | 470 K | $\frac{1}{2}$ watt |
| R107 | Composition | 1.2 M | 1 watt |
| R108 | Composition | 200 K | $\frac{1}{2}$ watt |
| R109 | Composition | 47 K | 2 watts |
| R110 | Potentiometer Composition | 3 M | $\frac{1}{2}$ watt |
| R111 | Composition | 220 K | $\frac{1}{2}$ watt |
| R112 | Composition | 18 K | 2 watts |

| | | |
|------|------|------------------------------|
| V6 | 0A2 | 150-Volt Regulator Miniature |
| V7 | 0A2 | 150-Volt Regulator Miniature |
| V8 | 0B2 | 105-Volt Regulator Miniature |
| V9 | 6X4 | Vacuum Tube Miniature |
| V10 | 0A2 | 150-Volt Regulator Miniature |
| V101 | 6SL7 | Vacuum Tube |
| V102 | 6J6 | Vacuum Tube Miniature |
| V103 | 6C4 | Vacuum Tube Miniature |
| V104 | 6J6 | Vacuum Tube Miniature |
| V105 | 6C4 | Vacuum Tube Miniature |
| V106 | 6AL5 | Vacuum Tube Miniature |
| V107 | 6C4 | Vacuum Tube Miniature |
| V108 | 6SN7 | Vacuum Tube |
| V109 | 2C51 | Vacuum Tube Jumbo Miniature |
| V110 | 807 | Vacuum Tube |
| V111 | 6C4 | Vacuum Tube Miniature |
| V112 | 2K48 | Klystron Oscillator |

| | |
|----|--|
| T1 | Main Power Transformer NRL Designed |
| T2 | Thordarson T13R19 |
| T3 | Filament Transformer (6.3 v, a.c.) |
| T4 | Filament Transformer for 2K48 NRL Design (6.3 v, a.c.) |

| | | | |
|----|-----|-----|-----------------|
| P1 | 110 | 15A | Male Panel Plug |
|----|-----|-----|-----------------|

