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A FIXED FREQUENCY, 9.1 Gc, FIELD INTENSITY RECORDING RECEIVER WITH EXTREMELY NARROW BANDWIDTH

BY R.W. HUBBARD AND J.V. CATEORA

U. S. DEPARTMENT OF COMMERCE
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ABSTRACT

A specialized field intensity recording receiver designed to operate in the X-band (9.1 Gc) portion of the radio spectrum is described in this paper, and its operational characteristics presented. The receiver was developed by the Radio Propagation Engineering Division, Central Radio Propagation Laboratory, National Bureau of Standards. Its purpose is to provide an advanced system to augment the facilities of the CRPL in a program of basic tropospheric radio propagation research.

The receiver normally operates on a fixed frequency of 9100.1 Mc but may be operated at ± 100 Mc intervals from the nominal, in the band 8.5 to 9.6 Gc. It displays an extremely narrow bandwidth of 45 cps, held by a stable and flat crystal filter element. The latter may be switched out of the system, providing a wider bandwidth of operation to 500 cps. The narrow bandwidth (approximately 5×10^{-7} percent at the X-band frequency) makes possible a high signal-to-noise figure, a desirable characteristic for a receiver used in tropospheric research. Maintaining this bandwidth of operation requires an extremely high degree of stabilization of the klystron oscillator frequencies. This has been accomplished in the design, utilizing a unique frequency/phase type control loop with an overall stability of approximately ± 2 parts in 10^9.

A true logarithmic response is obtained for a wide dynamic range of the recorded input signal variations, over the lower frequency portion of the recorded spectrum. The higher portion of the spectrum may be recorded separately on a linear expanded scale record, with a dynamic range up to 25 db. This system alleviates a common problem in most field strength recording systems, i.e., where the full dynamic range is recorded on a single record. In these systems the low frequency portion of the signal variations

have a wide dynamic range, and consequently they mask the smaller amplitude variations of the higher frequency components. The actual division of the spectrum recording is accomplished by closing a servo-controlled loop around the receiver from the output of the second detector to a variable attenuator at the antenna input to the receiver. The loop serves to maintain a constant output level over the response time of the loop, and over a maximum dynamic range of 40 db (the range of the attenuator). The higher frequencies are then recorded at full gain of the receiver in a separate channel, with a maximum dynamic range of 25 db. The time response of the servo loop is variable in ten discrete steps.

The application of the receiver is primarily for remote unattended operation. To this end an integral self-calibrating system has been provided, which may be controlled remotely at the transmitting terminal of any experimental propagation path. The system makes use of a calibrated noise source as a fixed in-line component, applying a noise input to the receiver of a known excess noise ratio when ignited. Also, gain-stable amplifier design techniques and modular plug-in type construction have been used whenever practical in the development to reduce operational and maintenance problems.

SUMMARY OF CHARACTERISTICS

(1) Operating Frequency - 9100.1 Mc (normal). May be operated at 100 Mc intervals thruout the range 8.5 to 9.6 Gc

(2) Receiver Type - double conversion superheterodyne

(3) Bandwidth
 (a) Narrow Band - 50 cps at -6db
 45 cps at -3db
 (b) Wide Band - 1000 cps at -6 db
 500 cps at -3 db

(4) Noise Figure - 11 db

(5) Sensitivity - -146 dbm narrow band
 -136 dbm wide band

(6) Dynamic Range - 65 db { 40 db low freq. channel; 25 db high freq. channel }

(7) Local Oscillator Stability - ≈ 1 part in 10^9 per day

(8) Intermediate Frequencies - First: 9.9 Mc
Second: 100 kc

(9) Outputs
(a) Low Freq. Recording - servo driven recording potentiometer (tape or graphic recorder)
(b) High Freq. Recording - low impedance d-c amplifier to magnetic tape recorder

(10) Recorded Spectrum
(a) Low Frequency - servo time response variable in 10 discrete steps from 3 seconds to 50 minutes full scale (40 db)
(b) High Frequency - from f_c of low frequency channel up to 50 cps

(11) Calibration
(a) Low Frequency - logarithmic calibration of the input attenuator
(b) High Frequency - linear voltage calibration of the high-pass recording circuit
(c) The calibration is checked periodically with use of an automatic system which inserts a calibrated noise source at a level of 14.6 db excess noise ratio.

INTRODUCTION

A great amount of effort has gone into the study of tropospheric radio propagation in the UHF and VHF portion of the RF spectrum in the last decade. The Central Radio Propagation Laboratory of the National Bureau of Standards has been a recognized leader in this work. Very little effort has been expended to date in the SHF region of the spectrum, however, especially in beyond line-of-site conditions and troposcatter circuits.

The development reported[1] in this paper represents the initial phase of a plan by the Radio Propagation Engineering Division of CRPL to extend their basic research program into the SHF region.

SYSTEM DESCRIPTION

A. General

A complete block diagram of the receiver is shown in Figure 1. Basically, it is a conventional double-conversion superheterodyne receiver with a first IF of 9.9 Mc and a second IF of 100 kc. The receiver has been designed with an extremely narrow bandwidth, which requires a very high degree of stabilization of the first local oscillator klystron frequency. The latter is accomplished in a frequency/phase type control loop [2], [3] consisting of the 10 Mc reference oscillator, the x10 multiplier, and the frequency/phase discriminator unit indicated in Figure 1. The reference oscillator is a crystal controlled unit operating at 10 Mc with a stability of approximately 1×10^{-9}. A multiplier is used to multiply the reference oscillator signal to a frequency of 100 Mc. This signal is then fed to a harmonic generating crystal at the top of the directional coupler in the control loop. A very high order harmonic (x91) is extracted from this crystal at 9100 Mc and propagated down the guide of the directional coupler to the reference mixer crystal, where it is mixed with a small portion of the local oscillator klystron power. The LO klystron is mechanically tuned to a frequency of 9110 Mc, which yields a 10 Mc beat frequency in the reference mixer crystal. This signal is then amplified, and applied to a frequency discriminator of the gated beam tube type. The 10 Mc reference oscillator signal is also fed to the quadrature grid of the gated beam disciminator as a phase reference and a phase lock between this oscillator signal and the 10 Mc loop signal is effected. The discriminator output is applied as an error signal to the repeller of the klystron, and in this manner the local oscillator frequency is held to approximately the stability of the reference oscillator, i.e., a few parts in 10^9 per day.

The first IF amplifier consists of two amplifier stages each employing feedback for gain stability and low output impedance. The first stage is a conventional cascode circuit with a cathode follower output, and the second a pentode amplifier stage with a cathode follower output. Both stages are tuned at 9.9Mc. The first stages have been designed with low impedance outputs to facilitate installation of the receiver in locations which require the antenna to be several hundred feet from the receiver. In this type of installation the X-band portion of the receiver may be placed physically near the antenna, and the output of either the first or second stage of the first IF amplifier carried by coaxial cable to the rest of the receiver in a remotely located operations building.

The second mixer and second IF amplifier consist of feedback-couple stages designed for the best gain stability possible[4/], and narrow bandwidth operation. The 100 kc amplifier stages utilize high-Q cup-core assemblies, with inverse current feedback from the second stage of each couple to the input stage. A crystal filter unit is employed as the coupling network in the IF output stage. This filter may be inserted or removed with a front panel selector switch, thus providing a variable bandwidth feature. The crystal filter used has a 6 db bandwidth characteristic of 50 cps at 100 kc, and excellent flat response over a wide portion of this bandwidth. This filter establishes the narrow bandwidth of the receiver. The IF output stage provides a low impedance cathode follower output which can be used if desired to drive directly a 1 ma or 5 ma low impedance recorder thru a crystal diode detector. A low impedance 100 kc output is also available from this stage.

The IF output and detector stage normally feed a servo-control amplifier which drives mechanically a precision variable calibrated attenuator at the input to the receiver. This system closes a complete loop around the receiver, and is a technique used to provide a split in the recorded frequency spectrum. The closed-loop servo system maintains a constant signal-to-noise ratio throughout the receiver over the low pass-band of the loop. The time response of this loop is variable in fixed steps from 3 sec. to as high as 50 min. full scale (40 db), the full range of the input variable attenuator. The loop thus serves to take out of the input signal all of the slow variations including the diurnal and other long term changes, which generally represent the largest portion of the dynamic range of the received signal. Because of this action only the input attenuator itself is required to have a wide dynamic range, and the dynamic range and linearity of the receiver are of secondary importance.

The relatively fast fluctuations present in the received signal represent a small portion of the overall dynamic range. This portion of the spectrum is amplified at full gain by the receiver, and can be displayed separately on an expanded scale type of record. The low portion of the spectrum may be directly recorded from an electrical analog of the servo shaft position, as indicated in Figure 1.

The variable attenuator employed in the loop has been modified to provide a true logarithmic characteristic with shaft rotation. A small precision cut cam is used in the drive mechanism, replacing the original linear lead-screw.. This modification was necessary in order to provide a constant rate-of-change of attenuation for any operating position of the attenuator within its calibrated range. It also provides a logarithmic calibration of the receiver response, which is a desirable feature.

In recording the high-pass portion of the data spectrum, it is necessary to compensate this output of the receiver for the dynamic changes introduced by the response of the input attenuator to the low-pass spectrum. Compensation is accomplished automatically in the receiver by using a logarithmic potentiometer, driven by the servo motor shaft, as a variable attenuator in the high-pass recording amplifier. The compensation is provided with a slope equal but negative to that of the input attenuator characteristic, over the entire calibrated range of 40 db. The dynamic range of the receiver proper is approximately 25 db which may be utilized completely for the high-pass portion of the data spectrum, and the full 40 db of the input attenuator loop utilized for the low portion. In this manner, the overall dynamic range of the receiver system is 65 db.

It can be seen that once the receiver sensitivity has been determined, the calibration of the system is completely dependent upon the calibration of the input attenuator, which is a fixed and stable characteristic. To monitor the performance of the electronic sections, it is then only necessary to make a periodic check of the gain of the receiver, and its noise level. For this purpose, an X-band calibrated noise source has been provided as an in-line component in the input section of the receiver. This tube is a small gaseous noise generator of the argon type with a very low VSWR in the extinguished state. It provides a broad-band noise spectrum at a fixed and constant excess noise ratio of 14.6 db when fired. The noise source thus provides a calibrated check point for the entire receiver, the output being recorded on the high-pass channel record. This system lends itself readily to automatic calibration procedures as well as unattended operation. The noise source is controlled by the limit switch on the servo shaft in Figure 1. Thus, when received signal is lost, the limit switch is actuated by the input attenuator seeking its lower limit, turning on the noise source. The calibration cycle can therefore be controlled remotely at the transmitter terminal by merely turning off the transmitter for a short period of time. A time delay is provided in the calibration system to enable the receiver to partially distinguish between a complete signal fade and a transmitter outage. During this delay, the receiver noise level is recorded on the output record.

Since the primary application of this receiver is for remote unattended operation, several important design features have been incorporated. First, all of the electronic circuitry has been designed in a modular plug-in form for rapid replacement, thus eliminating most field maintenance. Solid state circuitry has been employed in all power sources, and each section of the receiver provided with its individual source. As mentioned earlier, gain-stable techniques have been used wherever possible in the electronics to provide reliable and stable operation over long periods of time. These features may be seen more in detail in the following sections of this paper.

Another important feature of the receiver should also be described, which is a modified mode of operation. In locations where the received signal is fairly strong and not subject to rapid fading, the local oscillator klystron may be phase-locked directly to the received signal, providing even a higher degree of stability. In this mode, the AFC loop may be fed directly from the signal mixer crystal, with the klystron retuned to 9110.1 Mc. Thus the first IF becomes a 10.0 Mc beat, and it is necessary to retune slightly the first IF stages.

The freq./phase loop operates as described above, and a second local oscillator of 10.1 Mc is substituted for the 10 Mc reference oscillator in this capacity. The second local oscillator need only have a stability on the order of one part in 10^6 or better. An oscillator having a stability of approximately 1 part in 10^7 has been provided for this application.

B. Complete Receiver

Figures 2 and 3 are photographs of the completed receiver, showing the front panel view and the rear view with the rack door open.

C. SHF Input Section

This unit contains all of the WR-90 waveguide components including the input variable attenuator, the gaseous noise source, a 10 db directional coupler for inserting the local oscillator power, a variable attenuator for adjusting the local oscillator power level, and a tunable crystal mount for housing the signal mixer crystal. This unit also contains the servo motor, induction generator, limit switches, the low-pass recording potentiometer, and the logarithmic compensation potentiometer. A schematic diagram of the unit is shown in Figure 4.

A variable speed mechanical drive assembly is used in this section to provide the following gear reduction ratios between the servo motor and the calibrated attenuator shaft: 1 : 1, 2 : 1, 5 : 1, 10 : 1, 20 : 1, 50 : 1, 100 : 1, 200 : 1, 500 : 1, and 1000 : 1. The gear reduction ratio is used to establish the time response of the low-pass servo loop, and is selected by a turret control knob on the variable speed assembly box. The recording and compensation potentiometers, limit switch assembly, and the input attenuator are all geared to the output of this unit by the ratios indicated in Figure 4.

Figures 5 and 6 are photographs of the SHF section in which all of the components mentioned above are visible. The micrometer dial of the input attenuator and the control for the local oscillator power level attenuator have been provided on the front panel as seen in Figure 5. Also visible in this figure is the gaseous noise tube at the upper left, with its power cable attached. Figure 6 is a rear view of the unit, with a clear picture of the cam drive mechanism on the input attenuator. The variable speed drive unit is partially visible at the lower center of the photo.

Figure 7 is a plot of the input attenuator characteristics.

D. Calibration Unit

The calibration unit contains the gaseous noise source power supply, and the timing and control circuitry used in the automatic calibration cycle. In manual position, the timing and control unit is bypassed, and the noise source may be turned on manually for any period. In the automatic setting of the control switch (Figure 8), the unit is controlled by the limit switch in the SHF unit. When the limit switch is closed due to loss of received signal, a time delay relay is energized. After approximately 30 seconds the timing and control unit is energized and first turns on the filament power to the noise source. During a short period, the receiver is thus reading out its own noise level. The noise source plate supply is then turned on, and the new noise level recorded for a short period. The timer then extinguishes the noise source, and the receiver again records its own noise level until the transmitter signal is restored. The length of each portion of this cycle may be varied by cam adjustments in the timing section.

Figure 8 is a photograph and Figure 9 is a schematic diagram of the calibration unit. The meter in Figure 8 monitors the noise source tube current, and the controls are for coarse and fine adjustment of this current.

E. First Local Oscillator and Freq./Phase Control System

The first local oscillator of the receiver is a type VA 203 B reflex klystron oscillator operating in a closed loop frequency control system. The schematic diagram of this unit is shown in Figure 10. Figure 11 is a photograph of the unit with the top shield plate removed. The klystron is mounted within the shielded enclosure, and a small centrifugal blower provides a cooling air stream directly on the tube. All of the essential controls of this unit are available on the front panel, including the mechanical tuning control, the attenuator control for adjusting the power level to the mixer crystal, and the direct reading reactive type frequency meter. A crystal and 0-1 ma panel meter are provided as a power monitor for the klystron, as well as an indicator in conjunction with the frequency meter. The crystal mount at the lower left of Figure 11 houses the harmonic generating crystal in the system. The mixer crystal is mounted at the opposite end of the same directional coupler. Both are type 1N23B crystals.

The harmonic generating crystal[5/] is driven from the output of the 100 Mc multiplier shown in Figure 12. This photograph shows the multiplier strip removed from the power supply panel in the foreground. The multiplier is a balanced circuit which multiplies the reference oscillator frequency of 10 Mc to a push-push output of 100 Mc. The 91st harmonic of this reference signal is generated in the harmonic crystal, supplying the final reference of 9100 Mc to the mixer crystal. This system is shown in block diagram form in Figure 13. The schematic diagram of the 100 Mc multiplier and its power supply are presented in Figures 14 and 15.

The 10 Mc signal developed in the mixer crystal is fed into the Amplifier-Discriminator unit shown in Figure 16. The sub-chassis assembly of the amplifier and discriminator has been removed from the supporting panel in this photo. A block diagram of the unit is shown in Figure 17 and a complete schematic diagram in Figure 18. The unit is composed of three stages of amplification followed by a limiter stage which drives the 6BN6 discriminator. The latter stage is of the gated beam type in which the phase reference signal is transformer coupled into the quadrature grid. The averaged d-c output of the discriminator is applied as an error signal to the repeller of the local oscillator klystron completing the control loop. The characteristic of the discriminator is presented in Figure 19. The front panel meter of Figure 16 is provided to measure the mixer crystal current. A vernier control of the repeller voltage is also available, providing a small range of electronic tuning of the oscillator to initially establish a phase lock.

Figure 17 indicates an automatic reset circuit for the phase-lock system. This circuit employs a small thyratron, normally held cut-off by a bias developed in the amplifier-limiter stage in the presence of normal signal. When a phase-lock is lost, the thyratron is allowed to fire and a resonant tank in its plate circuit applies a ringing voltage of approximately 50 cps to the klystron repeller. The ringing voltage swings the repeller voltage of the klystron across the critical value until phase-lock is reestablished. The circuit has proven to be very fast and reliable in reset action. Also in Figure 17, a cathode ray tube monitor is noted. The monitor is provided so that a continuous visual 1 : 1 Lissajous pattern is presented on the scope to observe the phase lock. The Phase Monitor uses a 2" cathode ray tube with single stage vertical and horizontal amplifier circuits. A photograph of the unit is shown in Figure 20 and the schematic diagram in Figure 21.

Power for both the Amplifier Discriminator unit and the local oscillator klystron is derived from the Klystron Power Supply of Figure 22. A schematic diagram of the supply is presented in Figure 23.

F. IF Amplifier

The IF Amplifier strip shown photographically in Figure 24 is composed of five modular plug-in amplifier stages, a crystal filter coupling network, and a precision step attenuator. The first two plug-in stages comprise the first IF amplifier at a frequency of 9.9 Mc. The first stage is a conventional cascode input amplifier followed by a low impedance cathode follower output stage. Negative feedback is used on the input cascode stage for gain stability. The overall gain of this stage is 32 db with a bandwidth of approximately 100 kc. A photograph of this plug-in is shown in Figure 25. The construction is typical for all of the plug-in sections of the IF amplifier as well as other sections of the receiver. Miniature coaxial cable and fittings have been used to interconnect the sections of the amplifier strip. The input and output coaxial jacks are visable in Figure 25. A schematic diagram of the cascode amplifier is given in Figure 26. The grid of the input stage is returned to a front panel meter of the strip to monitor the signal mixer crystal current. The second plug-in consists of a tuned plate pentode amplifier stage and a cathode follower with an output impedance of 50 ohms. The latter is to match the input impedance of a strip attenuator provided between this stage and the input to the second mixer. A schematic diagram of the amplifier and cathode follower is shown in Figure 27. The gain of this stage is approximately 10 db with a 3 db bandwidth of 100 kc. The input of the third plug-in assembly is a pentagrid converter stage used as a second mixer in a feedback-couple circuit at 100 kc. This circuit and the following gain-stable amplifier at 100 kc, which is also a feedback-couple, compose the main second IF amplifier. Their schematic diagrams are shown in Figures 28 and 29 respectively. Typical construction of each couple may be seen from the photograph of the gain-stable amplifier in Figure 30.

Both of these amplifier-couples have been designed with approximately 30 db of negative feedback to provide excellent gain-stable characteristics which are shown in Figures 31 and 32. Figure 31 presents the gain stability of the two couples in cascade vs. the plate supply voltage, and Figure 32 the same parameter plotted against the filament supply voltage. These results are not only representative of the stability expected with operating voltage variations, but also serve to indicate somewhat the performance of the amplifiers over long periods of time with gradual changes in g_m of the vacuum tubes. It is for this reason that gain-stable features are important.

Care must be taken in tuning of these couple stages in order to prevent regeneration. As seen in the schematic and in Figure 30, a small toggle switch has been provided to open the feedback path. The tuning procedure is to peak each stage independently with the feedback path open, then close the feedback switch and retune only the output stage. The coils of the amplifiers are powdered-iron cup-core assemblies with high Q characteristics. The entire assembly is housed in a silver plated cylinder, with a top mounting tuning slug.

Figure 33 is a plot of the frequency response for the 100 kc Gain Stable Amplifier-Couple and Figure 34 is the response for both the mixer-couple and the amplifier-couple in cascade. Figure 34 indicates a slight degree of non-symmetry after following the tuning procedure outlined above. If this degree is too severe, it may be corrected by slightly adjusting the tuning of the input stages of each couple.

The final unit of the IF strip is a pentode amplifier and a cathode follower stage, designed to match the input and output impedances of a crystal filter coupling network. This filter establishes the narrow bandwidth of the receiver when inserted. It may be removed from the circuit with a front panel switch seen in Figure 24. When removed the operating bandwidth is established by the amplifier-couples with the characteristic of Figure 34. Attenuation characteristics of the crystal filter are shown in Figure 35. The response is seen to be flat within 1/2 db over a bandwidth of approximately 20 cps. The insertion loss of the network is approximately 4 db.

The cathode follower of the final unit provides a low impedance output jack for the 2nd IF, as well as a driver for a crystal diode detector circuit. The schematic diagram of this stage is shown in Figure 36. This circuit is capable of driving directly either a 1 ma or 5 ma strip chart recorder, or a variety of high impedance voltage recorders when desired. In normal operation, the detector output is fed to the Servo Control Amplifier, and the IF output is used to drive the High-Pass Recording Amplifier discussed in a later section.

Measurements of the overall gain stability and response of the complete IF Amplifier have been made, and the results presented in Figures 37 and 38. A schematic wiring diagram of the assembly chassis is shown in Figure 39 and the RF cabling diagram in Figure 40.

A separate power supply is provided for the IF strip which is shown in Figure 41. A plug-in voltage regulator is used in this supply, and its schematic diagram shown in Figure 42. The schematic of the supply is Figure 43.

G. Servo Amplifier and Power Supply

The Servo Amplifier and Power Supply, used to drive the input variable attenuator of the receiver is shown in Figure 44. The servo amplifier sub-assembly is shown removed from the power supply panel in this figure. The schematic diagram of the amplifier plug-in is shown in Figure 45. A miniature 60 cps synchronous-chopper input network is used to compare differentially the output level of the detector and a stable reference voltage. The reference voltage is supplied by a mercury cell housed in a panel mounted receptacle on the power supply panel. The reference level is adjustable by a precision potentiometer control, also mounted on the panel. Both of these components may be seen in Figure 44. Internal as well as induction or rate generator feedback is applied to the amplifier for stability. The output circuit is a pair of power pentodes in push-pull, transformer coupled directly to the control phase of the servo motor. A shunting diode is used to balance the input to the amplifier whenever received signal is lost and the limit switch closes. When signal returns the diode balance is upset, and the amplifier returns to normal operation. A schematic diagram of the power supply section is shown in Figure 46. Regulated plate voltages are used on all of the preamplifier stages, and an unregulated supply for the final power amplifier.

A typical frequency response for the low-pass servo driven attenuator loop is shown in Figure 47, with the selectable gear reduction ratio as a parameter. This response was measured with a 10 db peak-to-peak variation in the received signal at the indicated frequencies. Dotted portions of the curves represent extrapolated values and not direct measurement. This set of curves may be used as a universal response for any peak-to-peak value of input signal variation by applying the following multiplier to the frequency scale:

$$\text{Multiplier (M)} = \frac{10}{A}$$

where A is the peak-to-peak signal variation in db. It should be noted from Figure 47 that the response is almost inversely proportional to the gear reduction ratio except at the lower ratios (higher speed) where the torque load of the driven components is more pronounced.

H. High-Pass Recording Amplifier

The High-Pass Recording Amplifier is used to provide a low impedance output, either balanced or unbalanced, for compensating and recording the high frequency data spectrum, above the cut-off of the servo loop. A photograph of the unit is shown in Figure 48 and the schematic diagrams in Figures 49 and 50. The amplifier is a plug-in sub assembly like those shown in previous sections.

Compensation of the gain variations due to the dynamic action of the servo loop attenuator is accomplished by passing the amplifier output thru a logarithmic potentiometer, driven by the servo motor. The potentiometer thus acts as a variable attenuator in the amplifier output. The attenuation characteristic vs. shaft rotation of this potentiometer is made equal to that of the X-band attenuator (Figure 7) but with negative slope. The d-c level of the detector is balanced out at the input to the amplifier by a positive potential developed in a voltage divider circuit. A front panel mounted precision potentiometer is provided for this balance control. A smaller potentiometer is also provided to balance the circuit against the receiver noise level for calibration purposes.

The amplifier consists of a pair of cathode follower input stages, a phase inverter, and a push-pull cathode follower output stage. The circuit is isolated above chassis ground, allowing either balanced or unbalanced output selected by a front panel switch. A miniature balance control potentiometer is provided in the amplifier as a screw driver adjustment. One position of a panel mounted operational selector switch marked BAL opens the input to the amplifier for adjusting and checking the d-c balance. A voltmeter in the output circuit with a selected range of 10-0-10 volts or 1-0-1 volt is used for making all balance adjustments. The operational selector switch is also used to insert or remove a filter capacitor at the input of the amplifier providing either a narrow bandwidth (2 cps) or a full wide bandwidth for the recorded spectrum up to 50 cps.

The output of this unit is used in making the automatic noise source calibration check for the entire receiver. For this purpose, a relay circuit is provided to perform various switching functions when the receiver is calibrated. The relay is energized when the servo limit switch is closed. First, the relay switches the input balance reference from the signal reference potentiometer to the noise reference potentiometer. This balances the recording amplifier to the receiver noise level. Secondly, the compensating potentiometer is switched out of the circuit allowing the stage to operate with maximum sensitivity. The relay also inserts the filter capacitor mentioned above, filtering out all of the high-frequency noise components. When the X-band noise source is turned on during calibration, the recorded output is then a measure of the d-c unbalance in the recording amplifier due to the increased noise output of the receiver. In this fashion, the calibration check point is a function of the entire receiver response, all the way from the X-band input to the recording terminals. A direct reading of the receiver noise figure, as well as a comparative check on the calibrated output record is automatically provided and recorded.

I. Second Local Oscillator

The Second Local Oscillator is a 10.1 Mc crystal controlled oscillator for use when the receiver is operated in the modified mode described previously in paragraph A of this section. A photograph of this unit is shown in Figure 51. The oscillator is constructed in a plug-in assembly, and a crystal oven is used to house the crystal unit. The voltage regulator in the power supply is the same unit as shown in Figure 42. Further details on the oscillator are omitted, since it is not considered an integral part of the receiver design. Any oscillator with a stability of 1 part in 10^6 or better, with an output of 2 to 3 v rms is suitable.

CONCLUSIONS

The receiver described, with its very narrow bandwidth and high sensitivity, lends itself to a great variety of tropospheric circuits to be studied in the SHF band. Tests of the system have been performed over a short line-of-sight path between the Boulder Laboratories and a field site at Table Mesa, northeast of Boulder, Colorado, a distance of approximately 10 miles. A target transmitter using a VA 203 B klystron oscillator was constructed for the tests. The test transmitter equipment is shown in Figures 52 and 53.

Operational transmitting equipment is under development by the Radio Propagation Engineering Division and will be described in a subsequent report. A CW klystron of the fixed tuned type, controlled in a similar AFC loop as described for the receiver local oscillator, is being employed. This tube has a nominal power rating of 100 watts, with good efficiency and requiring light water cooling. A photograph of the tube is presented in Figure 54. A high power transmitter using a recently developed klystron capable of 2 kw CW power output is also under development. These facilities will provide practically unlimited horizons for propagation studies at the SHF frequencies.

