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VHF AND UHF POWER GENERATORS FOR RF INSTRUMENTATION

BY

A. H. MORGAN AND P. A. HUDSON

U. S. DEPARTMENT OF COMMERCE
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ABSTRACT

The work described in this report was undertaken to provide certain projects in the Radio Standards Division with a series of fixed frequency rf generators having good stability with respect to both frequency and power output level and continuously adjustable in power output from 1 to 100 watts. Prior to the completion of the generators the work of some of the standards projects was seriously hampered because the rf generators available were lacking in either sufficient power output, frequency stability, or power output stability. For example, bolometer bridges used for rf voltage and power measurements are sensitive to power input variations as small as a few parts in 10^4. Power stability of at least one part in 10^3 is considered an absolute necessity to obtain measurement accuracies of from 0.5% to 1%.

VHF AND UHF POWER GENERATORS FOR RF INSTRUMENTATION

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1. INTRODUCTION

1.1 Purpose

The work described in this report was undertaken to provide certain projects in the Radio Standards Division with a series of fixed frequency rf generators having good stability with respect to both frequency and power output level and continuously adjusted in power output from 1 to 100 watts. Prior to the completion of the generators the work of some of the standards projects was seriously hampered because the rf generators available were lacking in either sufficient power output, frequency stability, or power output stability. For example, bolometer bridges used for rf voltage and power measurements are sensitive to power input level variations as small as a few parts in 10^4. Power stability of at least one part in 10^3 is considered an absolute necessity to obtain measurement accuracies of from 0.5% to 1%. Good power stability is likewise desirable in the use of rf calorimetric wattmeters andin the substitution method of attenuation measurement.

Frequency stability is required in many measurements because tuned elements, such as quarter-wave stubs and narrow band detectors, may be part of the measuring system.

A survey of commercially available generators was made but nothing was found at that time (1955) which would satisfy all the requirements. Hence it was decided to design and construct a set of generators in the laboratory.

1.2 Design Specifications

A set of design specifications was arrived at after consultation with the project leaders in need of better rf generators. The adopted specifications were as follows:

Frequencies:	100, 200, 300, 400, Mc
Frequency Stability:	Within 0.0005% after 15 minute warmup

Power Output:	Continuously adjustable from 1 watt to 100 watts into 50 ohm load
Power Output Stability:	± 0.1% per hour
Residual AM:	Less than 0.05% of output voltage
Harmonic Content:	60 db below fundamental with single filter
Shielding:	At least 80 db when generator is enclosed in a shielded rack
Output Impedance:	50 ± 5 ohms
Duty:	Continuous operation at full power output
Size:	Suitable for standard rack mounting

Power output stability and frequency stability were considered of major importance and design features were chosen which enhanced these qualities.

2. EXCITER DESIGN

2.1 General Description

The arrangement of the exciter part of each generator, with the exception of the 100 Mc unit, consisted of an oscillator-doubler, a buffer stage, an intermediate amplifier and a combined tripler amplifier for the output. In the 100 Mc unit the output was from a straight power amplifier. High frequency crystal units were employed to minimize the number of multiplication stages and to reduce the number of sidebands in the generator output. For example, in the 400 Mc generator the crystal frequency was 66.666 Mc. Such crystals were readily available from commercial sources with the desired tolerance.

The choice of tubes in the output stage was determined by available power from the exciter. Each stage of the exciter will be described in the following paragraphs. A circuit diagram for a typical exciter (400 Mc) is shown in Fig. 1.

2.2 Oscillator Section

The oscillator is a modified Butler type and was chosen because of its simplicity, good frequency stability, and reliability. In addition, the circuit is not critical with respect to design, adjustment, or interchange of tubes (1).

A circuit diagram of the two-stage oscillator section is shown in Fig. 1 a. No claim is made to originality of the design used because numerous modifications of the basic Butler circuit have been made by others including, in all probability, the one described here.

The first stage of the oscillator includes a plate tank circuit tuned to the crystal frequency f_c while the plate tank of the second stage is tuned to 2 f_c. Thus, frequency doubling is accomplished. The plate tank in the first stage, which is a modification of the basic Butler circuit, serves to increase the output of the oscillator. The 100 Mc generators employ 50 Mc crystals and, with the doubling, no further frequency multiplication was necessary. In the 200, 300 and 400 Mc generators the crystal frequency is 1/6 of the exciter output frequency with doubling and tripling required. This arrangement was used because the exciter output tube, type 5894, has a high input capacity and it is difficult to effectively employ input frequencies above 160 Mc.

2.3 Buffer Stage

The purpose of the buffer stage as shown in Fig. 1 b is, of course, to isolate the oscillator from the amplifier stages and prevent frequency variations due to varying amplifier loading conditions. The design and construction of the stage is straightforward, as shown in Fig. 1 b. The oscillator output is coupled to the 6AH6 input by a 10μμf capacitor. With inductive coupling on the input to the 6AH6 higher output may be obtained, but under those conditions there was a strong tendency to oscillate. The plate tank circuit of the buffer is tuned to the oscillator output frequency with inductive coupling to the following amplifier stage.

(1) "Handbook of Piezolectric Crystals for Radio Equipment Designers", John P. Buchanan, Philco Corporation, Wright Air Development Center, Technical Report 56-156, October 1956. For sale by Office of Technical Services, U. S. Department of Commerce, Washington 25, D. C.

