A STUDY OF A REENTRANT OSCILLATOR USING DISK-SEAL TUBES

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PREFACE

In the past twenty years it has been necessary to increase the usable radio frequency spectrum to many times its former limit. This is due to greatly increased commercial demands and requirements of the armed forces for new and better equipment.

The piece of equipment studied for this paper is used as a bench signal generator and as a local oscillator for microwave receivers. The purpose of this paper is to give a brief description of the apparatus, its faults, and possible alterations to enable it to give better performance.

Chapter 1

DEVELOPMENT OF MICROWAVE VACUUM TUBES

Within the last twenty years, the development of radio communication and its allied fields, such as radar and television, has made mandatory the use of higher and higher frequencies. Part of this need for high frequencies came from the need for more channels of communication, and part came from the requirements of wartime radar which necessitates use of highly directional equipment. Only the very high frequencies can give high directivity without compelling the use of extremely large antenna systems. Whatever the reason may be for requiring the upper frequency range, the development pace has been set by the progress made in designing electron tubes capable of generating the higher frequencies efficiently and reliably.[1]

Vacuum tubes of conventional design are limited greatly in their frequency range by three factors. They are: (1) the inductance of the leads to the different tube elements, (2) the transit time of the electrons due to wide spacing of the tube elements, and (3) the losses by radiation from the tube itself and the connecting leads.

Probably the greatest difference between microwave tubes and those used at lower frequencies is that the former use cavities for the resonant circuits. This avoids the effects of lead inductances and radiation losses.

As may be seen later, about the only similarity between microwave triodes and conventional tubes is the base connections used for the heater and cathode direct current connections.

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[1] D.R. Hamilton, J. K. Knipp, and J. B. H. Kuper, Klystrons and Microwave Triodes, p. 1.

The development of microwave tubes has reached such a point that the usable frequency spectrum has been multiplied to at least thirty times its prewar limit.

At the present time, the term, "microwave", is used to designate the portion of the frequency spectrum from about 1,000 megacycles per second to the infra-red portion of the spectrum.

Chapter 2

DESCRIPTION OF MICROWAVE TRIODES AND ANALYSIS OF THE REENTRANT OSCILLATOR

Although there are several types of tubes used to generate frequencies in the 3000 megacycle region, this paper deals with the particular type known as disk-seal triode. The two most widely known and used triodes of this type are the 2C40 and the 2C43. The numbers 446A, 446B, and 1656, have been given to the 2C40 tube at various times, and denote either a new development or that the tube may be selected for its exceptional operating qualities. These designations are given because the tubes vary considerably from group to group during manufacture.

Referring to Figure 1, page 4, it may be seen that the disk-seal tube is constructed in such a manner as to use cavities for the tuning elements. Figure 1 is a cutaway view of the tube, showing the most important features of the tube without the cavities.

To reduce the transit time of electrons to a minimum, the elements of the tube are spaced extremely close. In the case of the 2C40 tube, the grid-cathode spacing is one-tenth of a millimeter (four-thousandths of an inch) and the grid-plate spacing is about three-tenths of a millimeter (twelve-thousandths of an inch). As a matter of interest, it is pointed out that the spacing between the grid wires is somewhat greater than the grid-cathode spacing.

The complete oscillator unit without a power supply is shown in Figure 2. The only parts of the oscillator normally removed from the assembly are the tube and the grid cylinder. The rest of the unit may be broken down into its component parts by removal of several screws found at the end of the assembly away from the tube.

To assemble the unit, the grid cylinder is fastened to the tube at the

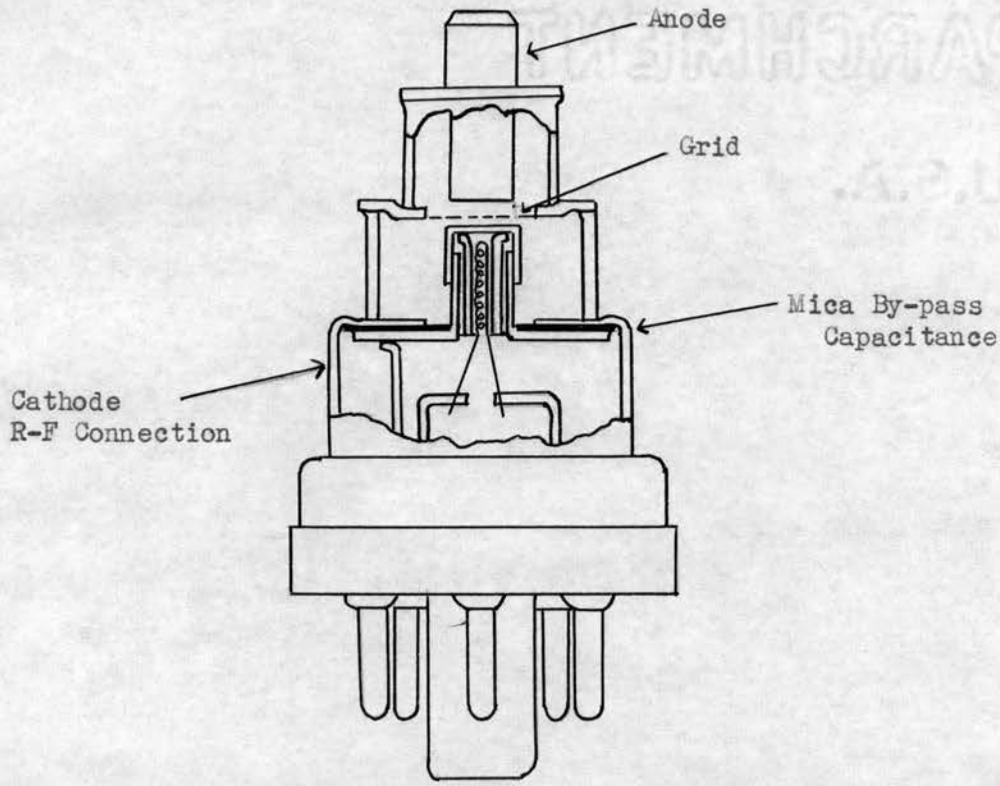


Figure 1.