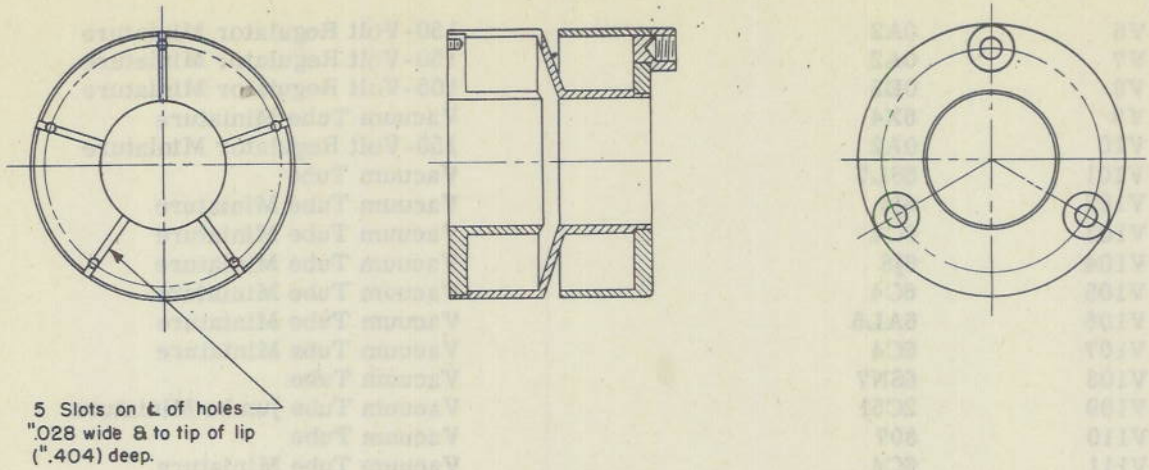


Figure 26 - TS-621 signal generator 5-slot "Z" plunger

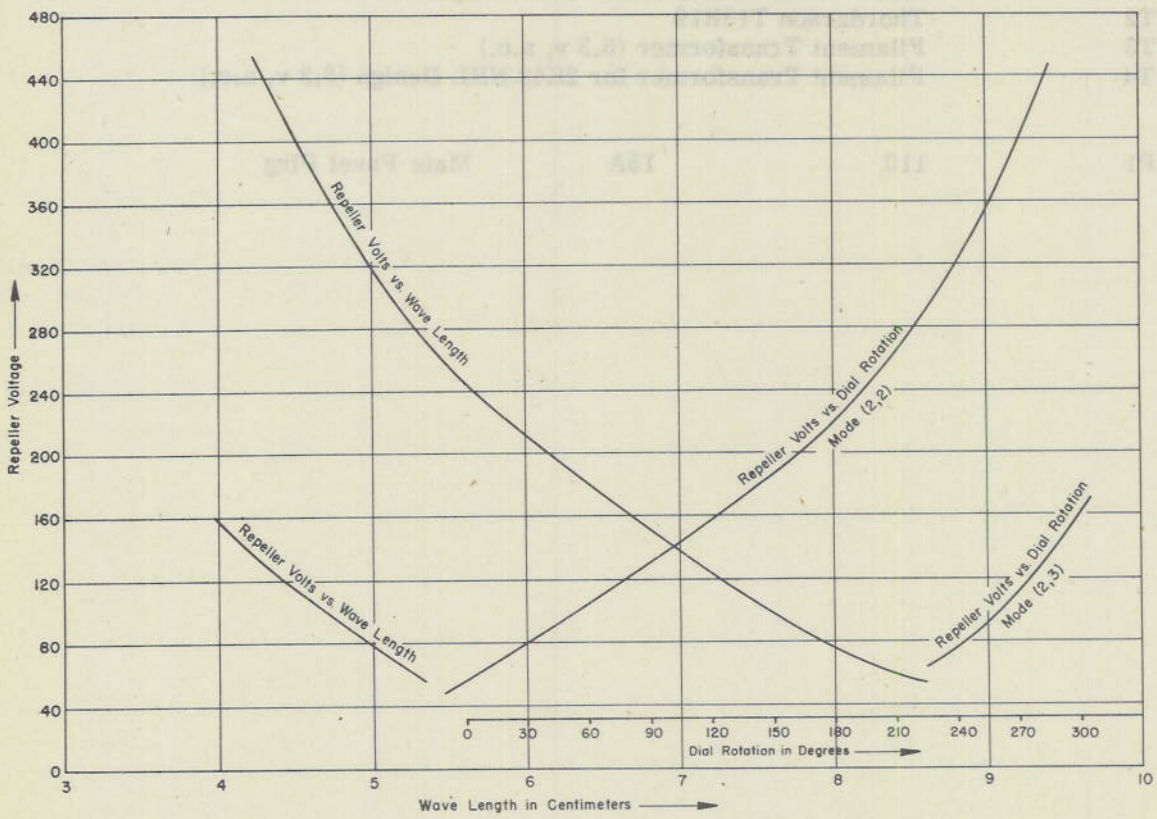


Figure 27 - Repeller characteristics, TS-621 signal generator development

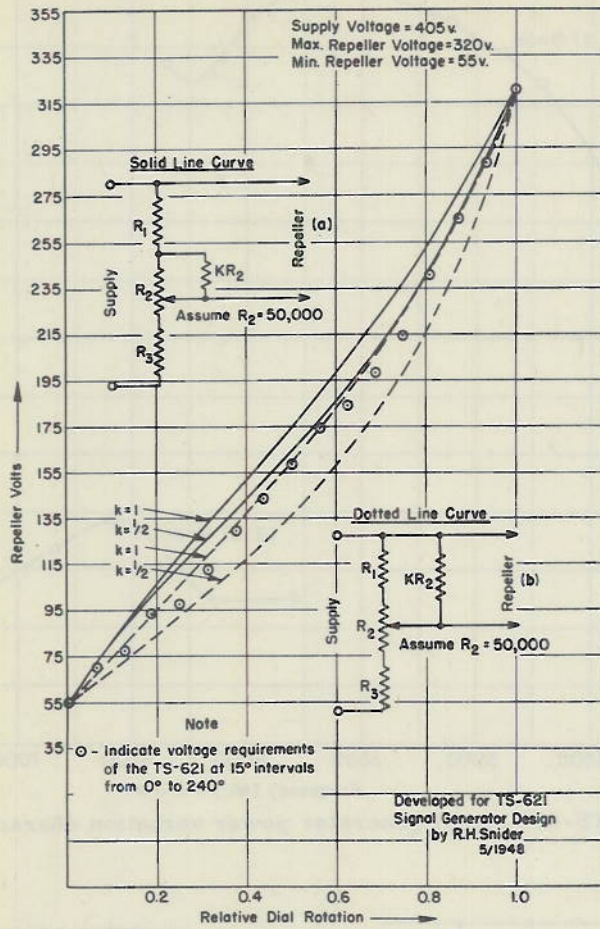


Figure 28 - TS-621 signal generator tracking systems

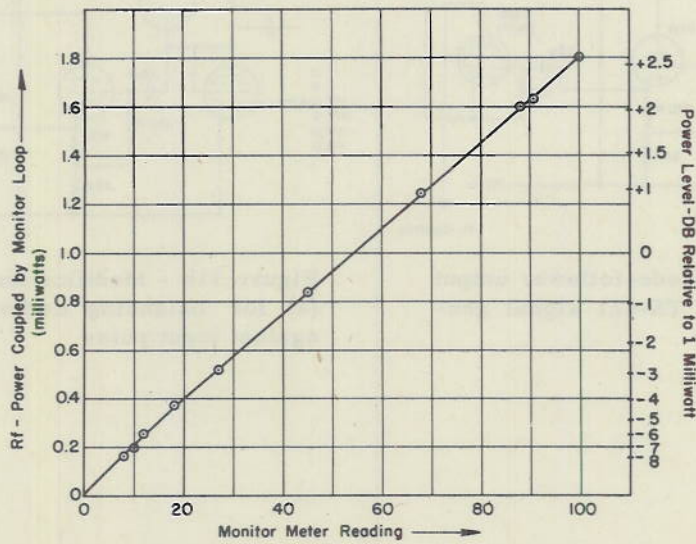


Figure 29 - Power monitor characteristics, TS-621 signal generator

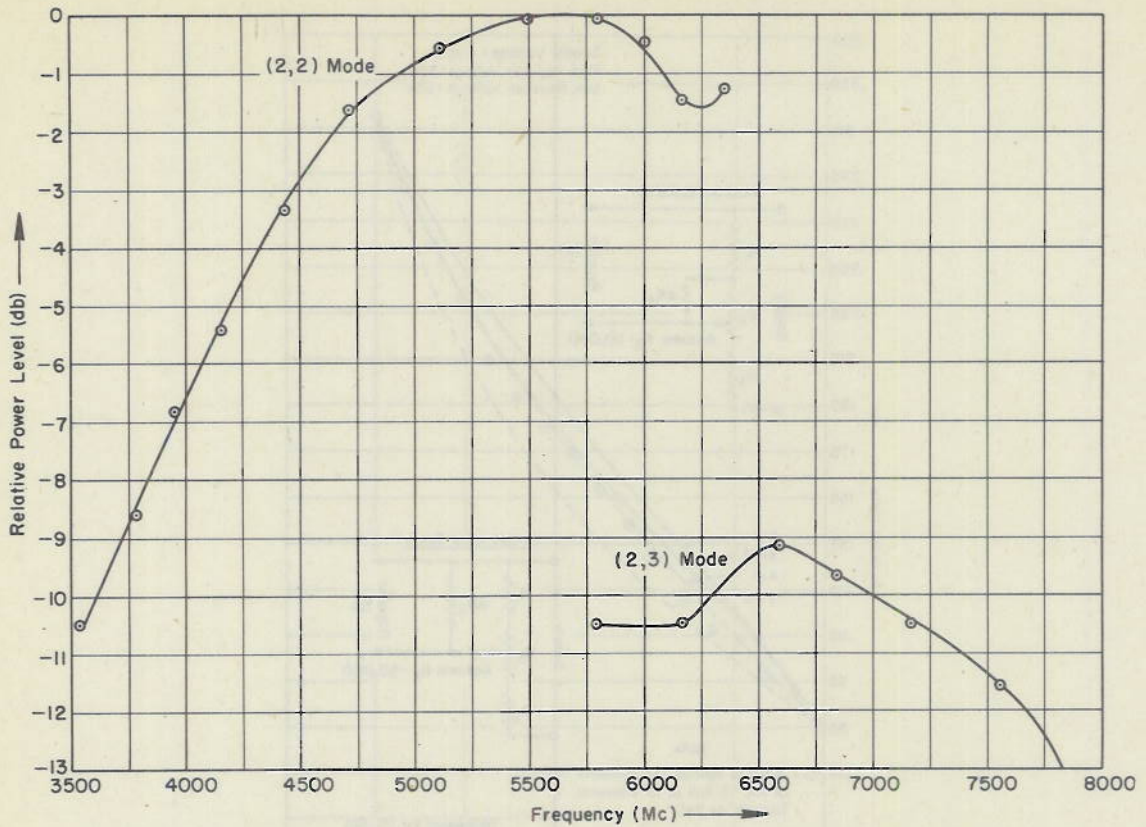


Figure 30 - TS-621 signal generator power variation characteristics

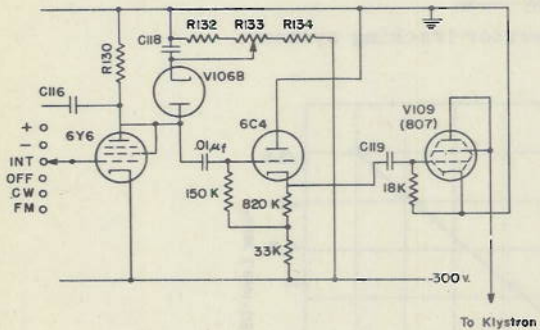


Figure 31a - Cathode-follower output circuit for NRL TS-621 signal generator modulator

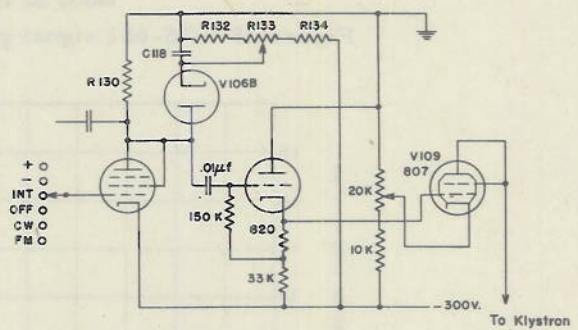


Figure 31b - Modification of circuit (a) for balancing cathode potential against input pulse

