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NATIONAL RESEARCH COUNCIL OF CANADA

RADIO AND ELECTRICAL ENGINEERING DIVISION

NR-20 PROJECT
PROGRESS REPORT NO. 1
MARCH 1951 - MARCH 1952

OTTAWA

APRIL 1952

ABSTRACT

The NR20 Receiver is an instantaneous, all-round-looking, wide band SH/F D/F set designed to indicate the bearings of pulse transmissions. Bearings are shown unambiguously as radial lines on a cathode-ray tube. The frequency range covered by the present model is approximately 8,000 to 11,500 Mc (2.6 to 3.75 cm.), with somewhat degraded performance at the extremes of the band. The equipment is intended for installation either on shipboard or on an aircraft. Although, in its present state, only 8- to 11-Kmc signals may be detected, it is anticipated, that by the addition of a second antenna system, provision will be made for the reception of S-band signals. It should be noted that the present antenna system is capable of receiving signals polarized in only the horizontal plane. For other polarizations different antennas will be required.

The principal advantage of a direction finder of this type is that it provides a probability of intercept of approximately unity for signals within the useful range. This is in contrast to the rotating-type of direction finder which has a much smaller probability of intercept.

The NR20 equipment to be described is similar in principle to the British Admiralty Type CX403 Direction Finder.

NR-20 PROJECT

Referring to Fig. 1, the equipment consists of the following units:

(a) Antenna Unit — four horns and associated waveguide and wideband crystal detectors
(b) Transmission lines from the antenna to the receiver
(c) Receiver and Display Unit
(d) Power Supply.

The Receiver and Display Unit (see Photos 1, 2, and 3) is divided into the following sub-units:

(a) Attenuator Unit
(b) Four Video Amplifier Units
(c) Mixer and Brightening Pulse Generator
(d) C.R.T. Unit.

These sub-units, together with remote switches for the power supply are mounted in one chassis which fits the standard Bl-Dl aircraft case (JAN-C-172A and JCNAAF-C-6), thus making the equipment suitable for airborne use.

A block diagram of the equipment appears in Fig. 1. The instantaneous, all-round-looking D-F properties are obtained by the use of a four-channel amplitude-comparison system. Each of the horns feeds through a separate crystal detector to one of the four video amplifiers, and the bearing of the received signal is determined by comparison of the amplitudes in the individual channels. Wide band reception is obtained by the use of a crystal detector in a wide band mount followed by a video amplifier, as opposed to the narrow band of the conventional superheterodyne receiver.

ANTENNA

The antenna consists of four, identical, horizontally polarized horns spaced 90 degrees in azimuth, together with their associated waveguide, crystal detector, and output matching transformer. Photo 4 shows a typical horn assembly.

The horns are designed to give a reception pattern which approximates that of $\cos^{\frac{1}{2}} \emptyset$ (as described in Appendix I) over the range of frequencies to be received. The incoming signal is fed by a short length of waveguide to the crystal detector. This, in effect, acts as a high-pass filter, since frequencies below 6500 Mc are very rapidly attenuated in the guide. The received pulse is rectified by the crystal detector, the output of which is the waveform of the pulse envelope. The output of the crystal is fed through a matching transformer to the 50-ohm transmission line which connects to the receiver.

CRYSTAL MOUNTS

The crystal mount used, known as the "MTS" crystal mount, is of the re-entrant type (see Photos 5 and 6). Radio-frequency energy is fed into one arm of a "Magic T Junction" with the two co-linear arms folded back on themselves in a $2\frac{1}{2}$-inch-diameter circle. The crystal is mounted at the mid-point, opposite to the Magic T. The fourth arm of the Magic T is left unterminated, as it has practically no effect on the operation.

Over the band of 8 to 11 Kmc the performance of the single-waveguide-feed type of mount, using Type 1N31 or 1N23B crystals, is very poor. This is because the crystals themselves are reactive at one or more points in this frequency band. The coaxial construction of the Type 1N31 crystal forms a $\frac{1}{4}\lambda$ line at one frequency, which makes its impedance highly reactive, giving a variation of impedance with change of frequency. With a single waveguide mount this reactance produces a mis-match at all frequencies except the one or two points where the reactance is tuned out.

The re-entrant mount has the characteristic that no matter what the mis-match at the crystal holder there will always be a voltage maximum at this point, so that all that is necessary for minimum standing-wave ratio is that the resistive component of the crystal be matched to the waveguide impedance. Thus, the reactance of the crystal itself has a much reduced effect on the standing-wave ratio.

For a detailed treatment of the general principles involved, reference may be made to Hoglund Foster, and Yakutis RRL/Harvard — "Wide Band Waveguide Mixers", and to Tyrrell — Nov. IRE Proceedings, 1947, "Hybrid Circuits for Microwaves". Another method of coupling a waveguide to a crystal was tried but not used, because fabrication was found to be more difficult than for the MTS crystal mount. This comprised splitting the waveguide in the E plane so that the radio-frequency power is divided, and fed in phase into both ends of a straight section with a crystal mounted at the center. This gives slightly better results at the upper and lower limits of the band, owing mainly to the low standing-wave ratio of the power-dividing junction over a wider frequency band than at the Magic T junction.

A British crystal Type VX 3053 was tested, using a straight crossbar mount. The standing-wave ratio was found to be fairly low over the whole band, with a sensitivity comparable with the Type 1N23B crystal (see Fig. 2,).

Referring to Figs. 3 and 4, the maximum sensitivities obtained are about 85 per cent of the theoretical maximum. Contrary to what might be expected the standing-wave ratios do not seem to have any correlation with the minimum detectable signal. The very low standing-wave ratio of the Type 1N31 crystal at 9.3 Kmc indicates that it may be a better crystal to use for narrower band applications. The dip in the sensitivity curve at 10.6 Kmc seems to be an instrumental error, as it occurs in all the mounts at the same frequency. Table I indicates the range of minimum detectable signal and of standing-wave ratio for a number of Type 1N23B crystals and crystal mounts.

Fig. 5 shows the relationship of standing-wave ratio, both in decibels and voltage ratio, to power loss and power into load.

TRANSMISSION LINES

At present the detected signals are fed from the matching transformers to the receivers by four RG 58/U transmission lines of a length suitable to the particular installation. This double shielded cable is necessary in order to avoid pickup of unwanted signals by the transmission lines. In the future this cable may be replaced wholly or in part by cables having a solid lead or aluminum sheath.

ATTENUATOR

The step attenuator in the inputs of the receiver is necessary to prevent overloading of the video amplifiers. The attenuation control on the front panel is labelled "Sensitivity". The same shaft also operates a switch to change the connection of the CRT deflection plates from the final stages of the video amplifier units to the antepenultimate stages. In the first position of the attenuator no attenuation is inserted in the 50-ohm line and the deflector plates are connected to the final stages of the amplifiers. In the second position the deflection plates are connected to the antepenultimate stages with no attenuation of the input signal. This operation is performed by a relay-actuated switch in the CRT Unit, and a decrease in gain of approximately 15 db results. In Positions 3, 4, and 5 attenuations of 17, 34, and 51 db respectively, are inserted in the inputs of all four amplifiers, giving a total attenuation of up to 65 db. The circuitry of the attenuator appears in Schematic Diagram # 1.

VIDEO AMPLIFIER (See Photos 7 and 8 and Schematic Diagram # 2)

Each video amplifier unit consists of a four-stage video amplifier, a cathode-follower stage which feeds a pulse stretching network, and a three-stage deflection amplifier.

The output of the attenuator is fed to the video amplifier through a matching transformer, in the high impedance side of which is a potentiometer for adjusting the sensitivity of the channel. The bandwidth of the video amplifier extends from 30 to 300 kc/s with a gain of approximately 115 db. Heavy negative feedback is employed to stabilize the gain. The noise level of the receiver is determined by the Johnson noise in the crystal and the associated input circuit.

The cathode-follower stage provides a low-impedance source for the pulse-stretching network. The pulse is first stretched by the action of a crystal diode and a 560-pfd condenser, and then integrated by the following 100,000-ohm resistor and 220-pfd condenser. This results in a positive pulse with a rising edge of approximately 20 microseconds, the slope of the rising edge being proportional to the amplitude of the output pulse of the video amplifier.

The stretched pulse is amplified by the first deflection amplifier, and from its anode a negative-going output is taken to the CRT deflection plates. This output is used in all but the highest gain position of the attenuator. The following stage is primarily an inverter, and from its anode a positive-going pulse is taken to the mixer unit for the generation of the brightening pulse and audio signal. The final stage produces a negative-going pulse which is fed to the deflection plates in the highest gain position of the attenuator. The noise voltage present at this output gives an appreciable deflection on the cathode-ray tube, so that this high gain output is used only in obtaining an approximate bearing on a very weak signal.