Partial Cross-section 2C40.

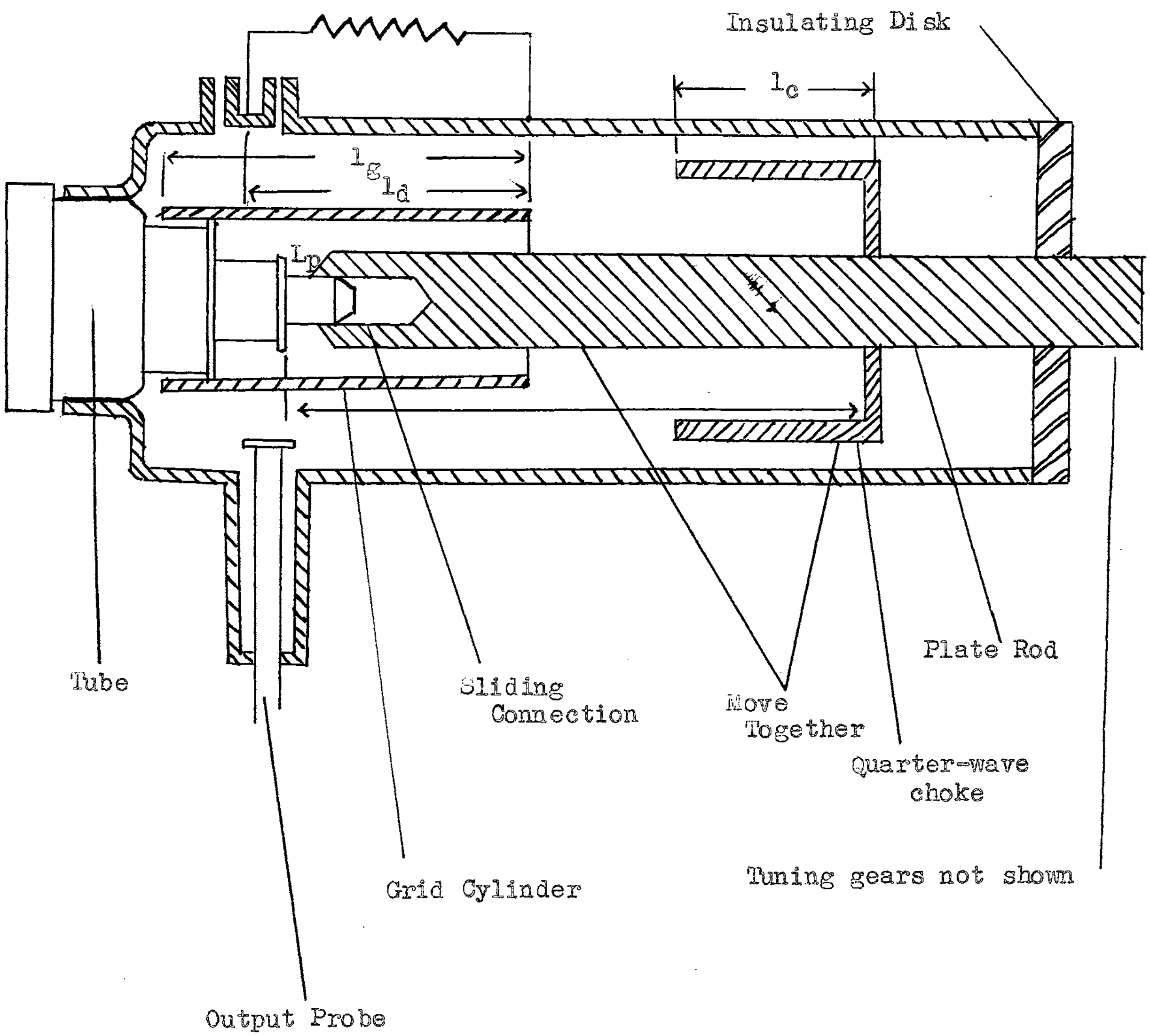


Figure 2.

Reentrant Oscillator Cavity With Tube Inserted.

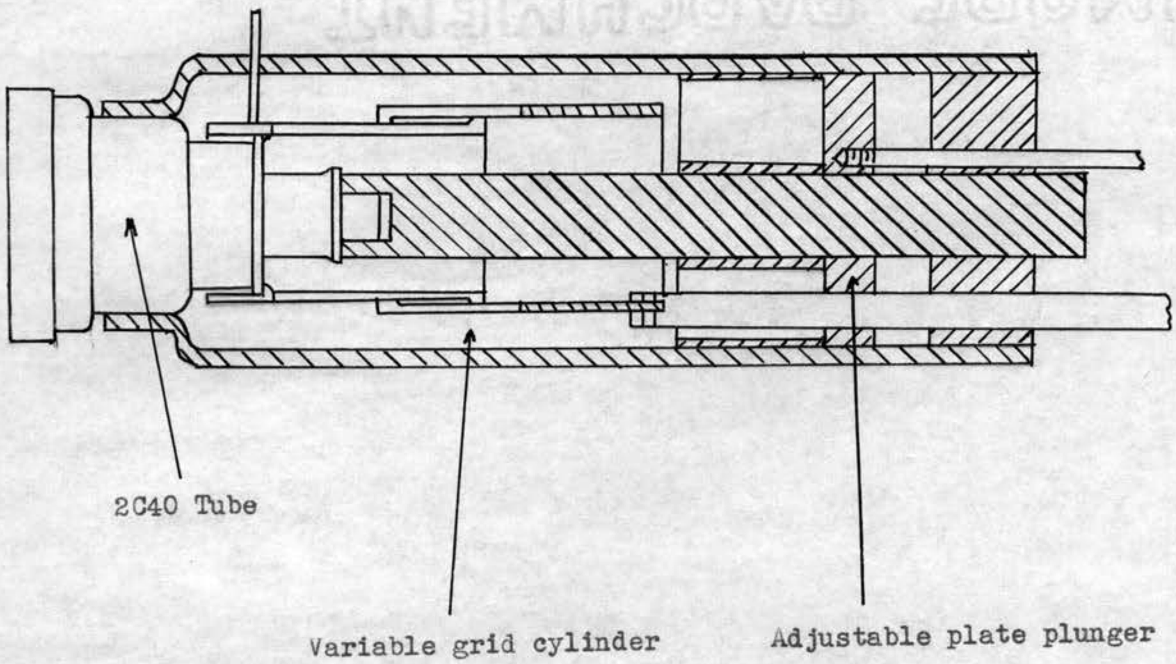


Figure 3.