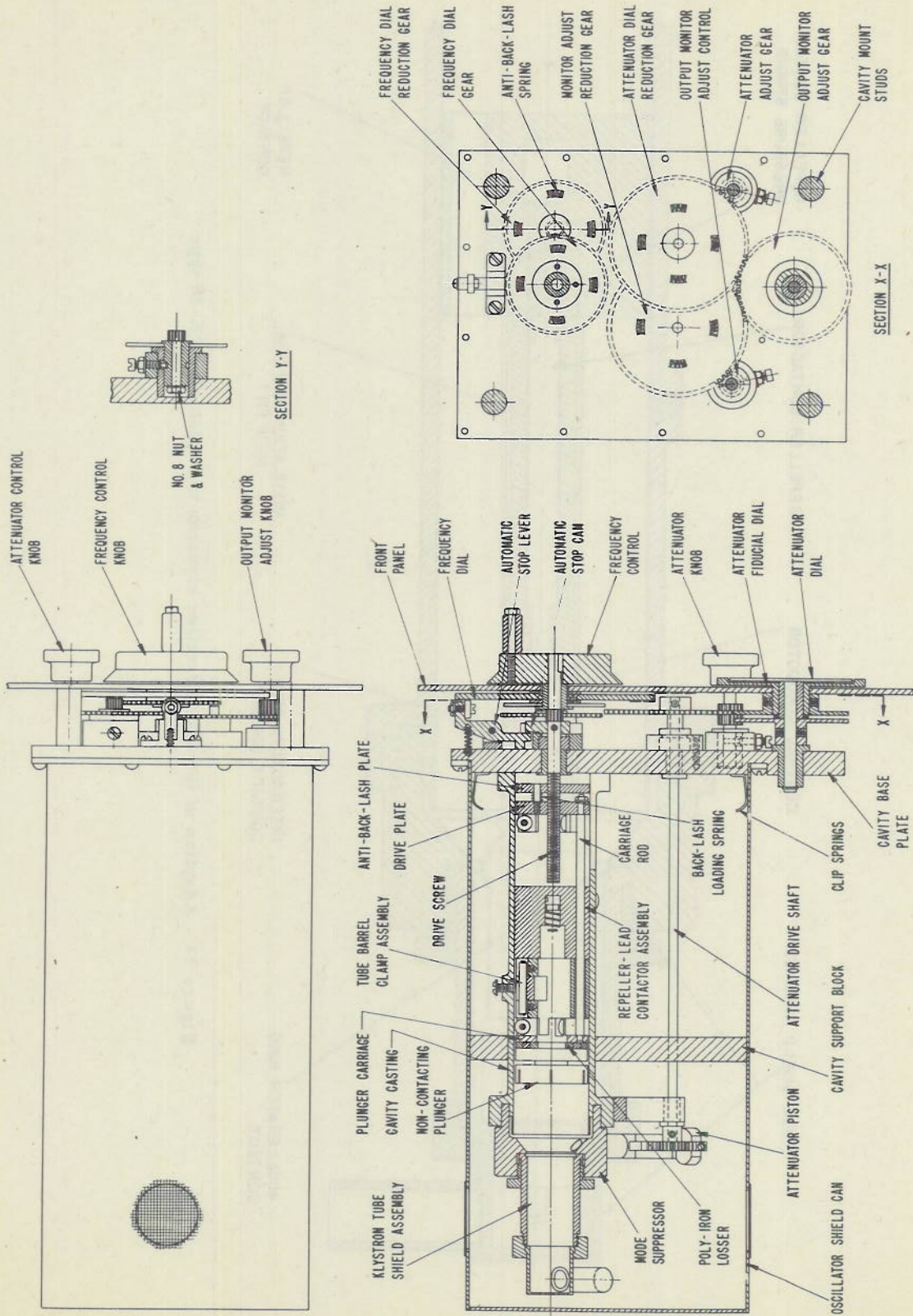


Figure 32 - TS-622 oscillator assembly

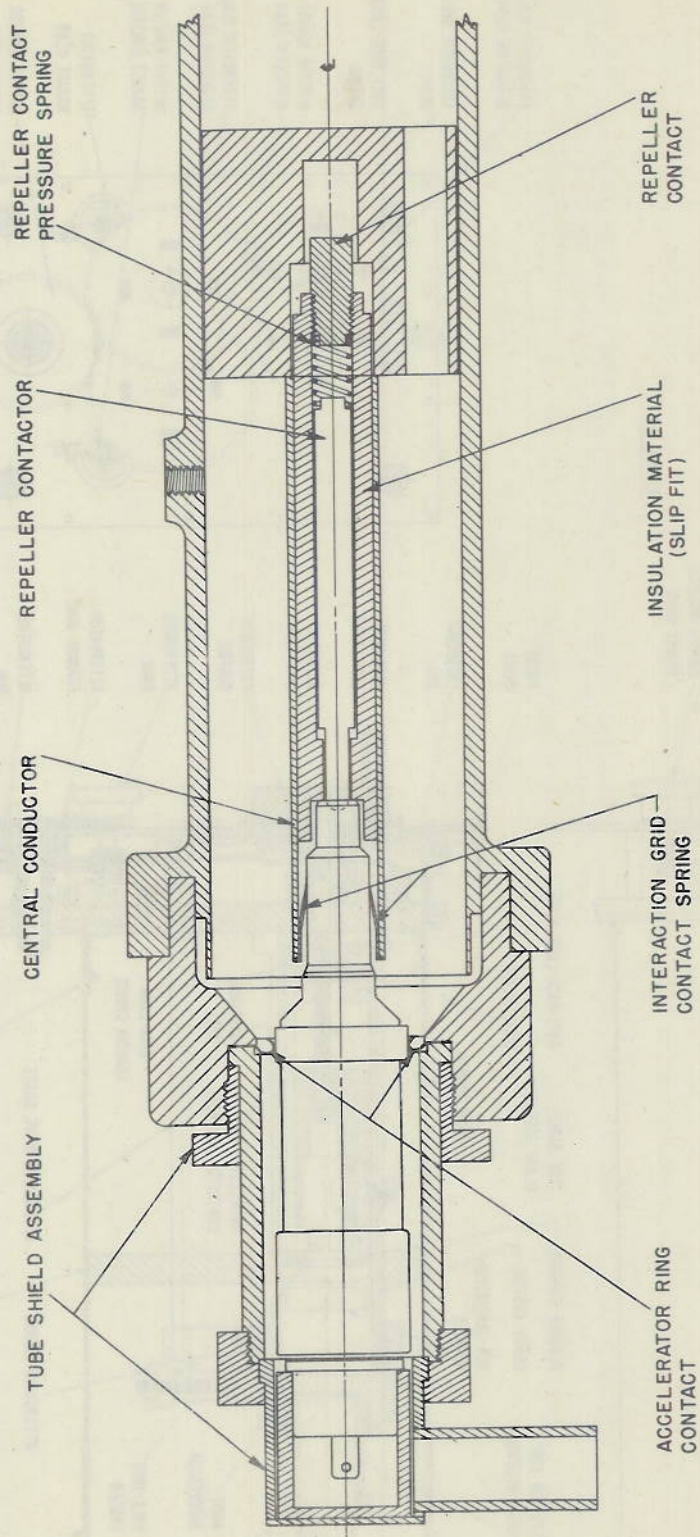


Figure 33 - Adaption of the QK-205 reflex klystron to replace the 2K-48 type

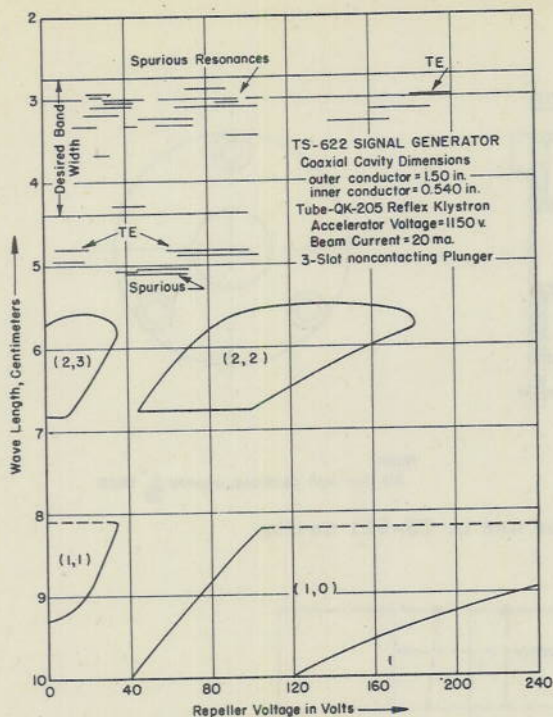


Figure 34 - Mode plot of QK-205 in resonator using 3-slot noncontacting plunger