2.4 Intermediate Amplifiers

The driving power required for the 5894 exciter output stage is approximately 3 watts when used as a straight push-pull amplifier at 100 Mc. When used as a tripler-amplifier, to frequencies of 200, 300 and 400 Mc, the driving power must be at least 6 watts. Thus, considerable power amplification (approximately 18 db) must be provided between the buffer and input to the type 5894 tubes. This gain is obtained with two stages utilizing the type 6360 twin-tetrode tube operating push-pull, class C. As shown in the schematic of Figure 1 c, butterfly capacitors are used on both input and output to balance the tank circuits to ground.

In order to prevent oscillation in the intermediate amplifiers a grounded metal shield is placed across the bottom of each tube socket so that the grid tank is shielded from the plate tank. Such an arrangement is shown in Figure 2. The 6360 tubes have tube shields of the heat dissipating type and adequate ventilation also is provided.

2.5 Exciter Output Stage

The exciter output stage is operated class C, with grid leak bias, as shown in Fig. 1 d. The value of the grid leak resistor is fairly critical as it determines the proper conduction angle. This is particularly true for the 300 Mc and 400 Mc generators. Operating voltages are given in the standard tube manuals available from the tube manufacturer. The power output is 16 watts for the 400 Mc exciter. At lower frequencies the output powers are as follows: 300 Mc - 22 watts, 200 Mc - 30 watts, 100 Mc - 40 watts. The exciter output is brought out to a type N jack on the front panel and is connected to the 100 watt power amplifier input jack by a short length of cable. It may be used independently of the power amplifier when desired.

The power output is controlled either manually or by the automatic level control circuit (this is described in Paragraph 4.0). Selection of the method of control is made by means of the triple-pole, double-throw switch which connects the automatic level control circuit to the screen grid of either the 5894 exciter output or the 4X250 B power amplifier. With the switch in the "PA" position the exciter output is controlled by the rheostat (R_{20} in Fig. 1).

It should be noted that lumped-constant tank circuits are used at all frequencies and that all rf coils are wound with #10 A. W. G. wire for good efficiency and stability.

3. 100 WATT POWER AMPLIFIER DESIGN

3. 1 100 Mc and 200 Mc Circuits

As was mentioned earlier, the 4X250 B tube is used as the power amplifier in all of the generators described here. This tube is a small radial-beam tetrode rated at 250 watts plate dissipation at frequencies up to 400 Mc. With 900 volts on the plate a power output of 120 watts into a 50 ohm load is easily obtainable with class C operation. Link coupling is used on the input to the tube with grid-leak bias of 90 volts as shown in Fig. 3. At 100 and 200 Mc approximately 8 watts of driving power are required.

The plate tank circuits at these frequencies are lumped-constant type with coils made of relatively large diameter wire. The circuits are series resonant to provide a relatively low impedance for the tube plate in accordance with the tube manufacturers' recommendation. In general, better coupling can be achieved on both the input and output if the coils are mounted coaxially rather than side-by-side. A perforated shield enclosure surrounding the tube, plate tank, and output link improved the performance as well as reduced unwanted radiation.

The tube manufacturers' recommendations for forced-air cooling of the tube were followed.

3. 2 300 Mc and 400 Mc Circuits

At frequencies of 300 Mc and above, the use of lumped-constant tank circuits and output loops with the 4X250 B appeared to be marginal. That is, with 900 volts on the plate of the tube, an output of 100 watts could only be obtained with the tube operating at maximum allowable plate dissipation. Since this type of operation shortens tube life considerably it was decided to use a quarter-wave cavity for the plate tank. Sectional views of the 400 Mc cavity are shown in Fig. 4. The length of the cavity was made $0.6 \times \frac{\lambda}{4}$, at the operating frequency, in order to better match the output impedance of the tube and to allow for capacitive tuning. With two capacitors the 400 Mc cavity tunes from 340 Mc to 430 Mc while the 300 Mc cavity tunes from 270 Mc to

330 Mc. Construction of the cavity is relatively simple and can be done in any good machine shop. Contact to the plate of the 4X250 B is made by a ring of beryllium-copper fingers soldered to the inner cylinder of the cavity.

Using plate cavities for the 4X250 B, load power outputs of 120 watts were obtained with the tube operating at 70% of maximum plate dissipation. In addition the cavity helps suppress the sub-harmonics normally present in the output of the tripler-exciter.

4. AUTOMATIC LEVEL CONTROL CIRCUIT

Measurements and tests on the first prototype rf generator (100 Mc) indicated that the specification on output level stability could not be met without extra circuitry for automatic control. This result was at least partly anticipated in view of some prior tests made on commercial rf power generators. It would thus appear that, in general, equipment of this type does not have the inherent output level stability necessary for instrumentation use.

The automatic level control circuit for the generator described here was designed to control the dc voltage to the screen of the output stage. The control grid of the tube could not be used for this purpose due to the fact that the stage is operated class C and thus the grids are driven to saturation. It was also desired that the circuit not include semiconductor diode rectifiers and reference batteries because of the inherent temperature and peculiar instability of these devices. In the final circuit, shown in Figure 5, a temperature-limited diode is used as the sensing and reference device. Since the diode is temperature limited its plate current is directly proportional to the filament emission current. This emission obeys Richardson's equation and is a very rapidly varying function of filament temperature. That is, doubling the temperature may increase the emission by a factor of 10^7(2). The filament temperature is, of course, proportional to power input. Even though the filament impedance is small while the plate load impedance can be quite large (of the order of 10^6 ohm) it is possible to achieve a voltage gain. In this circuit the gain is approximately 2000. The diode filament is heated directly by a portion of the rf energy from the generator.