<u>MIXER AND BRIGHTENING PULSE GENERATOR</u> (See Photos 9 and 10 and Schematic Diagram # 3)

The four inputs to the mixer unit from the video amplifiers are combined by using four isolating cathode-follower stages to avoid possible cross-coupling between units. The combined outputs of the cathode-follower stages are then amplified and fed through a short time-constant circuit to a triggered multivibrator stage. This produces a brightening pulse of 20 microseconds duration, which is applied to the cathode of the cathode-ray tube when the leading edge of the pulse is applied to the deflection plates. The output of the mixer amplifier is also fed to a further amplifer which feeds the audio output transformer.

<u>POWER SUPPLY FOR CATHODE-RAY TUBE</u> (See Photos 11 and 12 and Schematic Diagram # 4)

In order to simplify the power requirements, the high-voltage for the cathode-ray tube is provided by an audio oscillator operating at approximately 1500 cycles. The input voltage to this supply is 300 volts d-c. The output of the audio oscillator feeds the primary of a high-voltage transformer which operates a voltage doubler using selenium rectifiers. The unit, in addition to the cathode-ray tube and its associated controls, contains the relay-actuated switch for selection of the set of outputs from the video amplifier units to be fed to the deflection plates.

POWER SUPPLY (See Photo 13 and Schematic Diagram #5)

The present power supply is designed for shipboard use, and operates from an input of 115 volts at any frequency between 50 and 500 cycles per second. The output is 300 volts at 150 milliamperes, 6.3 volts at 7 amperes for filament supplies, and 24 volts at 1 ampere for relay operation. In an aircraft it is anticipated that this power supply will be replaced by a dynamotor having the required outputs. Consideration is being given to provision of an alternative connection for 28-volt operation of the filaments.

APPENDIX I

PRINCIPLES OF THE D/F SYSTEM

The basis of the CRDF system is comparison of the amplitudes of the signals in two adjacent antennas whose directions of maximum response are at right angles and whose reception pattern approximates the cosine law. The bearing is displayed on a cathode-ray tube as the vector sum of the amplified signals in the corresponding adjacent channels.

Let A_1, A_2, A_3, and A_4 (Fig. 6) be four antennas having cosine law reception patterns, with their directions of maximum response spaced at 90-degree intervals in azimuth. Assume a signal to be received from the direction OB at an angle ϕ with respect to the line OX. The voltages induced in A_2 and A_1 will be E cos ϕ and E sin ϕ, respectively, and the voltages induced in A_3 and A_4 will be zero.

If the antennas are connected through their respective amplifiers to the plates, P_1, P_2, P_3, and P_4, of the cathode-ray tube and the channel sensitivities are equal, the spot will be deflected by plate P_1 a distance proportional to the input on A_1, and by plate P_2 a distance proportional to the input on A_2. The resultant deflection will be at an angle θ such that tan θ is equal to sin ϕ / cos ϕ, which is tan ϕ, and the bearing as indicated on the face of the cathode-ray tube will be equal to the bearing of the received signal.

However, when using a square-law video crystal as a detector, the voltage input to the video amplifier is approximately proportional to the square of the received voltage. Thus, for a signal picked up by antennas designed for linear detectors, the deflection voltages applied to the plates will be proportional to $\sin^2 \phi$ and $\cos^2 \phi$. This will result in an erroneous indication on the cathode-ray tube except at integral multiples of 45 degrees. The error is octantal, with a maximum value of 12.8 degrees and an RMS error of 9.3 degrees.

In order to compensate for the square law detectors it is necessary to make use of antennas with a reception pattern proportional to the square root of the cosine. This is difficult to achieve over the wide band of frequencies it is desired to receive. The present horns will give a maximum error not greater than five degrees with a square law detector, this figure being based on calculations from the radiation patterns of the horns.

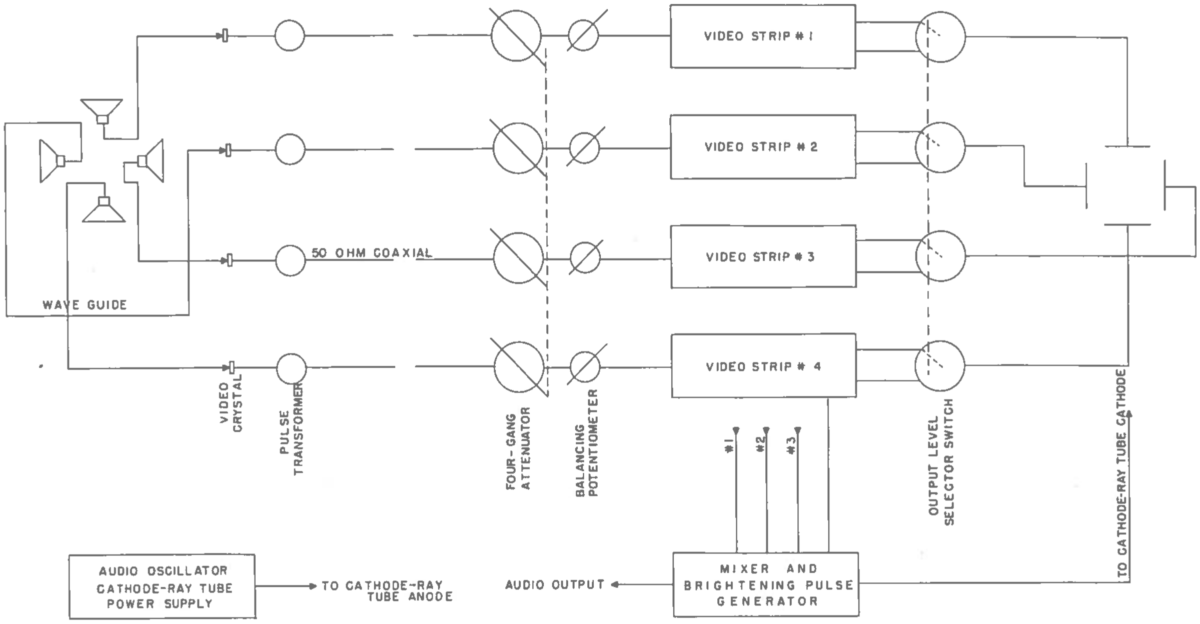
APPENDIX II

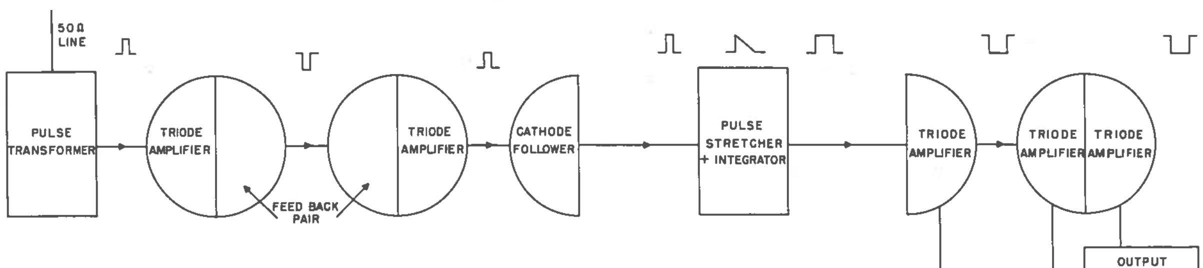
FACTORS AFFECTING BEARING ACCURACY

A major factor in determining the bearing accuracy of a D/F system of this kind is the design of the antennas. However, there are other factors which have considerable influence on the accuracy. The gains of all channels must be equal within narrow limits, the limits depending on the degree of accuracy desired and the error contributed by the other components of the system. Figs. 7 and 8 show the effect on the bearing accuracy of a difference in gain between adjacent channels. Since the detector operates approximately on a square-law characteristic, a difference of 1 db. in antenna gain between the two channels is equivalent in its effect to a difference of 2 db in the gains of the amplifiers following the detectors. The error due to unequal channel gains is quadrantal in effect, with zero error occuring at integral multiples of 45 degrees. For small differences in gain, the maximum error occurs at, or near 45 degrees, but moves towards the end of the quadrant as the difference becomes large. In the NR20 receiver the channel gains are adjusted to equality by means of potentiometers in the input circuit of the video amplifiers.