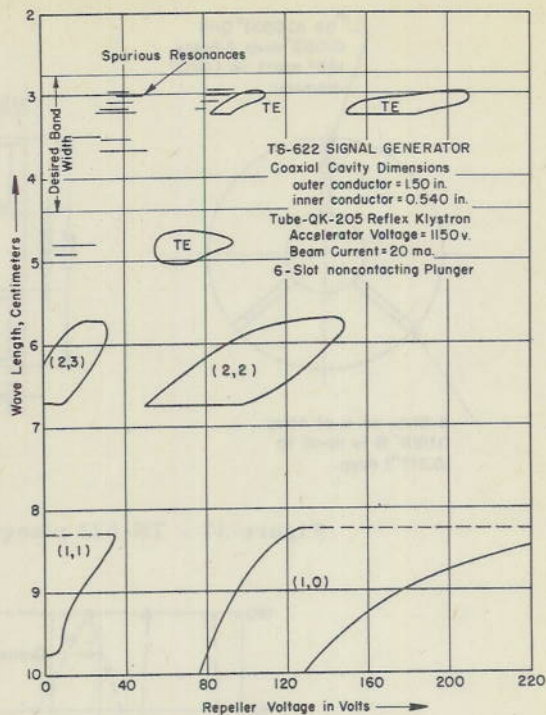


Figure 35 - Mode plot of QK-205 in resonator using 6-slot noncontacting plunger

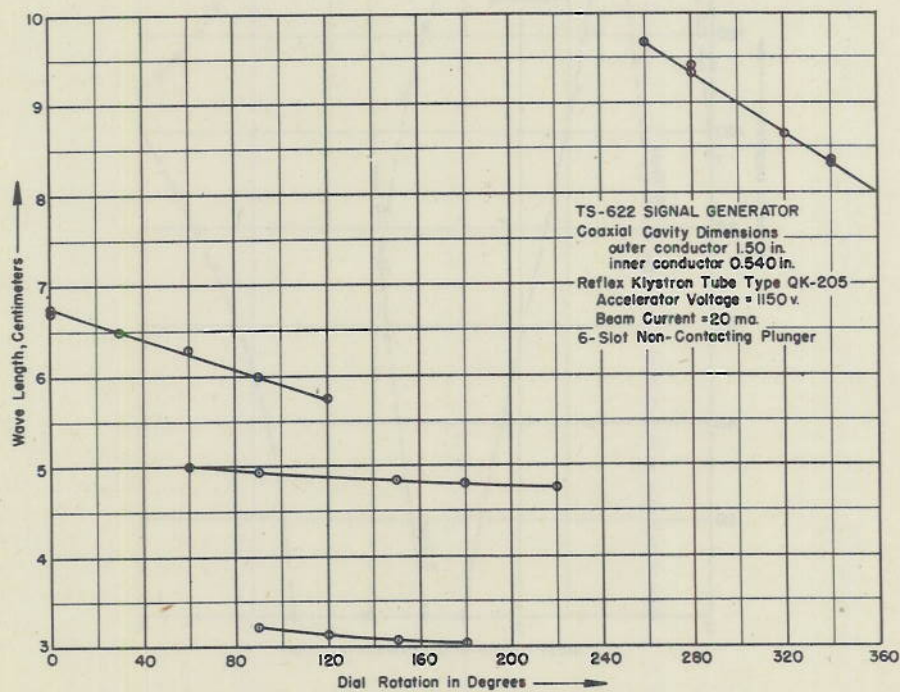


Figure 36 - Tuning curves of QK-205 with resonator

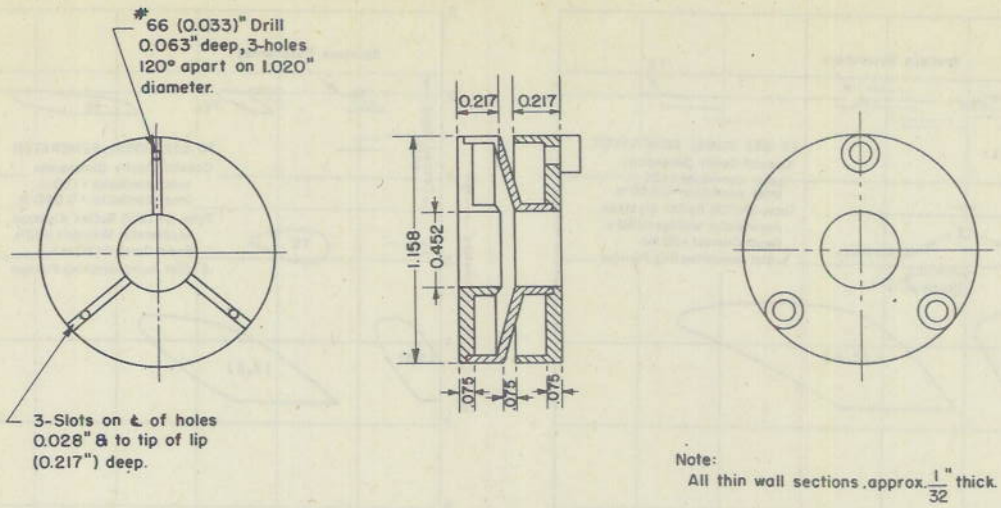


Figure 37 - TS-622 plunger for use in TS-621 cavity