Variations in output power cause variations in the plate voltage of the diode which are 180° out of phase with those of the rf output. This phase difference is maintained through the output of the cathode follower V_3. The stage V_2 is a cathode coupled dc amplifier with a

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(2) Karl R. Spangenberg, "Vacuum Tubes", McGraw-Hill Book Co., 1948.

gain of 10. The VR tube V_4 provides a constant voltage drop between V_3 and the screen of the generator output stage. More than one VR tube may be used, when necessary, to provide the proper screen voltage for the generator output tube. In these generators the complete circuit is mounted on the same chassis as the other components and tubes of the generator. A type N jack is provided on the front panel to feed power to the diode filament. The capacitor C_2 may be either fixed or variable and serves to tune out the inductance of the diode filament. When the diode filament emits sufficient current to cause the proper plate current to flow then the control circuit will oppose any further variations in the filament temperature of the diode. Thus there was no need for an external reference voltage in the circuit.

Adjustment of the generator, with the automatic level control, is as follows: Connect the generator to a load through a tee. On one leg of the tee, connect a variable capacitor in series with the center conductor. The capacitor may be mounted inside a small metal box with coaxial connectors on both ends. Small piston type capacitors have been found quite satisfactory. The output end of the capacitor box is then connected back to the input to the temperature-limited diode filament.

The presence of the feed-back capacitor in parallel with the load introduces some mismatch and it is necessary to tune the generator plate-tank and output circuits for minimum dc plate current. A block diagram of a typical setup is shown in Figure 6.

It should be noted that when using a capacitor for feed-back to the diode the load sees a nearly constant-voltage-generator at the tee where the capacitor is connected. Output impedance of the power generator is approximately 0.1 ohm. With inductive coupling the generator becomes a nearly constant-current-source and, with a directional coupler, a source of nearly constant incident-power. Adjustme nt of the output level with the latter two devices is, however, not as convenient as with the variable capacitor.

5.0 PERFORMANCE CHARACTERISTICS

5.1 Frequency Stability

The output frequency stability of the generator is essentially that of the oscillator. The crystals used have a turnover point of 75°C and are operated in relatively simple 75°C ovens. After warmup the stability is better than 5 parts in 10^6 per hour and 10 parts in 10^6 per day.

5.2 Output Level Stability

Using the automatic level control with a typical generator, the output voltage variations did not exceed 0.5% per hour. For periods of 10 minutes a maximum variation of the order of 0.05 to 0.1% may be expected. These figures are from 10 to 20 times better than were found for the same generators without the automatic level control.

5.3 Spurious Outputs

The harmonic content of the output voltage varied with the frequency of the generator and with generators at the same frequency. In all cases the harmonic voltages were at least 30 db down from the fundamentals. Where necessary, commercially available filters have been used to reduce spurious outputs to at least 60 db below the fundamental.

5.4 Residual Modulation

Residual amplitude modulation in all the generators was found to be mostly at the 60-cycle and 120-cycle frequencies. At these frequencies the residual amplitude modulation was not greater than 0.1%.

Some trouble was experienced with low frequency modulation due to the vibration of the cooling fans when they were mounted directly on the chassis. This was overcome by mounting the fans remotely and connecting to the chassis with flexible tubing.

5.5 Shielding

As was mentioned earlier each tube and tank circuit extending above the chassis was shielded individually by a tube shield or a perforated copper enclosure. In addition the entire generator was enclosed in a copper box with screened openings for forced air cooling. All wires entering the box were through low pass electrical filters. Finally, the generators were mounted inside special racks which had close-fitting doors and filters for the input power. In Figures 7 and 8 photographs are shown of the shielding, filter box and tube layout.

6.0 ACKNOWLEDGMENTS

The authors are indebted to Mr. C. M. Allred for several suggestions including the use of the temperature-limited diode in the automatic level control circuit and to the following members of the staff for contributing to the development of the generators:

Mr. J. H. Shoaf, Mr. D. H. Russell, and Mr. L. E. Mann

7. FIGURES

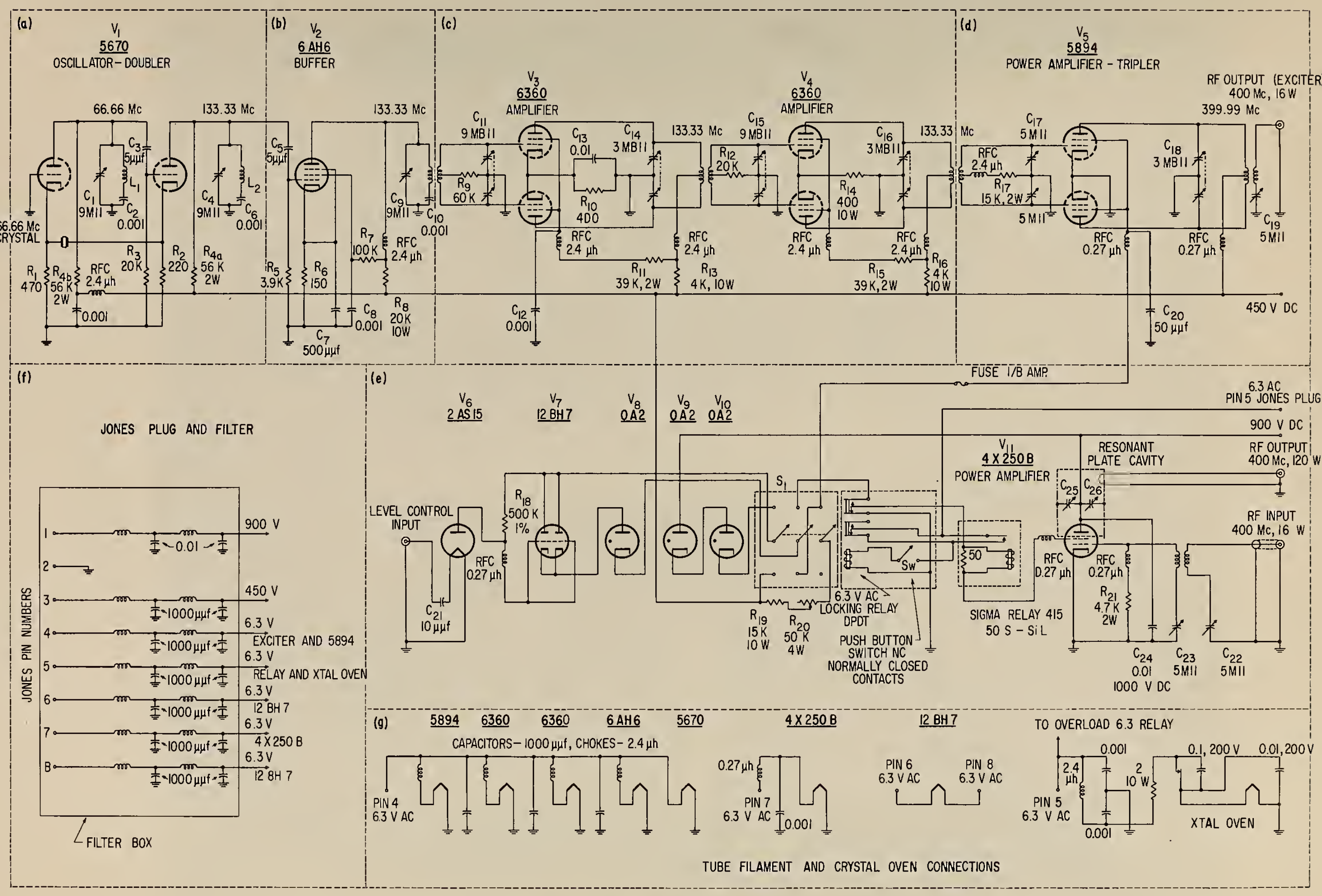
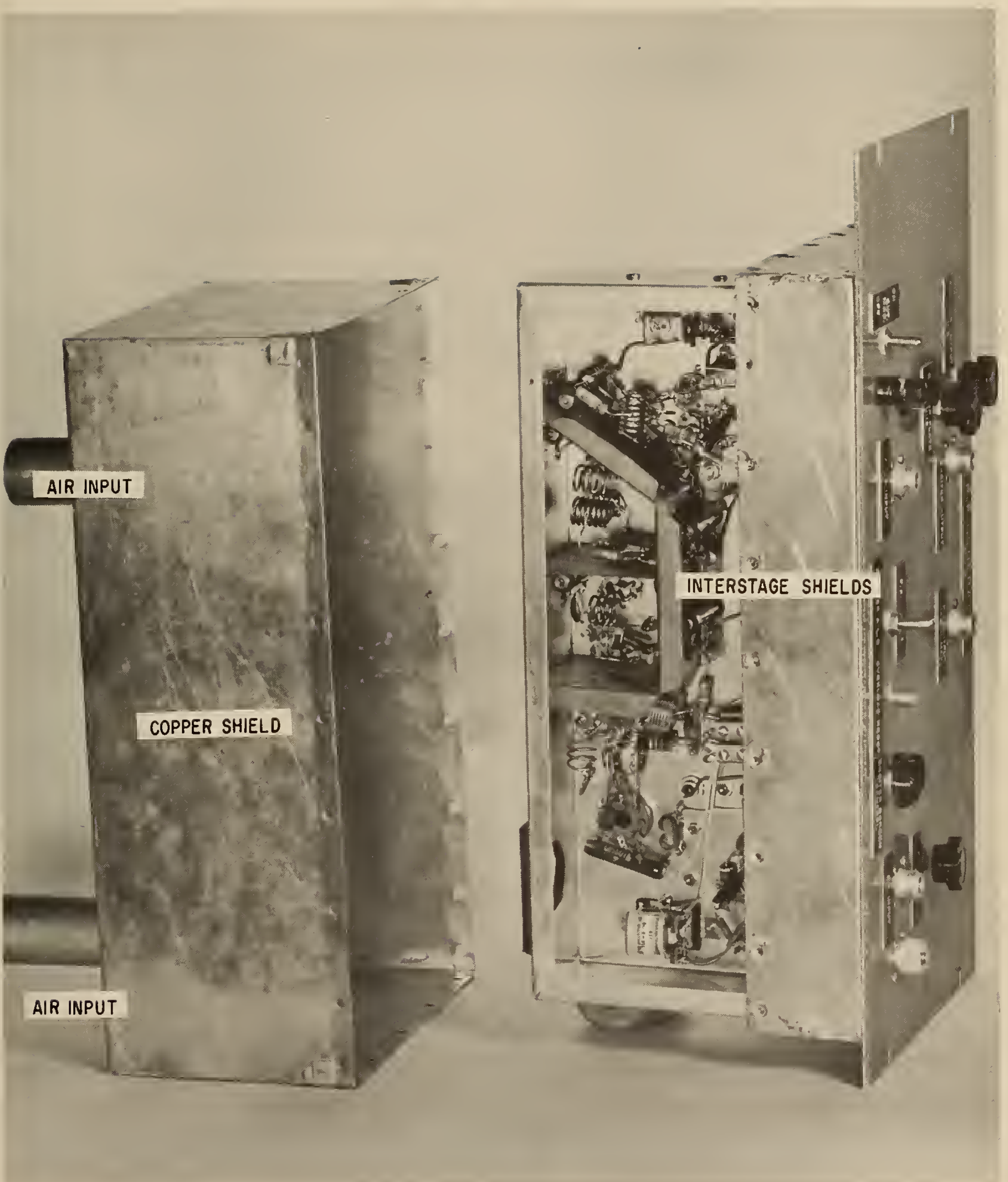