Ideal Reentrant Cavity Allowing Greater Frequency Change.

grid disk by sliding the cylinder over the tube until the groove on the inside surface of the cylinder snaps over the grid disk.

The anode extension is tightened to the tube with a screw connection, and the cathode is tightened after the tube is inserted by a locking screw on the outside of the cathode cylinder. The anode connection between the voltage source and anode extension is made by a tight fitting sliding contact to enable tuning by changing the plate plunger position.

For an equivalent circuit analysis of the behavior of a reentrant oscillator, it is necessary to introduce a simplified picture as shown in Figure 4.[1]

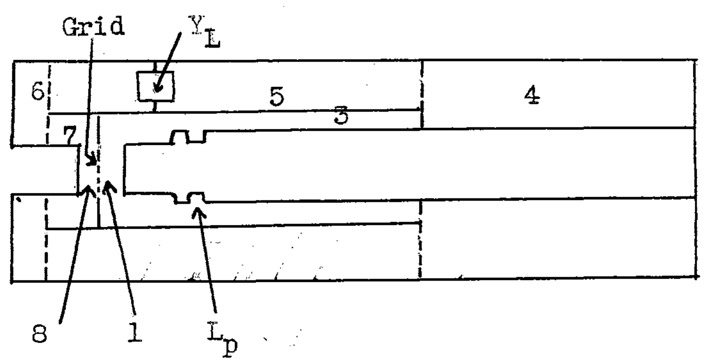


Figure 4.

Simplified Reentrant Cavity.

In this figure the load is represented by an admittance Y_L, the direct current grid connection is omitted, and the effect of the output probe is disregarded. Tuning for this type of oscillator is accomplished by sliding

[1] D.R. Hamilton, J. K. Knipp, and J. B. H. Kuper, Klystrons and Microwave Triodes, p. 254-260.

the plate connection away from the plate of the tube through use of the anode extension described above. The range of tuning for this method is about fifteen percent for any single grid cylinder.

It is noticed in Figures 2 and 4 that a discontinuity, L_p, is introduced when the plate plunger is pulled away from the tube. This change, in its effect at least, may be treated as an inductance, because as L_p is made larger the frequency is lowered. A change in L_p of one millimeter brings about a change in frequency of 40 to 50 megacycles per second. Tuning over a wider range could be accomplished by using an oscillator with the cavity configuration shown in Figure 3. This is somewhat better than Figure 2 for two reasons. One is that the frequency is changed by changing the grid cylinder length without removing the tube, and the other is that the phase of the feedback angle can be changed to an optimum position without a change in frequency because L_p is non-existent.

To draw the equivalent circuit for the reentrant oscillator, it is necessary to get an idea of the nature of the fields at the ends of a concentric cylinder formation. For this, refer to Figure 5, below.

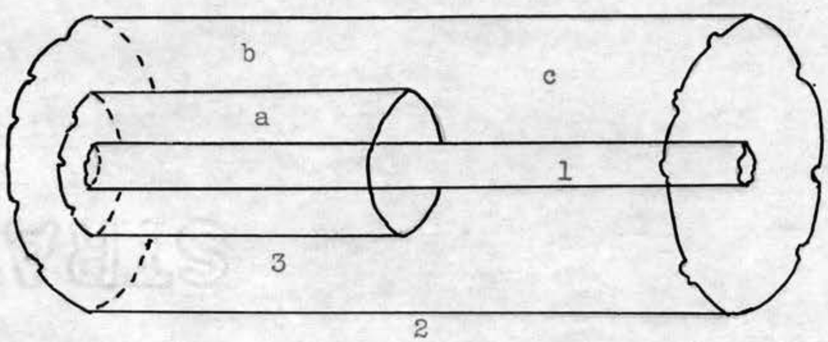


Figure 5.

Coaxial Line Configuration Similar to That at the End of Grid Cylinder.

In this figure, line a refers to the portion between the grid cylinder and the plate line. Line b is the portion between grid cylinder and cathode cylinder, and line c is the portion beyond the end of the grid cylinder.

With this drawing it is seen that a wave traveling to the left in c will split into waves whose amplitudes are proportional to the characteristic impedances of a and b. However, a wave sent to the right in line a will be partly reflected and partly transmitted into b and c. Similarly, a wave going to the right in b will behave like one going to the right in a. The discontinuity at the ends of line a and line b may be treated in an equivalent circuit as capacitances. The equivalent circuit of Figure 5 is then shown in Figure 6, where the discontinuity across line c is an inductance L_c. This combination will then give a resonant circuit of C_a and C_b in series with L_c. The only additional parameter that comes into effect is the short-circuiting plunger across line c. This may be thought of as a variable

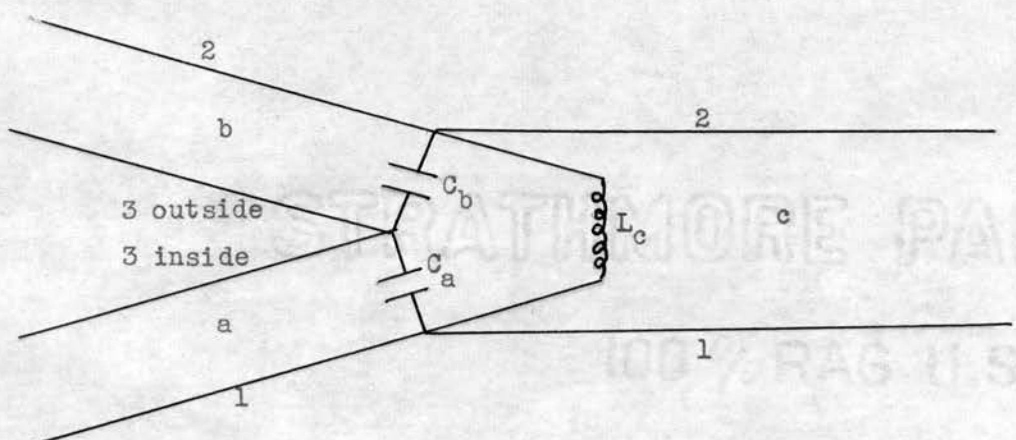


Figure 6.