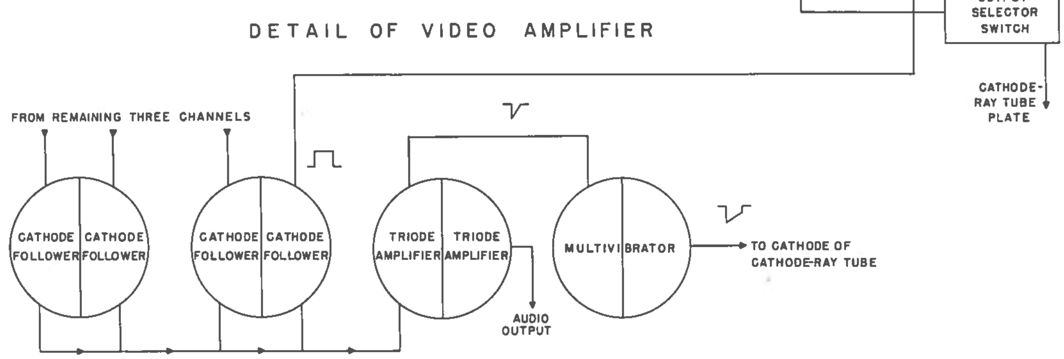
Slight variations between the amplifiers may result in differences in the time delay applied to the leading edge of pulses in passing through the amplifiers. The effect on the bearing accuracy is greatly reduced by the action of the pulse-stretching and integrating circuits. In Fig. 9 is shown the effect of applying two equal pulses to adjacent plates of the cathode-ray tube, when the pulse in one channel is slightly delayed with respect to that in the other. It can clearly be seen that pulse stretching results in a more accurate bearing. A further advantage of pulse stretching is that the writing speed on the cathode-ray tube is also greatly reduced, and this results in a brighter trace.

Since the overall gain of the amplifier is very high, the dynamic range from noise level to saturation is small in relation to the range of input signals, and saturation of the output stages will result on all but the weakest signals. For a small amount of overload, the result is a hook at the outer end of the trace, which is not too serious. However, at higher input levels the stages before the pulse-stretching stage saturate. This results in a fixed-amplitude output from the pulse-stretching stage for all signals greater than the saturation level, which, in turn, results in erroneous bearings. The dynamic range from noise level to the maximum level is about 25 db. Provision of the step attenuator in the input circuit makes it possible to adjust the signal input to such a level that an adequate indication is obtained on the display, without danger of bearing inaccuracies due to overloaded amplifiers.





DETAIL OF VIDEO AMPLIFIER



DETAIL OF MIXER AND BRIGHTENING PULSE GENERATOR

FIG. 1

BLOCK DIAGRAM
OF
NR-20 INSTANTANEOUS MICROWAVE DIRECTION FINDER

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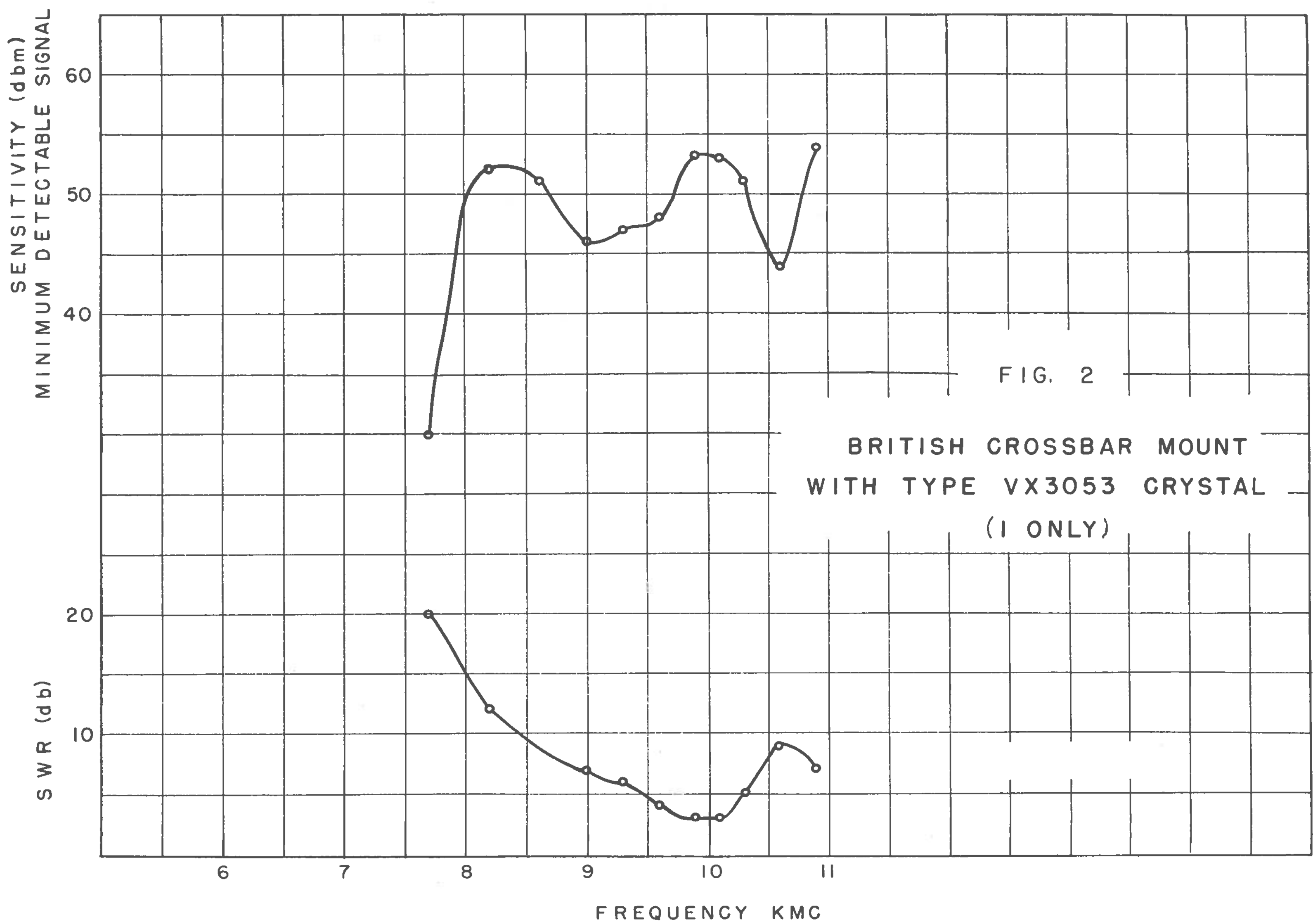

FIG. 2

BRITISH CROSSBAR MOUNT
WITH TYPE VX3053 CRYSTAL
(1 ONLY)