FIG. 1 GENERATOR CIRCUIT DIAGRAM (400 Mc)



BOTTOM VIEW OF CHASSIS
Figure 2

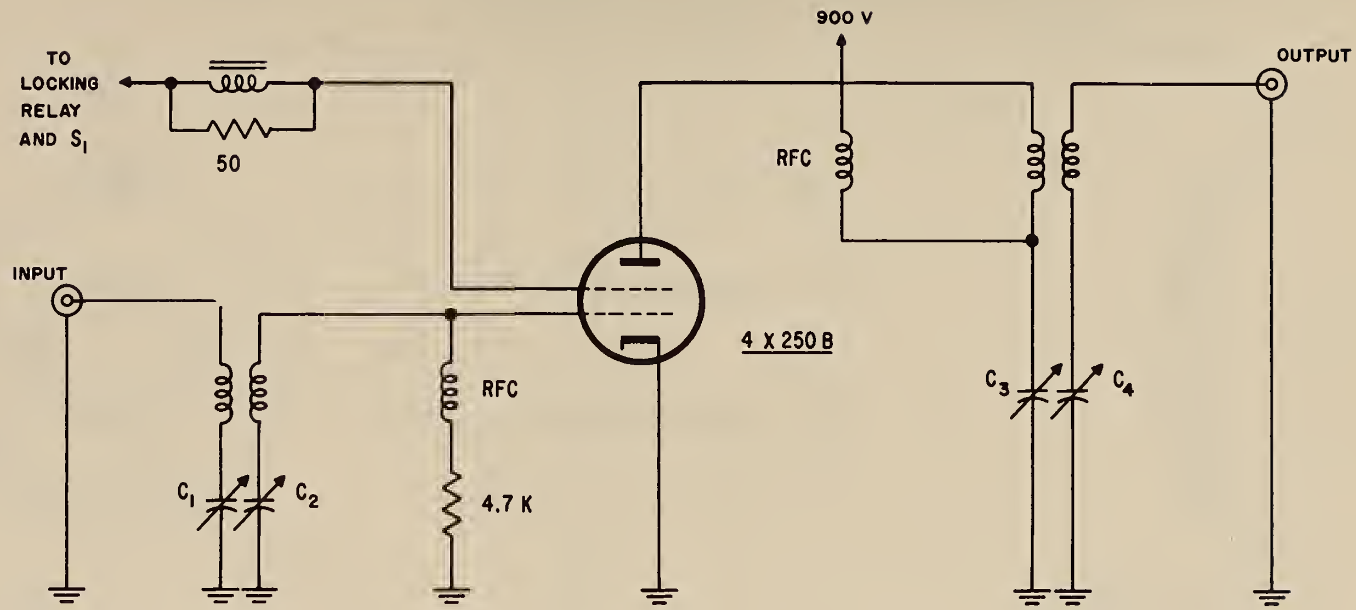


FIG. 3 100 Mc AND 200 Mc POWER AMPLIFIER CIRCUIT