Equivalent Circuit of Figure 5.

reactance lumped with L_c. As a final result for this section we have the grid cylinder terminated by line b in series with a variable reactance which will, if we have a dissipative load in line b, produce a phase shift in b with respect to a.

To complete the circuit for the entire assembly, we have to add the load, Y_L, and the circuit consisting of the short sections of line to the left of Y_L in Figure 4. The associated capacitances and inductances will be the same as those in Figure 5.

The complete equivalent circuit for Figure 4 may now be drawn as Figure 7, page 10.

For oscillations to be maintained, the current, $Y_m V_g$, fed into the left end of the circuit, must give a voltage, V_g', of the correct phase at the right end. Too, if oscillations are to build up, V_g', must be larger than V_g.

If it were not for the effect of L_p becoming larger as the shorting plunger is pulled out, there would be positions for l_4 every half wave length for which the proper phase of feedback could be obtained for any particular wavelength. Too, even though the phase of feedback may be correct, oscillations may not be obtained if the magnitude of the shifted wave is too small.

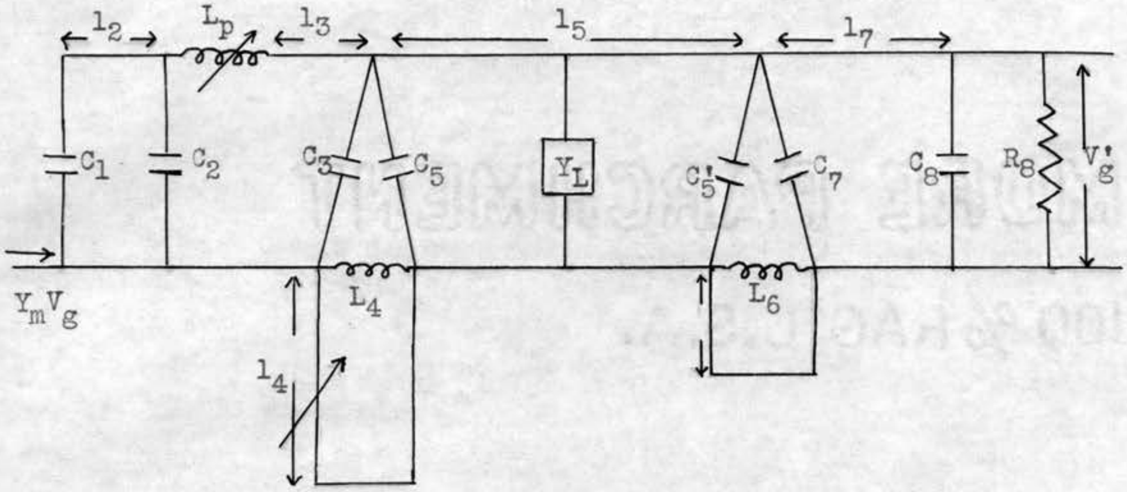


Figure 7.

Equivalent Circuit of Figures 2 and 4.

C_1	Grid-plate capacitance.
C_2	Discontinuity capacitance at plate disk.
l_n	Lengths of coaxial line with n corresponding to numbers in Figure 4.
C_3	Discontinuity capacitance at the end of cylinder 3.
L_4	Inductance due to shorting plunger.
C_5	Discontinuity capacitance at right end of cylinder 5.
C_5'	Discontinuity capacitance at left end of cylinder 5.
C_7	Discontinuity capacitance at end of cylinder 7.
L_6	Inductance due to short-circuiting effect at left end of cylinder 6.
C_8	Capacitance of input region of the tube.
R_8	Resistance of input region of the tube.

Chapter 3

PRACTICAL BEHAVIOR OF THE REENTRANT OSCILLATOR

In studying the behavior of a microwave triode for this paper, the effect of grid cylinder length on frequency and power output was noted. Nine grid cylinders were made of seven-eighths inch copper tubing, ranging in length from 3.45 centimeters to 5.64 centimeters.

Oscillation was easily obtained using the five longer cylinders for a frequency range from below 2400 megacycles per second to above 3000 megacycles per second. All oscillations were obtained with a plate voltage of 150 volts and a grid resistor of 10,000 ohms.

For the unit to oscillate through use of the four shortest cylinders, the plate tuning plunger had to be altered somewhat by inserting an aluminum washer in the quarter-wave choke cup. This change merely extended the otherwise limited range of feedback phase angles, and is shown in Figure 8.

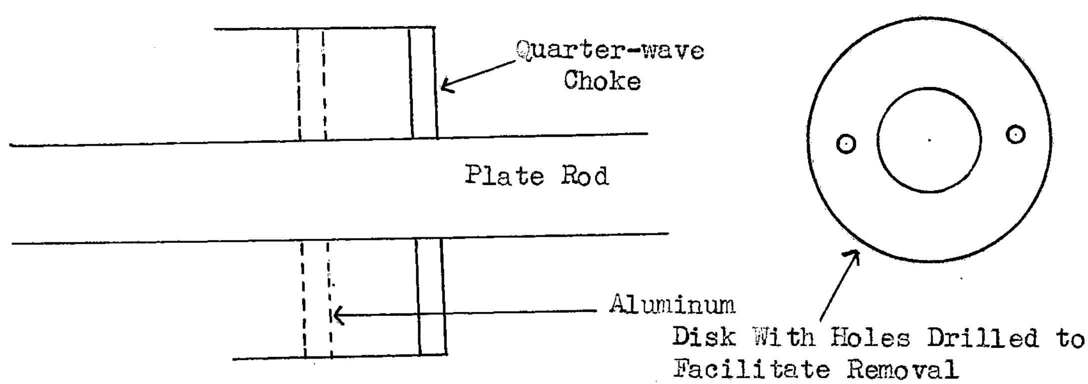


Figure 8.