SECRET

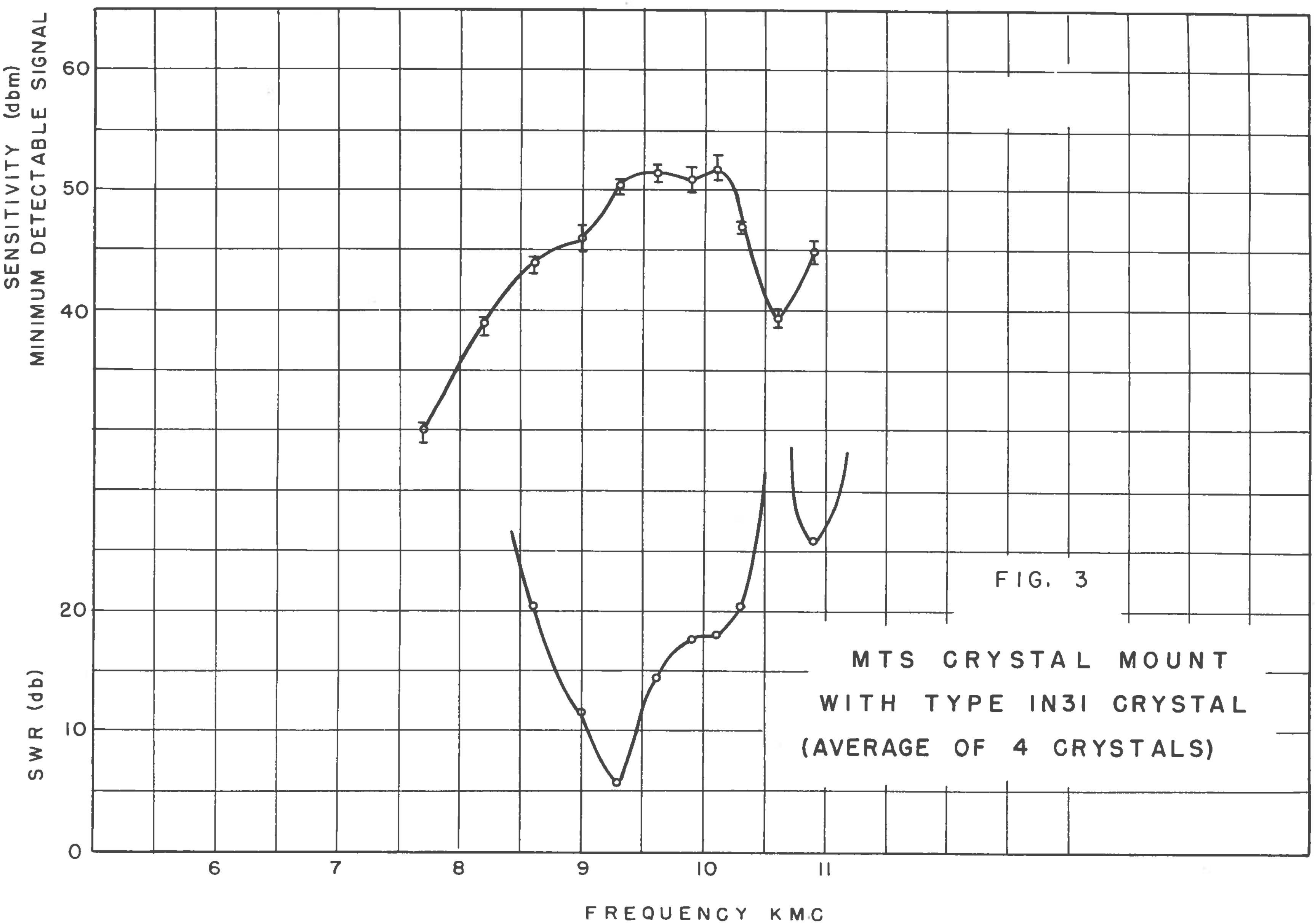
SENSITIVITY (dbm)
MINIMUM DETECTABLE SIGNAL
60
50
40
20
SWR (db)
10
0
6
7
8
9
10
11
FREQUENCY KMC
MTS CRYSTAL MOUNT
WITH TYPE IN31 CRYSTAL
(AVERAGE OF 4 CRYSTALS)

FIG. 3

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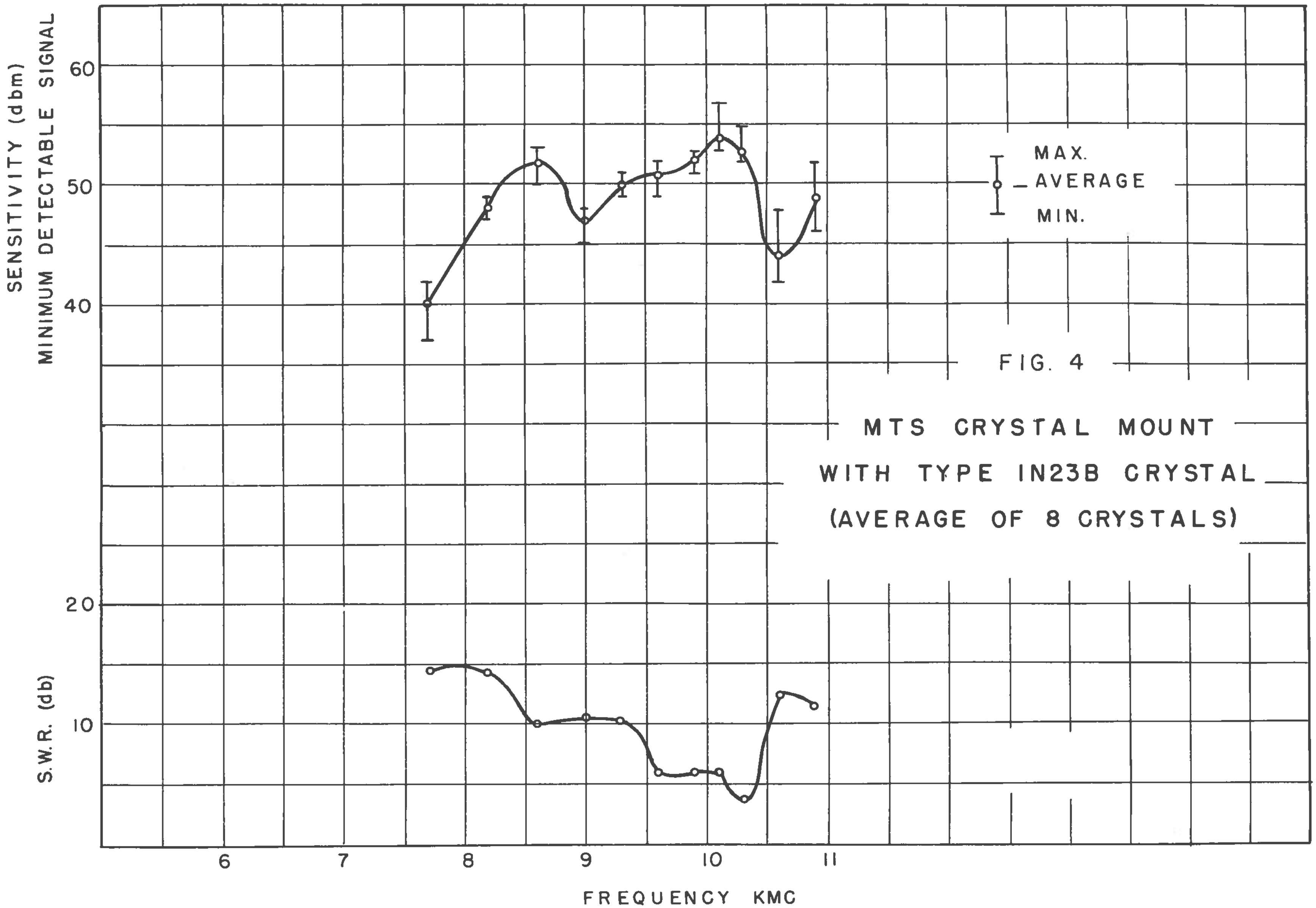


FIG. 4

MTS CRYSTAL MOUNT
WITH TYPE IN23B CRYSTAL
(AVERAGE OF 8 CRYSTALS)