It should also be mentioned here that the receiver described may be very useful in the lower VHF and UHF propagation studies. The practicality of designing input heads at these frequencies using parametric type up-converter amplifiers is being studied. In this way all of the features of the X-band receiver could be utilized at the lower frequencies.

The receiver as described has been used as a prototype for construction of three additional receivers, and several experimental programs for their use are being planned.

ACKNOWLEDGEMENTS

The authors wish to acknowledge the work of D. V. Glen, L. J. Maloney, J. A. Sykes and Boyce Talbutt who assisted in the construction and testing of the receiver system, and the helpful suggestions of M. J. Vetter and D. M. Waters. They also wish to acknowledge the partial support of this project by the U.S. Army Signal Corps under Contract MIPR R-56-0027-SC-91.

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2. Peter, M., and M.W.P. Strandberg, Phase stabilization of microwave oscillators, Proc. IRE 43, 869-873 (July 1955).

3. Thompson, M.C., Jr., and M.J. Vetter, Single path phase measuring system for three-centimeter radio waves, RSI 29, No. 2, (February 1958)

4. Montgomery, G. Franklin, Intermediate-frequency gain stabilization with inverse feedback, Proc. IRE 38, 662-667 (June 1950).

5. Thompson, M.C. Jr., and J.V. Cateora, High-order harmonics for X-band oscillator stabilization, RSI 28 (August 1957).

X-BAND FIELD INTENSITY RECORDING RECEIVER

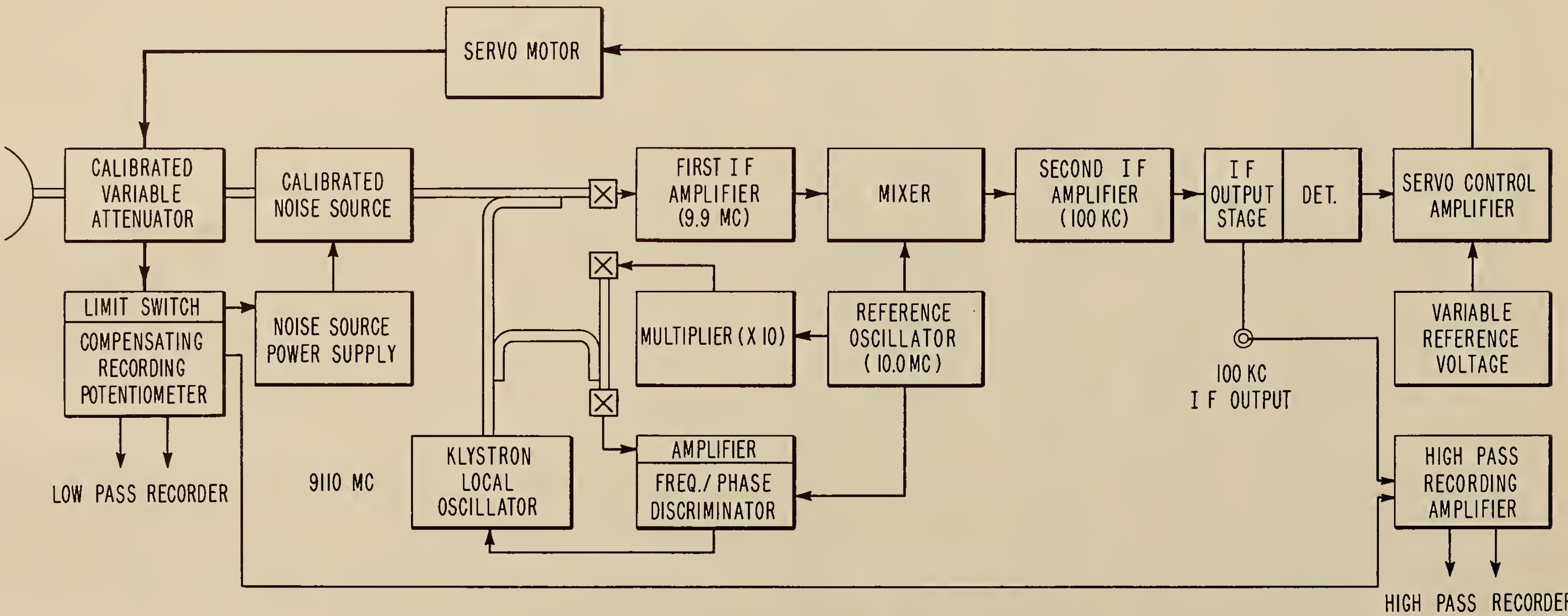