It may be seen from Graph I, page 14, that the frequency is increased as the grid cylinder is decreased if a fixed position of the tuning plunger is maintained. This was to be expected in spite of the fact that the wave-length distance from the end of the grid cylinder to the plunger is not fixed, because the grid cylinder is approximately a half-wave length long.

It was shown experimentally that the position of the short-circuiting plunger has little effect on frequency. This was done by keeping L_p constant and varying the position of the plunger by using the washer described in Figure 8. A change in plunger distance of .58 centimeters caused a frequency change of 64 magacycles per second, whereas a change of .08 cm in L_p caused frequency change of 49 megacycles per second. It is seen from these figures that a change in plunger position alone has only about twenty percent as much tuning effect as changing L_p.

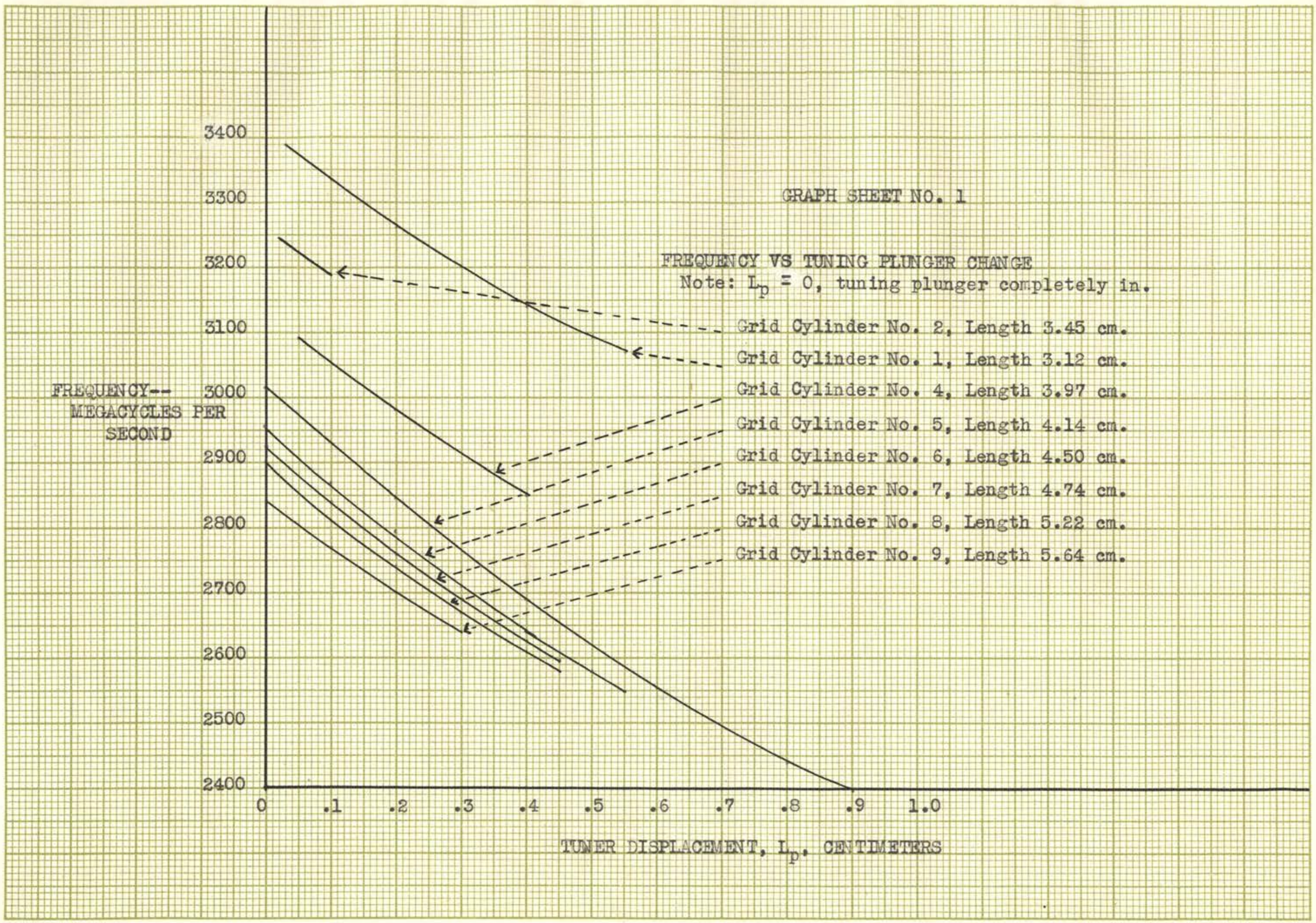
The value of the plate voltage, E_p, has little effect on frequency. Plate voltage was varied from 125 volts to 200 volts, but the change in frequency was barely great enough to be noticed.

The power supply used for this experiment was a conventional full wave rectifier with a capacitance input filter. Output voltage was controlled by using a variac transformer to control the input voltage. The tube used was a 6A5 tube, the filter capacitances were 20 and 8 microfarads, and the choke coil was 20 henries.

Filament voltage was obtained by a filament transformer which stepped 110 volts down to 6.3 volts. Input voltage to the variac was kept constant at 110 volts by a constant voltage transformer.

A schematic diagram for the power supply is shown in Figure 7, page 15.