SECRET

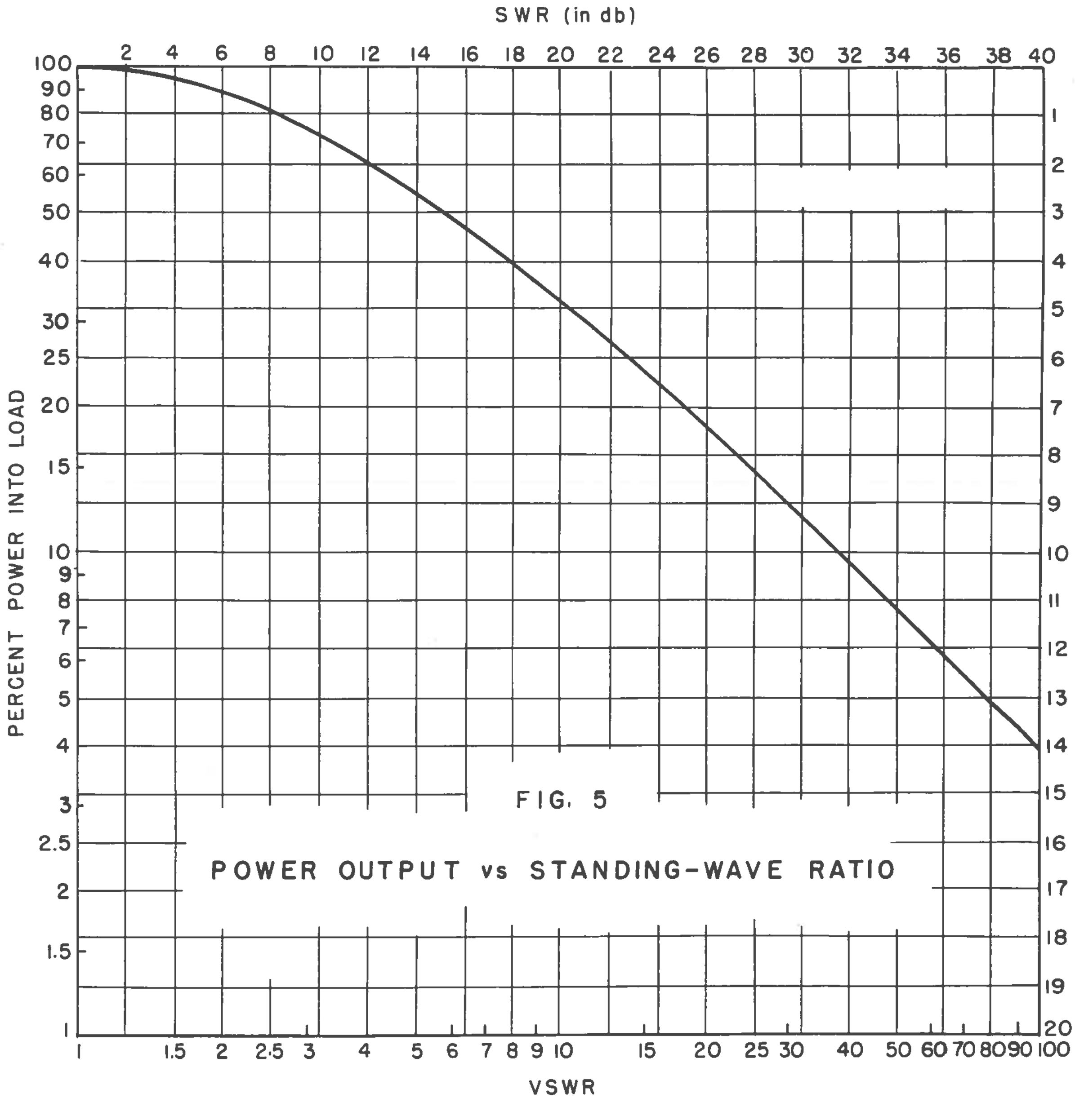
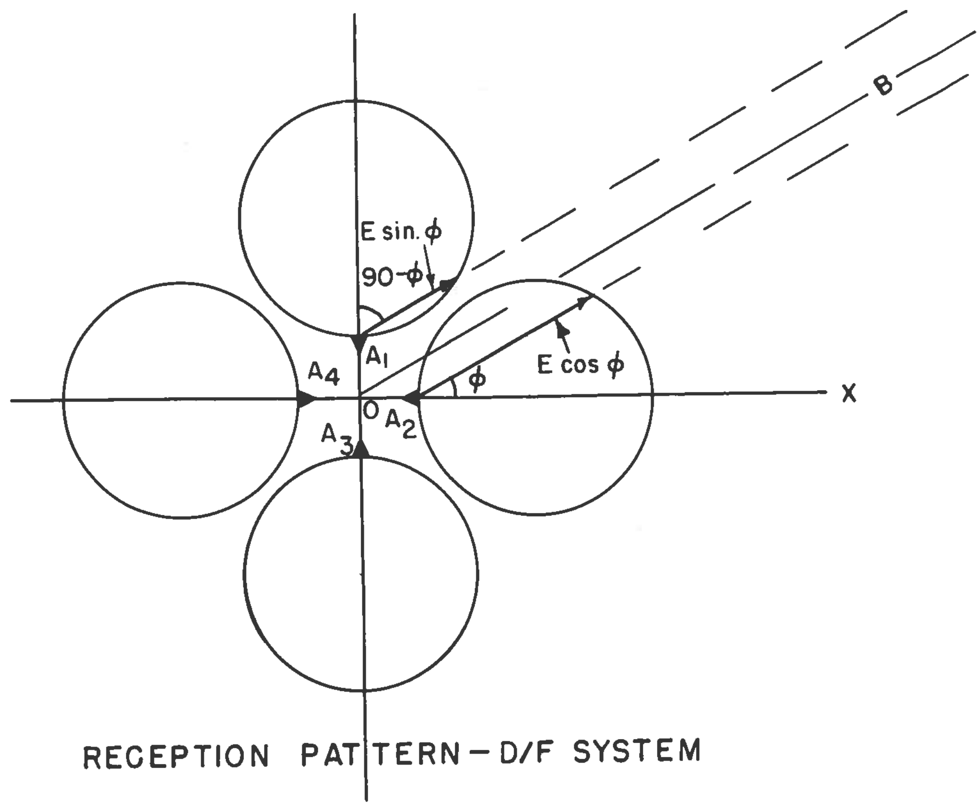
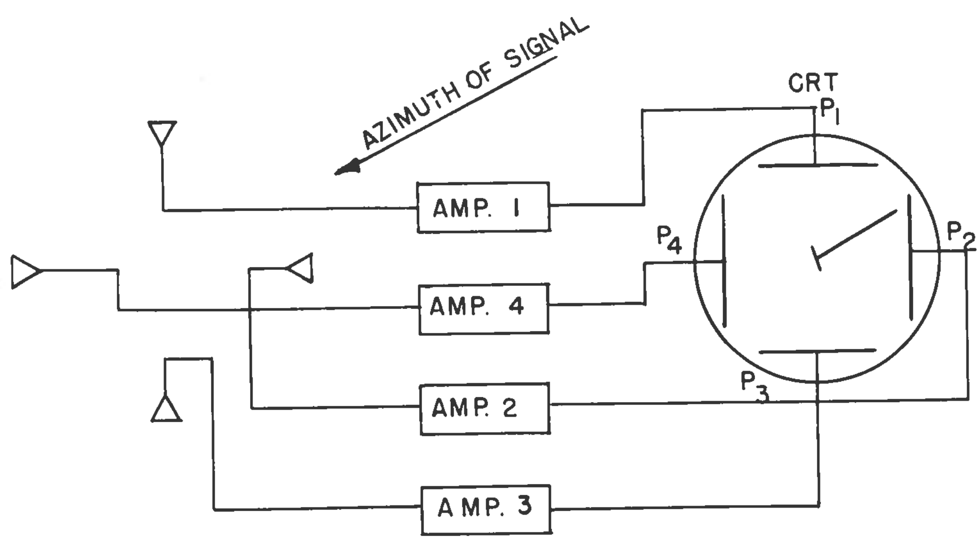