Figure 1

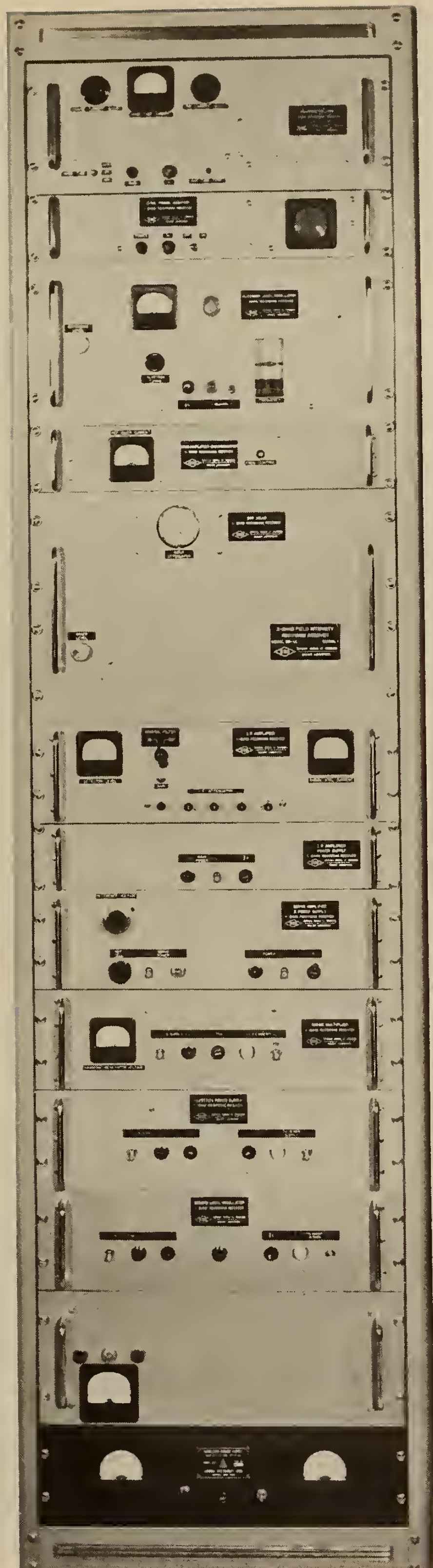

FIG. 2 X – BAND RECORDING RECEIVER — PANEL VIEW

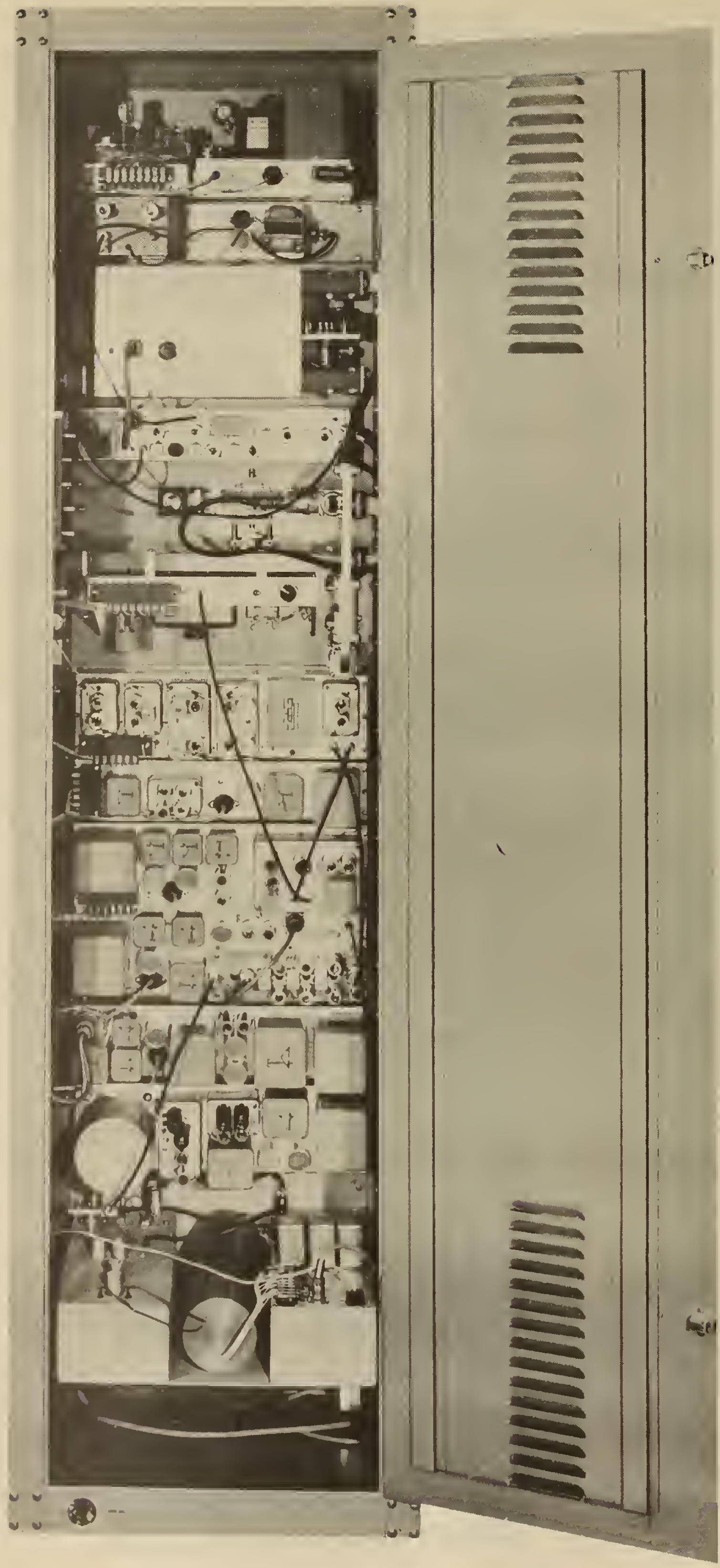

FIG. 3 X—BAND RECORDING RECEIVER—REAR VIEW

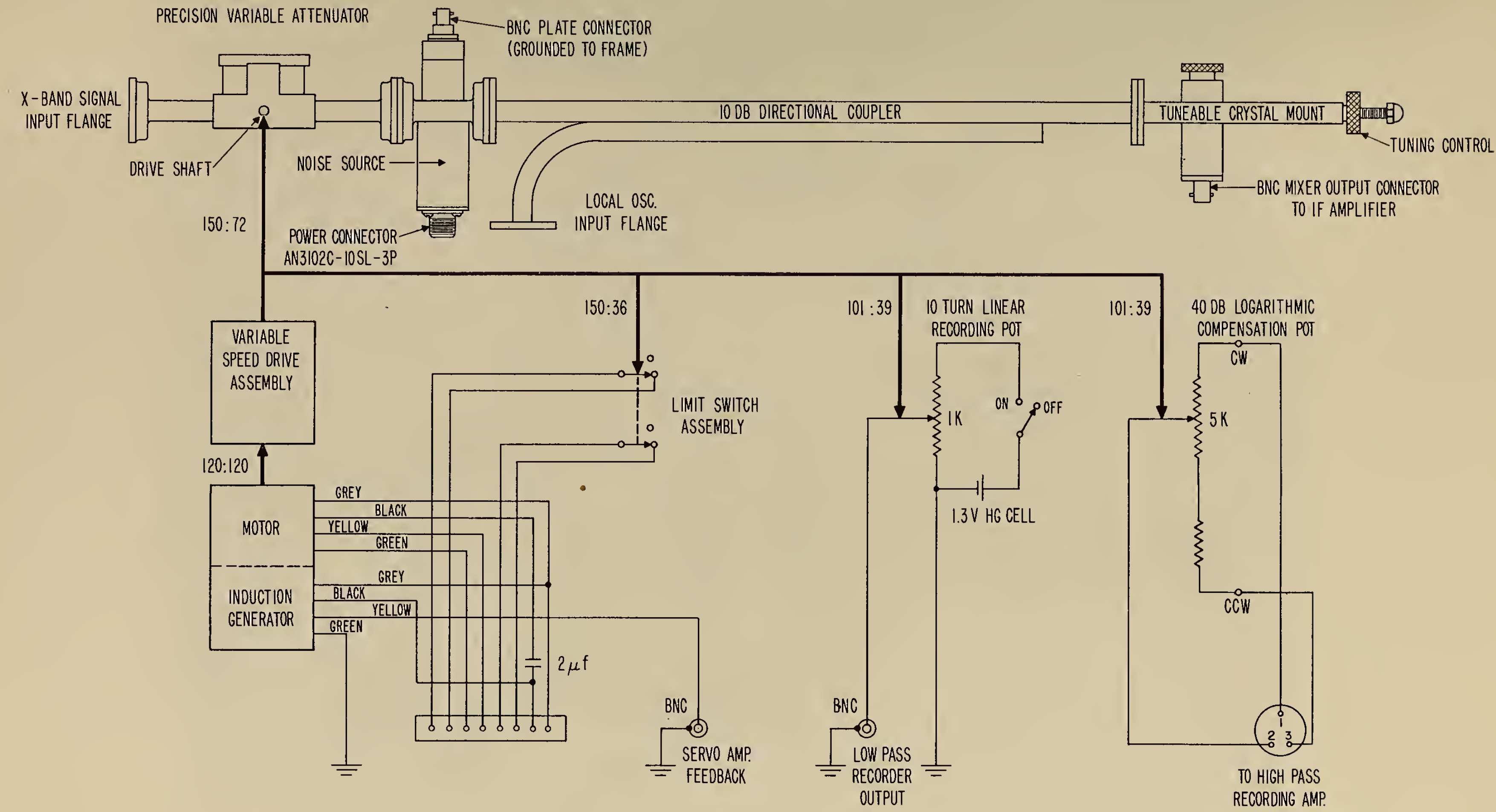

FIG.4 SHF HEAD

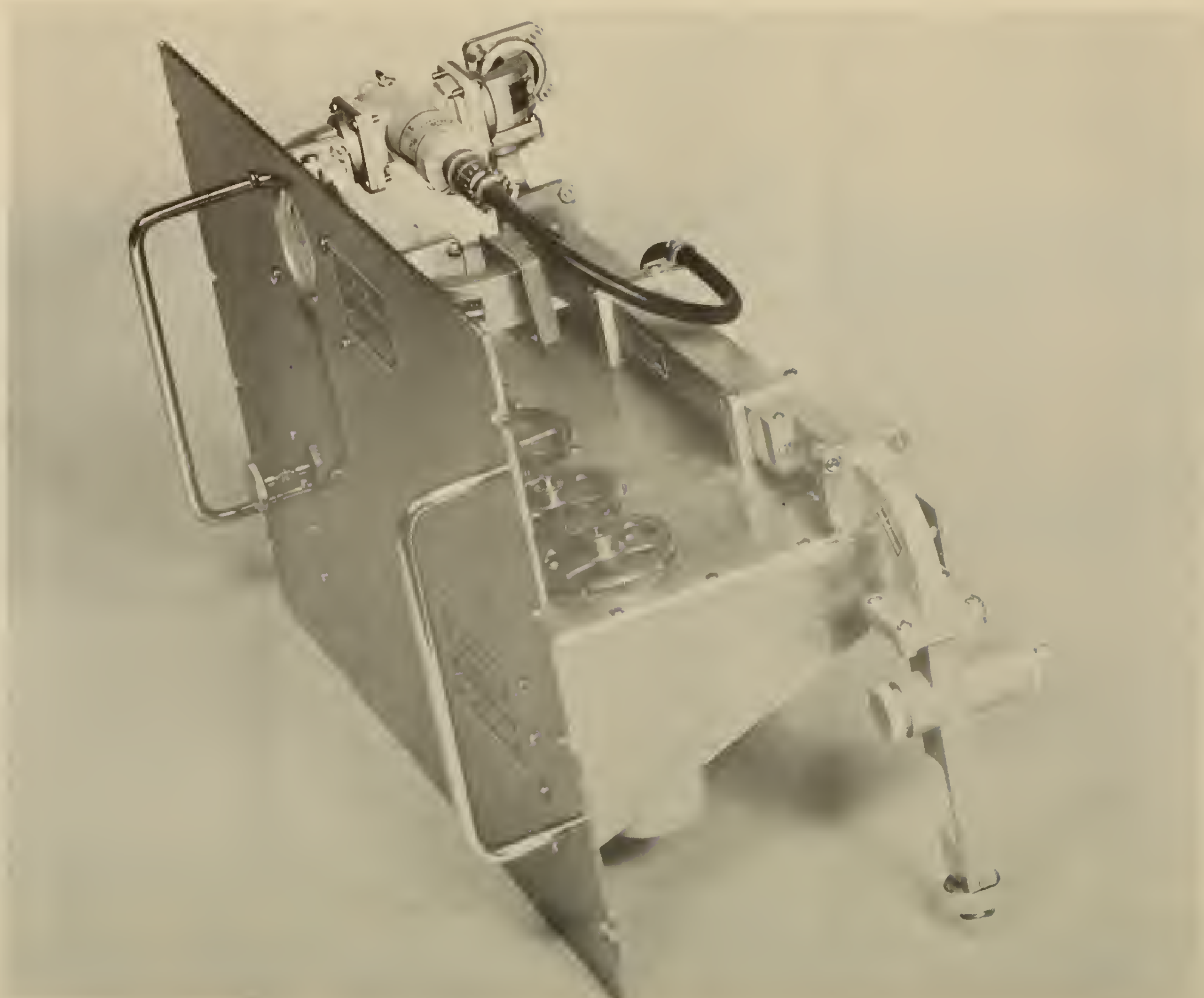

FIG. 5 SHF INPUT SECTION

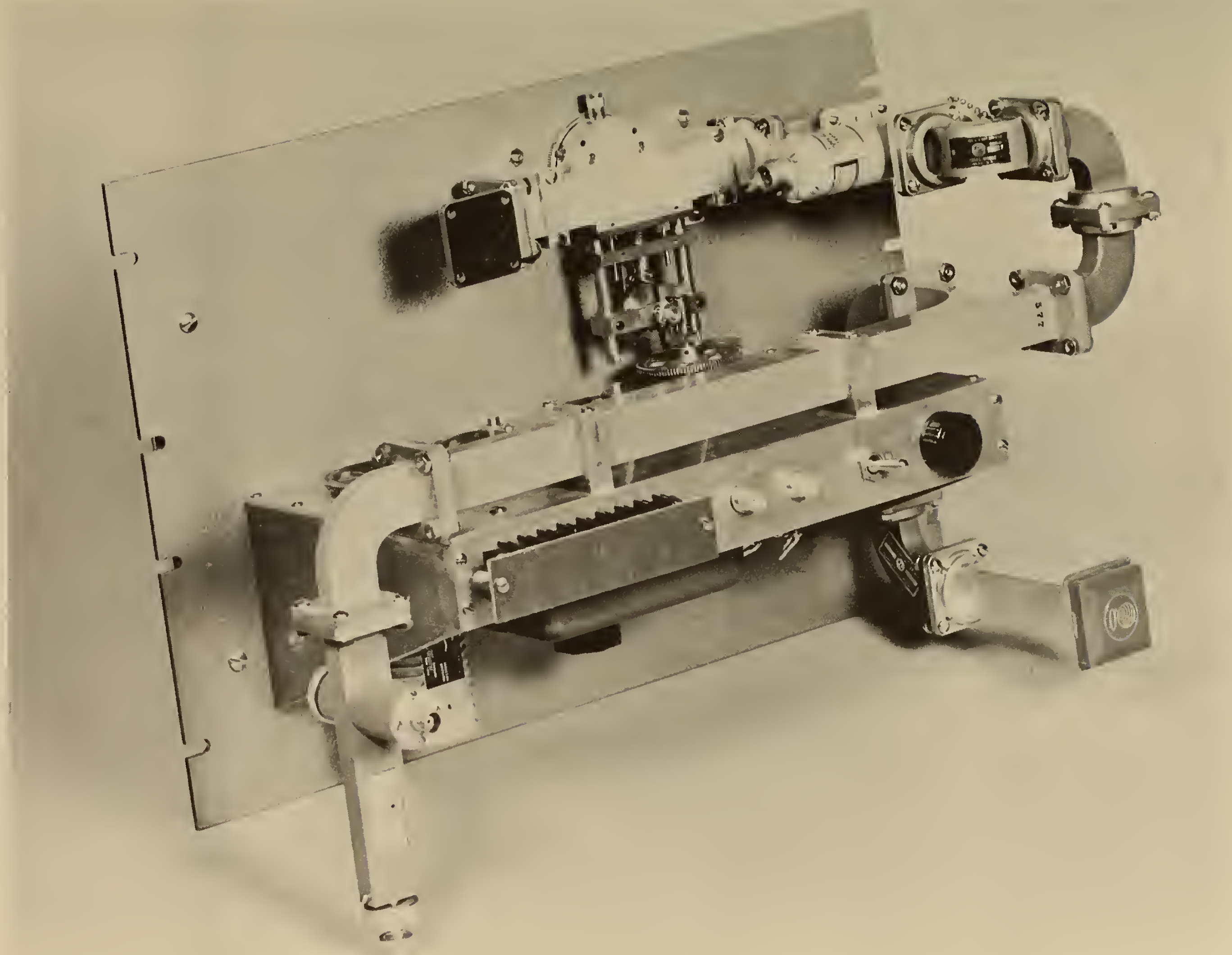

FIG. 6 SHF INPUT SECTION

CALIBRATED VARIABLE ATTENUATOR CHARACTERISTICS
X-BAND RECORDING RECEIVER

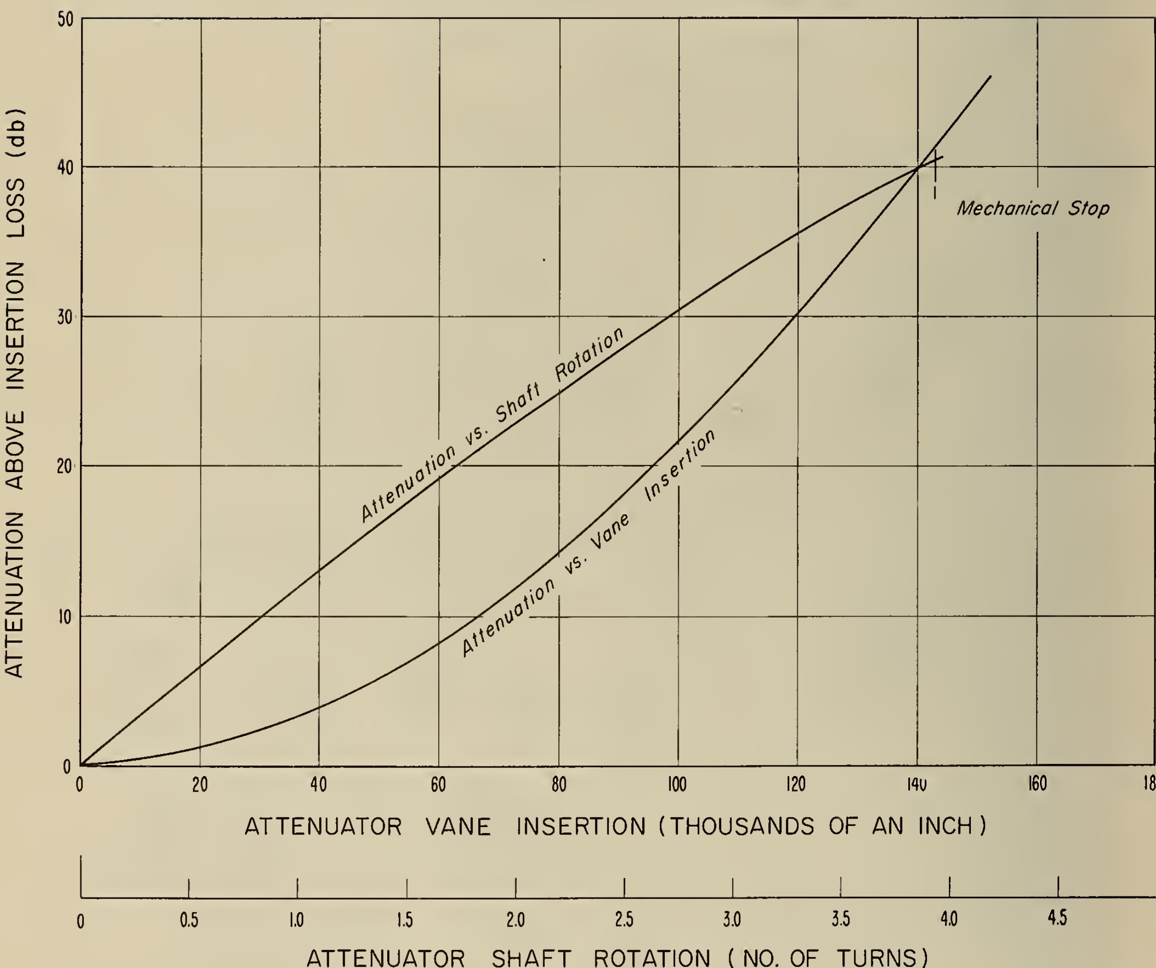

Figure 7

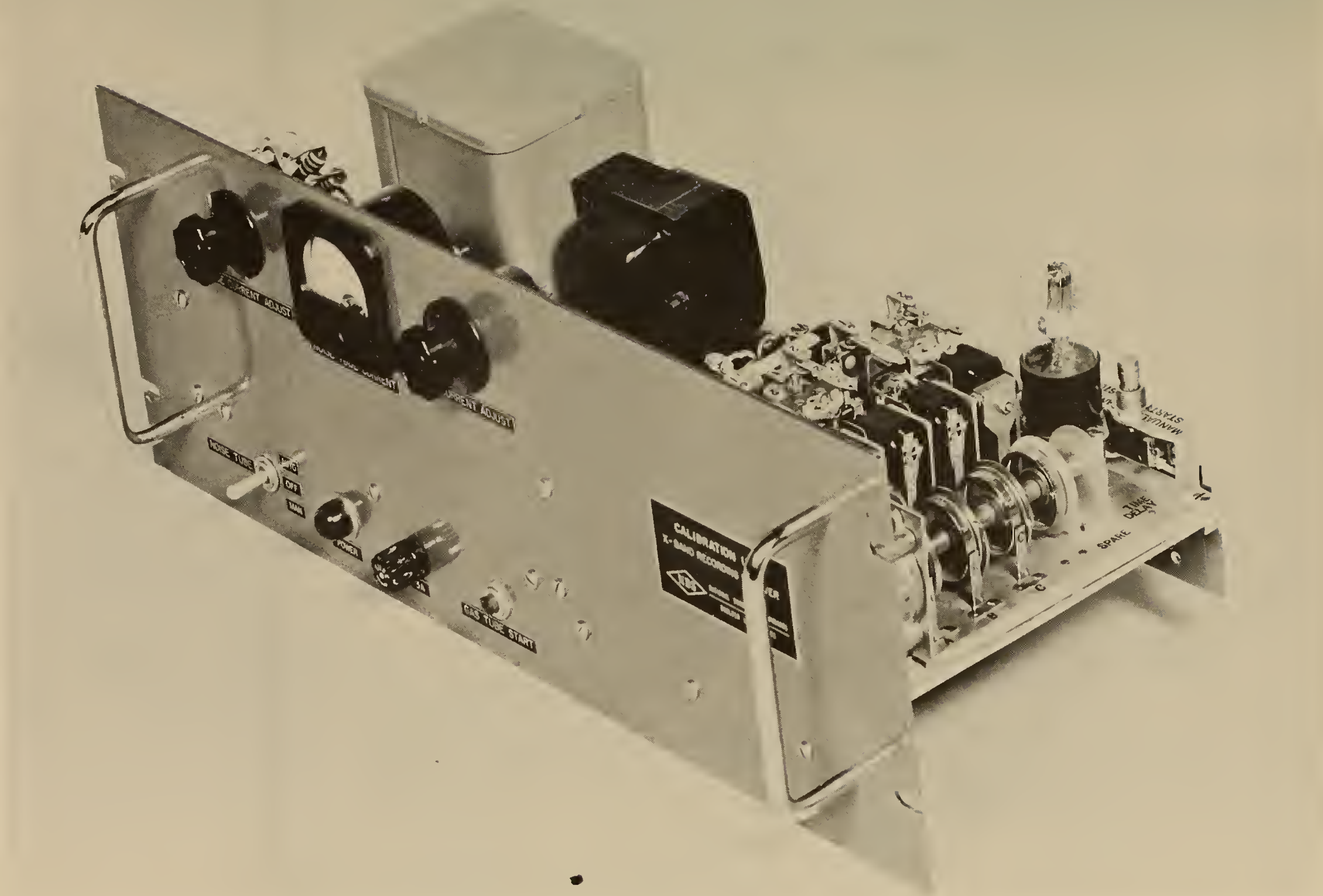

FIG. 8 CALIBRATION UNIT

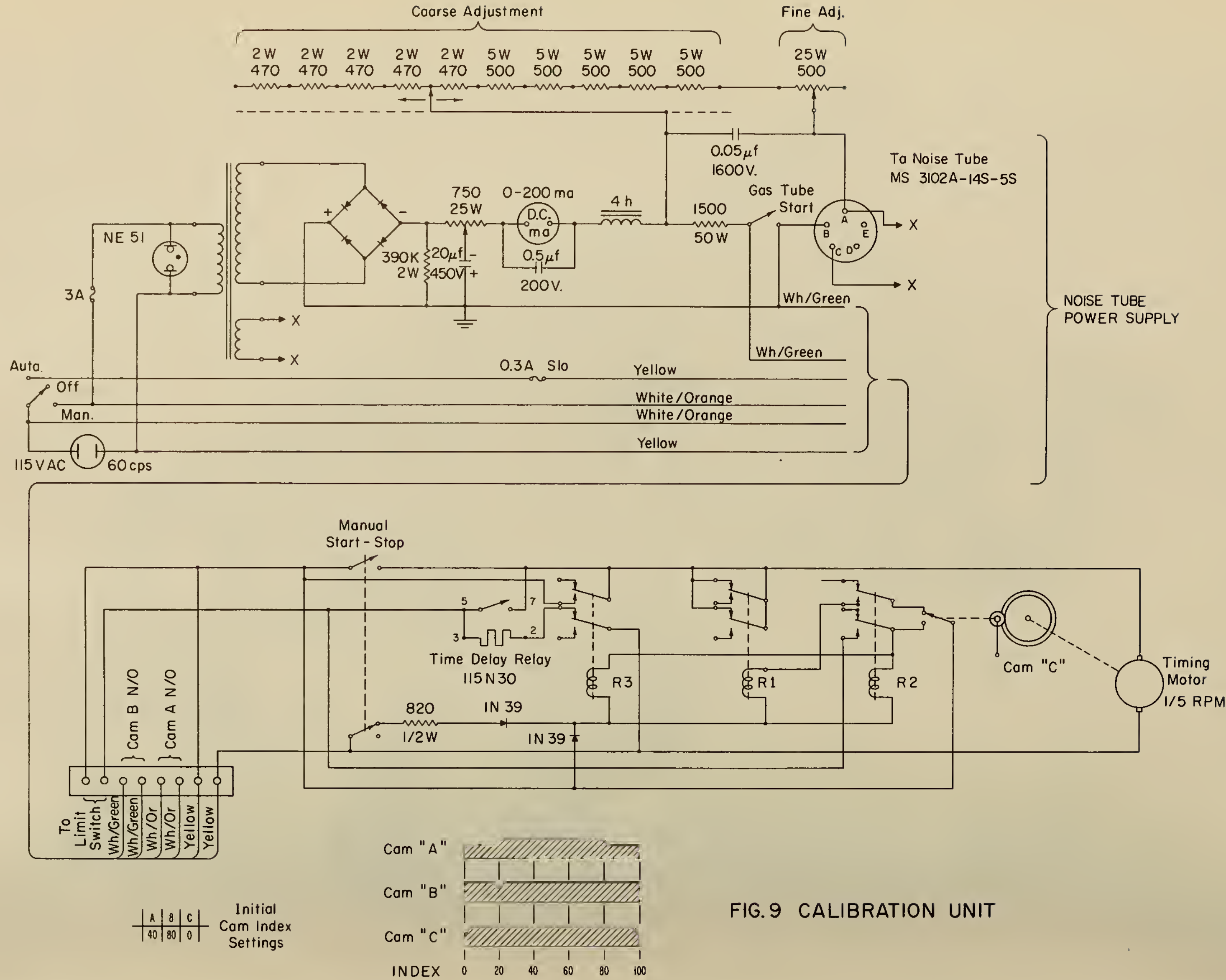

FIG. 9 CALIBRATION UNIT

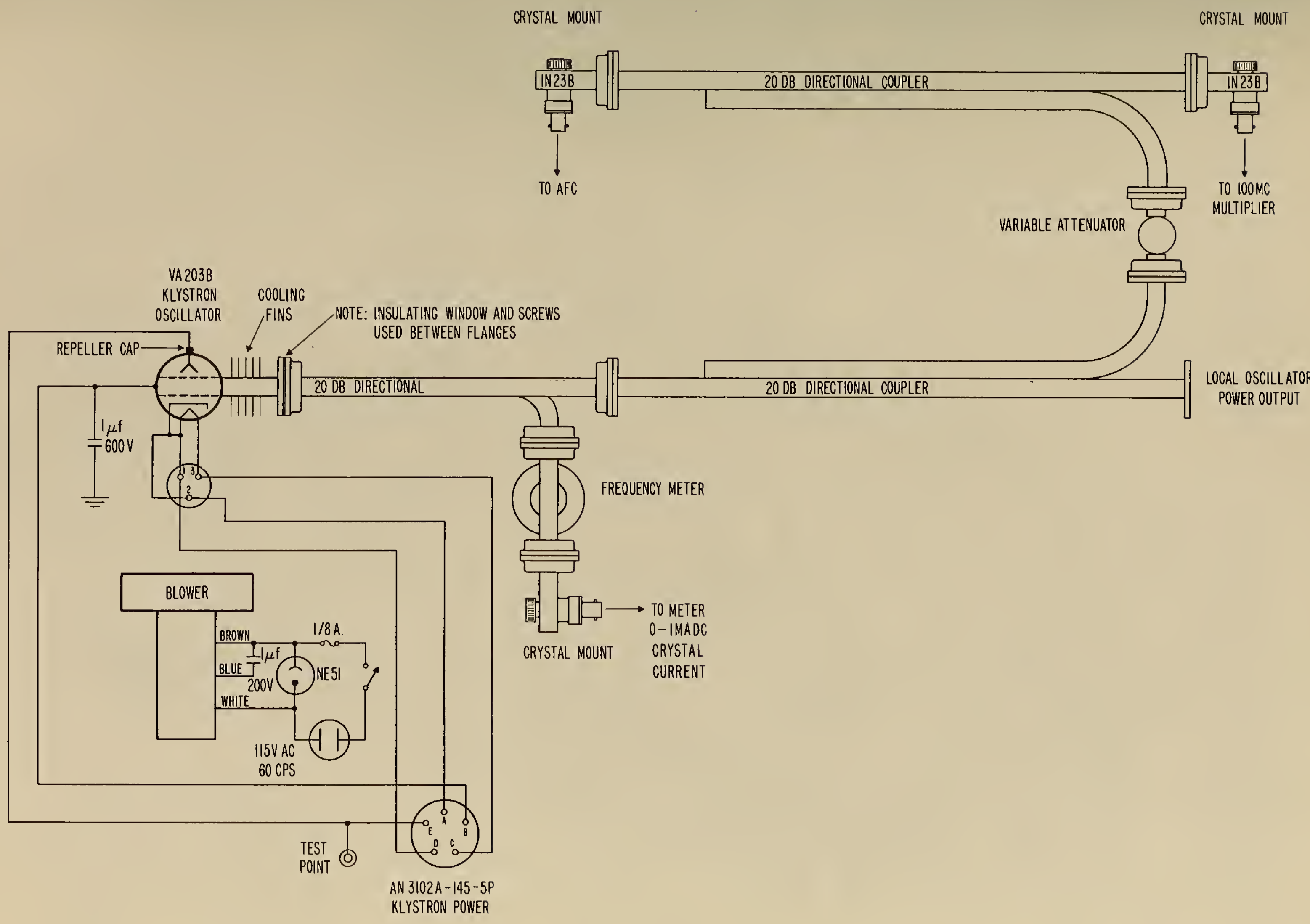

FIG. 10 FIRST LOCAL OSCILLATOR

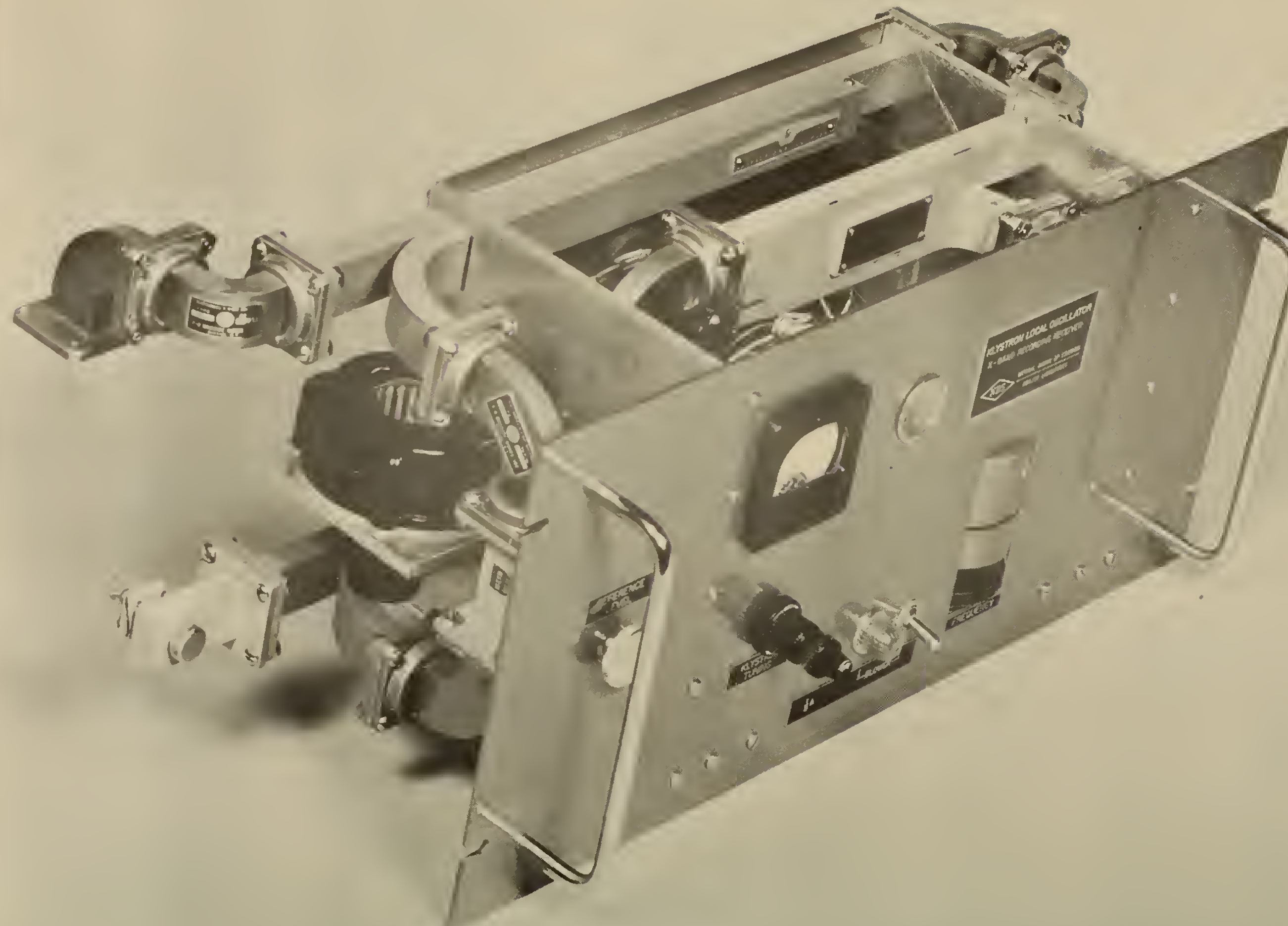

FIG. 11 FIRST LOCAL OSCILLATOR

FIG. 12 100 Mc MULTIPLIER

BLOCK DIAGRAM – REFERENCE SIGNAL SYSTEM
LOCAL OSCILLATOR AFC LOOP

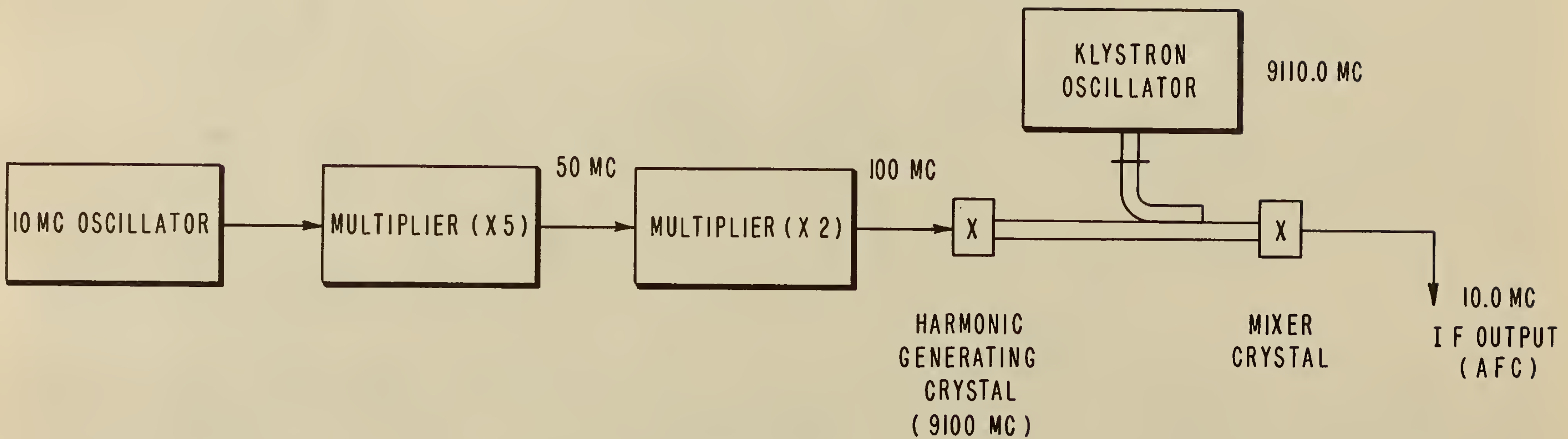

Figure 13

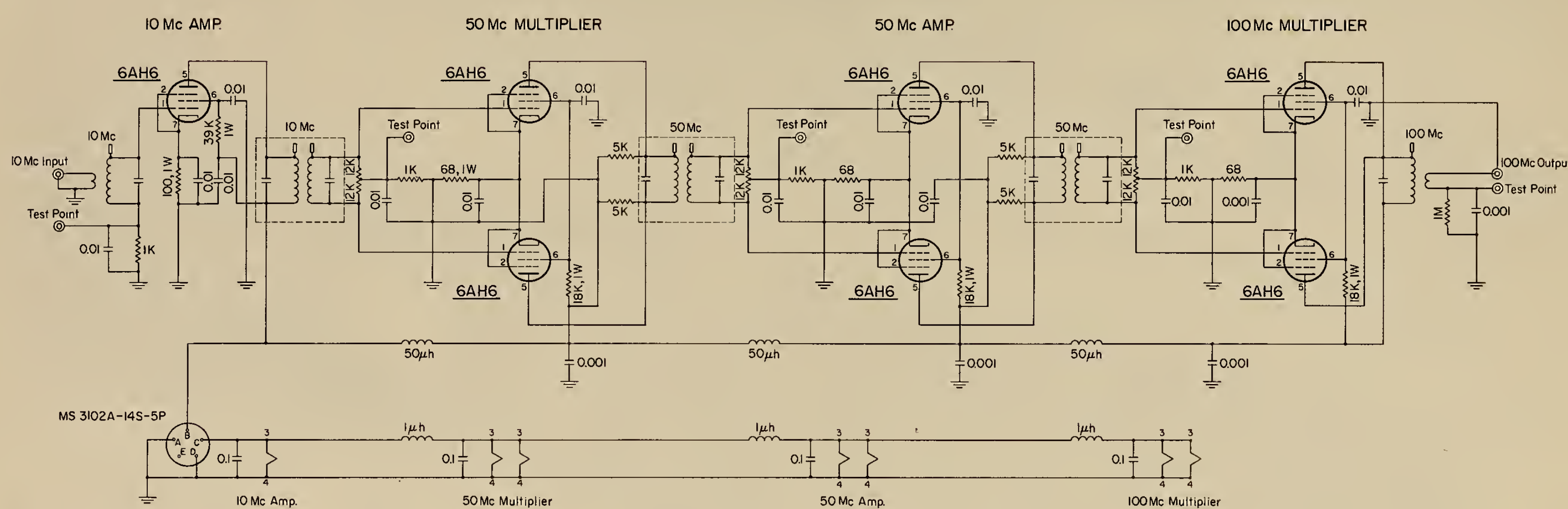

FIG. 14 100 Mc MULTIPLIER

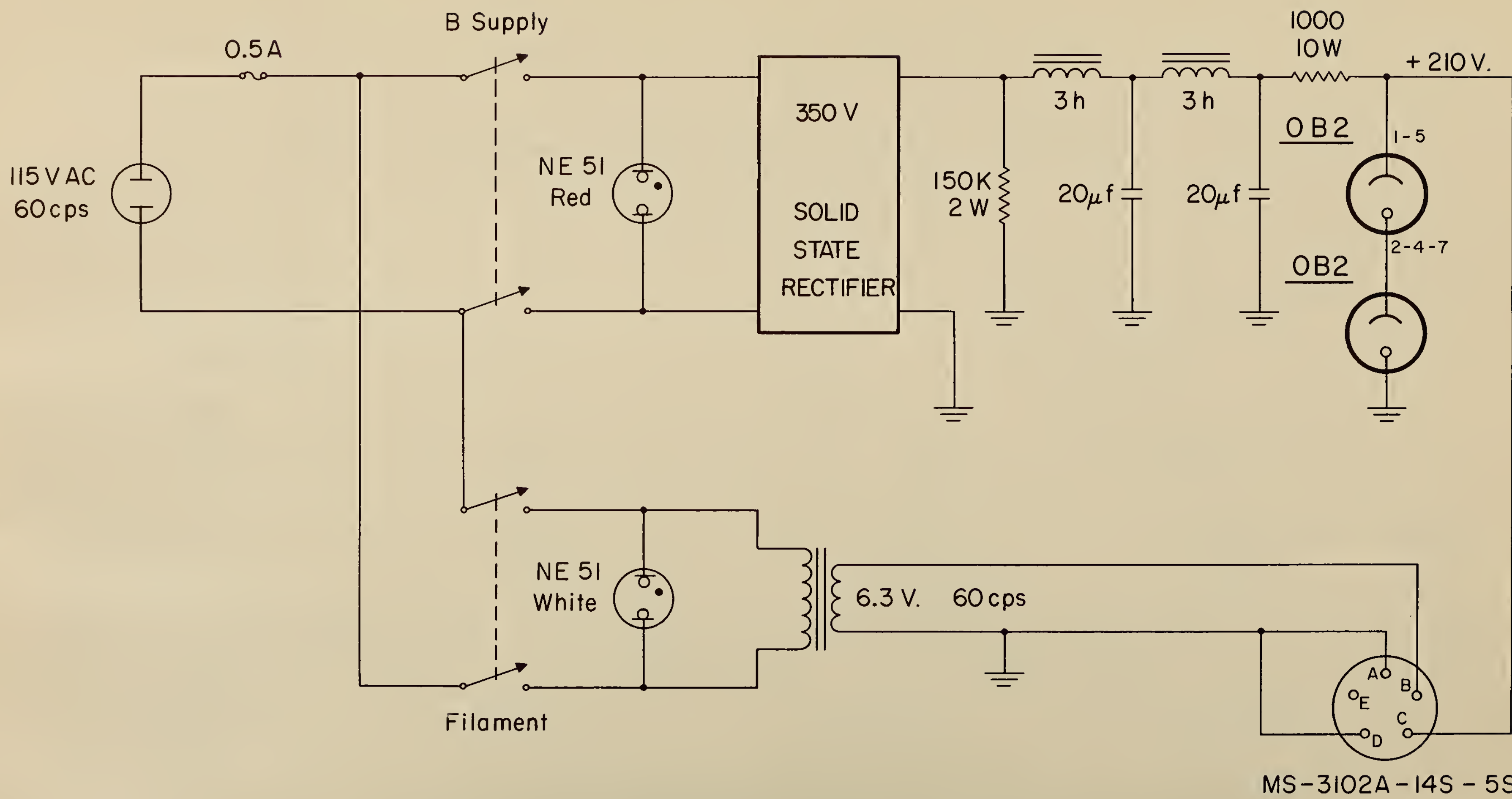

FIG. 15 100 Mc MULTIPLIER POWER SUPPLY

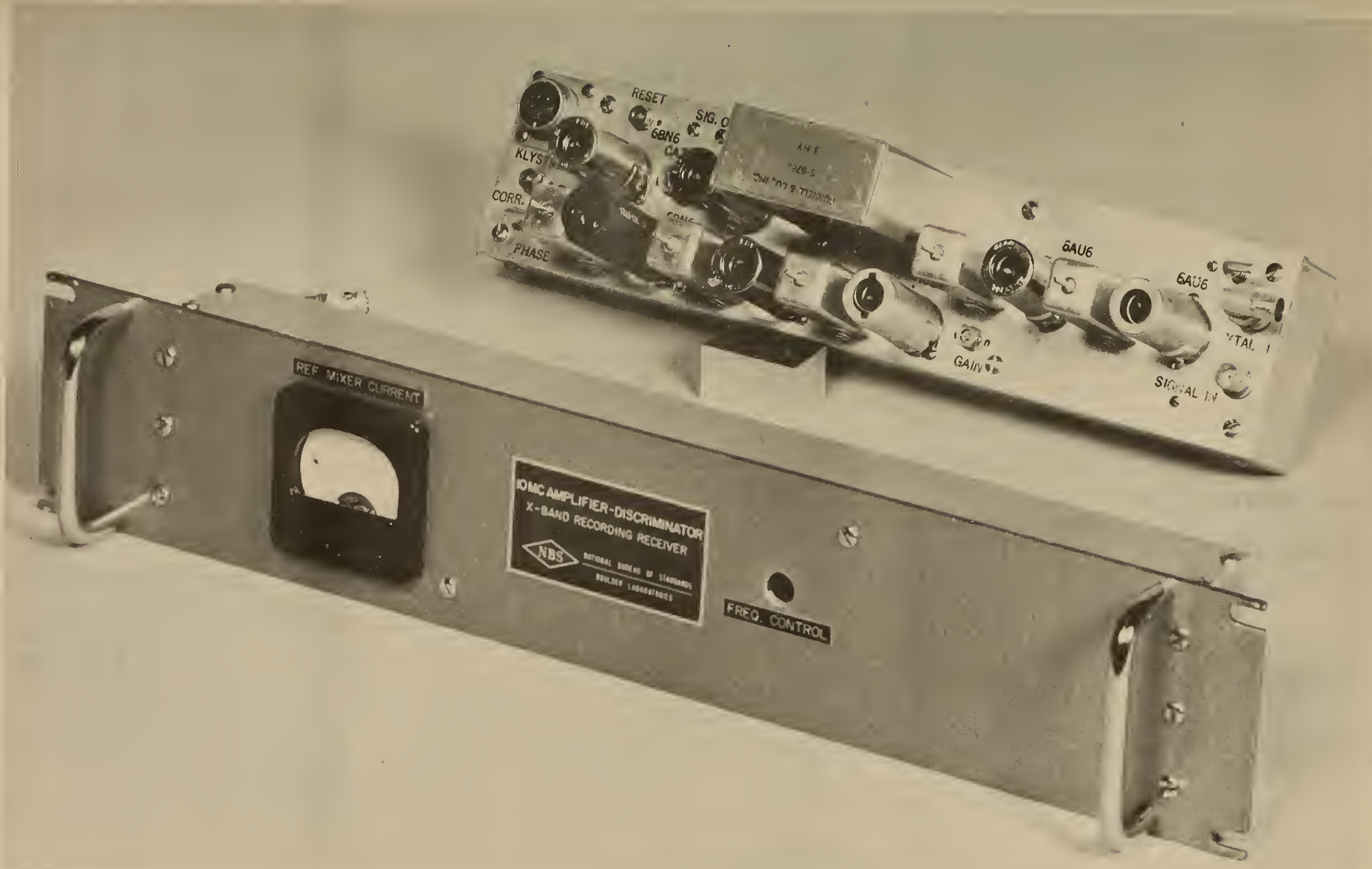

FIG. 16 IO Mc AMPLIFIER – DISCRIMINATOR

BLOCK DIAGRAM – PHASE / FREQUENCY DISCRIMINATOR CONTROL CIRCUIT

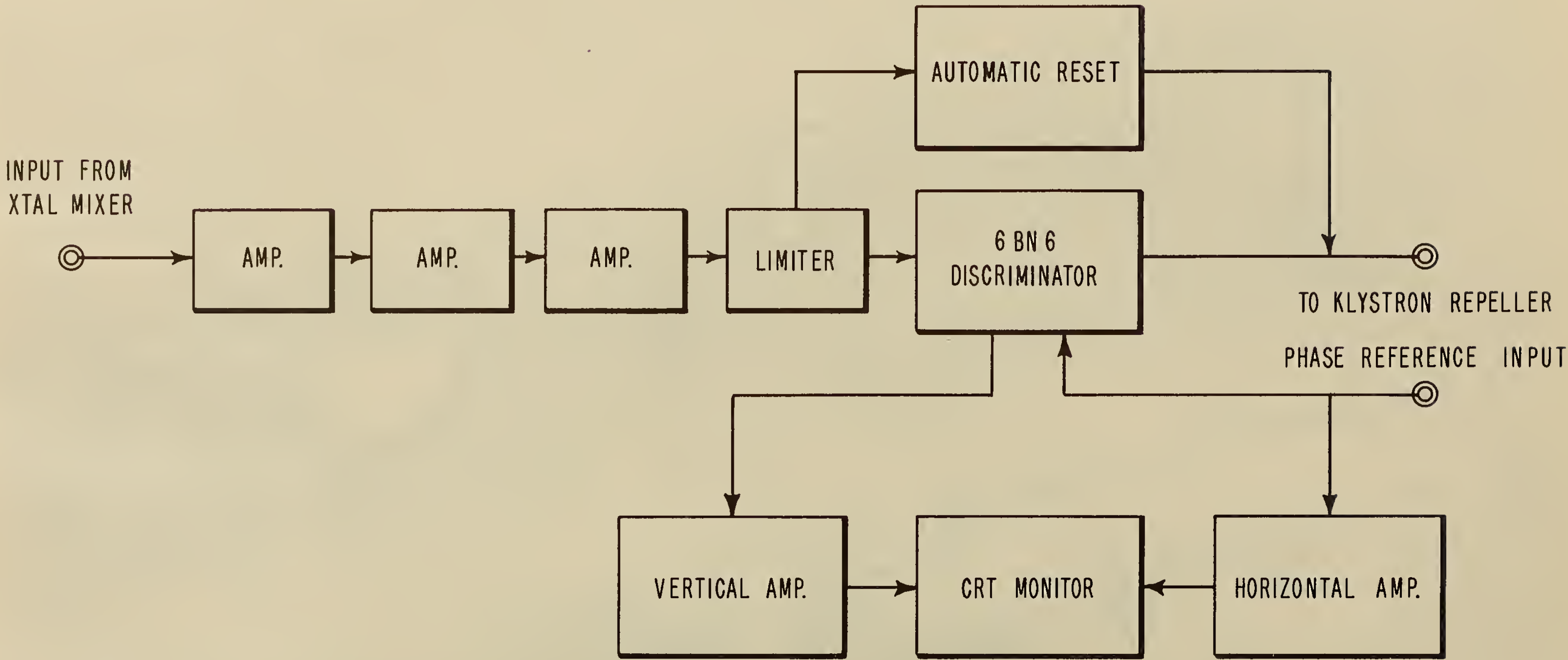

Figure 17

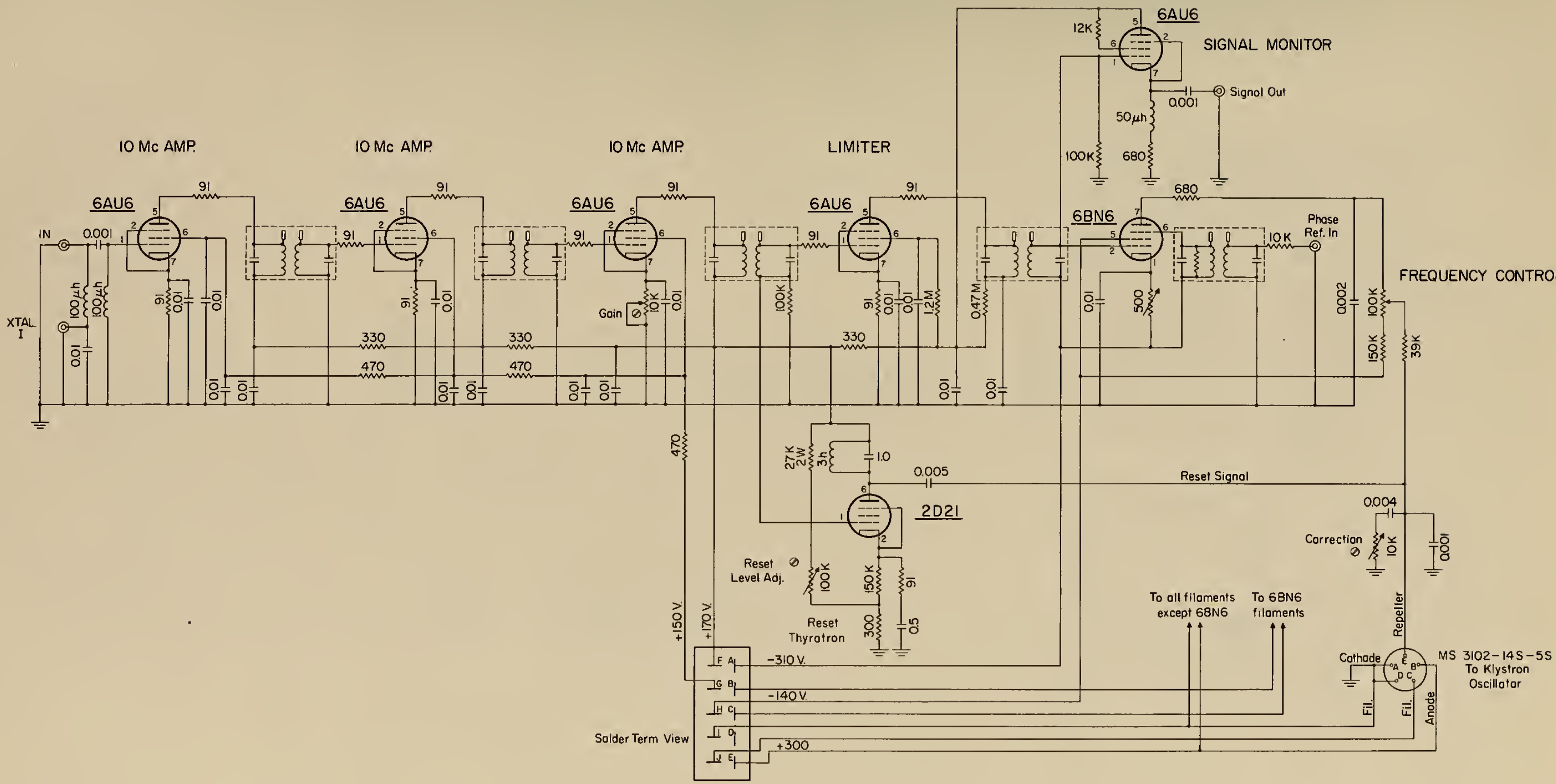

FIG. 18 10 Mc AMPLIFIER – DISCRIMINATOR

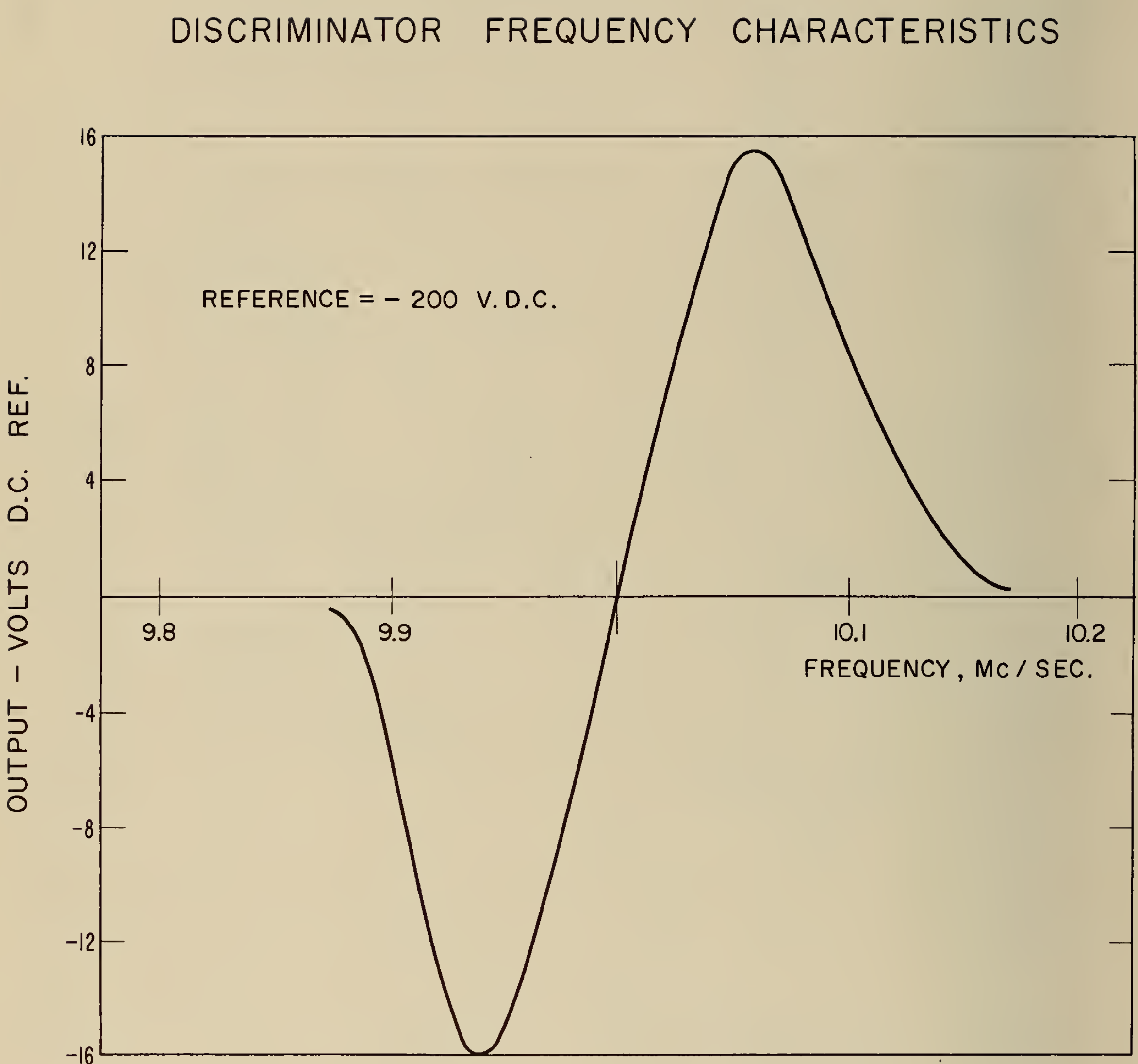
DISCRIMINATOR FREQUENCY CHARACTERISTICS
REFERENCE = − 200 V. D.C.
OUTPUT − VOLTS D.C. REF.
FREQUENCY , Mc / SEC.
16
12
8
4
-4
-8
-12
-16
9.8
9.9
10.1
10.2