C_1,C_2 — HF 30 AT 100 Mc
C_1,C_2 — HF 15 AT 200 Mc
C_3,C_4 — HF 30 X AT 100 Mc
C_3,C_4 — HF 15 X AT 200 Mc

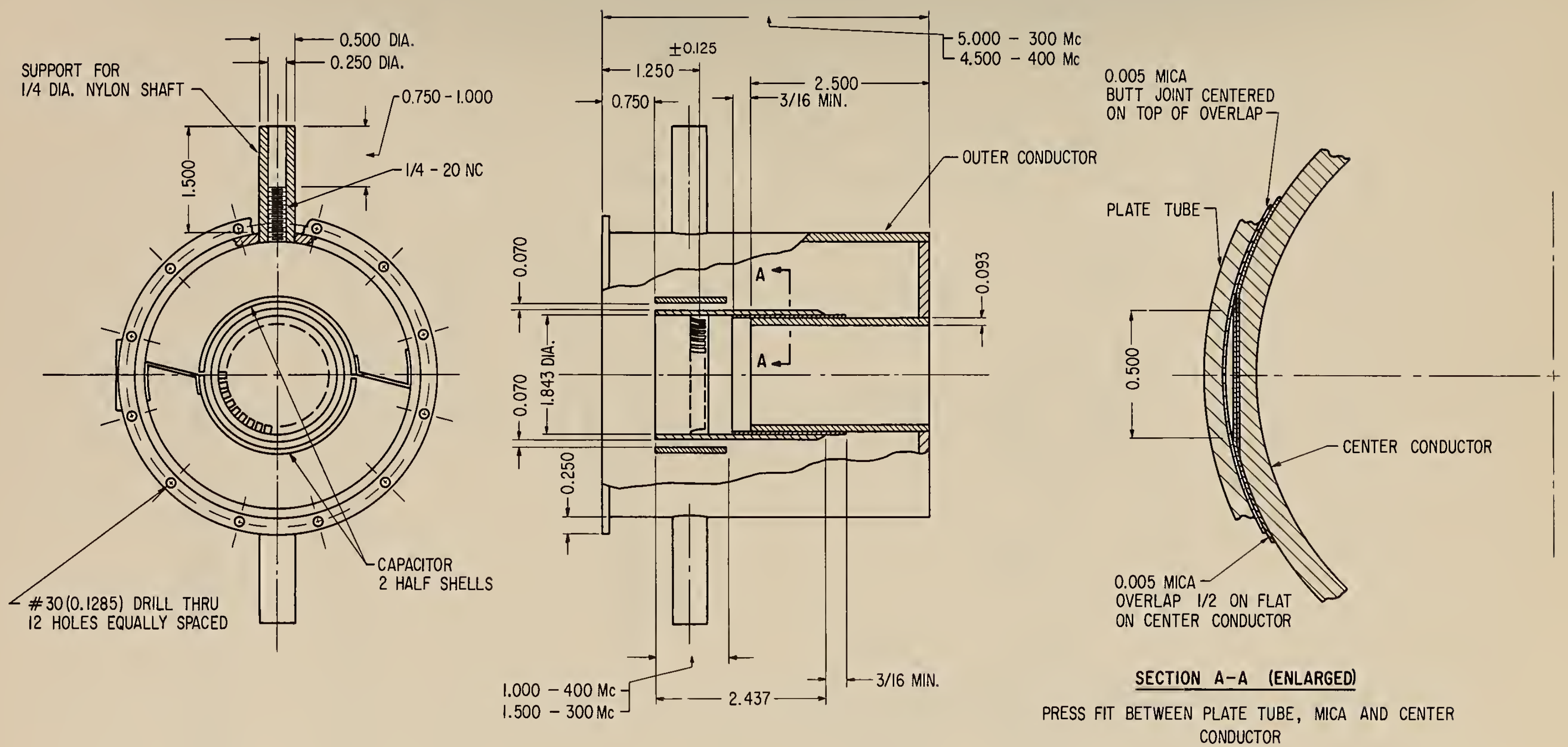
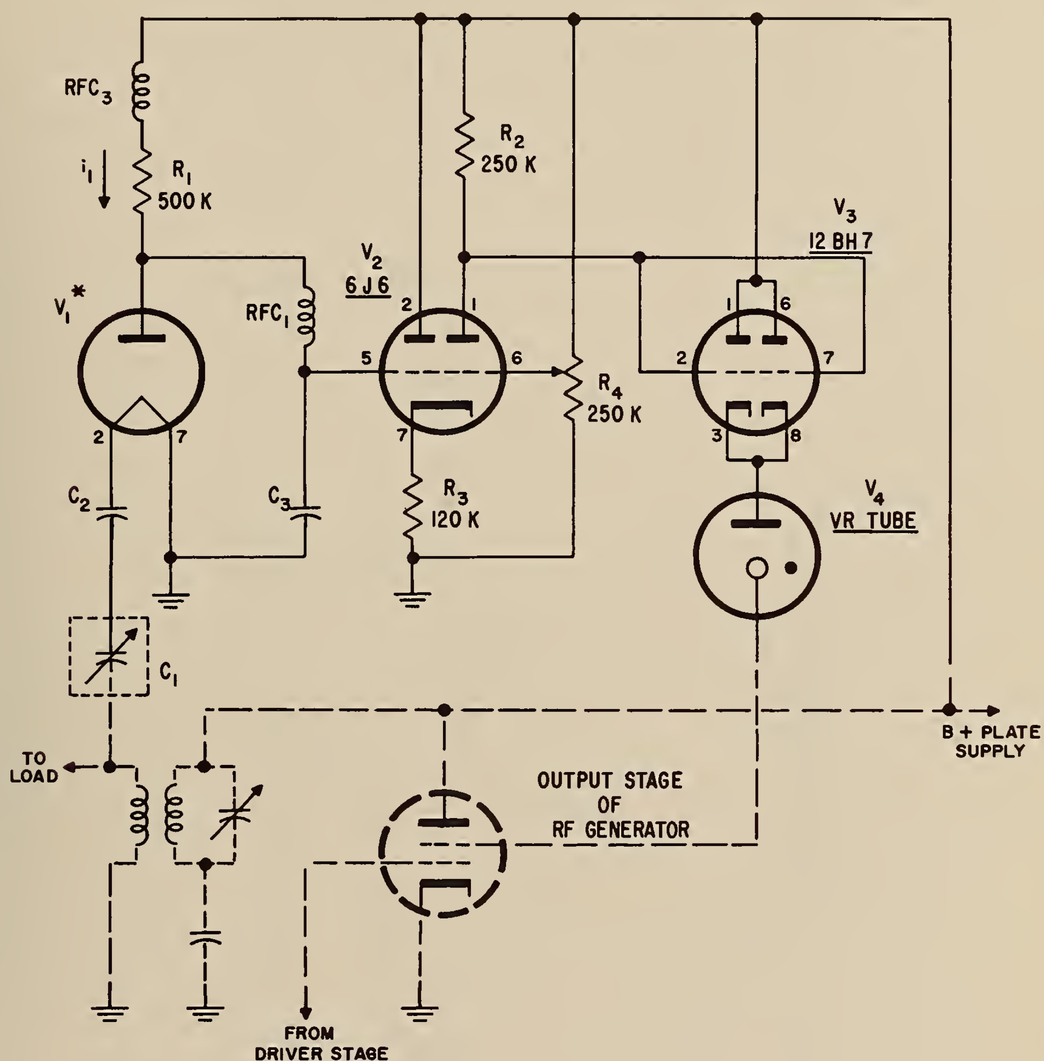