FIG. 5

POWER OUTPUT vs STANDING-WAVE RATIO



RECEPTION PATTERN — D/F SYSTEM



BEARING INDICATION — D/F SYSTEM

FIG. 6

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FIG. 7

MAXIMUM ERROR VS ERROR AT 45°

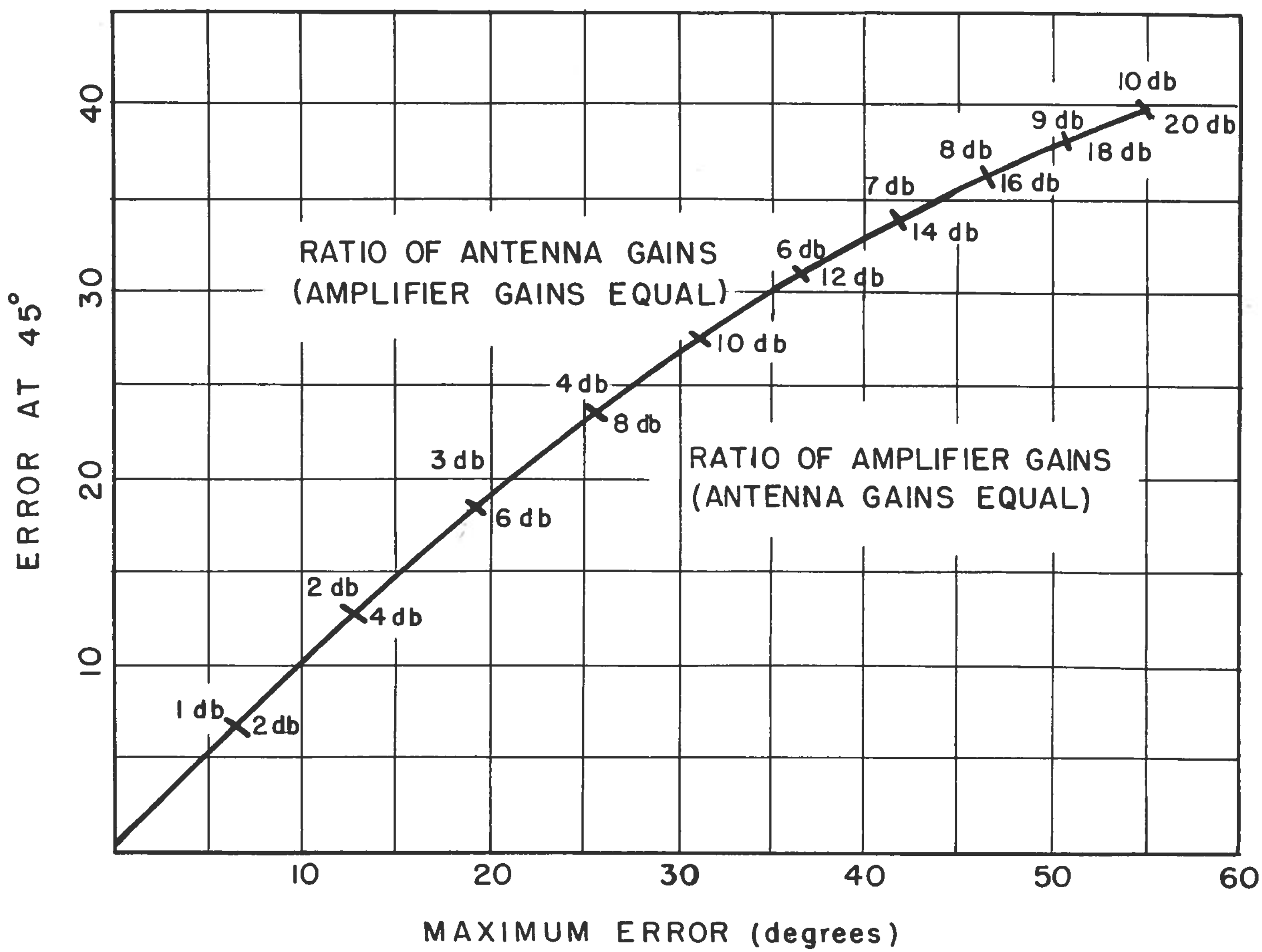

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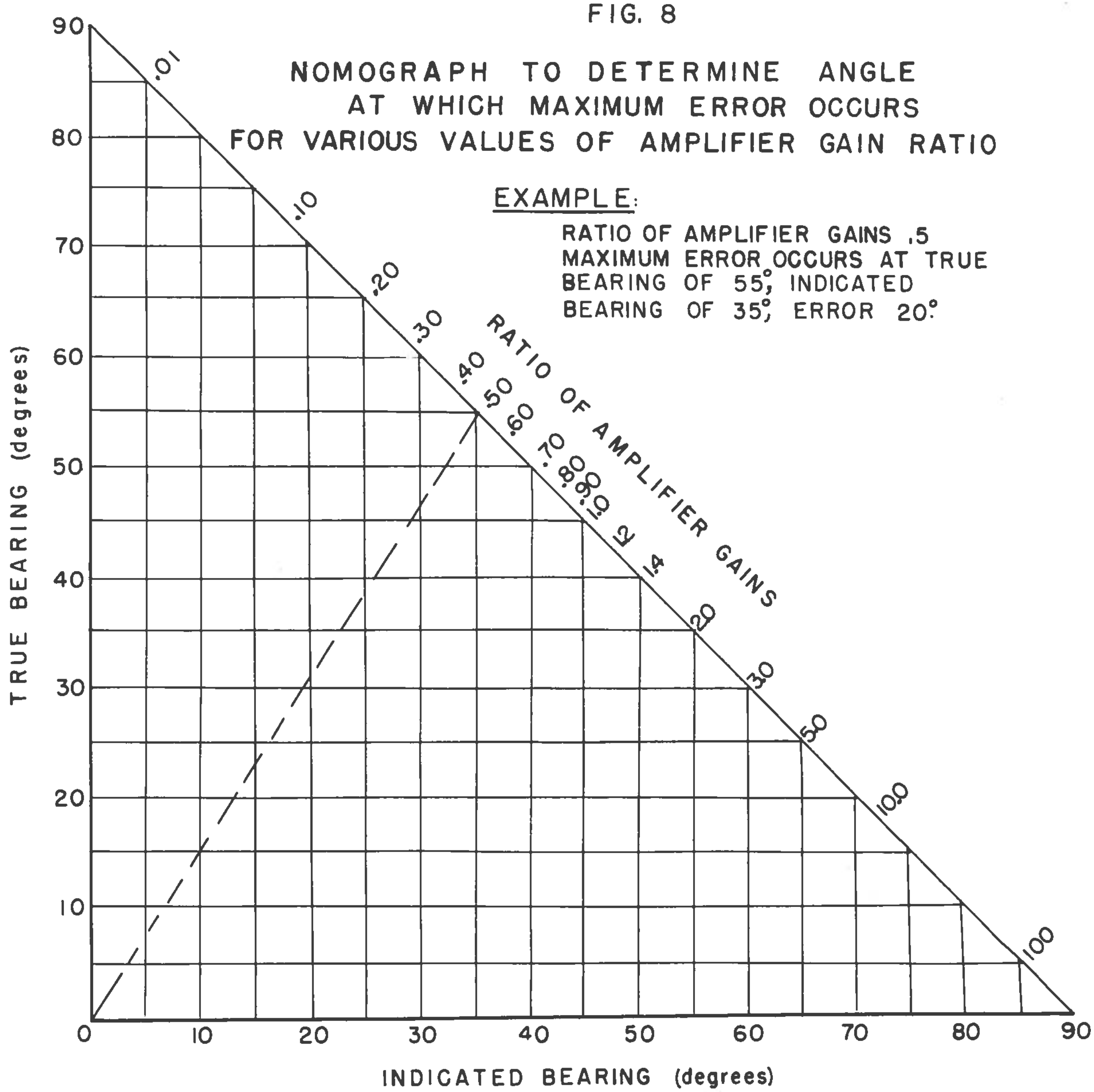
FIG. 8

NOMOGRAPH TO DETERMINE ANGLE AT WHICH MAXIMUM ERROR OCCURS FOR VARIOUS VALUES OF AMPLIFIER GAIN RATIO



EXAMPLE:

RATIO OF AMPLIFIER GAINS .5
MAXIMUM ERROR OCCURS AT TRUE BEARING OF 55°, INDICATED BEARING OF 35°, ERROR 20°

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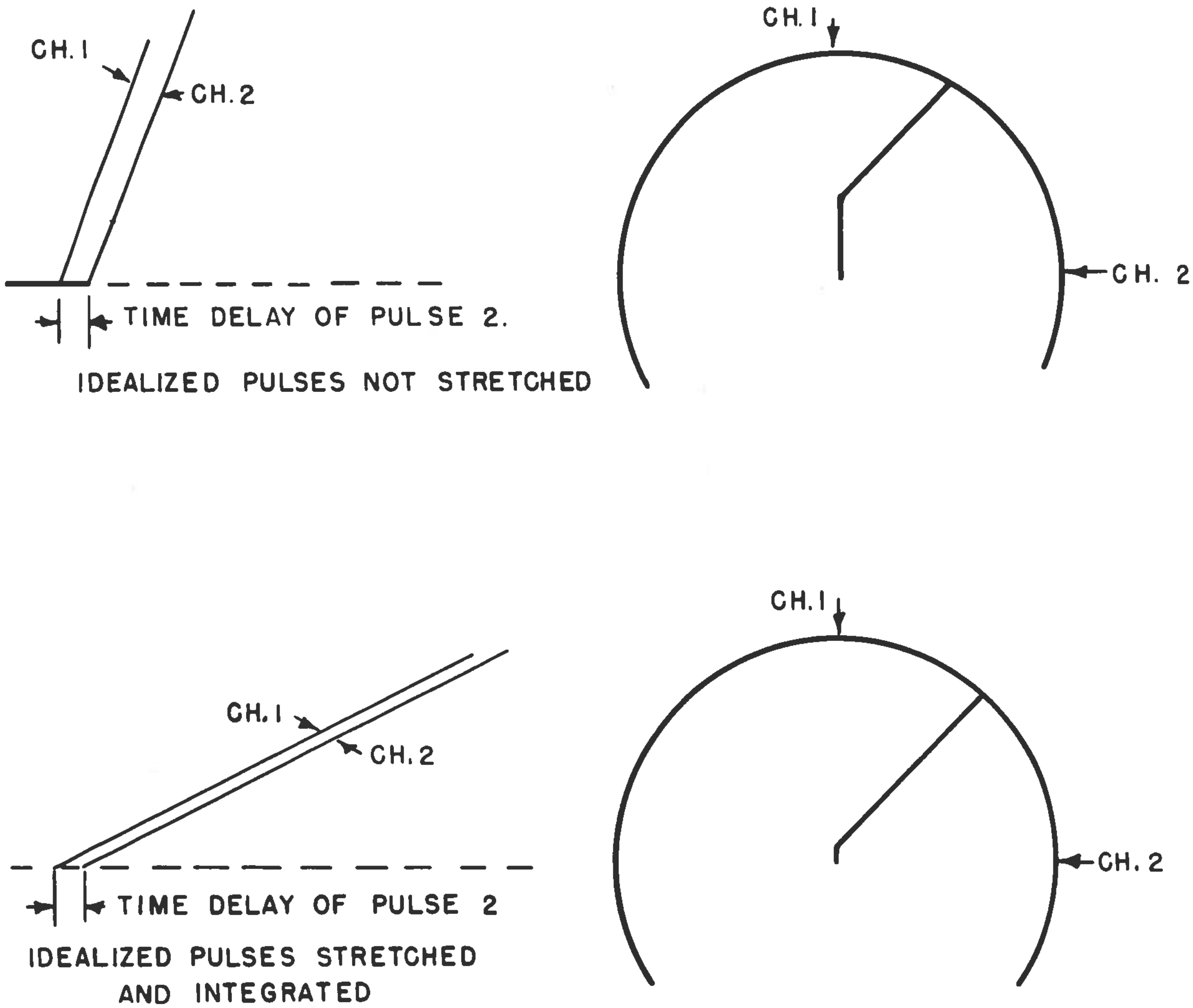
FIG. 9