Figure 19

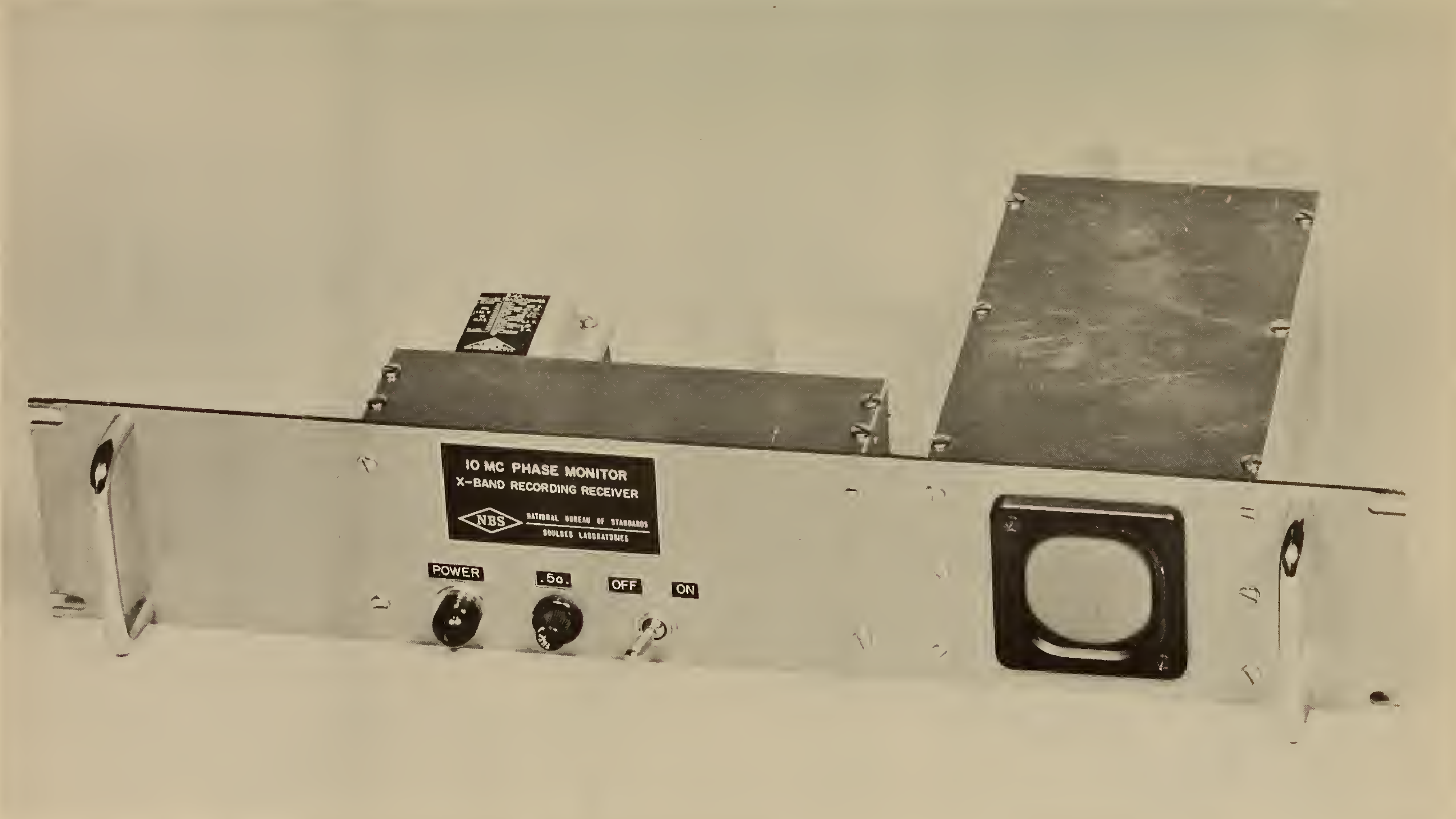

FIG. 20 10 Mc PHASE MONITOR

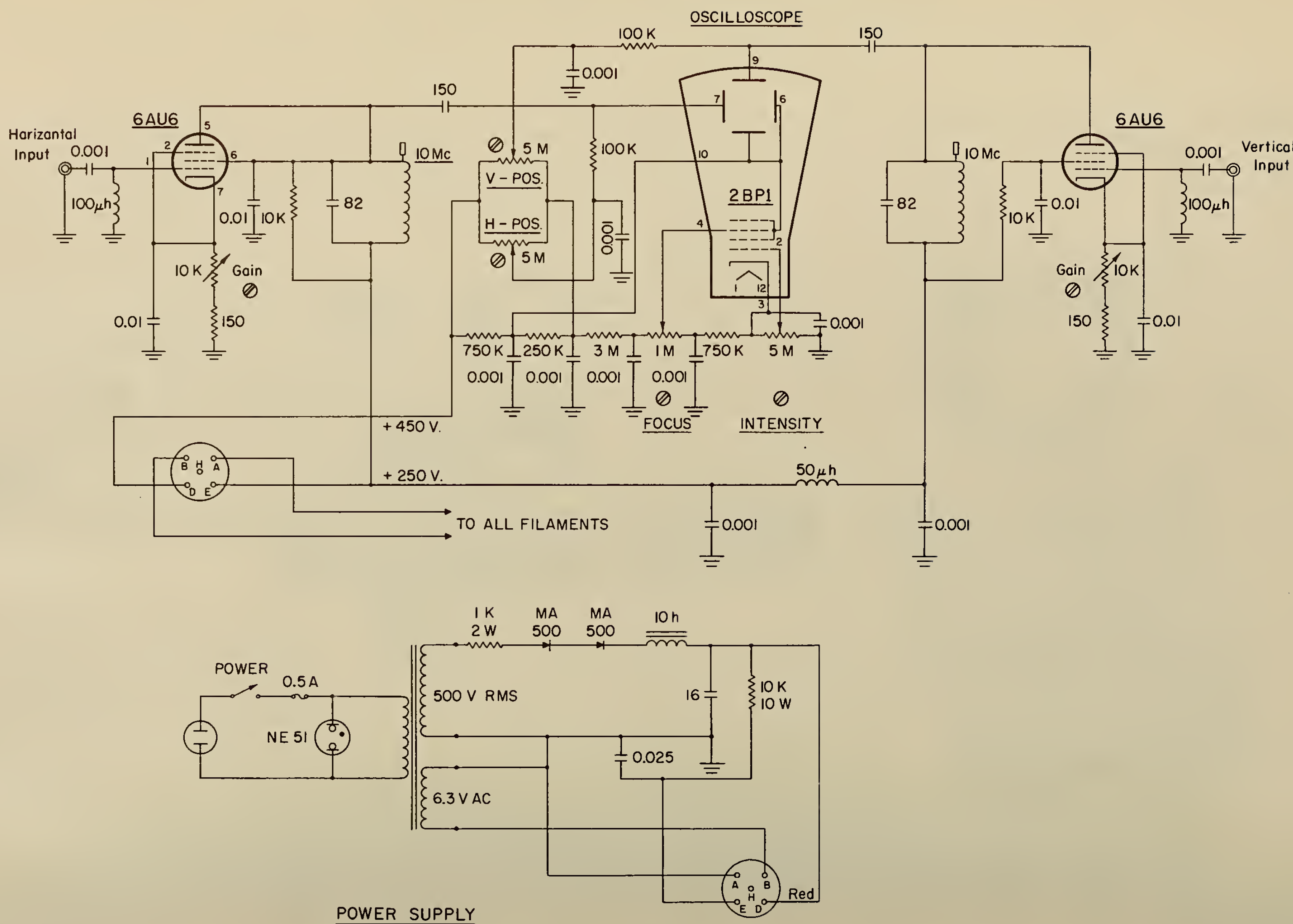

FIG. 21 10 Mc PHASE MONITOR

FIG. 22 KLYSTRON POWER SUPPLY

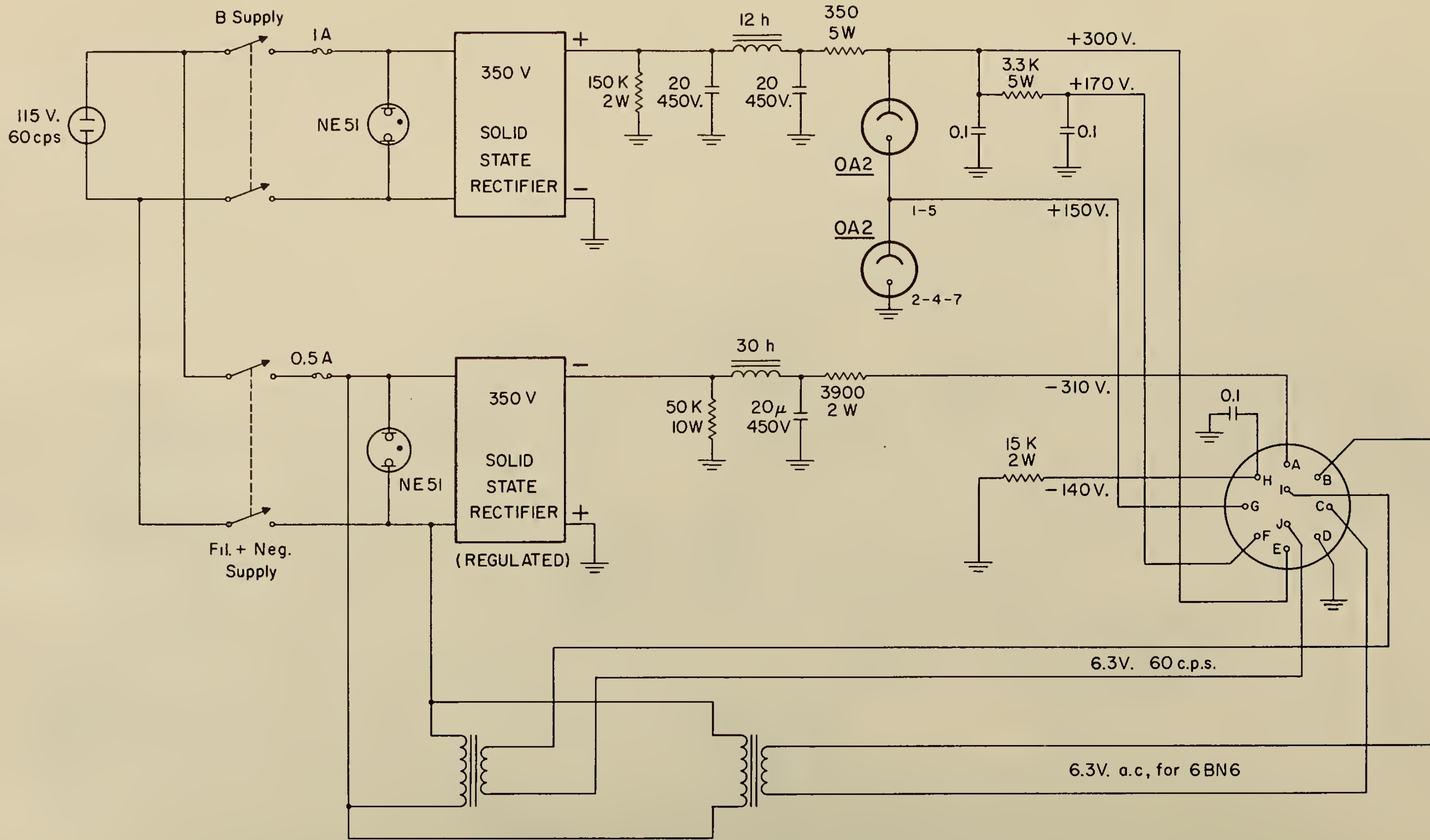

FIG.23 KLYSTRON POWER SUPPLY

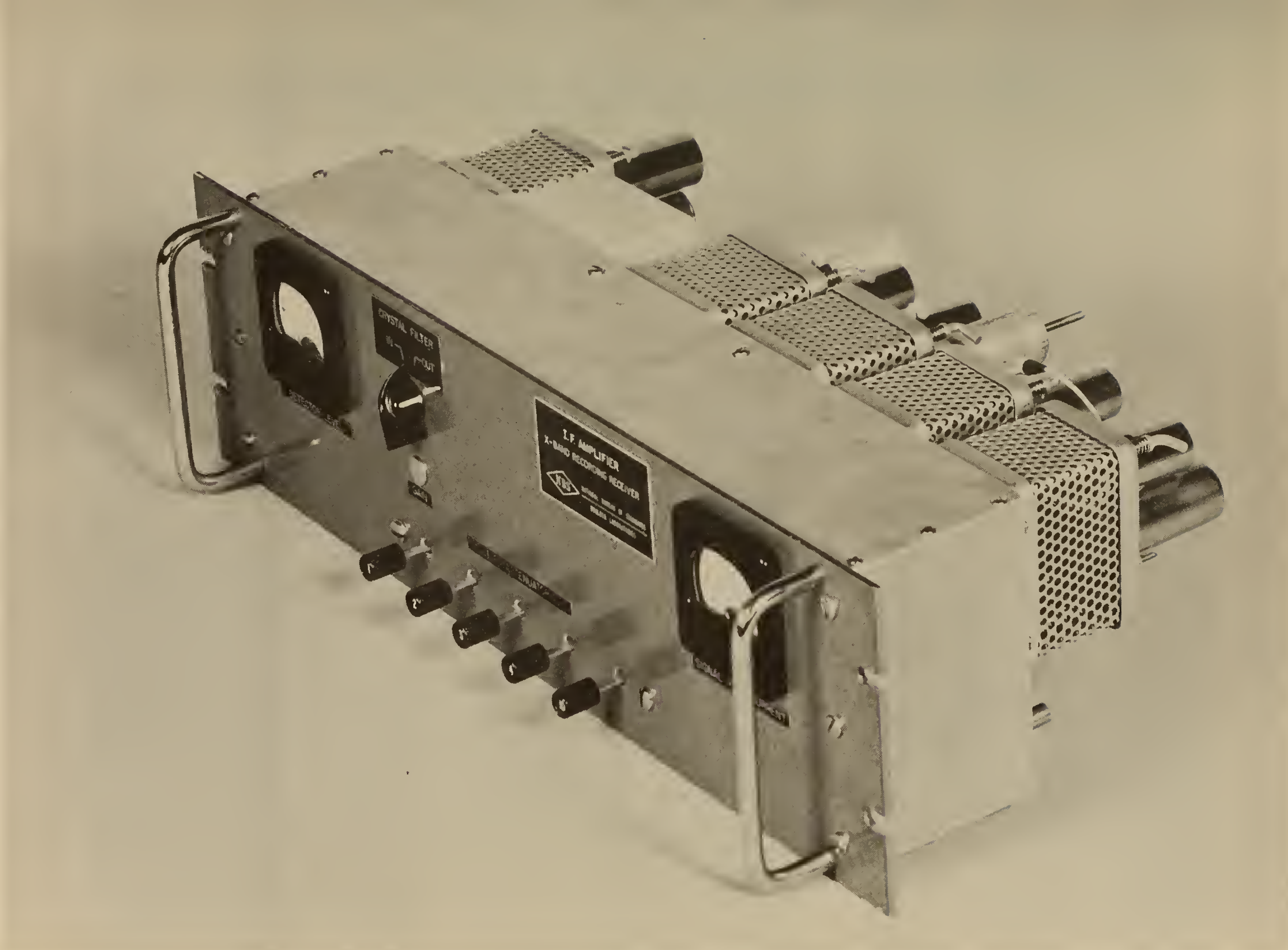

FIG. 24 I F AMPLIFIER

FIG. 25 9.9 Mc CASCODE AMPLIFIER

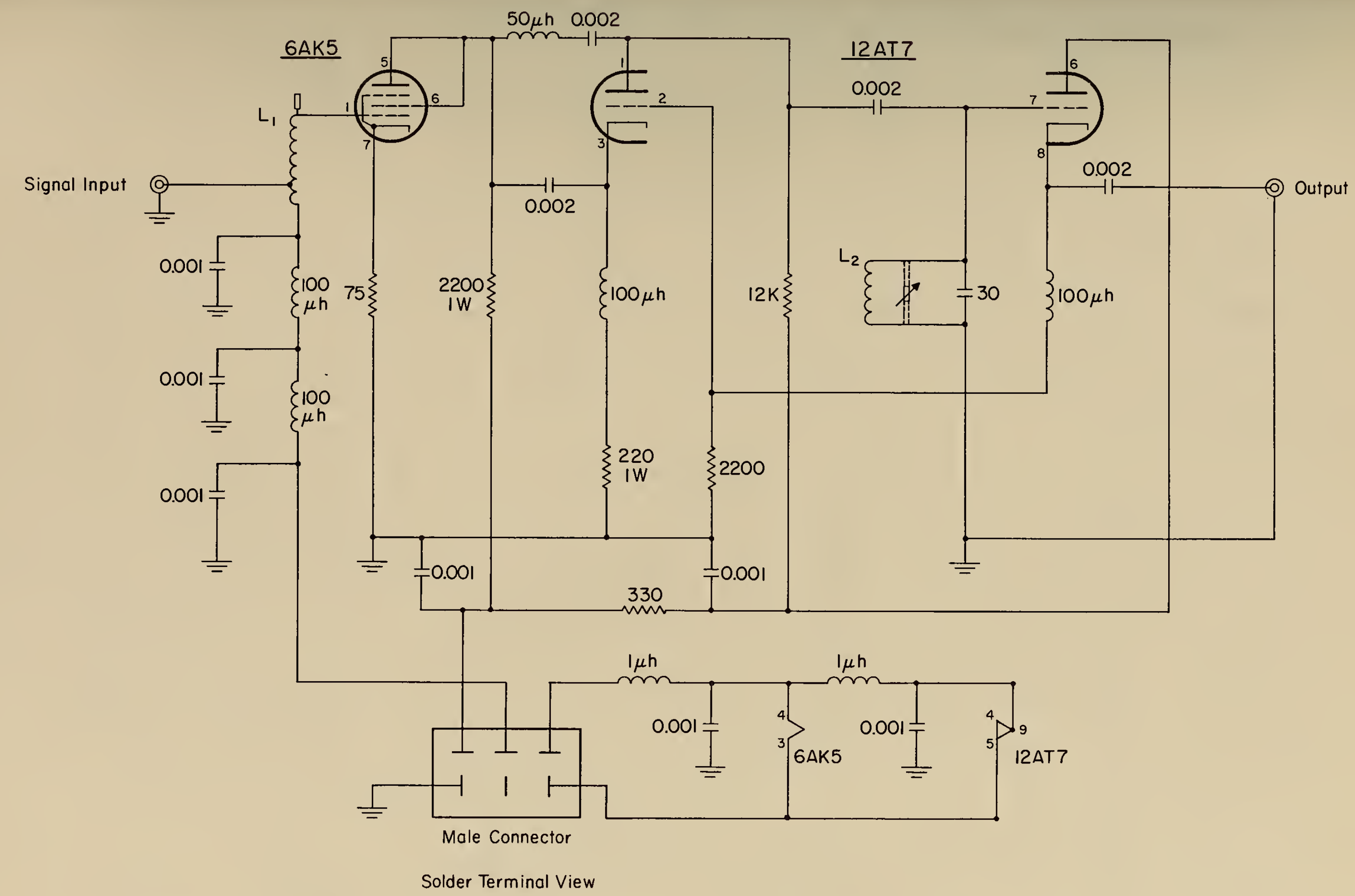

FIG. 26 9.9 Mc CASCODE AMPLIFIER

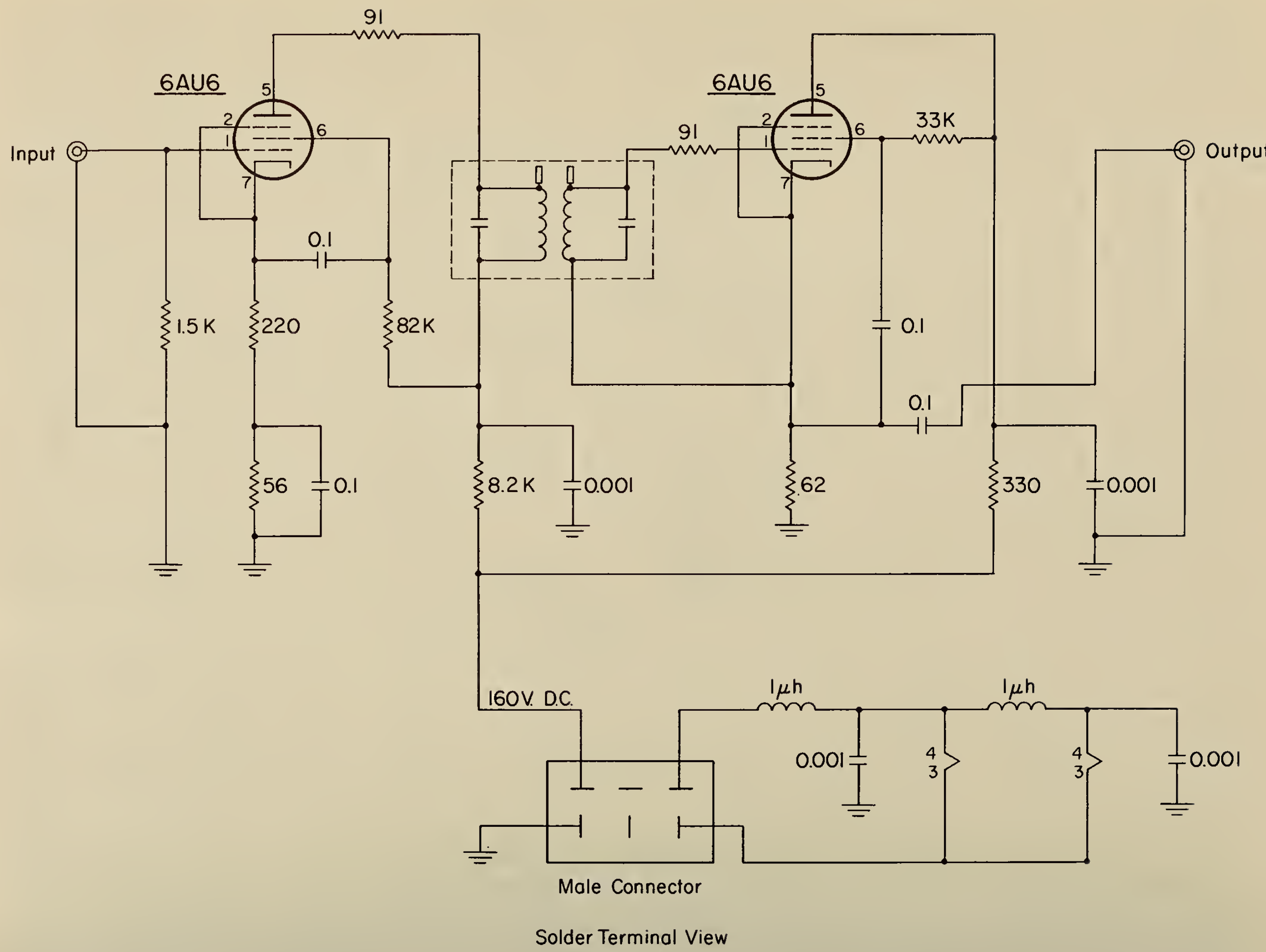

FIG. 27 9.9 Mc AMPLIFIER AND CATHODE FOLLOWER

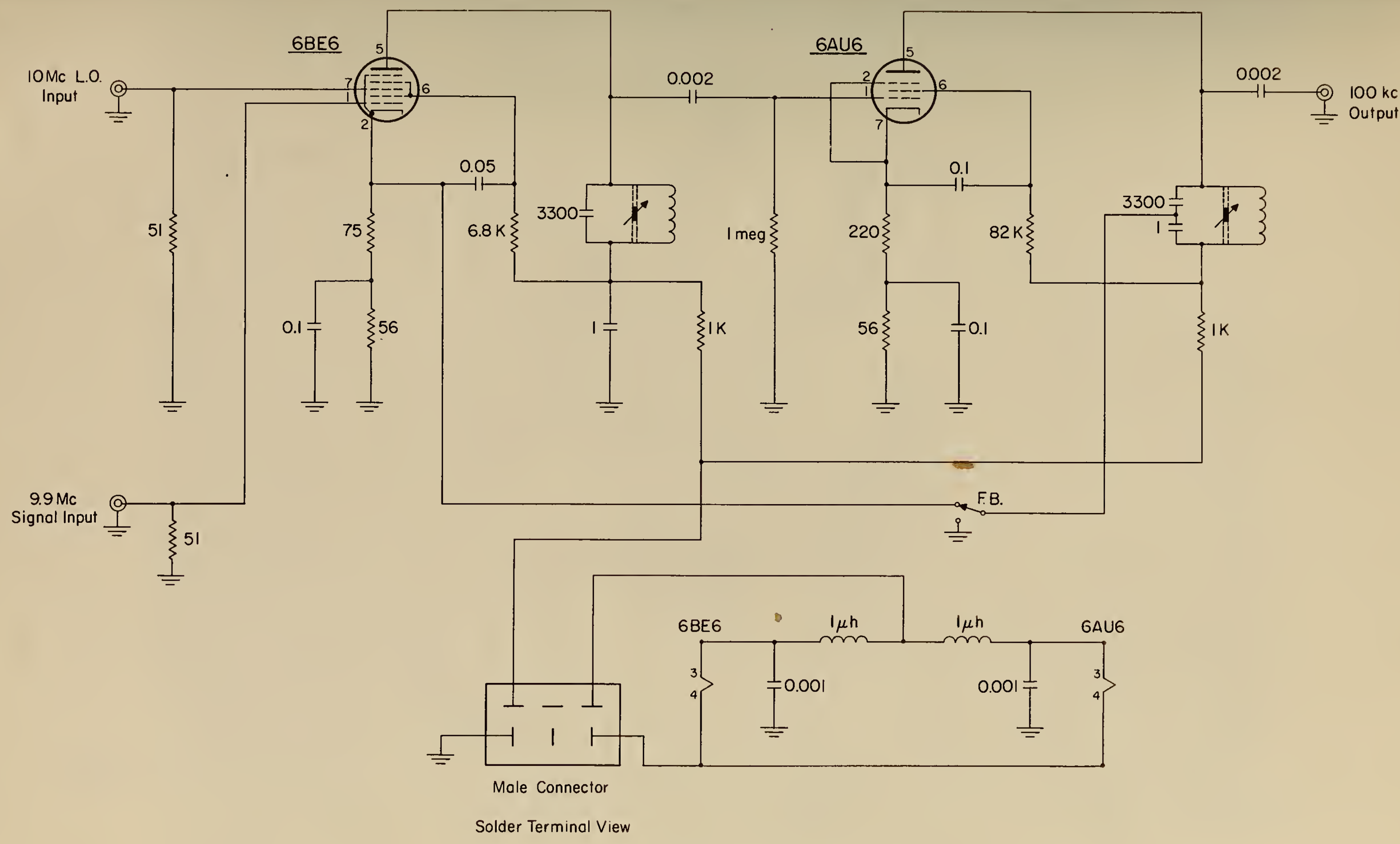

FIG. 28 GAIN STABLE MIXER – COUPLE