FIG. 4 PLATE CAVITY FOR 4 X 250 B TUBE
300 Mc AND 400 Mc



* KALOTRON TYPE 2 AS 15 OR 2 SM 15 OR SUPERIOR ELEC. CO. TYPE 1236 C

FIG. 5 AUTOMATIC LEVEL CONTROL (ALC) CIRCUIT

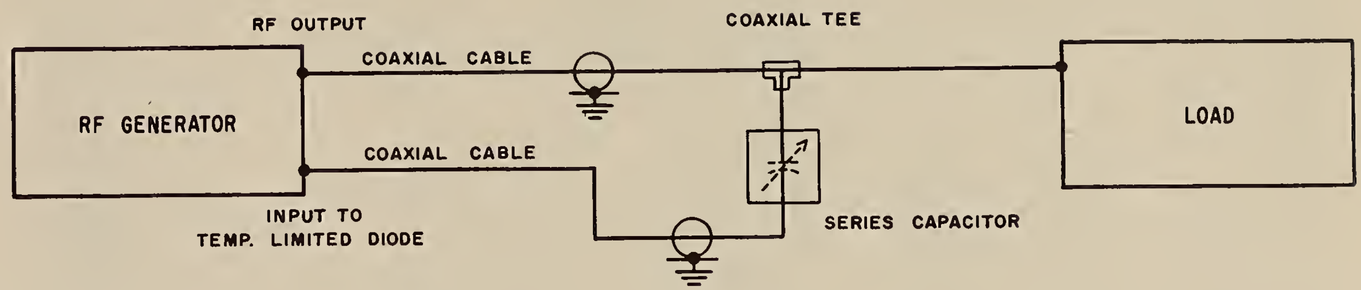
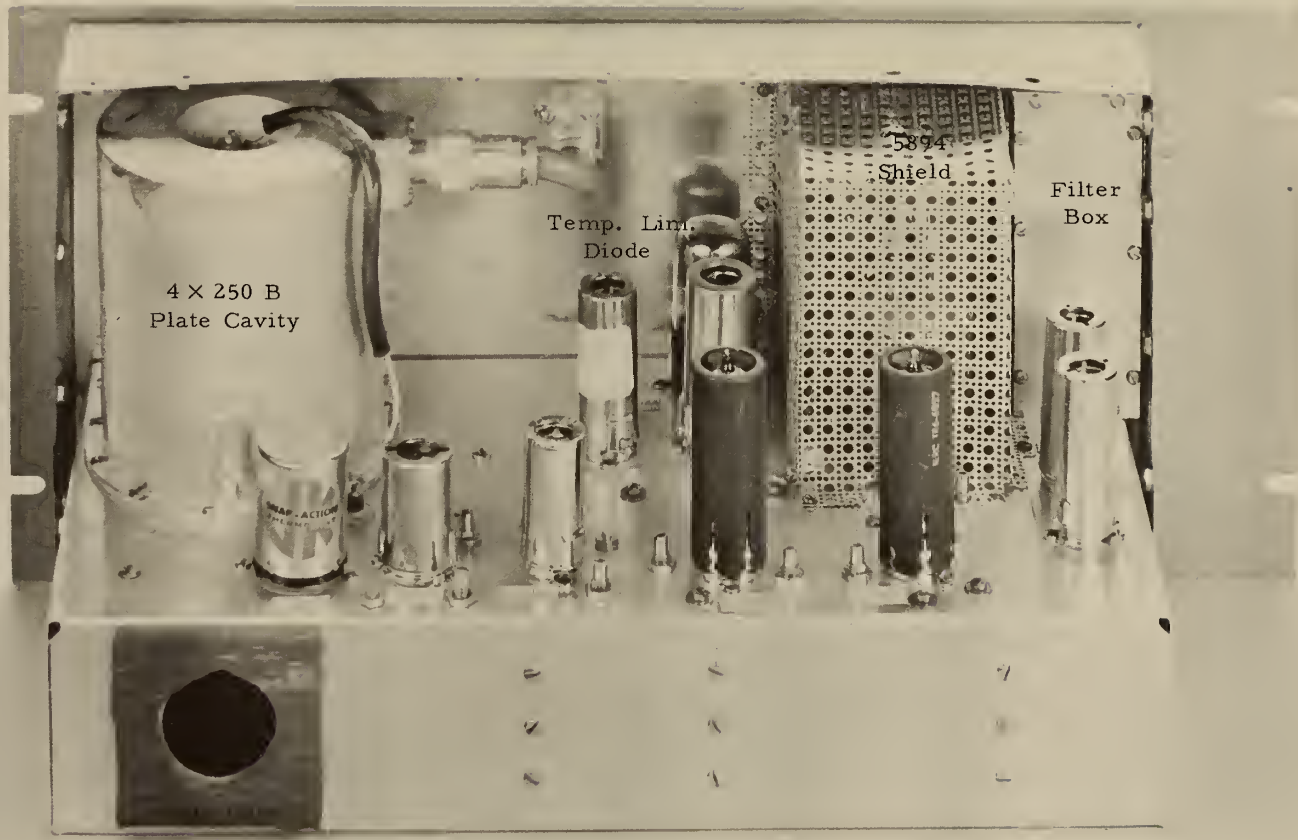