EFFECT OF TIME DELAY ON BEARING ACCURACY



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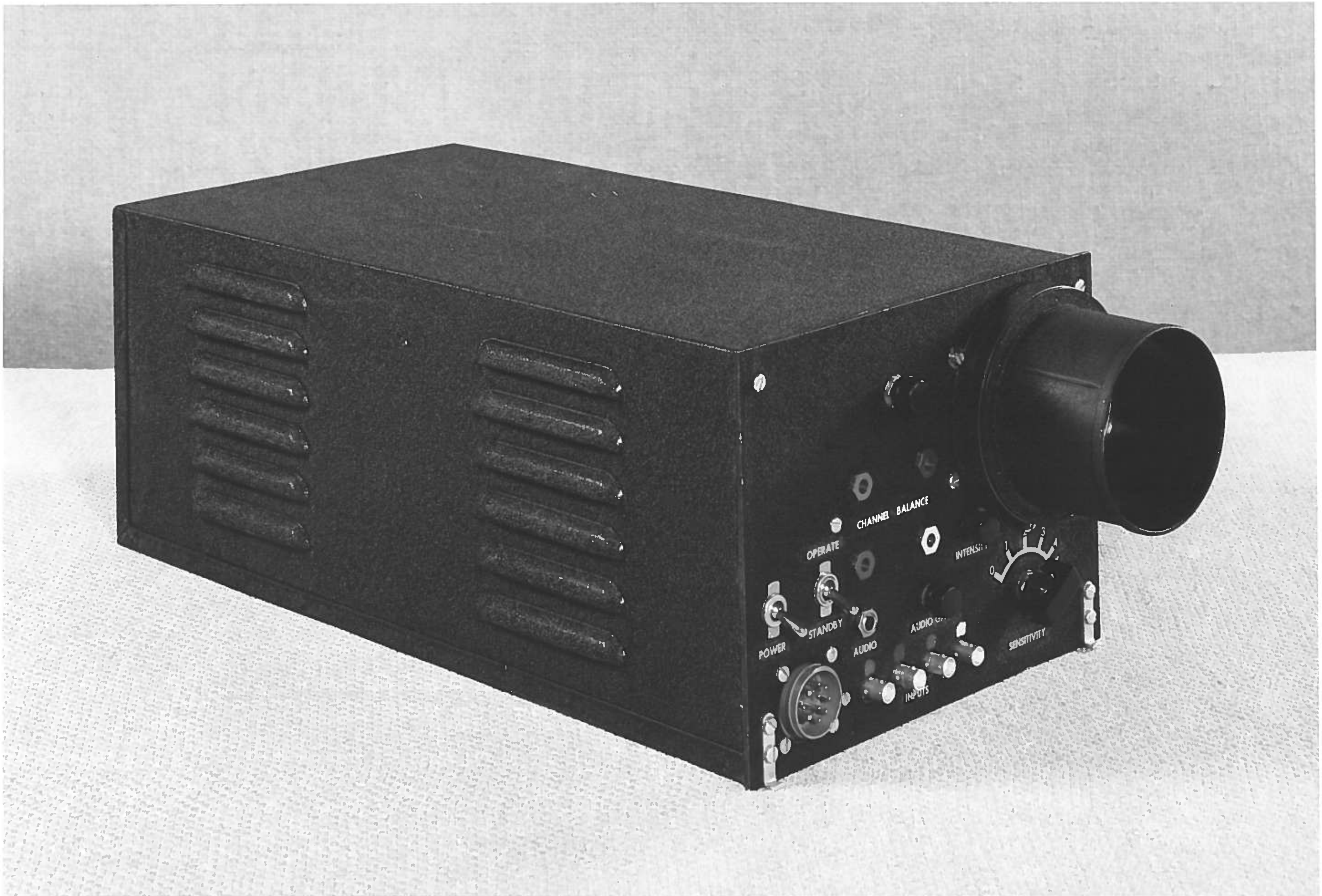

PHOTO 1
NR20 RECEIVER
SHOWING FRONT PANEL AND VISOR

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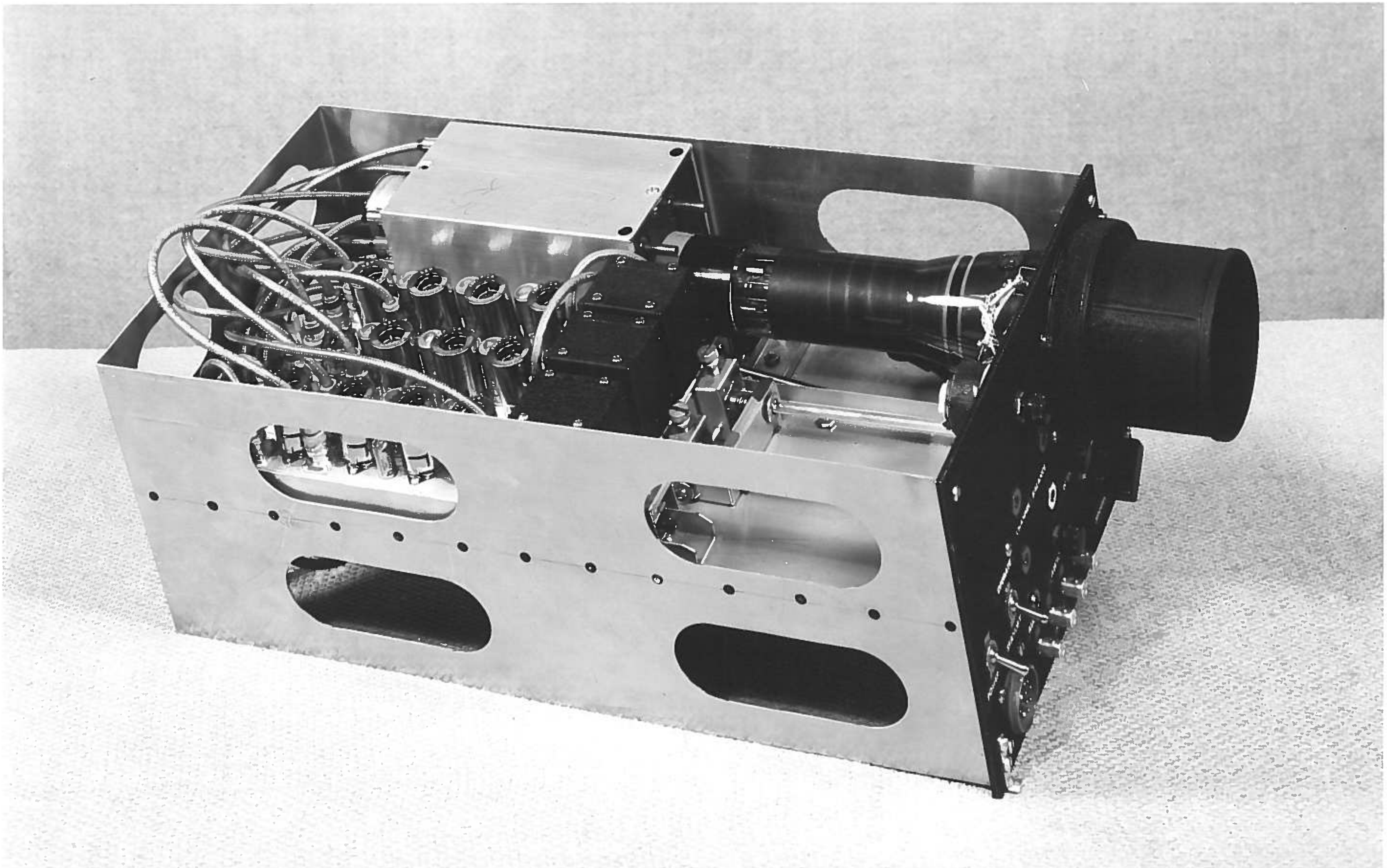