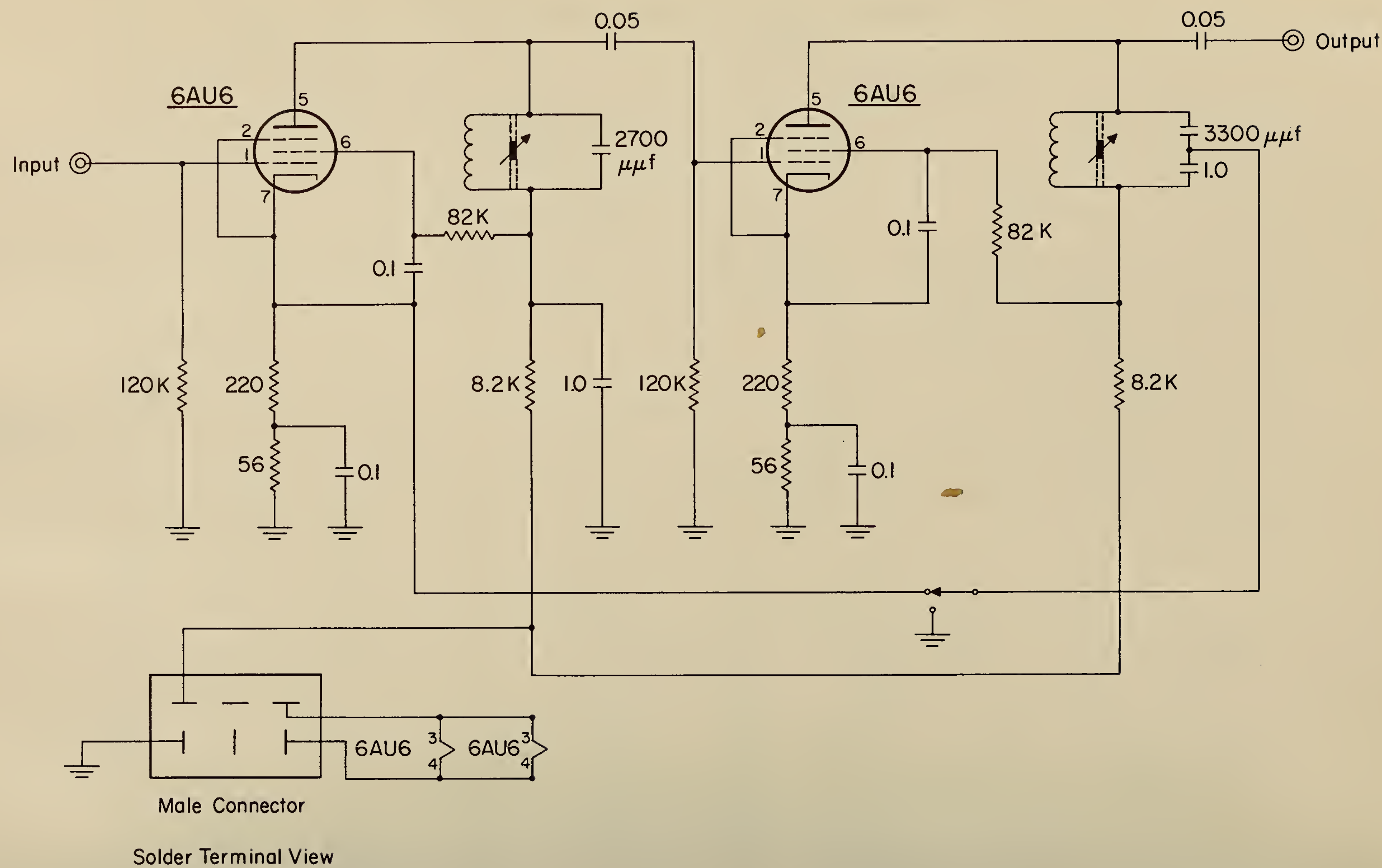

FIG. 29 100 kc GAIN STABLE AMPLIFIER COUPLE

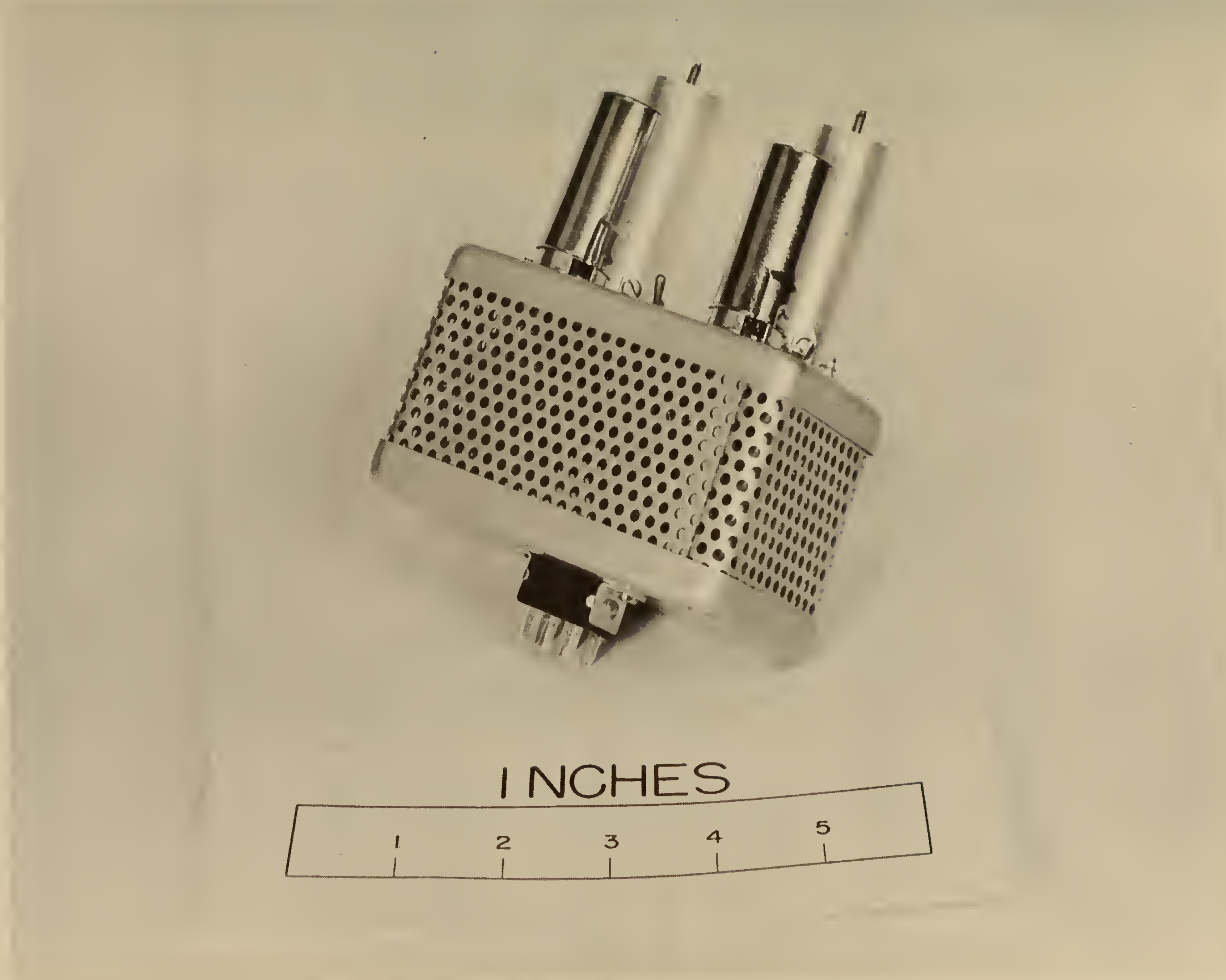

FIG. 30 100 Kc GAIN STABLE AMPLIFIER

CASCADE AMPLIFIER GAIN VERSUS PLATE SUPPLY VOLTAGE (E_{bb})

100 kc

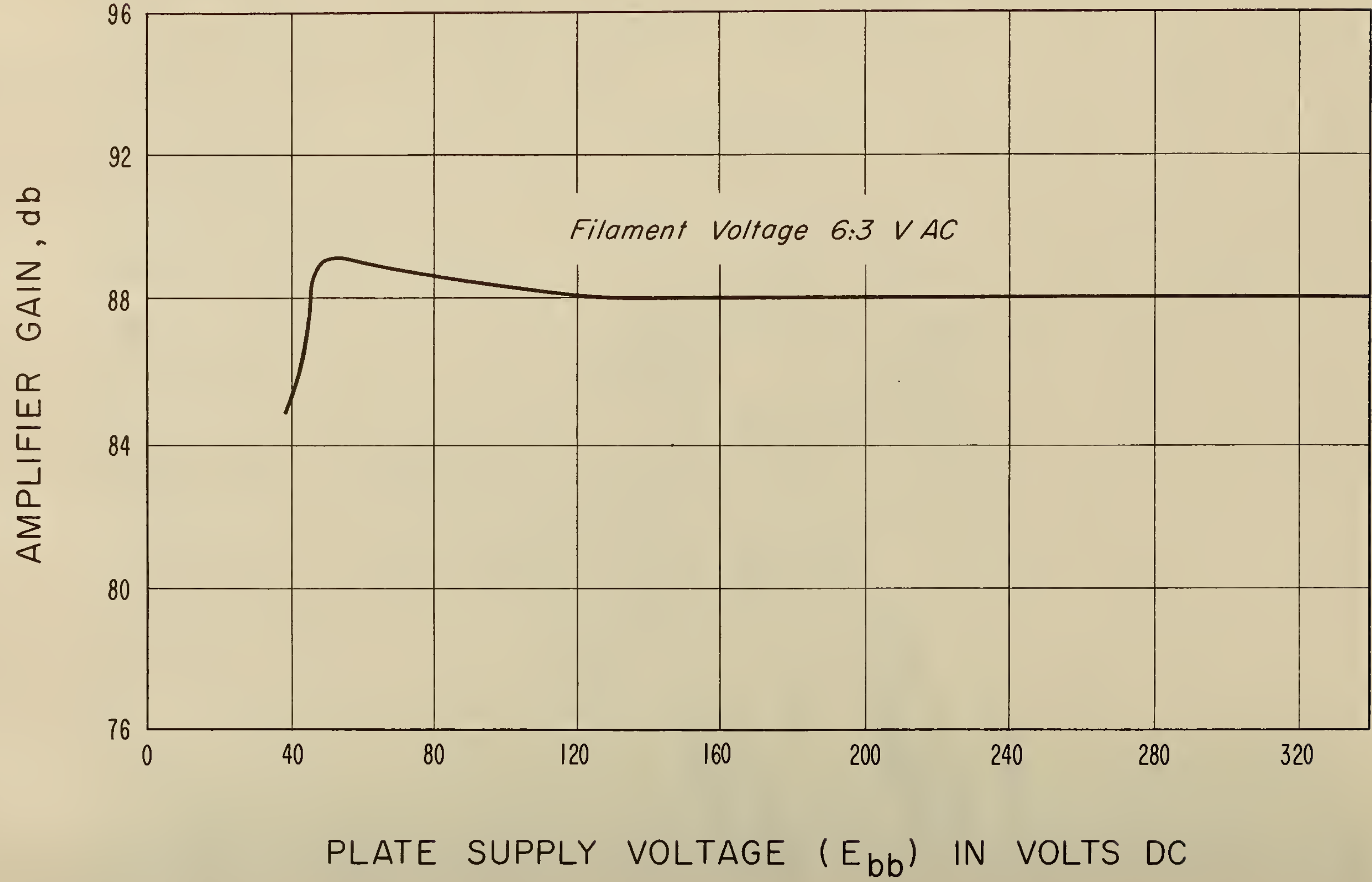

Figure 31

CASCADE AMPLIFIER GAIN VERSUS FILAMENT SUPPLY VOLTAGE
100 kc

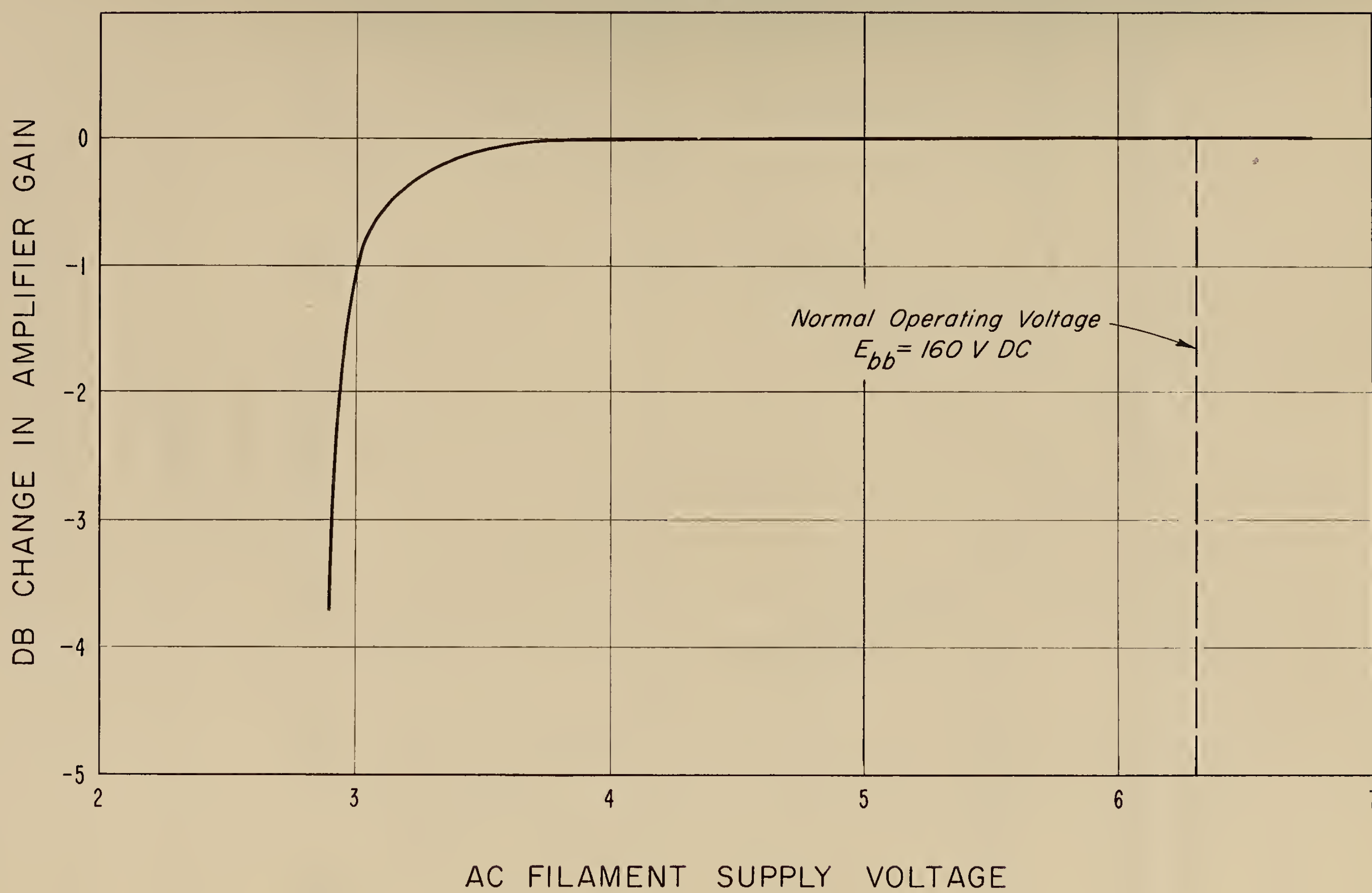

Figure 32

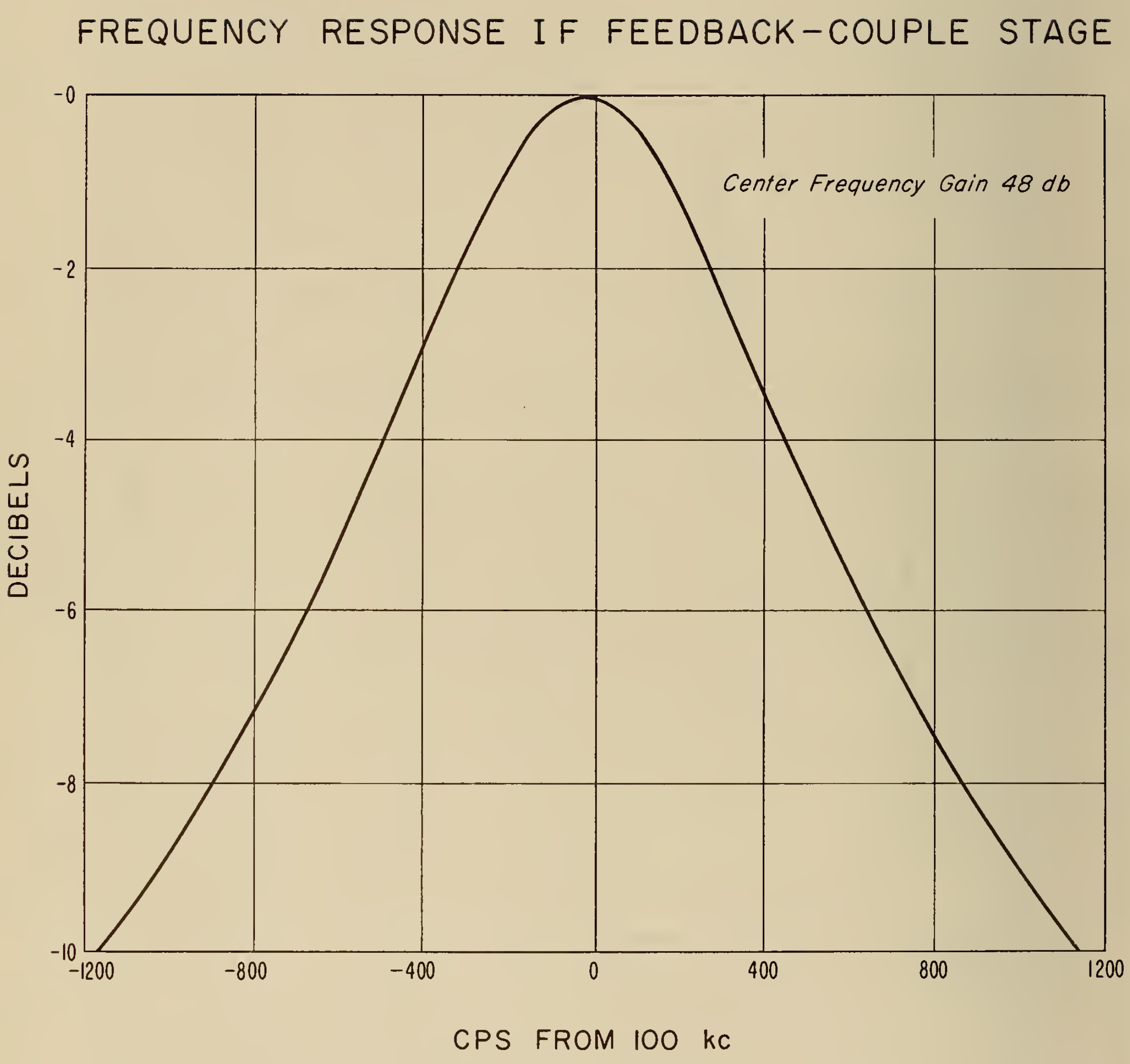
FREQUENCY RESPONSE IF FEEDBACK-COUPLE STAGE
Center Frequency Gain 48 db
DECIBELS
-0
-2
-4
-6
-8
-10
-1200
-800
-400
0
400
800
1200
CPS FROM 100 kc