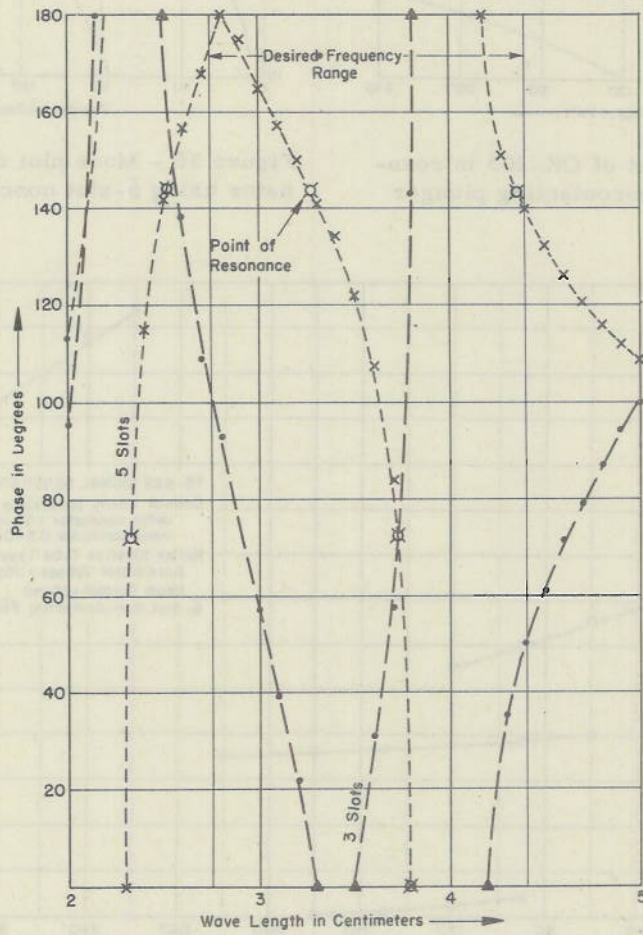


Figure 38 - Parasitic resonances in a slotted plunger

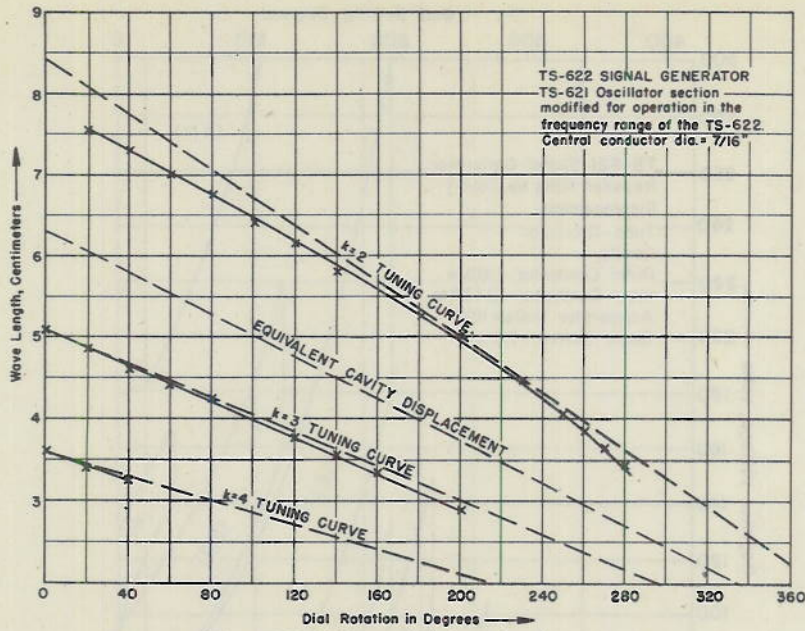


Figure 39 - QK-205 oscillator tuning curves

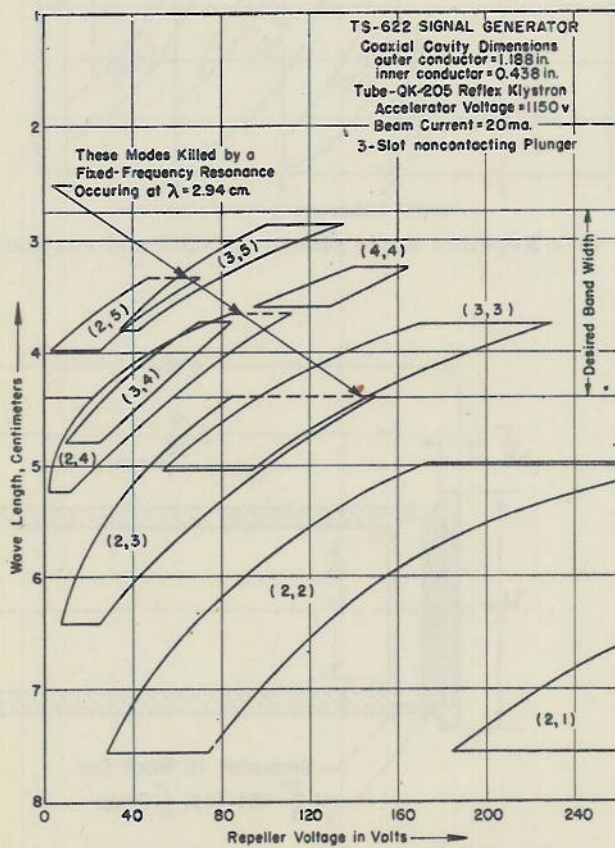


Figure 40 - Mode plot of QK-205 in resonator

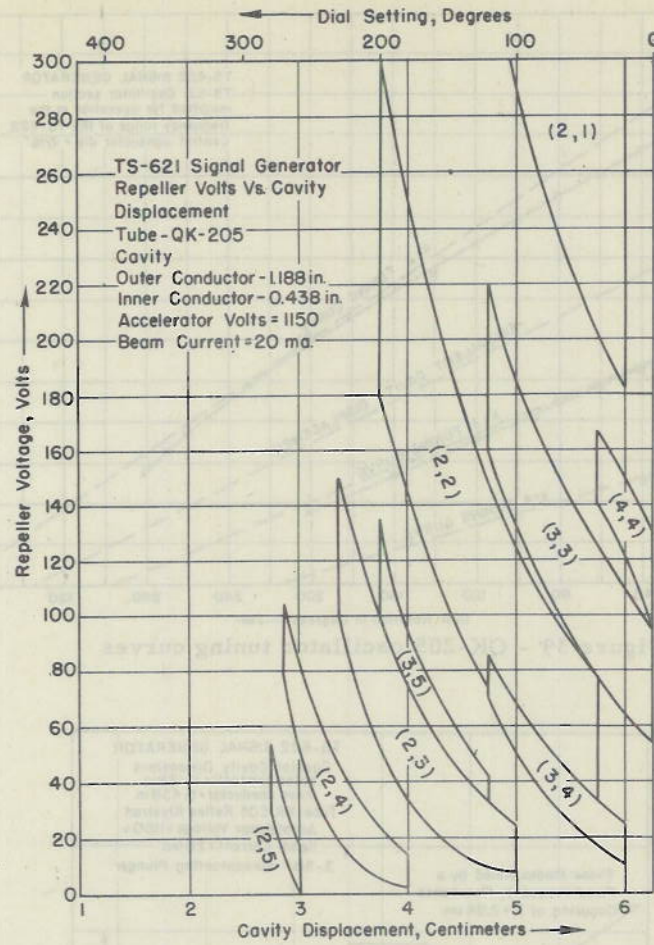


Figure 41 - Repeller mode plot of QK-205 and resonator