Frequency measurements for this paper were made with a Detector-Wavemeter manufactured by The Sperry Gyroscope Company. This meter, shown in schematic form on page 17, is designed for frequency measurements on systems operating


GRAPH SHEET NO. 1
FREQUENCY VS TUNING PLUNGER CHANGE
Note: L_p = 0, tuning plunger completely in.
Grid Cylinder No. 2, Length 3.45 cm.
Grid Cylinder No. 1, Length 3.12 cm.
Grid Cylinder No. 4, Length 3.97 cm.
Grid Cylinder No. 5, Length 4.14 cm.
Grid Cylinder No. 6, Length 4.50 cm.
Grid Cylinder No. 7, Length 4.74 cm.
Grid Cylinder No. 8, Length 5.22 cm.
Grid Cylinder No. 9, Length 5.64 cm.
FREQUENCY--MEGACYCLES PER SECOND
3400
3300
3200
3100
3000
2900
2800
2700
2600
2500
2400
0
.1
.2
.3
.4
.5
.6
.7
.8
.9
1.0
TUNER DISPLACEMENT, L_p, CENTIMETERS

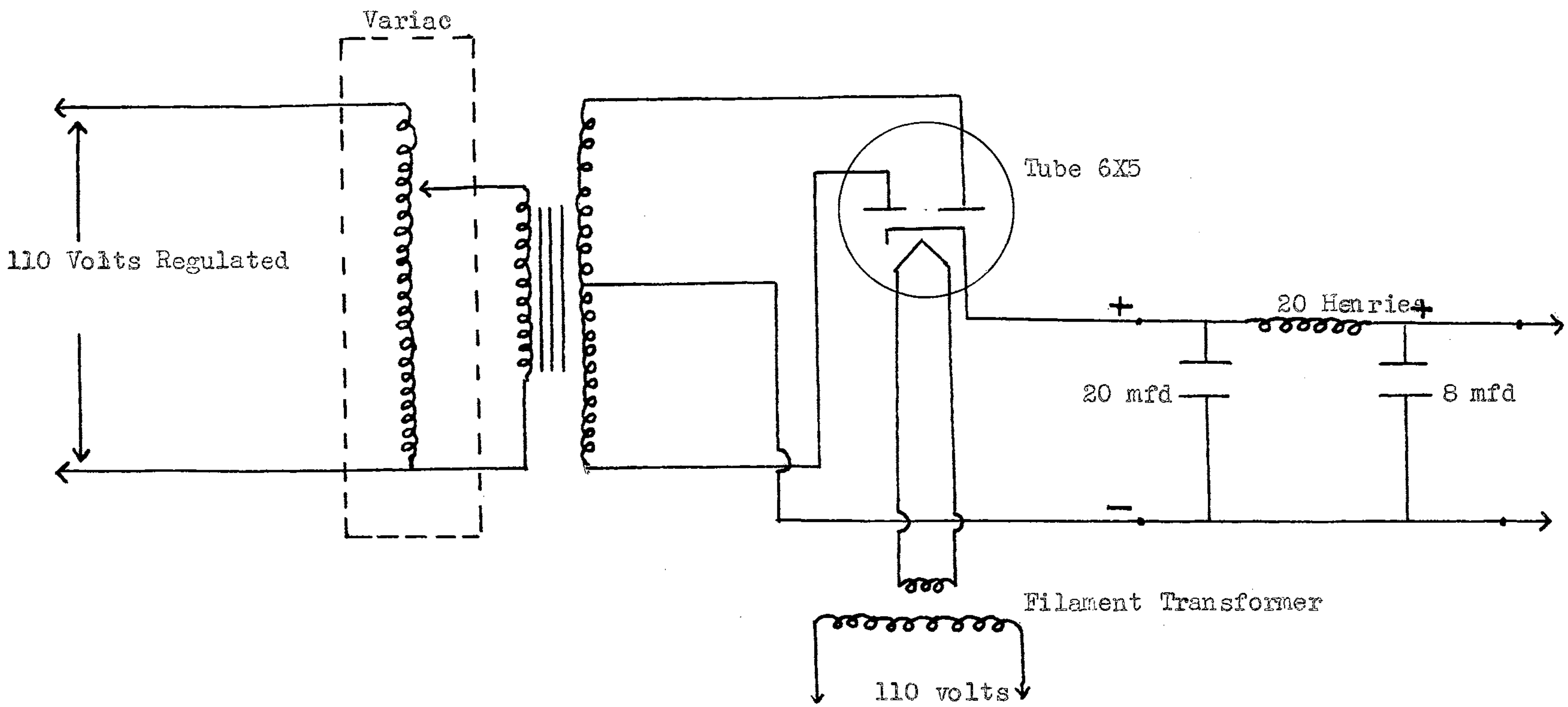


Figure 9.

Schematic Diagram of Power Supply

in the 2400 to 3400 megacycle per second band. The meter is entirely self-contained and requires no power except the strength of the signal being measured. For frequency measurements, the meter is accurate to one part in 2000 or .75 megacycles at 10 centimeters.

The operating principle of this meter is quite simple. Essentially it is a quarter-wave line shorted at one end and open at the other. Following the notation of the instruction book, it may be seen that the cavity has an outer conductor (B) provided with an extension (A). This line is open at end (J) and shorted at end (H). The extension is coupled to conductor (B) by means of the filter capacity (P)-(C)-(D). (P)-(C) is about a quarter wavelength, so that the high impedance at (C) obtained by means of a quarter wavelength line (D) shorted at the bottom, provides a good contact point at (P). This makes the losses at (P) negligible.

When the transmission method is used to measure frequency, the unknown signal is coupled into the meter by means of jack (E) and loop (K). When the cavity is tuned to resonance, the signal passes through loop (F) to the T-section (G) and then to the crystal detector (X). The rectified signal is then indicated on the meter (M), giving a peak reading.

When the absorption method is used, the unknown signal is fed to the T-section through jack (N) and then to the crystal rectifier. When the cavity is tuned to resonance at the incoming signal frequency, part of the power is absorbed by the cavity, thus lessening the signal current through the meter.

According to the instruction booklet, this meter can be used for power measurements by using the tune-to-dip jack and placing the meter antenna in the radiated field from some source. The field strength is supposed to be proportional to the deflection. At any particular frequency this may be true, but it was discovered during this experiment that a power peak was obtained at the same frequencies even though cylinders of different lengths were used.