Figure 33

FREQUENCY RESPONSE - I F CASCADE AMPLIFIER

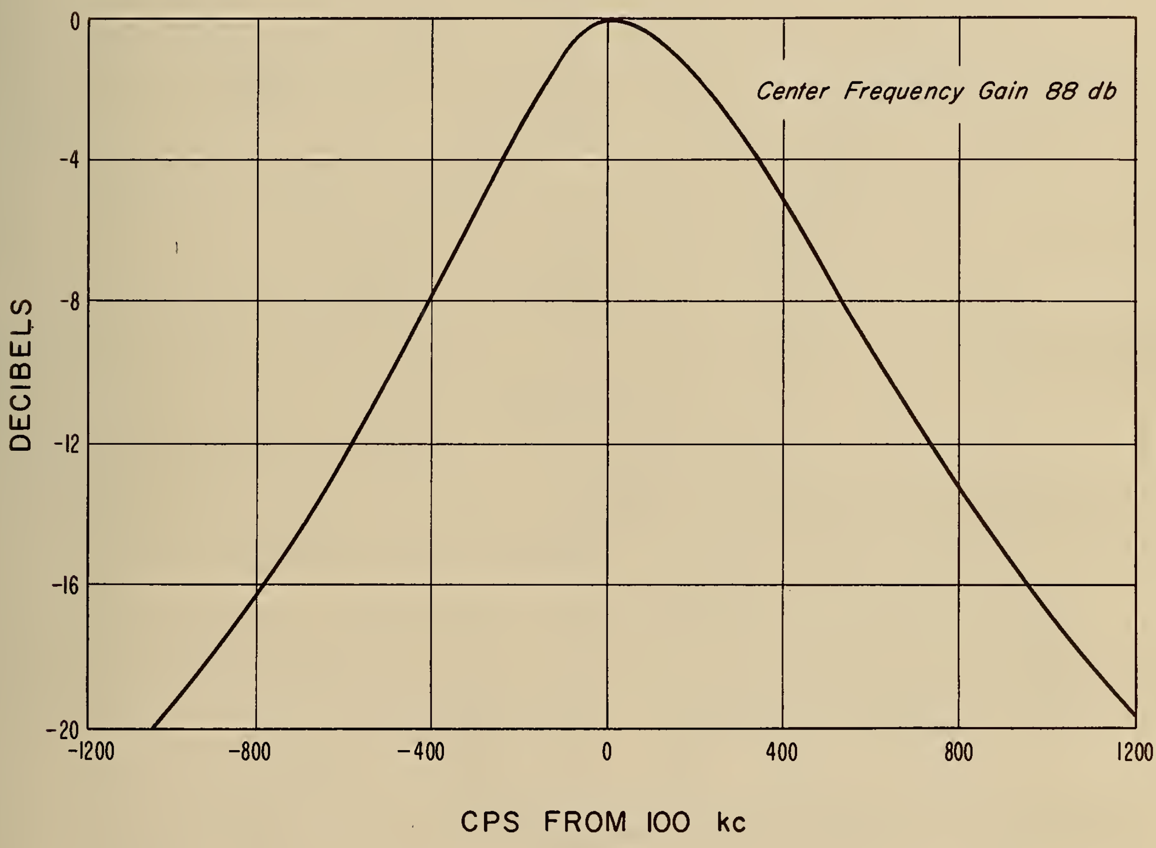

Figure 34

ATTENUATION CHARACTERISTIC — CRYSTAL FILTER

100 kc

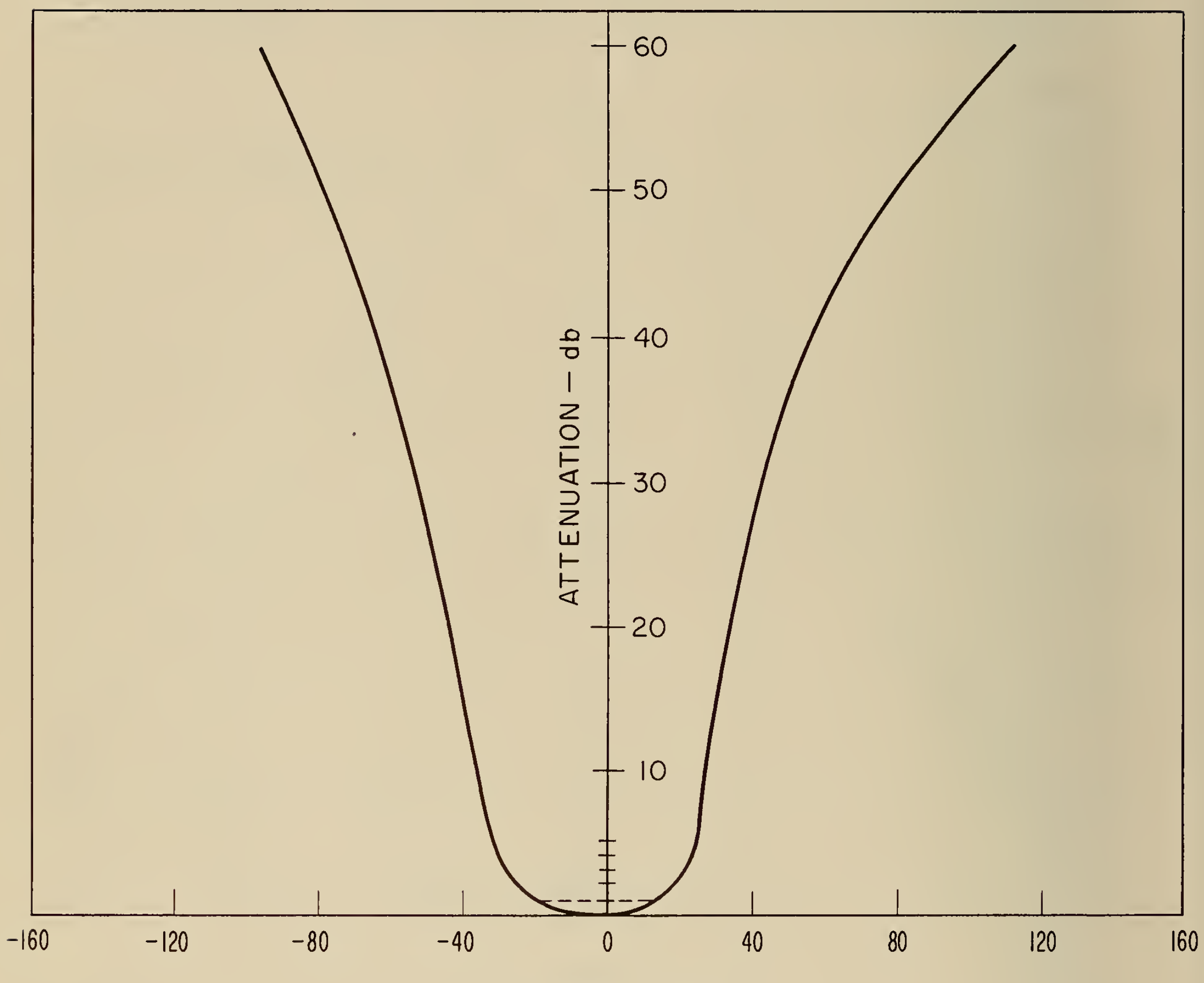

Figure 35

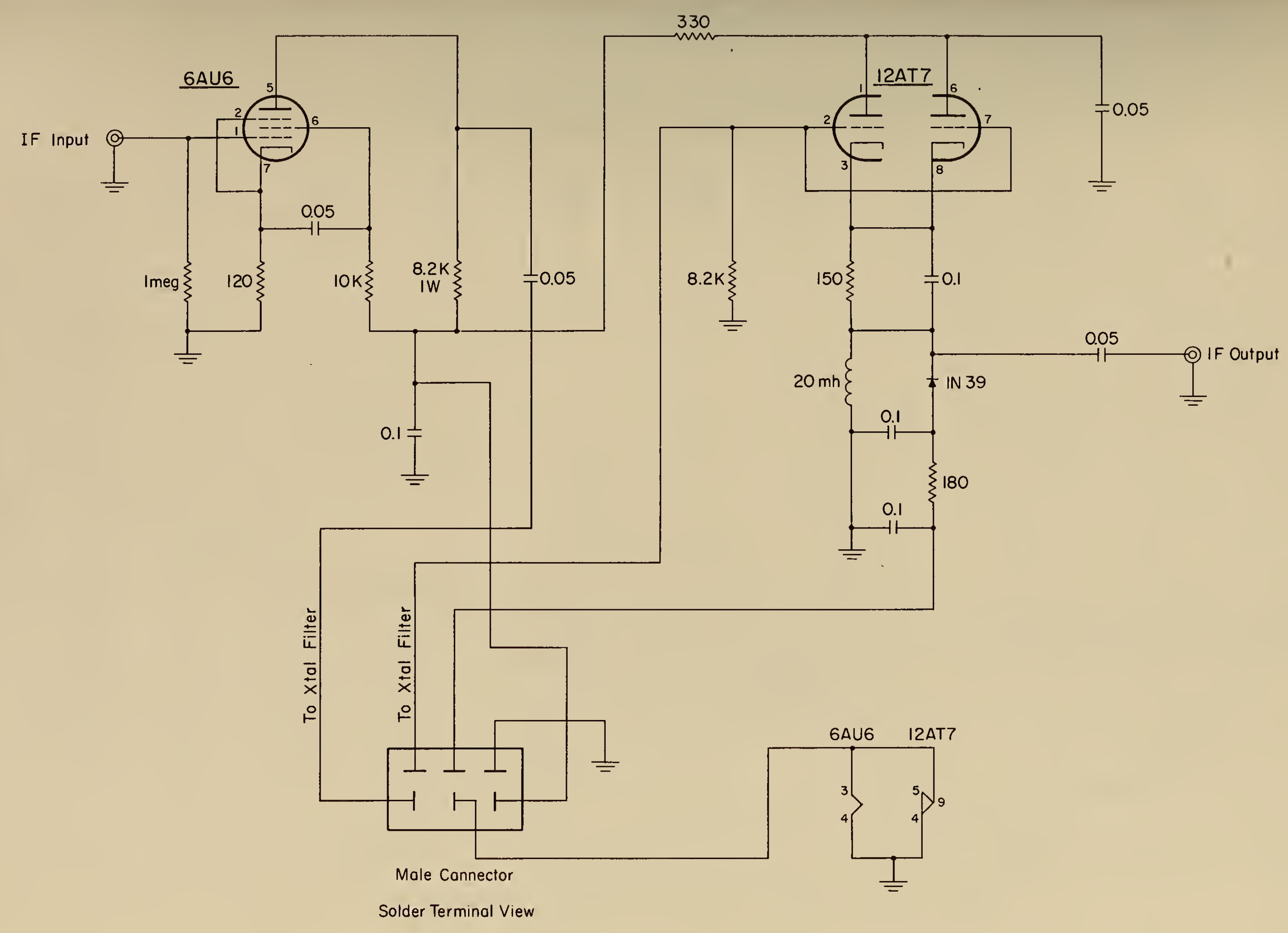

FIG. 36 FINAL IF AMPLIFIER AND DETECTOR

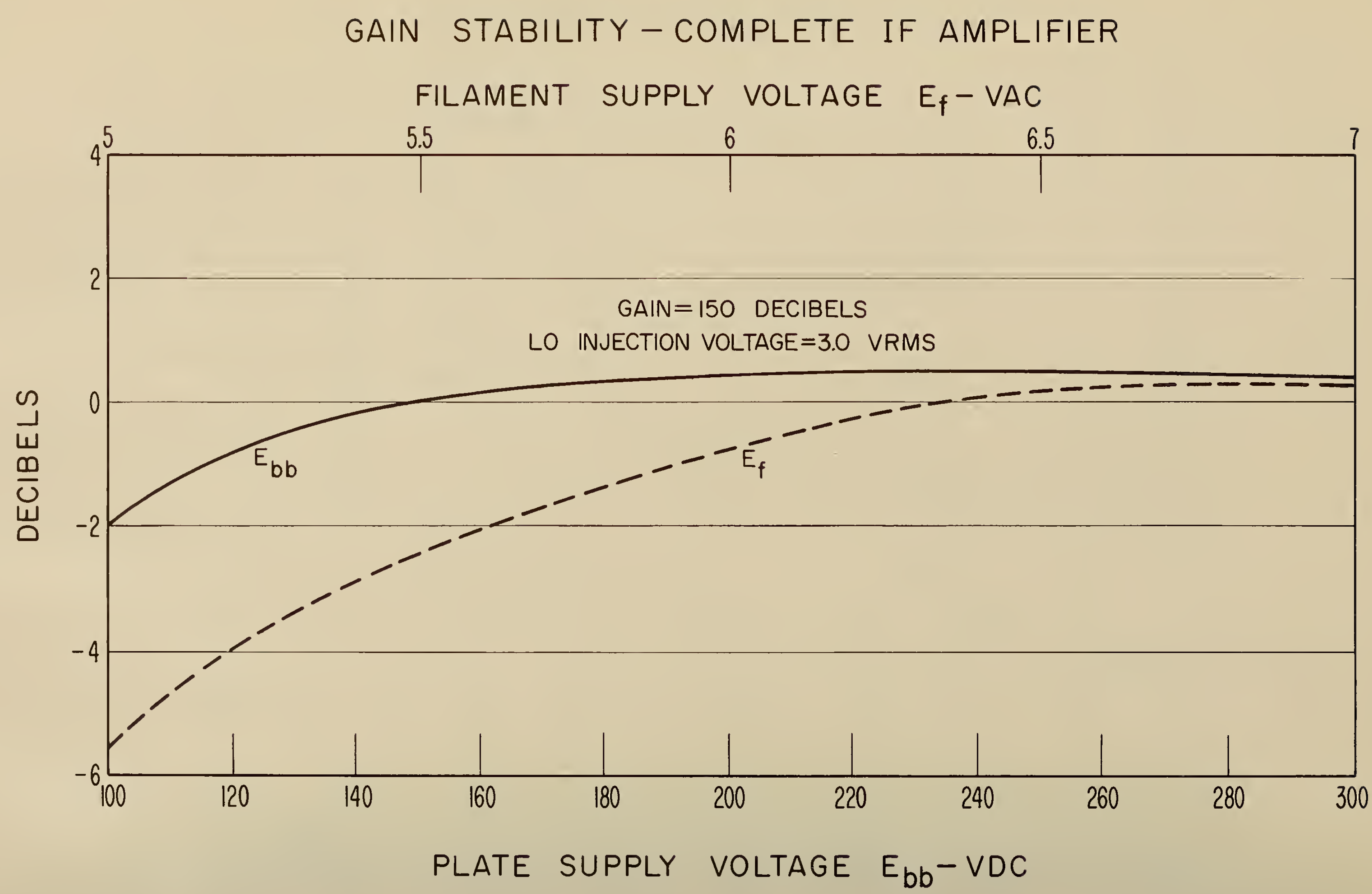
GAIN STABILITY – COMPLETE IF AMPLIFIER
FILAMENT SUPPLY VOLTAGE E_f – VAC
5
5.5
6
6.5
7
4
2
0
-2
-4
-6
DECIBELS
GAIN=150 DECIBELS
LO INJECTION VOLTAGE=3.0 VRMS
E_{bb}
E_f
100
120
140
160
180
200
220
240
260
280
300
PLATE SUPPLY VOLTAGE E_{bb} – VDC

Figure 37

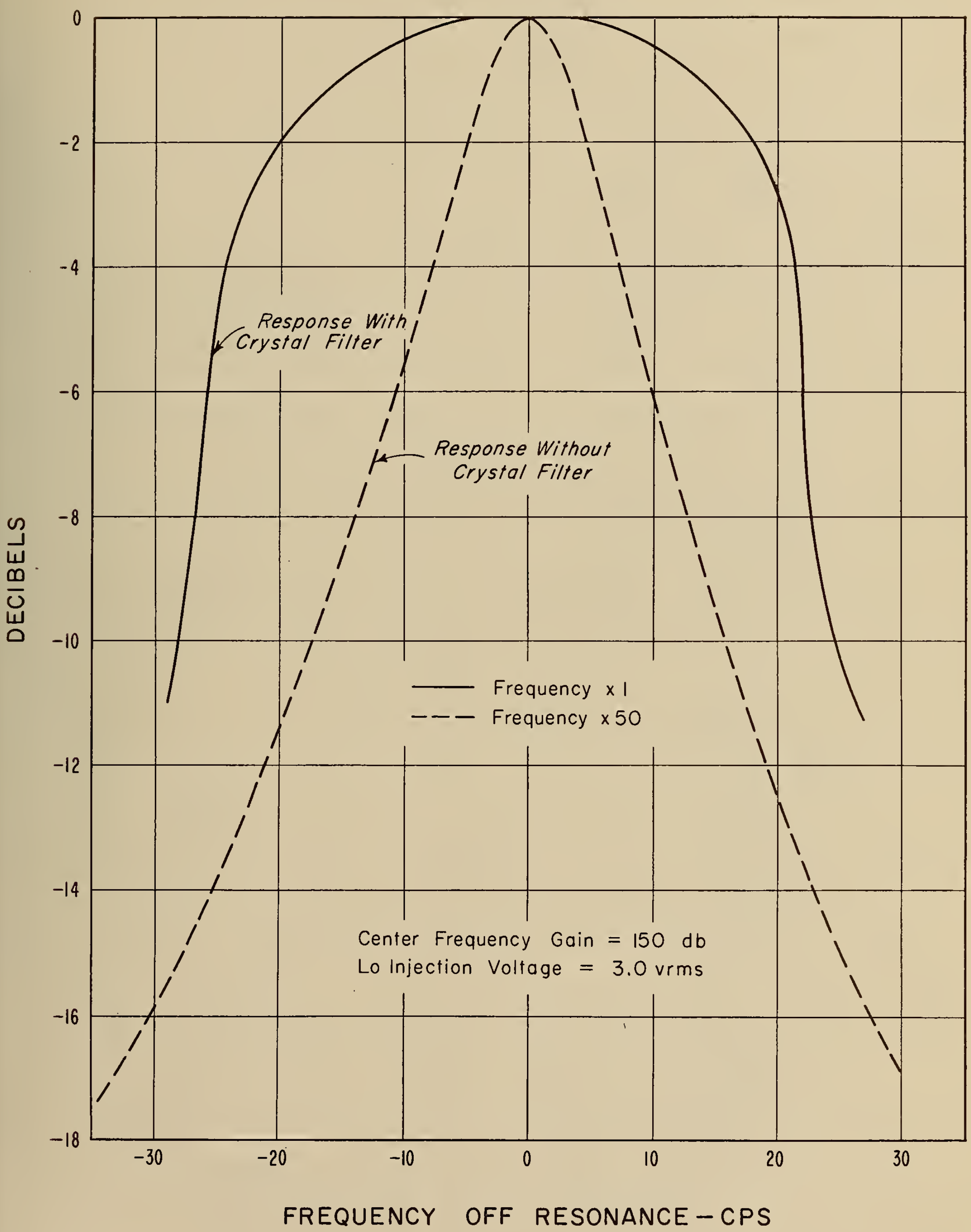
0
-2
-4
-6
-8
-10
-12
-14
-16
-18
DECIBELS
-30
-20
-10
0
10
20
30
FREQUENCY OFF RESONANCE — CPS
Response With Crystal Filter
Response Without Crystal Filter
Frequency x 1
Frequency x 50
Center Frequency Gain = 150 db
Lo Injection Voltage = 3.0 vrms