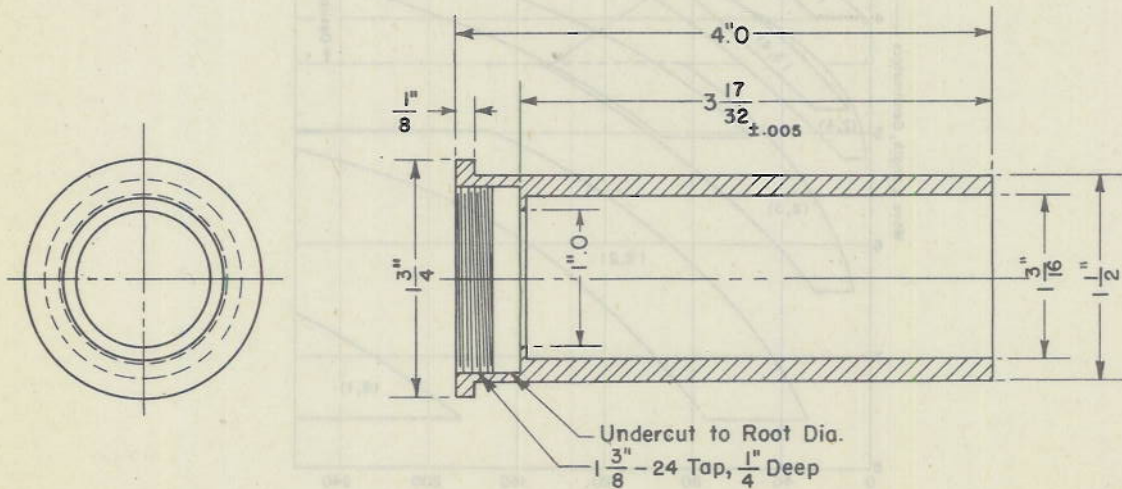


Figure 42 - TS-621 coaxial cavity sleeve insert

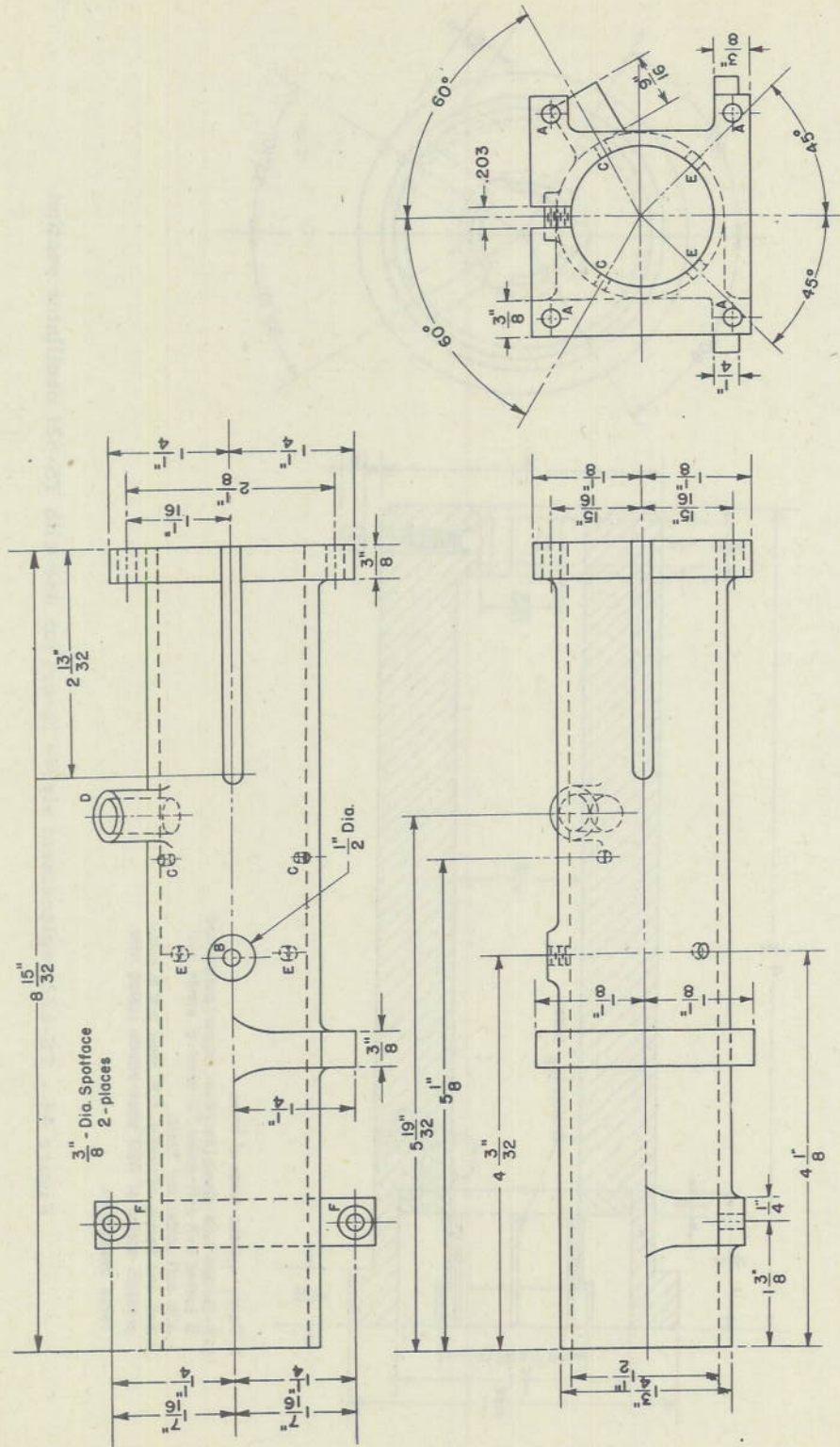


Figure 43 - TS-621 coaxial cavity casting

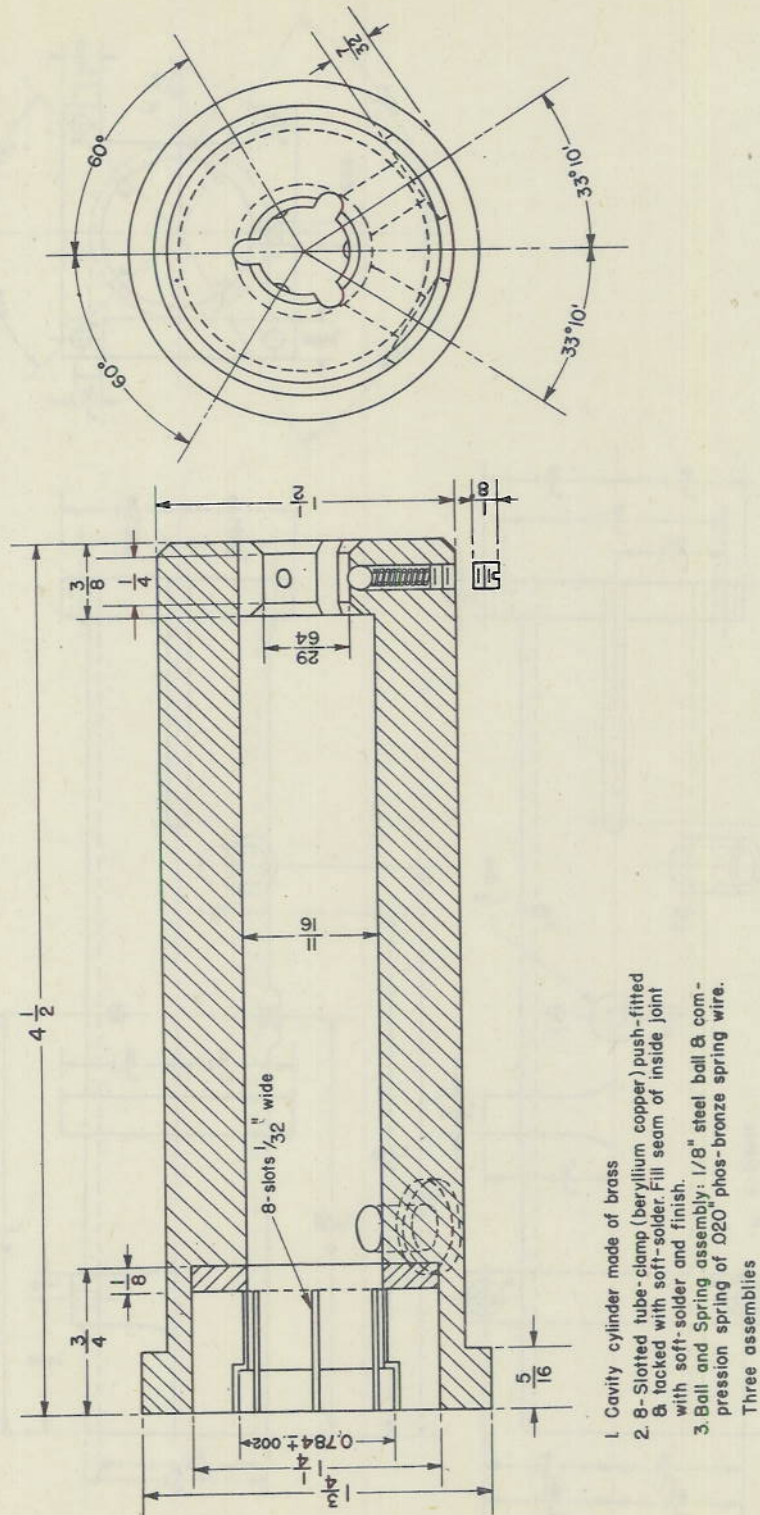


Figure 44 - TS-622 replacement sleeve insert for use with TS-621 oscillator section