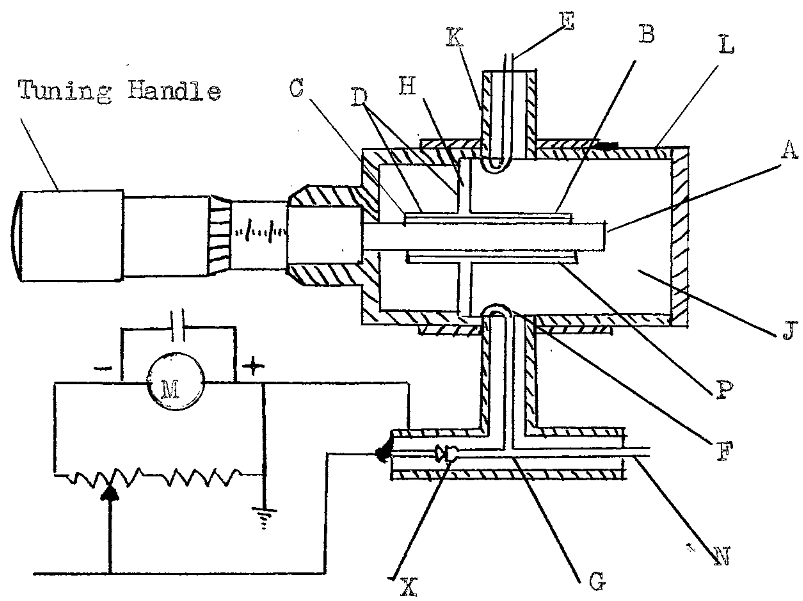


Figure 10.

Schematic Diagram of Detector-Wavemeter Type Mark S-22.

This seems to indicate that the meter is frequency sensitive. Too, the results obtained with this meter did not correlate with results obtained through use of the bolometer type device described below.[1]

The bolometer type power measuring element depends on a change in resistance as its temperature changes for its operation.

Referring to Figure 11, page 19, it is seen that if the resistance of the bolometer element is equal to the resistances of the other three arms, we have a balanced resistance bridge with the detector or galvanometer across the diagonal of the bridge giving a nil reading.

The particular bridge which was used for power measurements for this paper was of the balanced type. By this we mean that the bridge was balanced with no radio frequency signal applied, and the current, I_1, was noted. The r-f power is then fed into the circuit by the coupling loop shown. This r-f power is absorbed by the bolometer element which raises its temperature and lowering its resistance. By adjusting the zero control shown in the schematic, the current through all arms of the bridge is decreased until the detector shows a nil reading again. The current, I_2, is then noted on the meter. It is evident that the bolometer resistance is the same when both I_1 and I_2 were taken because the bridge was balanced. This proves that the total power dissipated in the bolometer element the same in both cases. All resistances are 100 ohms value, so the power dissipated with no r-f applied is $I_1{}^2$ times 100 and power dissipated with r-f applied is $I_2{}^2$ times 100 plus r-f power dissipated. This makes the r-f power output equal to $(I_1^2 - I_2^2)$ times 100. The power output of the tube was too great to be measured without attenuation. To find the value of the attenuator used, a signal was applied to the bridge without attenuation and power measured. The attenuator was

[1]Radio Research Laboratory Staff, Very High Frequency Techniques, Volume II, pp. 1023-1024.

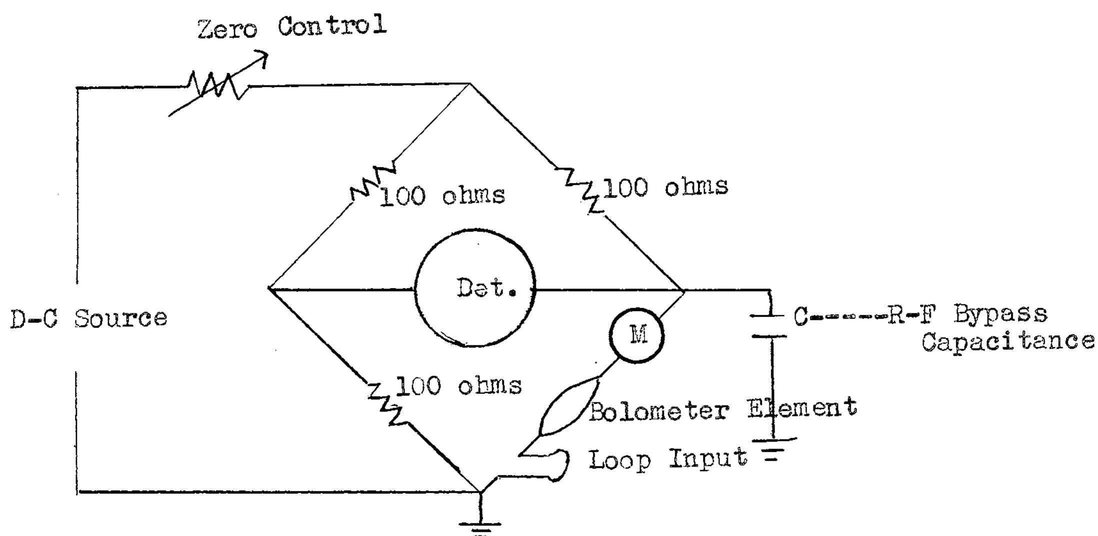


Figure 11.