Figure 38

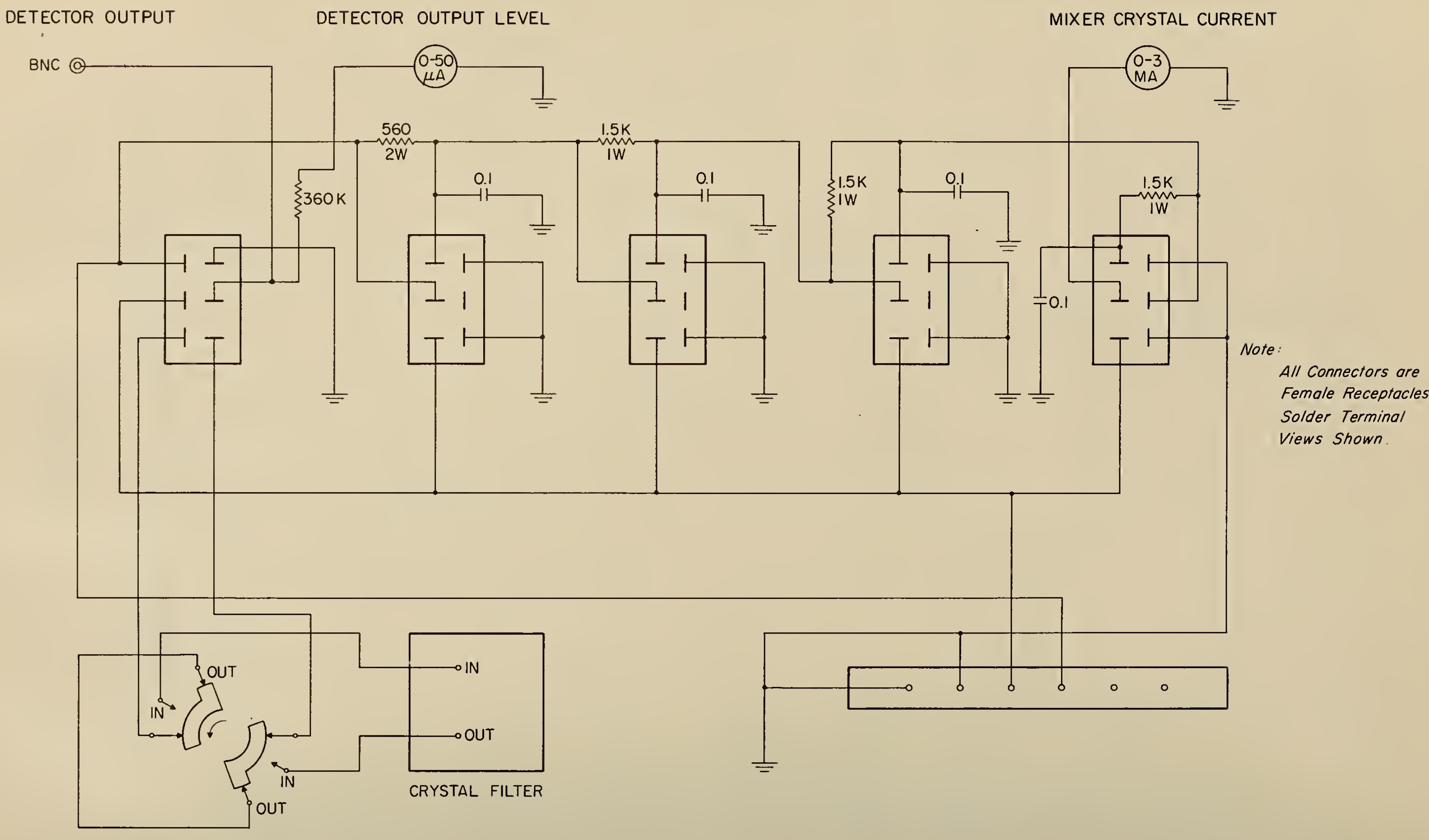

FIG. 39 WIRING DIAGRAM – IF AMPLIFIER CHASSIS

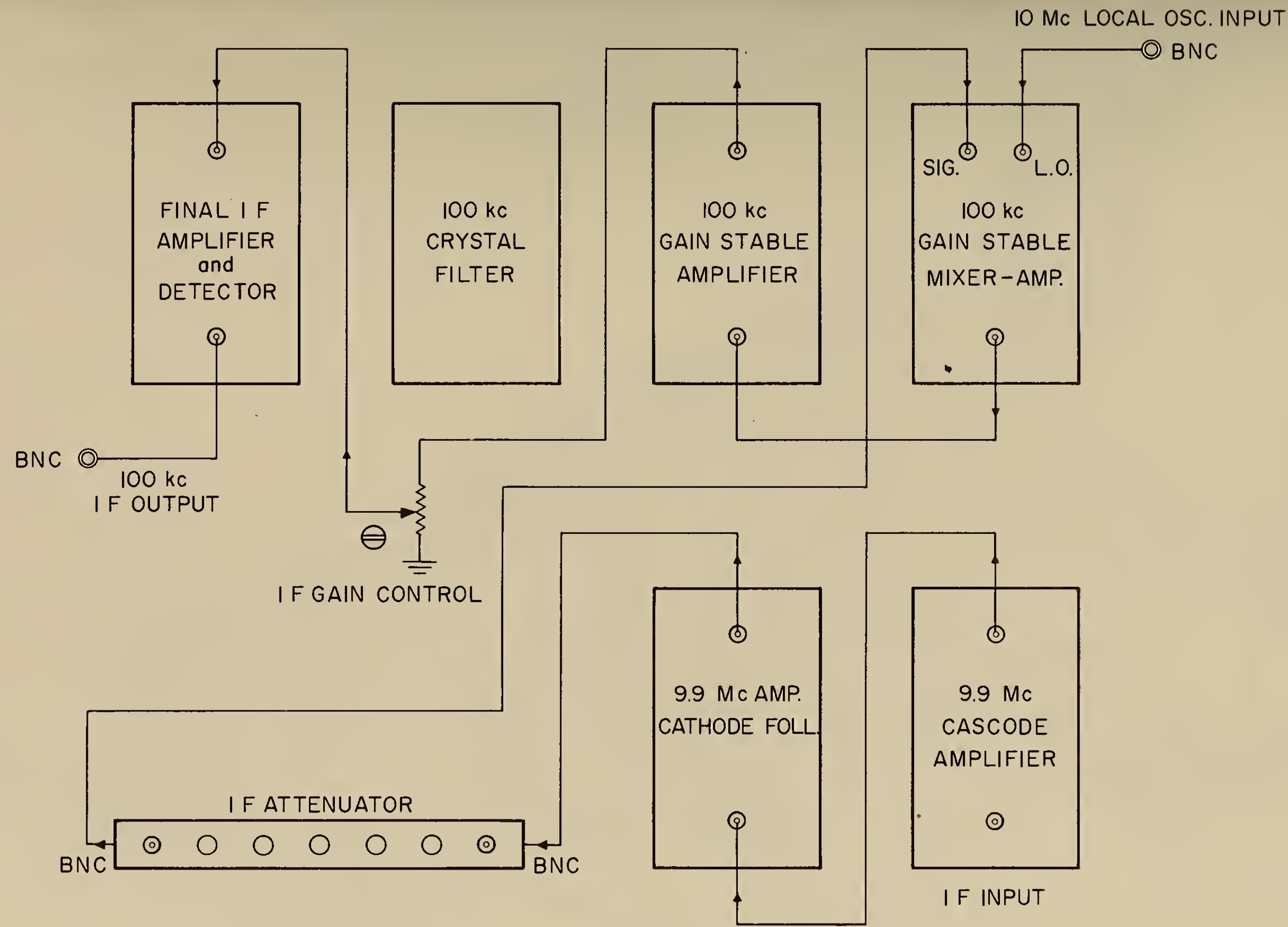

FIG. 40 RF CABLING DIAGRAM IF AMPLIFIER UNIT

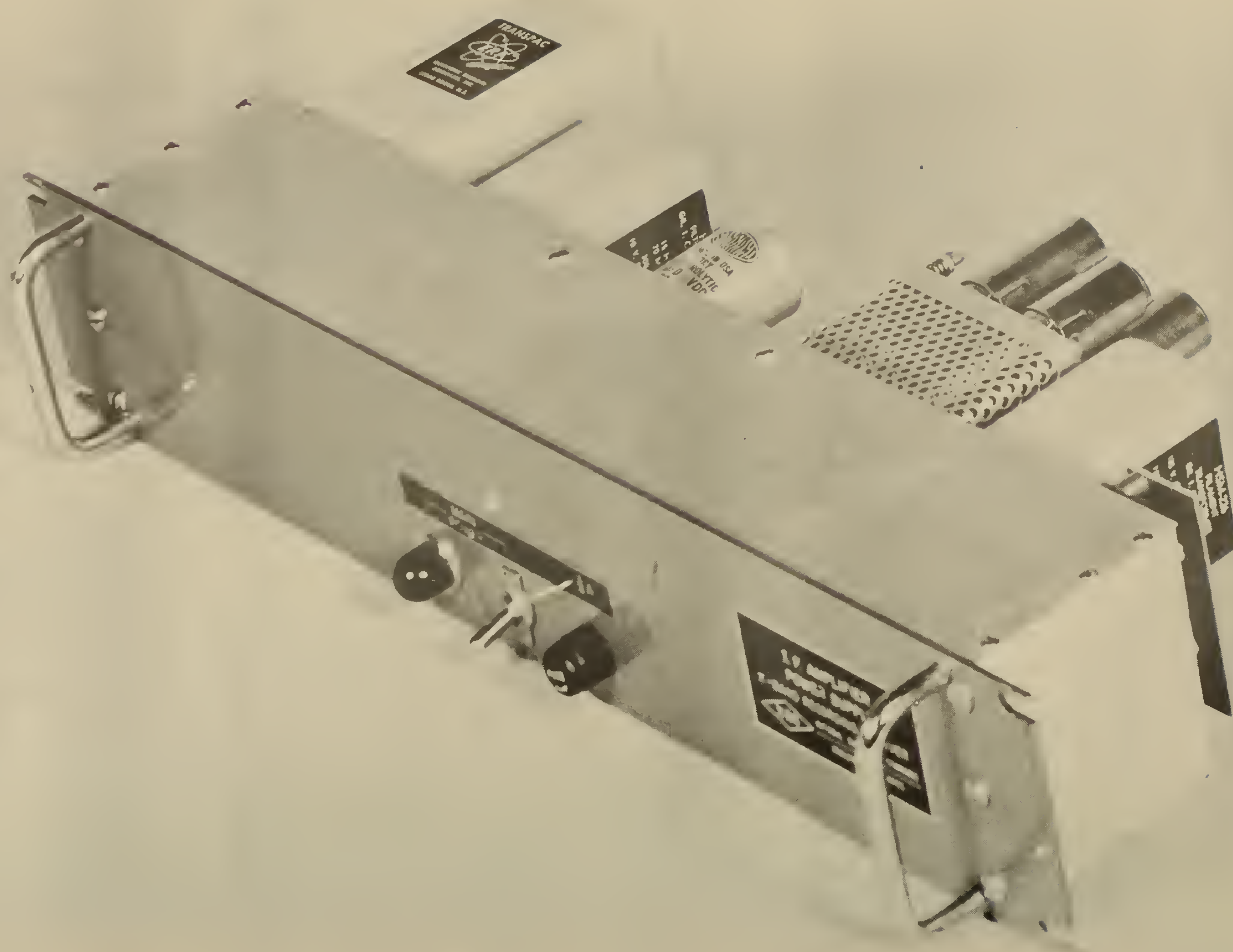

FIG. 41 I F AMPLIFIER POWER SUPPLY

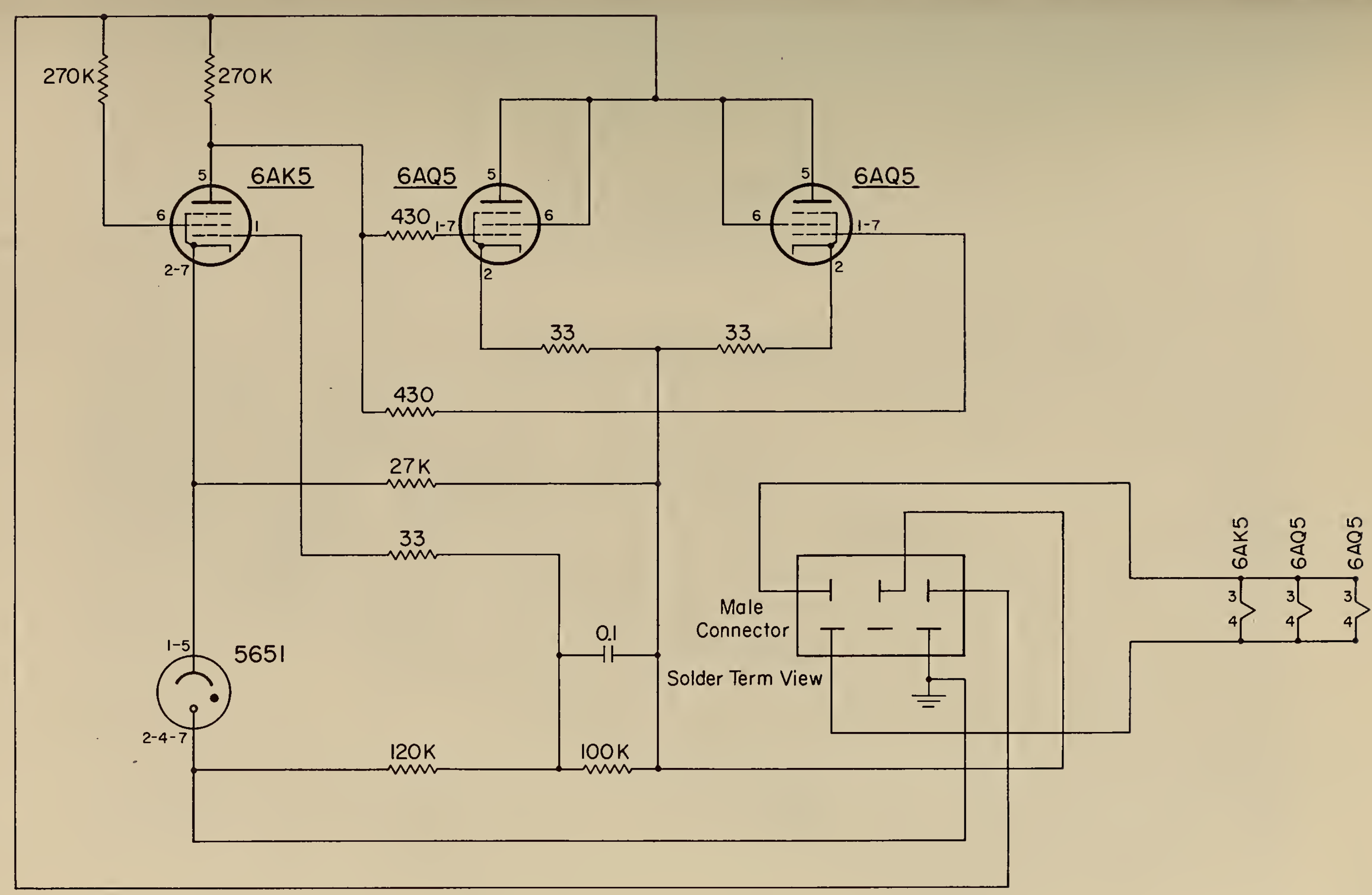

FIG. 42 VOLTAGE REGULATOR IF AMPLIFIER POWER SUPPLY

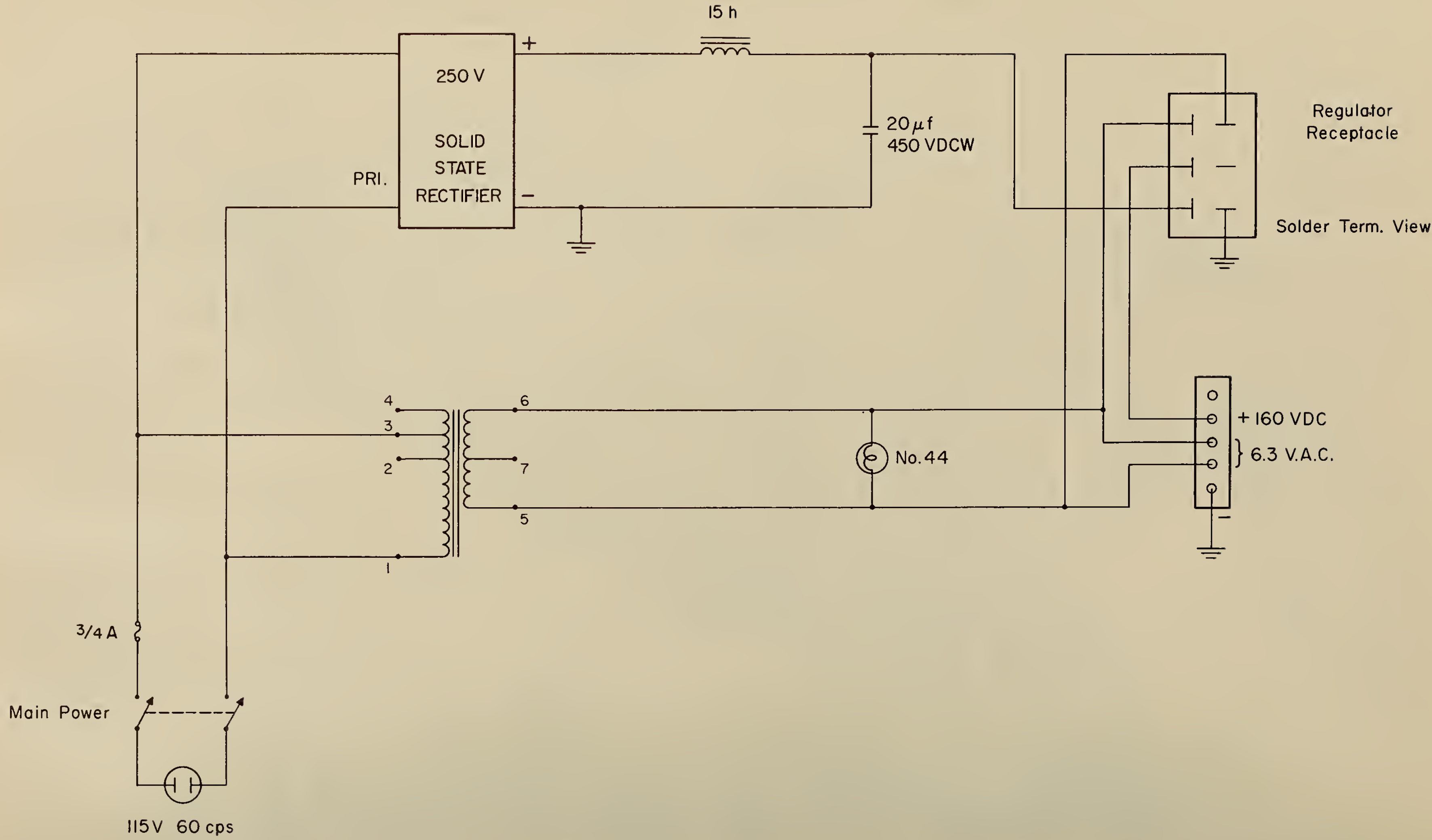

FIG. 43 I F AMPLIFIER POWER SUPPLY

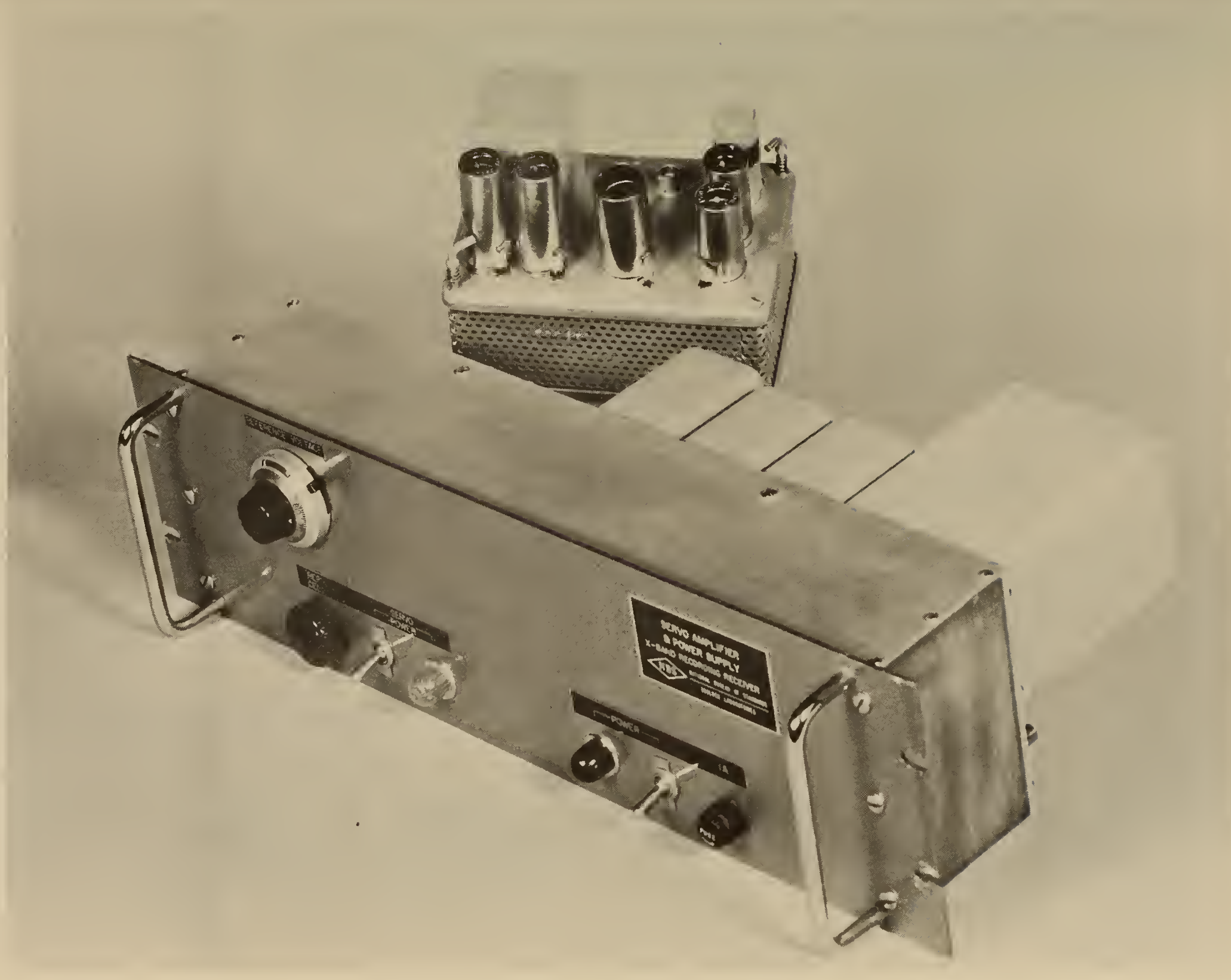

FIG. 44 SERVO AMPLIFIER

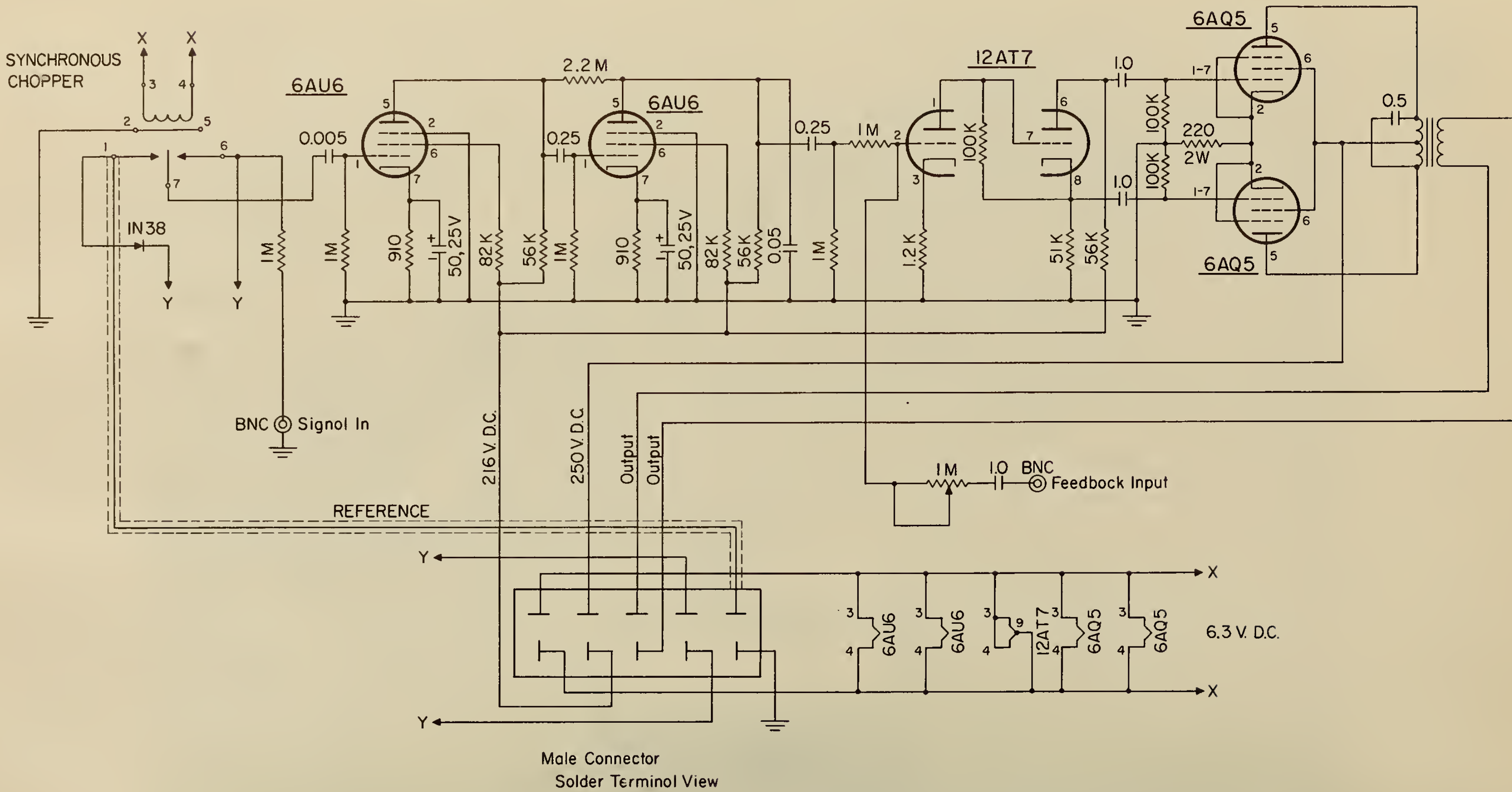

FIG. 45 SERVO AMPLIFIER

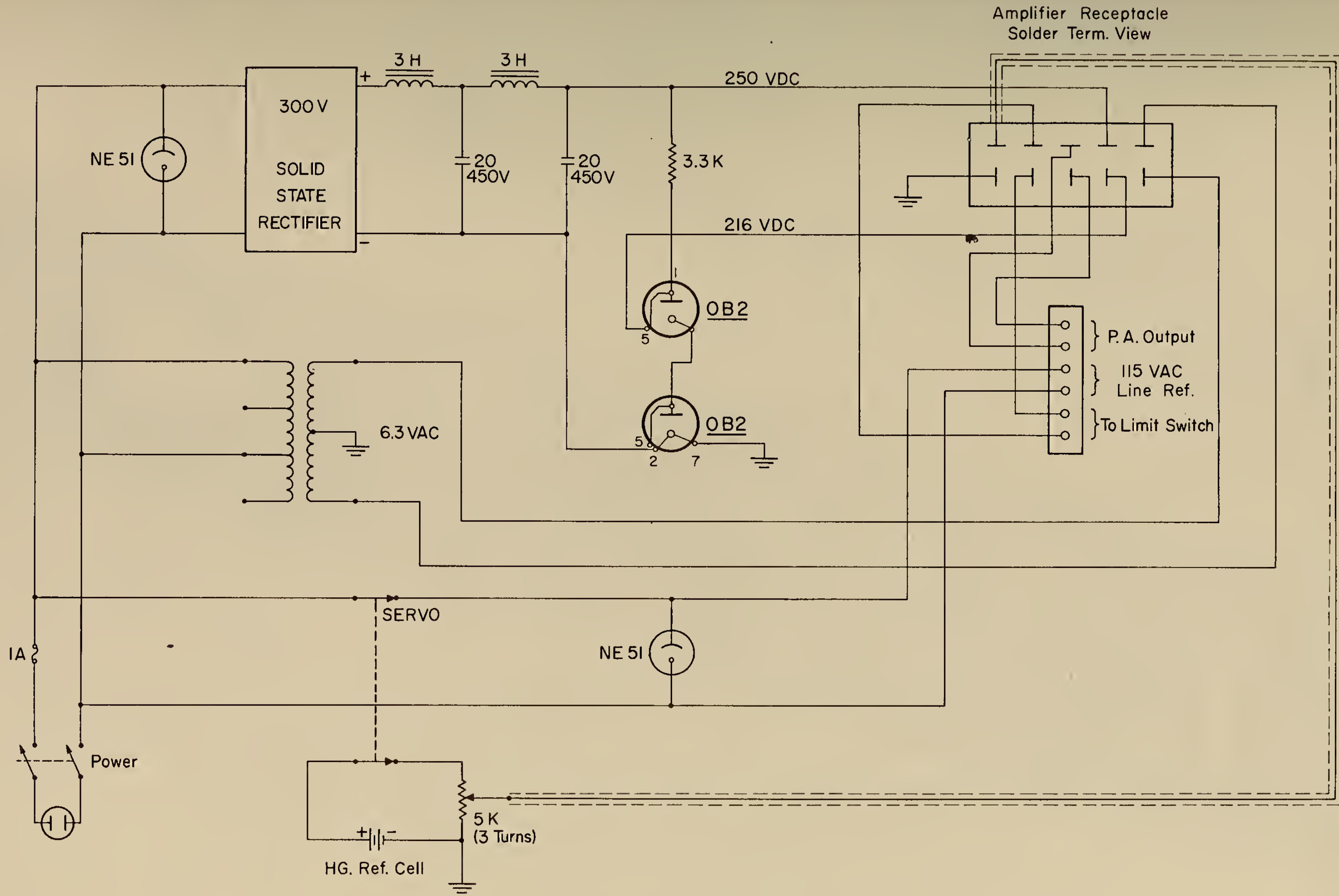

FIG. 46 SERVO AMPLIFIER POWER SUPPLY

FREQUENCY RESPONSE
LOW PASS SERVO-DRIVEN ATTENUATOR LOOP
X-BAND RECORDING RECEIVER

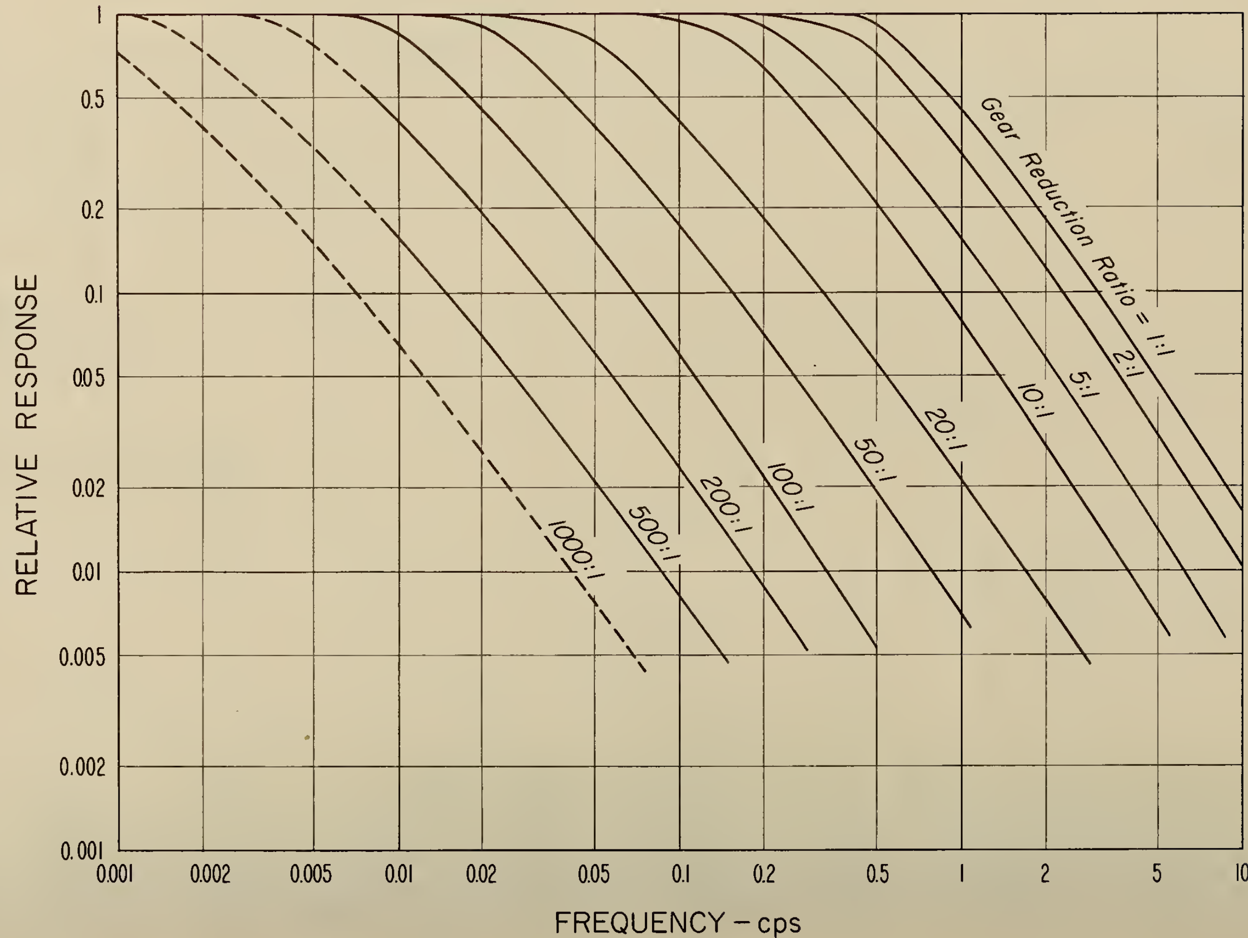

Figure 47

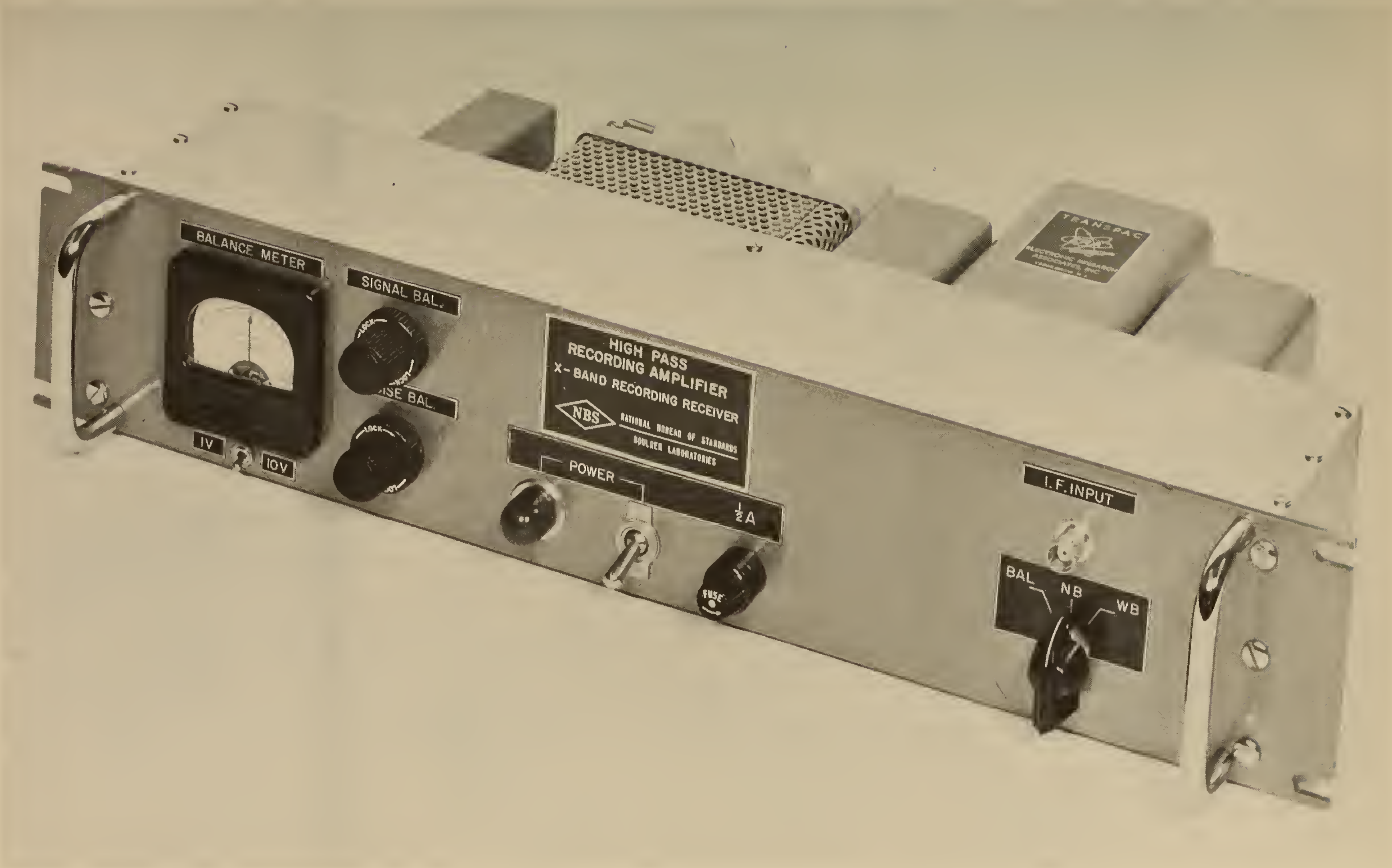

FIG. 48 HIGH—PASS RECORDING AMPLIFIER

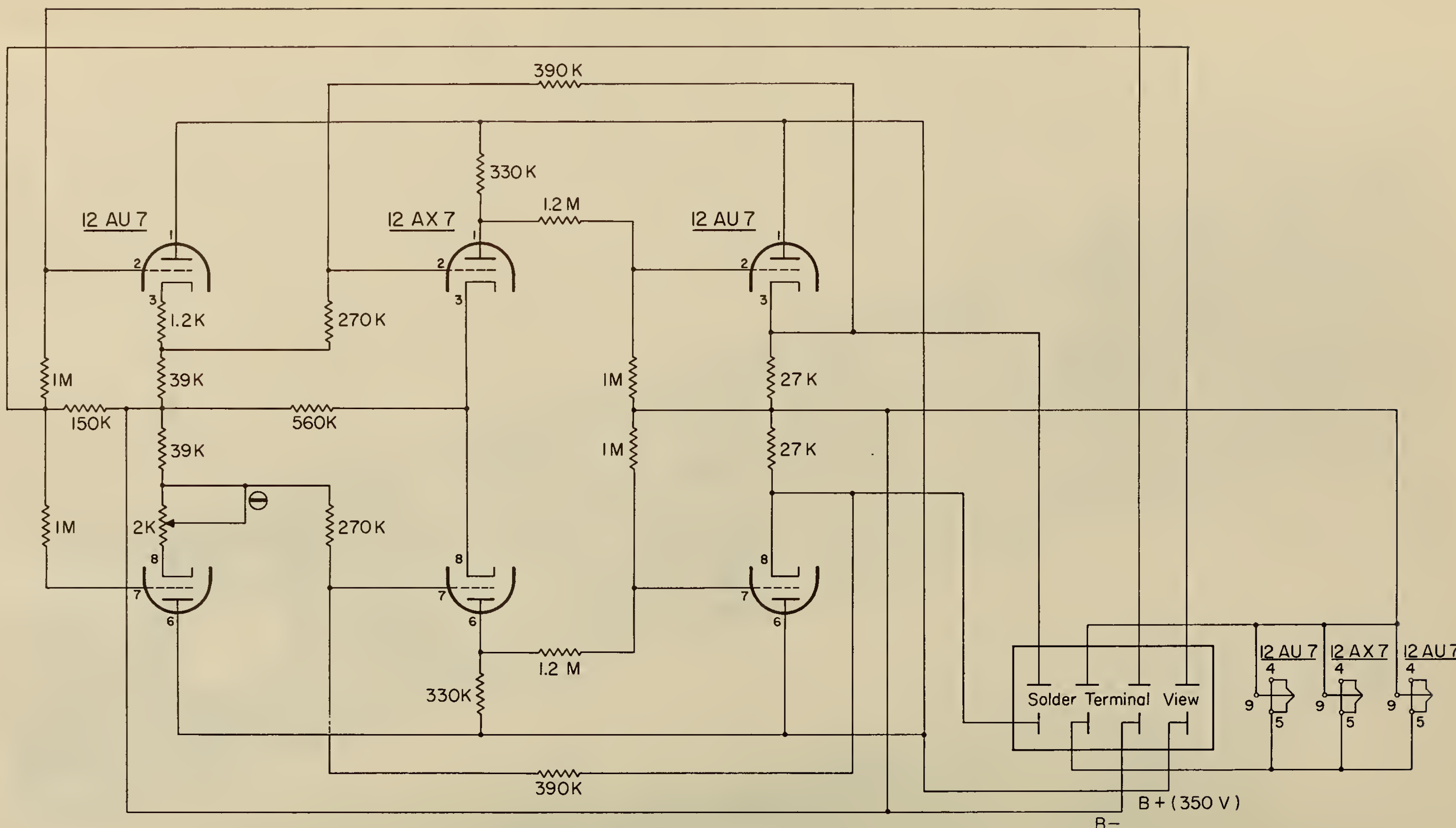

FIG. 49 HIGH PASS RECORDING AMPLIFIER

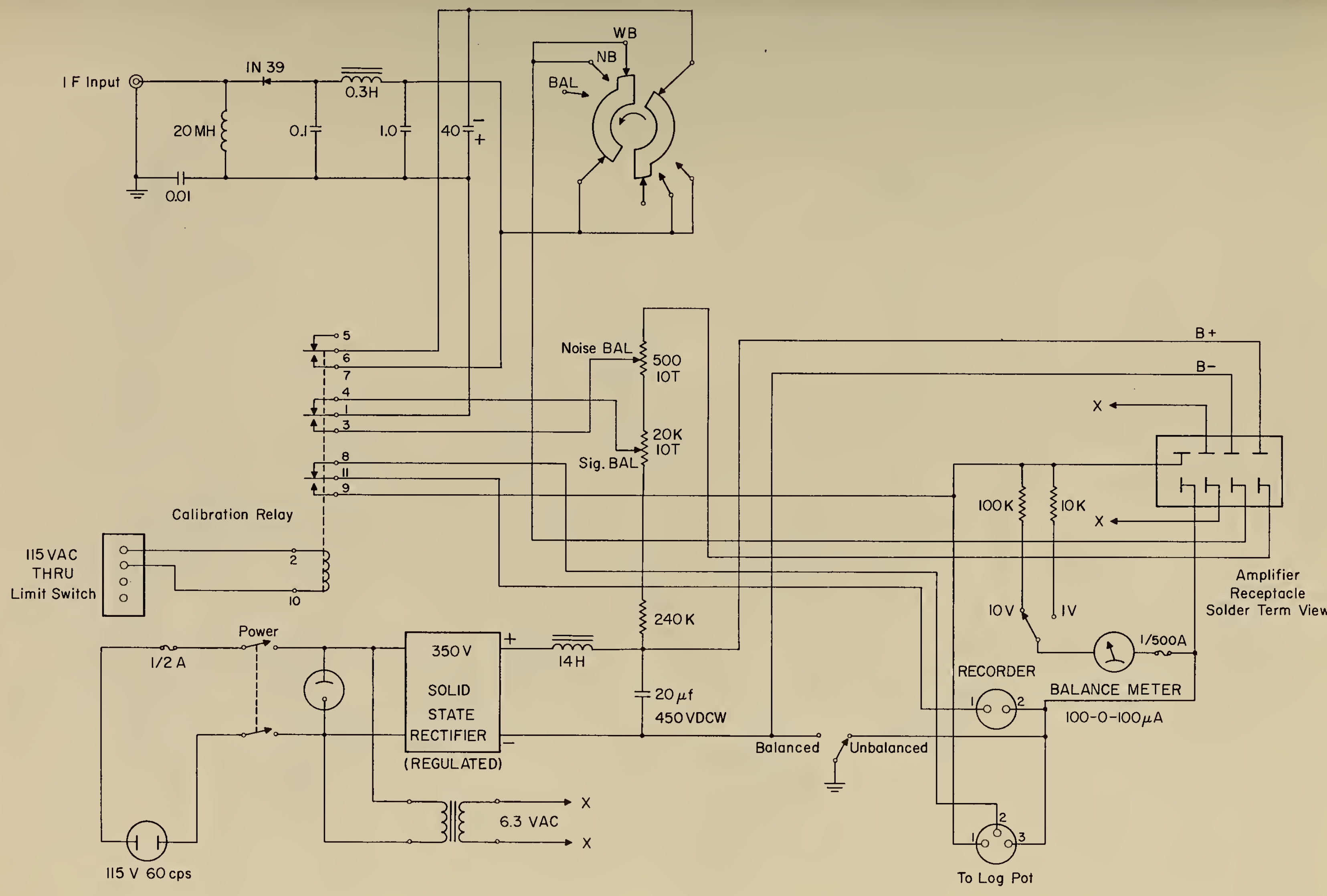

FIG. 50 HIGH PASS RECORDING UNIT

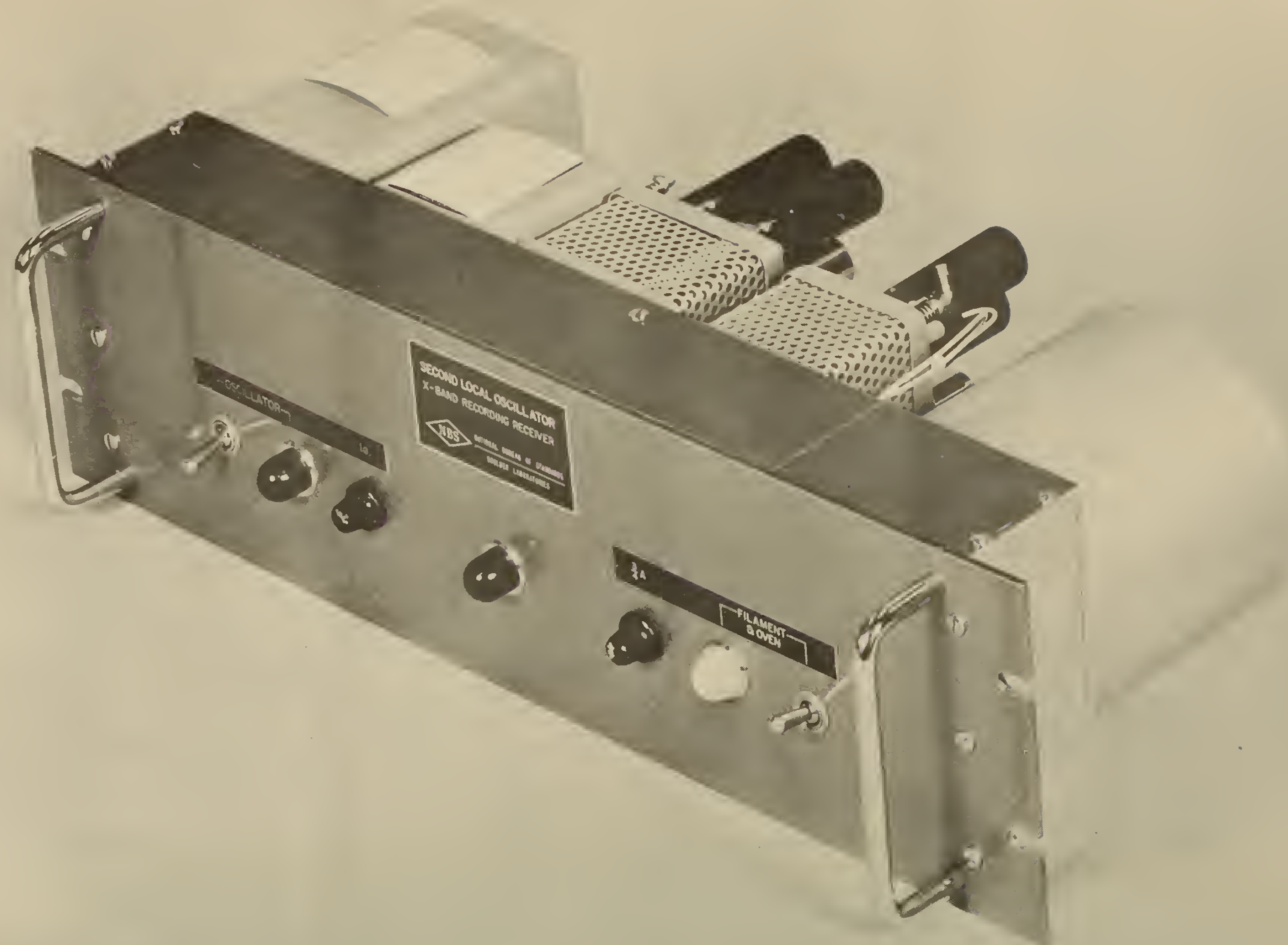

FIG. 51 SECOND LOCAL OSCILLATOR

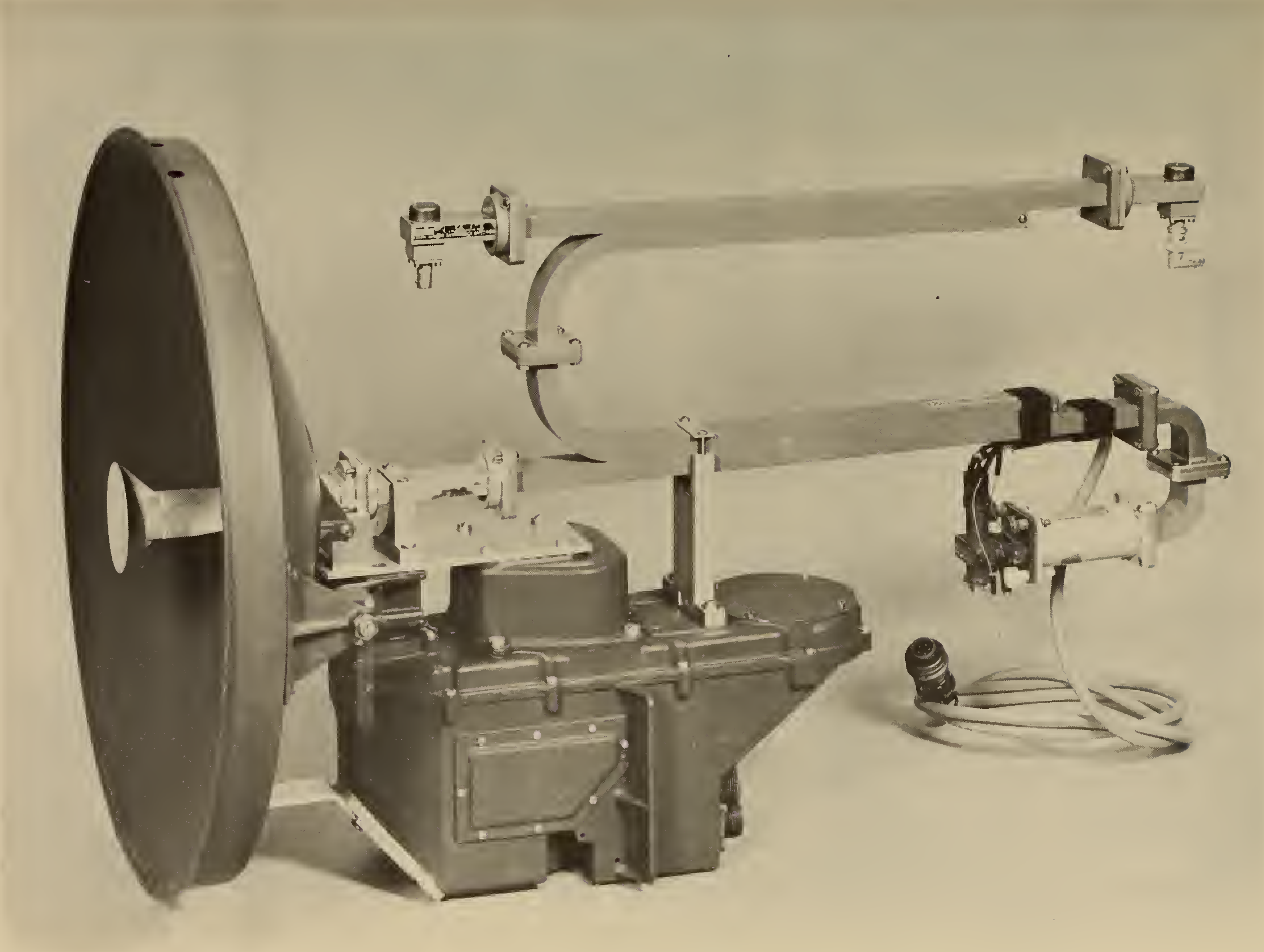

FIG. 52 TEST TRANSMITTER ANTENNA ASSEMBLY

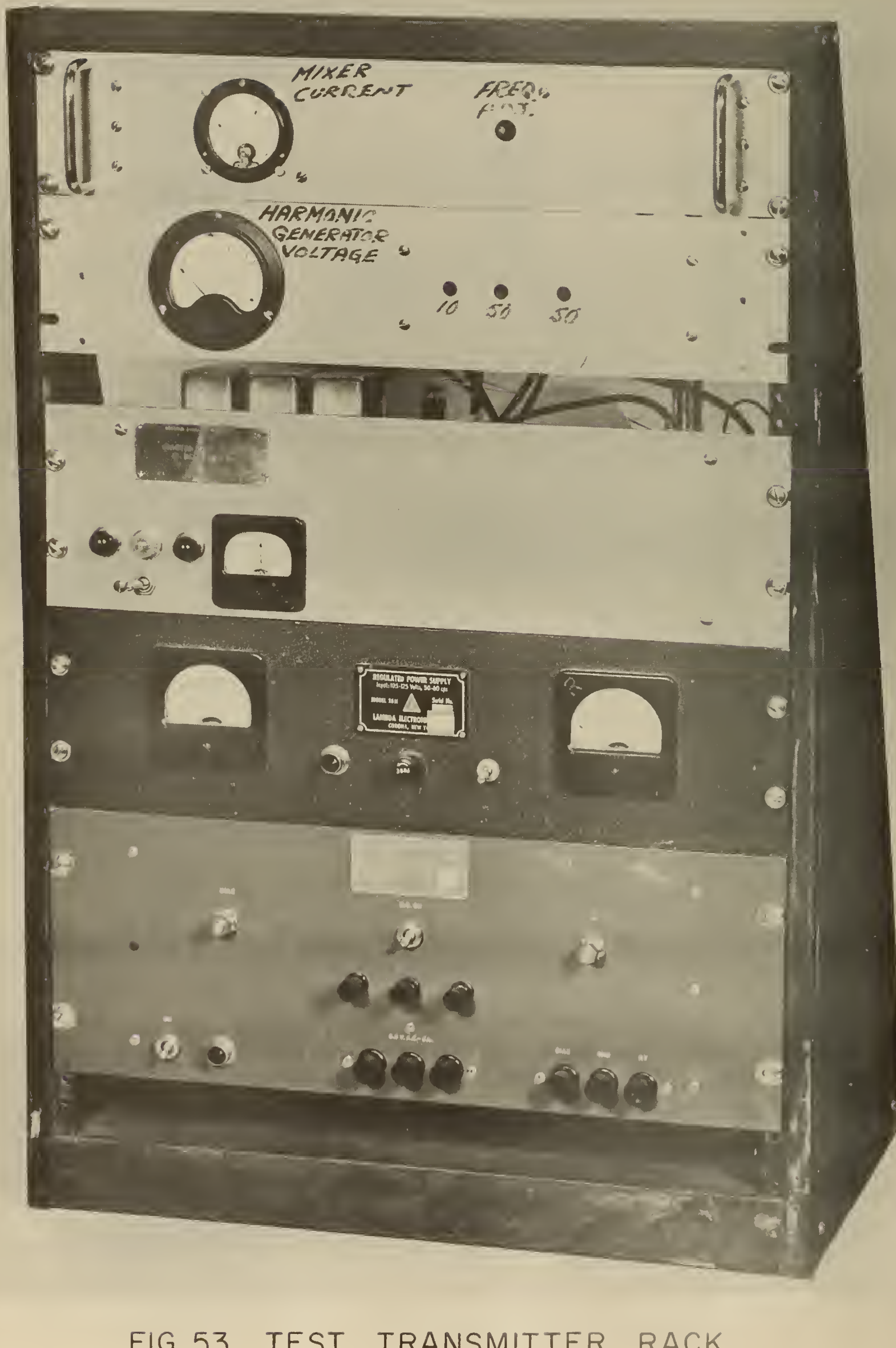

FIG. 53 TEST TRANSMITTER RACK

FIG 54 100 WATT CW KLYSTRON OSCILLATOR

U.S. DEPARTMENT OF COMMERCE
Luther H. Hodges, *Secretary*

NATIONAL BUREAU OF STANDARDS
A. V. Astin, *Director*

THE NATIONAL BUREAU OF STANDARDS

The scope of activities of the National Bureau of Standards at its major laboratories in Washington, D.C., and Boulder, Colorado, is suggested in the following listing of the divisions and sections engaged in technical work. In general, each section carries out specialized research, development, and engineering in the field indicated by its title. A brief description of the activities, and of the resultant publications, appears on the inside of the front cover.

WASHINGTON, D.C.

Electricity. Resistance and Reactance. Electrochemistry. Electrical Instruments. Magnetic Measurements. Dielectrics.

Metrology. Photometry and Colorimetry. Refractometry. Photographic Research. Length. Engineering Metrology. Mass and Scale. Volumetry and Densimetry.

Heat. Temperature Physics. Heat Measurements. Cryogenic Physics. Equation of State. Statistical Physics.

Radiation Physics. X-ray. Radioactivity. Radiation Theory. High Energy Radiation. Radiological Equipment. Nucleonic Instrumentation. Neutron Physics.