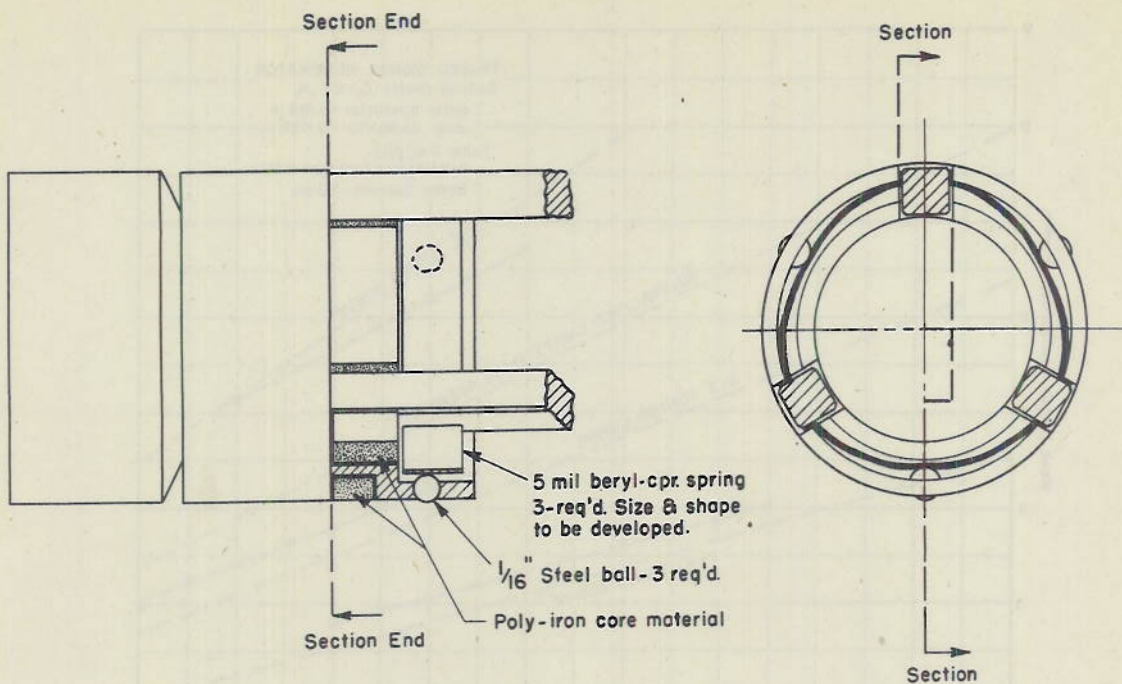


Figure 45a - Cross section of TS-622 cavity plunger

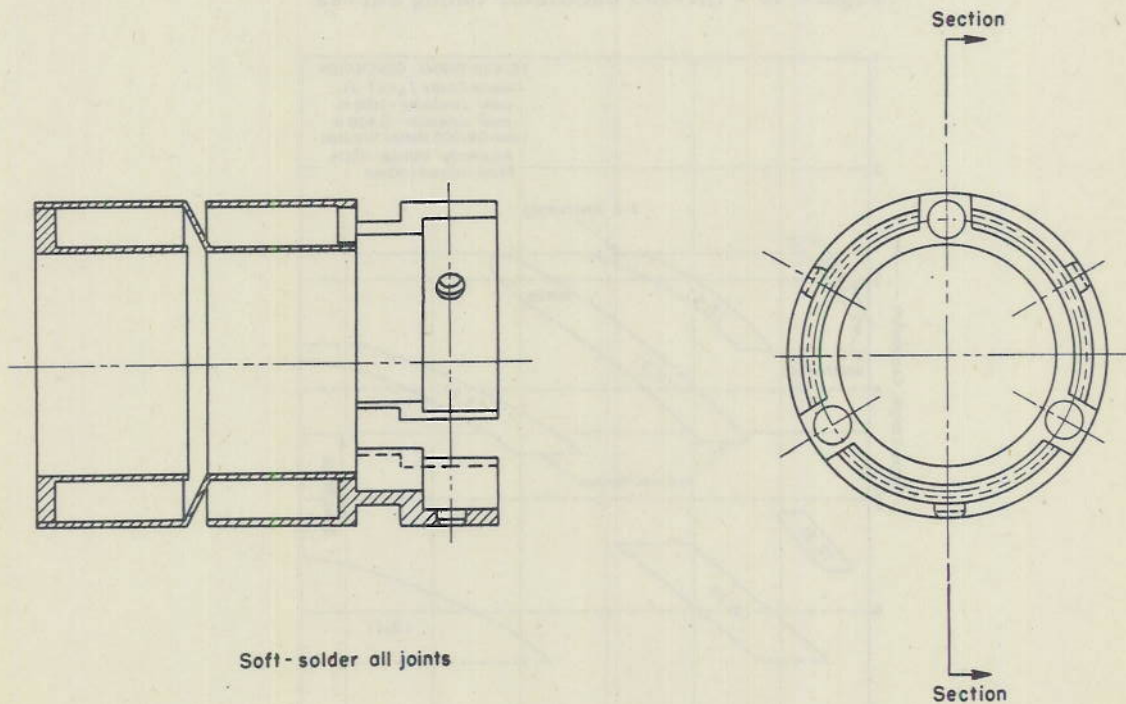


Figure 45b - Assembled drawing of TS-622 cavity plunger

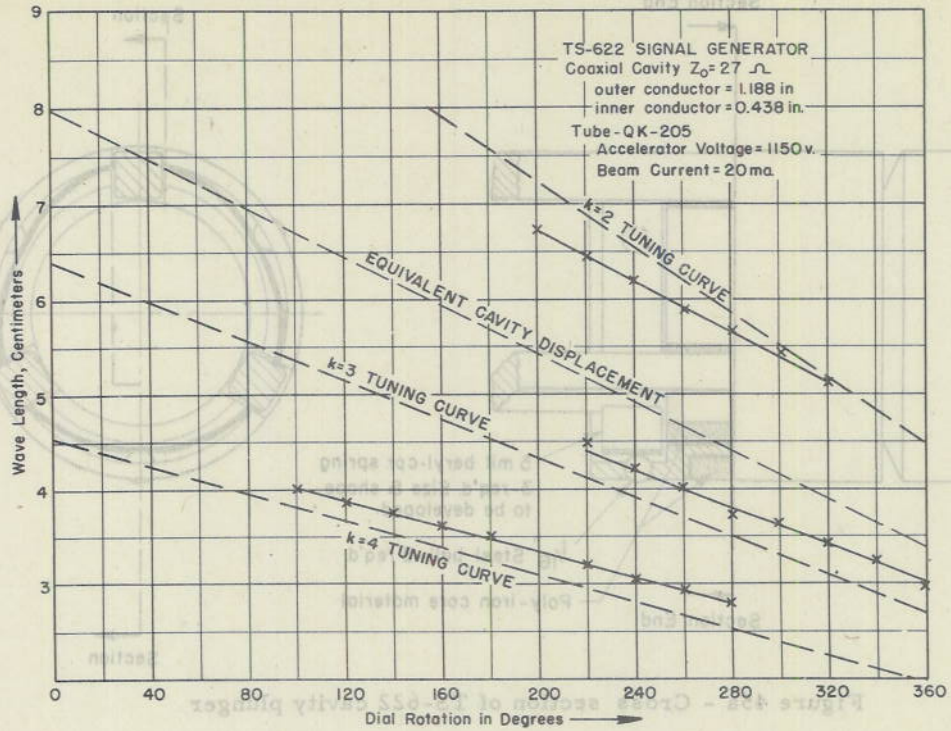


Figure 46 - QK-205 oscillator tuning curves

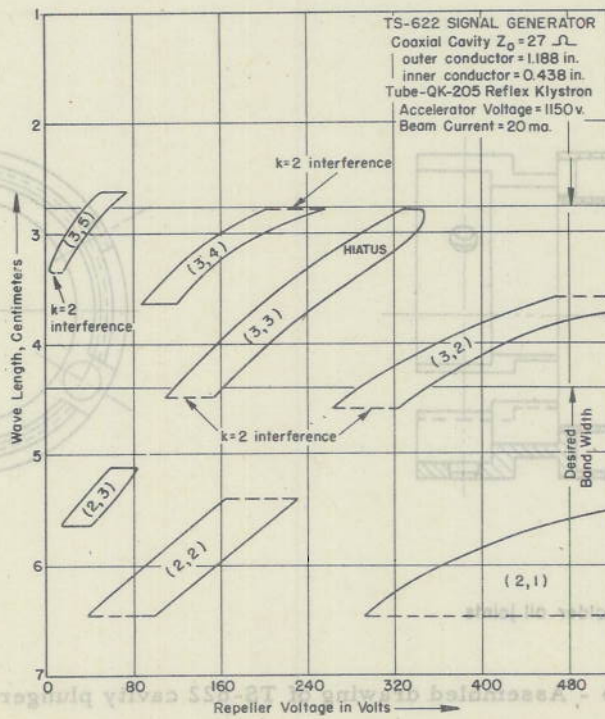


Figure 47 - $5/4\lambda$ cavity mode plot for QK-205 and resonator

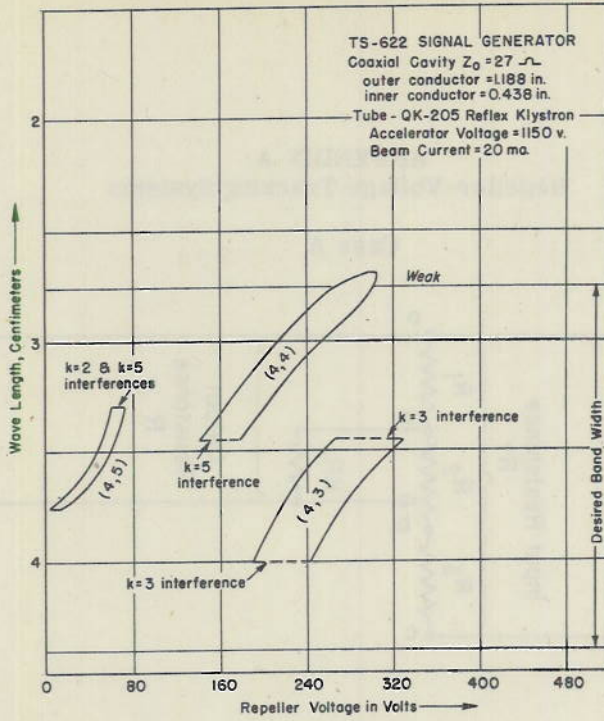


Figure 48 - $7/4 \lambda$ cavity mode plot for QK-205 and resonator

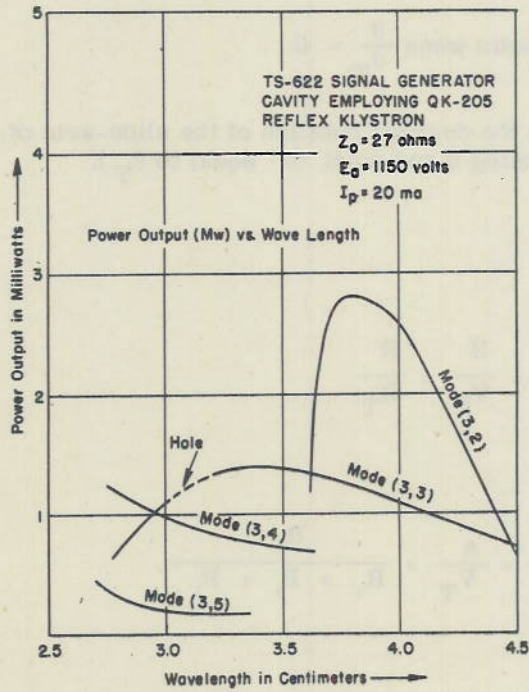
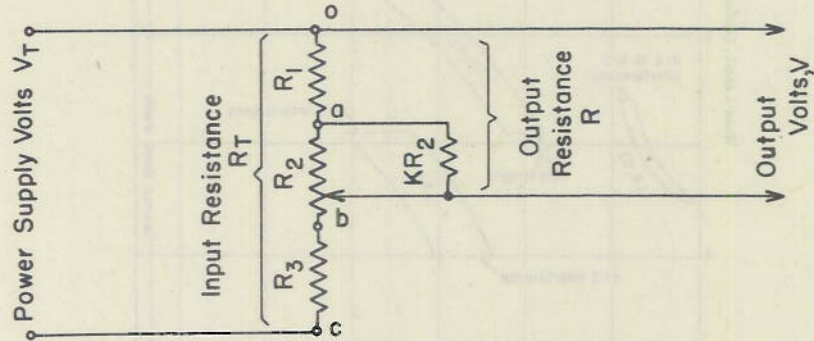


Figure 49 - Rf power coupled from TS-622 oscillator cavity

APPENDIX A
Repeller-Voltage Tracking Systems

Case A



Required that:

1. Voltage $V_{ob} = B$ volts when $\frac{\theta}{\theta_T} = 1$
2. Voltage $V_{oa} = A$ volts when $\frac{\theta}{\theta_T} = 0$

(where θ is the degrees rotation of the slide-arm of potentiometer R_2 , point "a" being 0 and point "b" equal to θ_T).