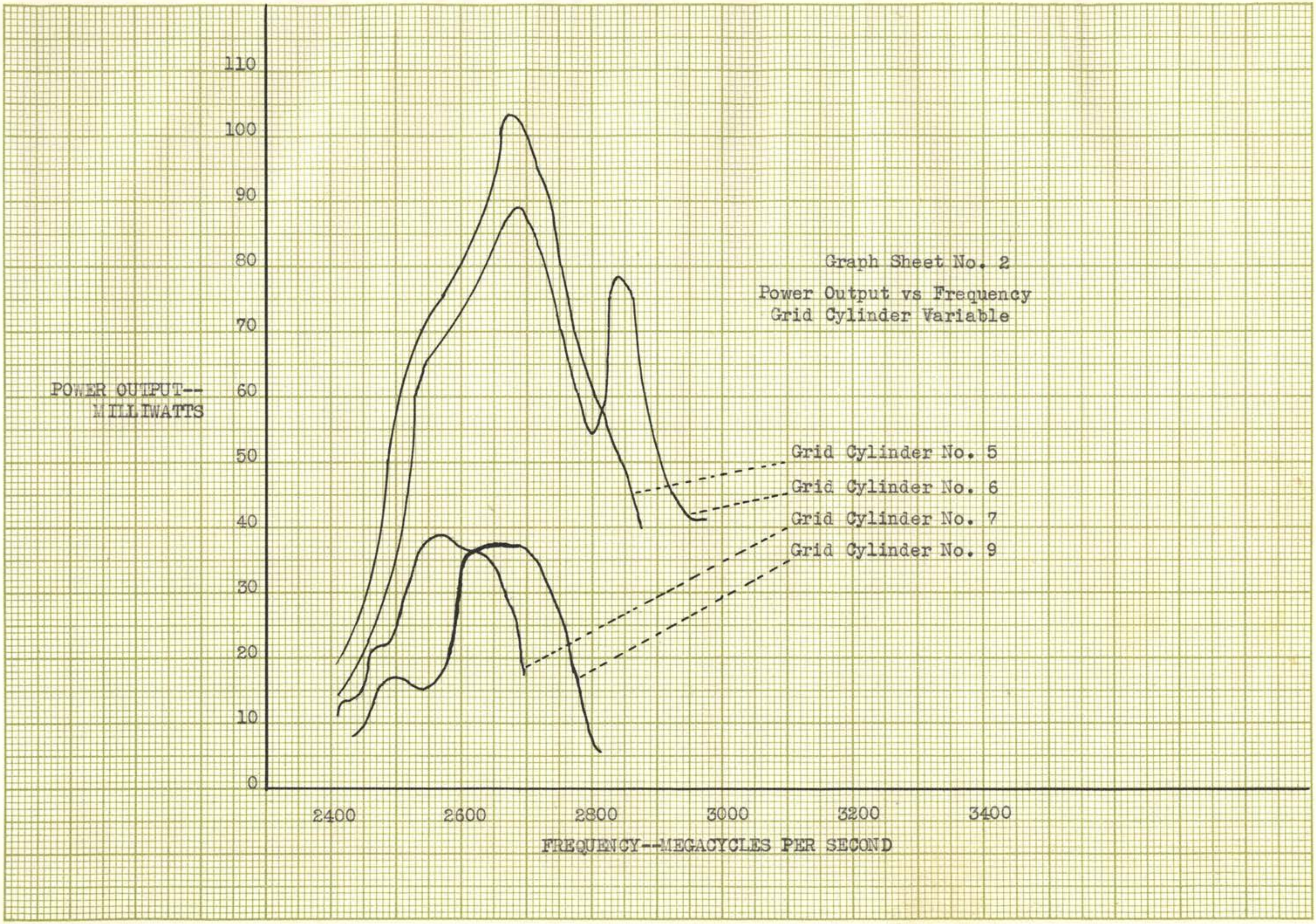
Schematic Diagram of Thermistor Bridge

inserted and power measured again. All measurements after this were made with the attenuator inserted and all power values obtained were multiplied by the attenuation factor of the attenuator.

Graph II, page 21, shows the power obtained at different frequencies using four different grid cylinders.

It was expected at first that peak power would be obtained at the lowest frequencies with the longer cylinders and at high frequencies with the short cylinders. It was also thought that the power would be greater for the lower frequencies. Neither of the two expectations listed above proved to be correct in spite of the fact that the tube is capable of putting out more power than is shown on the graph. As was pointed out before that the distance in wavelengths from the end of the grid cylinder to the shorting plunger is never the same for two frequencies with a single grid cylinder. This change may account for the unexpected power responses in that the phase angle of the feedback wave is so far from being correct that the maximum power which the tube is capable of generating could not be reached.

About the only conclusion that can be reached is that if the maximum power is to be obtained at a given frequency the complete oscillator unit must be designed for that frequency. On the other hand, if the unit is to be used as a local oscillator in a receiving set or as a low power signal generator for a bench setup, the power obtained is probably sufficient to satisfy those needs.


Graph Sheet No. 2
Power Output vs Frequency
Grid Cylinder Variable
POWER OUTPUT--
MILLIWATTS
110
100
90
80
70
60
50
40
30
20
10
0
2400
2600
2800
3000
3200
3400
FREQUENCY--MEGACYCLES PER SECOND
Grid Cylinder No. 5
Grid Cylinder No. 6
Grid Cylinder No. 7
Grid Cylinder No. 9

Chapter 4

SOME PRACTICAL USES OF MICROWAVE FREQUENCIES

It was pointed out at the end of Chapter 3 two of the uses for lower power high frequency generators. Other applications, of course, demand the use of high power at these same frequencies. Two of these uses are radar and radio telephony. Probably the greatest commercial use of the high power microwaves is the latter which is being used on a large scale tryout basis in the northeast section of the United States between large cities.[1]

The choice of microwaves in the 1000-7000 megacycle region was based on several factors. Theoretically any band of radio frequencies wide enough to meet the requirements set forth could be used, but in actual practice the range is limited.

First, frequencies below a hundred megacycles per second are unavailable because they are very much congested by amateur radio operators and frequency modulated commercial radio stations. Frequencies between 100 and 1000 megacycles are unsuitable because large transmitter powers must be used to obtain the directivity required. Above 1000 megacycles there are now available a large number of channels. Also, a high degree of directivity may be obtained by use of parabolic reflectors, and small antennas may be easily designed to meet practical requirements.

Frequencies above 7000 or 8000 megacycles per second involve further difficulties. At these frequencies such a high degree of directivity is obtained that the supporting structure for the antenna must be extremely rigid in order that the transmitting beam will not miss the receiving antenna. Diffraction and absorption effects become more important as frequency is increased.

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[1] D. D. Grieg and J. Racker, "Microwave Radio Links," Signals, (November-December, 1947), pp. 6-7

From the several reasons given above it is seen why the range is limited at the present time. But because new techniques are being developed nearly every day it may not be long until the usable radio frequency spectrum is extended for commercial purposes.

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Typist: Miss Betty Trumbly