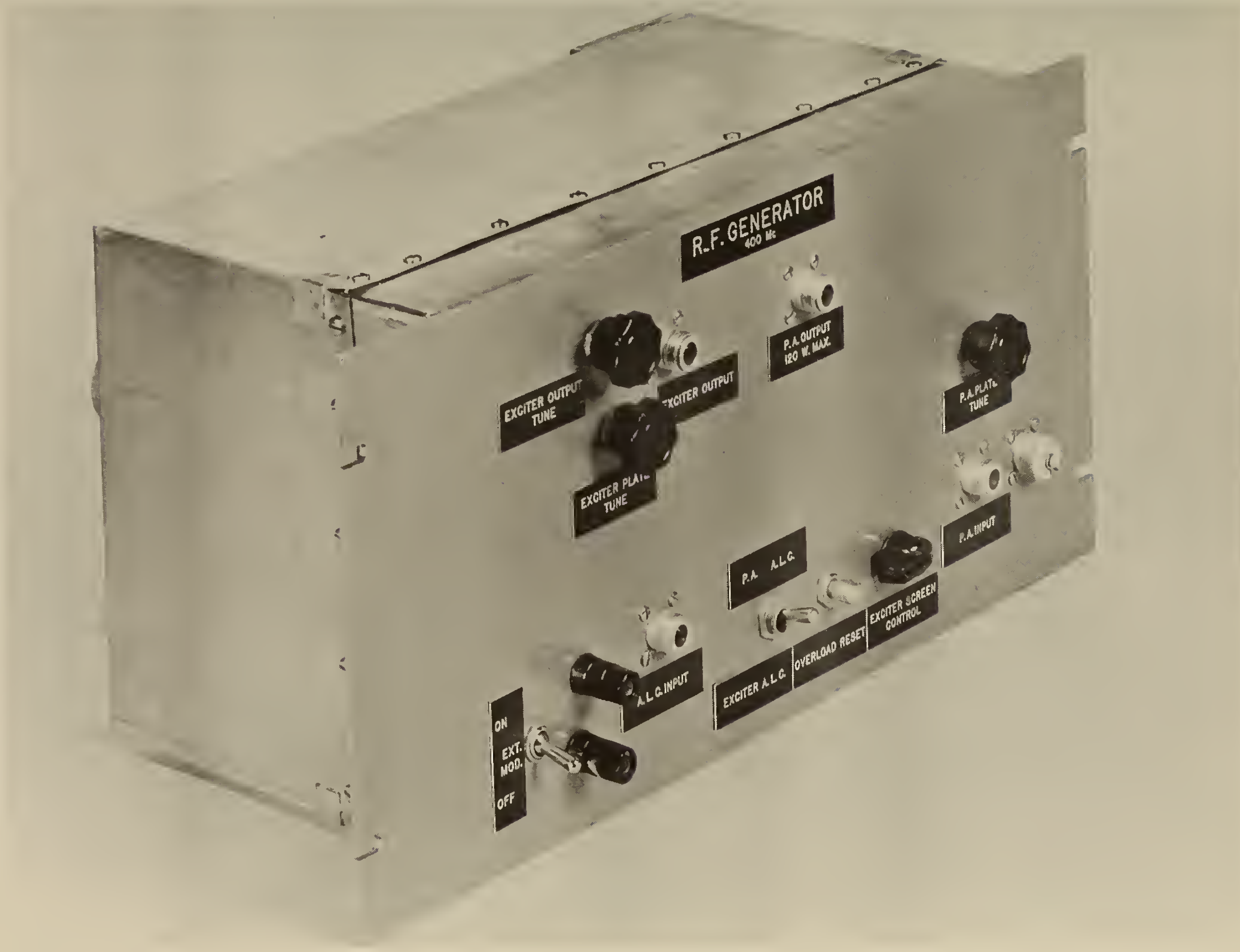


FIG. 6 BLOCK DIAGRAM
TYPICAL CONNECTION PROCEDURE
WHEN USING AUTOMATIC LEVEL CONTROL



GENERATOR TUBE LAYOUT
Figure 7



FRONT VIEW OF GENERATOR
WITH SHIELD IN PLACE
Figure 8

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