Under the condition of:

1. $\frac{\theta}{\theta_T} = 1$

then
$$\frac{V_{ob}}{V_{oc}} = \frac{B}{V_T} = \frac{R}{R_T}$$

2. $\frac{\theta}{\theta_T} = 0$

then
$$\frac{V_{oa}}{V_{oc}} = \frac{A}{V_T} = \frac{R_1}{R_1 + R_2 + R_3}$$

Since

$$R = R_1 + \frac{R_2 \times KR_2}{R_2 + KR_2}$$

$$= \frac{K(R_1 + R_2) + R_1}{K + 1} \quad \text{when } \frac{\theta}{\theta_T} = 1$$

also

$$R_T = R + R_3$$

$$= \frac{K(R_1 + R_2 + R_3) + (R_1 + R_3)}{K + 1} \quad \text{when } \frac{\theta}{\theta_T} = 1$$

from which

$$\frac{R}{R_T} = \frac{K(R_1 + R_2) + R_1}{K(R_1 + R_2 + R_3) + (R_1 + R_3)} = \frac{B}{V_T} \quad (1)$$

For Arbitrary Values of θ :

R becomes

$$R_1 + \frac{\left(\frac{\theta}{\theta_T} R_2\right) KR_2}{\frac{\theta}{\theta_T} R_2 + KR_2}$$

$$= \frac{K\left(R_1 + R_2 \frac{\theta}{\theta_T}\right) + R_1 \frac{\theta}{\theta_T}}{K + \frac{\theta}{\theta_T}}$$

and

$$R_T = R + \left[R_2 \left(1 - \frac{\theta}{\theta_T}\right) + R_3 \right]$$

$$= \frac{K(R_1 + R_2 + R_3) + \frac{\theta}{\theta_T}(R_1 + R_3) + R_2 \frac{\theta}{\theta_T} \left(1 - \frac{\theta}{\theta_T}\right)}{K + \frac{\theta}{\theta_T}}$$

from which

$$\frac{R}{R_T} = \frac{K\left(R_1 + \frac{\theta}{\theta_T} R_2\right) + \frac{\theta}{\theta_T} R_1}{K(R_1 + R_2 + R_3) + \frac{\theta}{\theta_T}(R_1 + R_3) + \frac{\theta}{\theta_T} R_2 \left(1 - \frac{\theta}{\theta_T}\right)} \quad (2)$$

which also = $\frac{V}{V_T}$.

From the Equations of Condition 2:

$$R_1 = \frac{R_2 + R_3}{\frac{V_T}{A} - 1}$$

Substituting this value for R_1 into Equation (1), and setting

$$\frac{B}{V_T} = N \quad \text{and} \quad \frac{V_T}{A} = M \quad \text{we have:}$$

$$\begin{aligned} \frac{B}{V_T} = N &= \frac{K\left(\frac{R_2 + R_3}{M - 1} + R_2\right) + \left(\frac{R_2 + R_3}{M - 1}\right)}{K\left(\frac{R_2 + R_3}{M - 1} + R_2 + R_3\right) + \left(\frac{R_2 + R_3}{M - 1} + R_3\right)} \\ N &= \frac{R_3(1 + K) + R_2(KM + 1)}{MR_3(1 + K) + R_2(KM + 1)} \end{aligned}$$

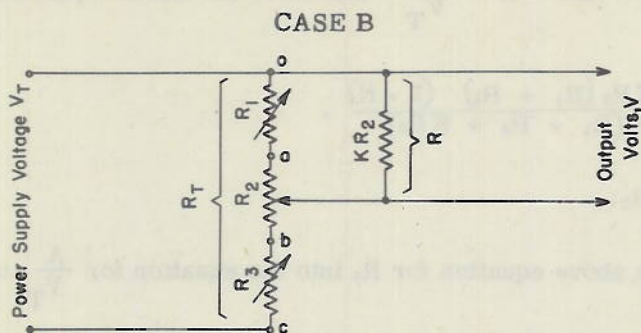
from which

$$\begin{aligned} R_3 &= \frac{R_2(KM + 1)(1 - N)}{(1 + K)(MN - 1)} \\ &= \frac{R_2\left(K\frac{V_T}{A} + 1\right)\left(1 - \frac{B}{V_T}\right)}{(1 + K)\left(\frac{B}{A} - 1\right)} \end{aligned} \quad (3)$$

Substituting this value for R_3 into the above equation for R_1 , R_1 becomes:

$$\begin{aligned} R_1 &= \frac{R_2\left[(1 + K)(MN - 1) + (KM + 1)(1 - N)\right]}{(1 + K)(MN - 1)(M - 1)} \\ &= \frac{R_2\left[(1 + K)\left(\frac{B}{A} - 1\right) + \left(K\frac{V_T}{A} + 1\right)\left(1 - \frac{B}{V_T}\right)\right]}{(1 + K)\left(\frac{B}{A} - 1\right)\left(\frac{V_T}{A} - 1\right)} \end{aligned} \quad (4)$$

In calculating a system assume an appropriate value for R_2 . Also assume a value for R_T that will perform the current limiting that is desired. K is an arbitrary constant, a value that must be determined graphically.



Required that:

1. Voltage $V_{Oa} = A$ volts when $\frac{\theta}{\theta_T} = 0$
 (where θ is the degrees rotation of the slide-arm of potentiometer R_2 , point "a" being zero and point "b" equal to θ_T).
2. Voltage $V_{Ob} = B$ volts when $\frac{\theta}{\theta_T} = 1$.

Under conditions of:

1. $\frac{\theta}{\theta_T} = 0$

$$\frac{V_{Oa}}{V_{Oc}} = \frac{A}{V_T} = \frac{\frac{KR_1 R_2}{R_1 + KR_2}}{\frac{KR_1 R_2}{R_1 + KR_2} + R_2 + R_3}$$

and
$$\frac{A}{V_T} = \frac{KR_1 R_2}{KR_2 (R_1 + R_2 + R_3) + R_1 (R_2 + R_3)}$$

2. $\frac{\theta}{\theta_T} = 1$

$$\frac{V_{Ob}}{V_{Oc}} = \frac{B}{V_T} = \frac{\frac{KR_2 (R_1 + R_2)}{R_1 + R_2 + KR_2}}{\frac{KR_2 (R_1 + R_2)}{R_1 + R_2 + KR_2} + R_3}$$

$$\frac{B}{V_T} = \frac{KR_2 (R_1 + R_2)}{KR_2 (R_1 + R_2) + R_3 (R_1 + R_2 + KR_2)}$$

Let

$$M = \frac{A}{V_T} \quad \text{and} \quad N = \frac{B}{V_T} \quad \text{and solve the above equation for } R_3.$$

$$R_3 = \frac{KR_2(R_1 + R_2)(1 - N)}{N(R_1 + R_2 + KR_2)}.$$

Solving for R_1 and R_3 :

Substituting the above equation for R_3 into the equation for $\frac{A}{V_T}$ under the heading of condition 1 gives:

$$\frac{A}{V_T} = M = \frac{KR_1R_2}{KR_1R_2 + R_1R_2 + KR_2^2 + \frac{(R_1 + KR_2)(1 - N)(R_1 + R_2)KR_2}{N(R_1 + R_2 + KR_2)}}.$$

Multiplying this equation out and setting the right-hand side equal to zero, we obtain the following:

$$R_1^2(MN + KM - KN) + R_1(2KMNR_2 + K^2MR_2 + MNR_2 + KMR_2 - KNR_2 - K^2NR_2) + (KMNR_2^2 + K^2MR_2^2) = 0.$$

This equation is now in the form:

$$aR_1^2 + bR_1 + c = 0$$

for which the solution is

$$R_1 = \frac{-b \pm \sqrt{b^2 - 4ac}}{2a}$$

and

$$a = (MN + KM - KN) = M(N + K) - KN$$

$$b = R_2 [MN(2K + 1) + K(K + 1)(M - N)]$$

$$c = KMR_2^2(N + K)$$

Substituting the above value for R_1 into the previous equation for R_3 :

$$R_3 = \frac{KR_2(-b \pm \sqrt{b^2 - 4ac} + 2aR_2)(1 - N)}{N(-b \pm \sqrt{b^2 - 4ac} + 2aR_2 + 2aR_2K)}.$$

For arbitrary values of θ :

$$\frac{V}{V_T} = \frac{\frac{KR_2 \left(R_1 + \frac{\theta}{\theta_T} R_2 \right)}{KR_2 + \frac{\theta}{\theta_T} R_2 + R_1}}{\frac{KR_2 \left(R_1 + \frac{\theta}{\theta_T} R_2 \right)}{KR_2 + \frac{\theta}{\theta_T} R_2 + R_1} + R_2 \left(1 - \frac{\theta}{\theta_T} \right) + R_3}$$

$$= \frac{KR_2 \left(R_1 + \frac{\theta}{\theta_T} R_2 \right)}{R_2^2 \left[K + \frac{\theta}{\theta_T} \left(1 - \frac{\theta}{\theta_T} \right) \right] + R_1 R_2 \left(1 - \frac{\theta}{\theta_T} \right) + R_2 R_3 \left(K + \frac{\theta}{\theta_T} \right) + R_1 (R_3 + KR_2)}$$

In calculating a system assume an appropriate value for R_2 . Also assume a value for R_T that will perform the current limiting that is desired. K is an arbitrary constant, a value that must be determined graphically.