Analytical and Inorganic Chemistry. Pure Substances. Spectrochemistry. Solution Chemistry. Analytical Chemistry. Inorganic Chemistry.

Mechanics. Sound. Pressure and Vacuum. Fluid Mechanics. Engineering Mechanics. Rheology. Combustion Controls.

Organic and Fibrous Materials. Rubber. Textiles. Paper. Leather. Testing and Specifications. Polymer Structure. Plastics. Dental Research.

Metallurgy. Thermal Metallurgy. Chemical Metallurgy. Mechanical Metallurgy. Corrosion. Metal Physics.

Mineral Products. Engineering Ceramics. Glass. Refractories. Enameled Metals. Crystal Growth. Physical Properties. Constitution and Microstructure.

Building Research. Structural Engineering. Fire Research. Mechanical Systems. Organic Building Materials. Codes and Safety Standards. Heat Transfer. Inorganic Building Materials.

Applied Mathematics. Numerical Analysis. Computation. Statistical Engineering. Mathematical Physics.

Data Processing Systems. Components and Techniques. Digital Circuitry. Digital Systems. Analog Systems. Applications Engineering.

Atomic Physics. Spectroscopy. Radiometry. Solid State Physics. Electron Physics. Atomic Physics.

Instrumentation. Engineering Electronics. Electron Devices. Electronic Instrumentation. Mechanical Instruments. Basic Instrumentation.

Physical Chemistry. Thermochemistry. Surface Chemistry. Organic Chemistry. Molecular Spectroscopy. Molecular Kinetics. Mass Spectrometry. Molecular Structure and Radiation Chemistry.

• Office of Weights and Measures.

BOULDER, COLO.

Cryogenic Engineering. Cryogenic Equipment. Cryogenic Processes. Properties of Materials. Gas Liquefaction.

Ionosphere Research and Propagation. Low Frequency and Very Low Frequency Research. Ionosphere Research. Prediction Services. Sun-Earth Relationships. Field Engineering. Radio Warning Services.

Radio Propagation Engineering. Data Reduction Instrumentation. Radio Noise. Tropospheric Measurements. Tropospheric Analysis. Propagation-Terrain Effects. Radio-Meteorology. Lower Atmosphere Physics.

Radio Standards. High Frequency Electrical Standards. Radio Broadcast Service. Radio and Microwave Materials. Atomic Frequency and Time Interval Standards. Electronic Calibration Center. Millimeter-Wave Research. Microwave Circuit Standards.

Radio Systems. High Frequency and Very High Frequency Research. Modulation Research. Antenna Research. Navigation Systems. Space Telecommunications.

Upper Atmosphere and Space Physics. Upper Atmosphere and Plasma Physics. Ionosphere and Exosphere Scatter. Airglow and Aurora. Ionospheric Radio Astronomy.

NBS