PHOTO 2
NR20 RECEIVER — CASE REMOVED — TOP VIEW
SHOWING CATHODE-RAY TUBE, H.V. POWER SUPPLY,
TWO VIDEO CHANNELS AND MIXER CHANNEL

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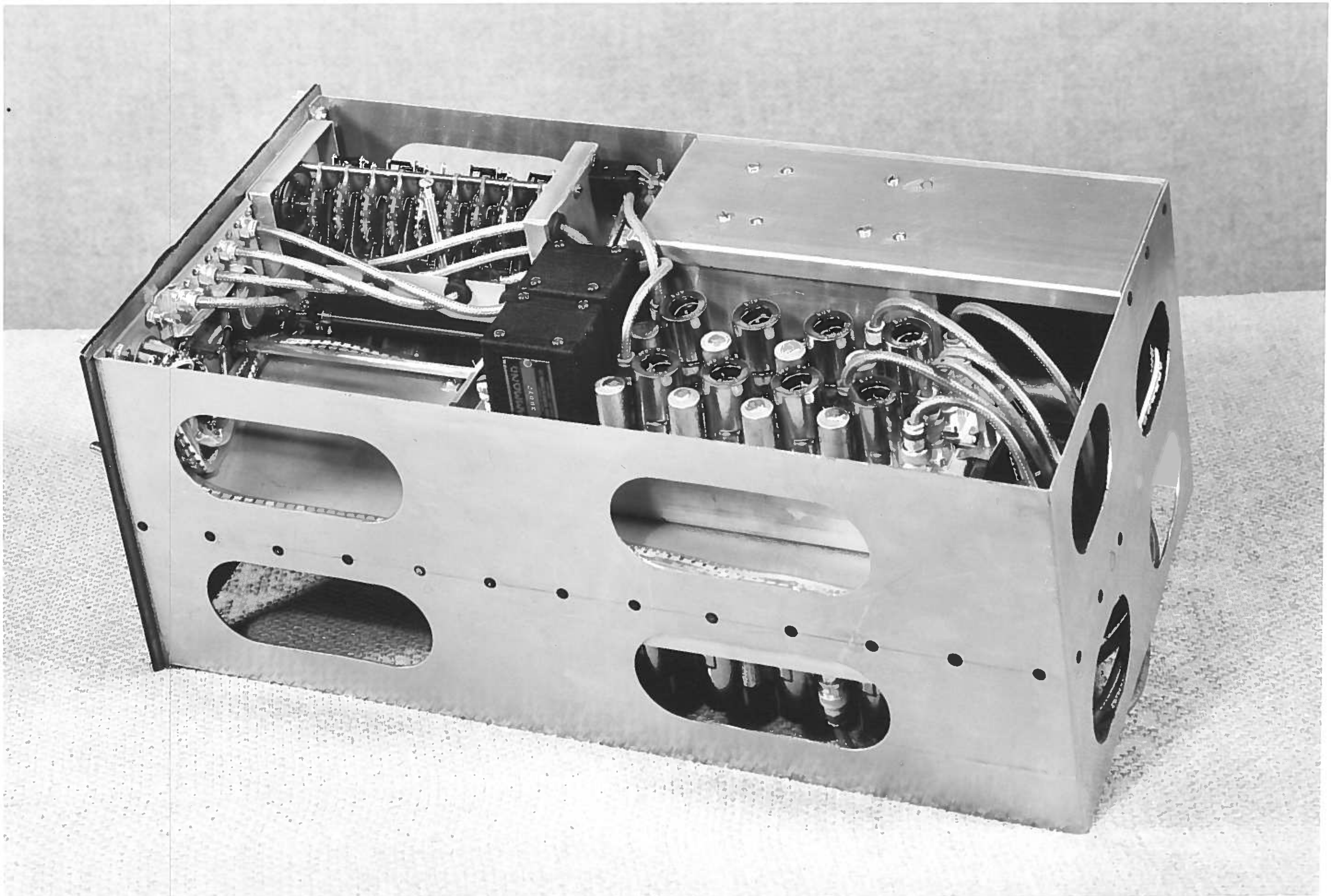

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PHOTO 3
NR20 RECEIVER — CASE REMOVED — BOTTOM VIEW
SHOWING ATTENUATOR UNIT AND TWO VIDEO CHANNELS

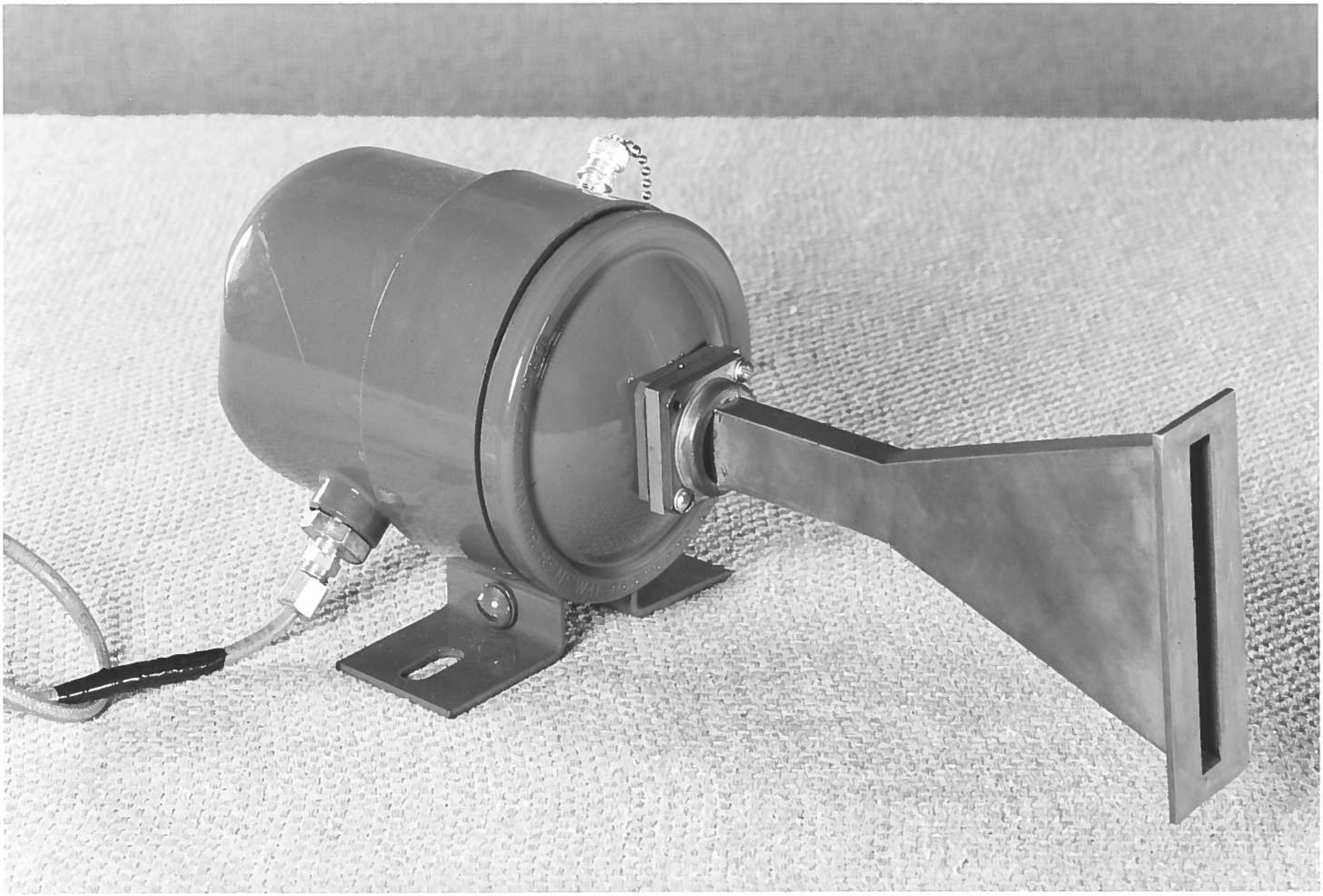

PHOTO 4
ASSEMBLED HORN AND CRYSTAL MOUNT

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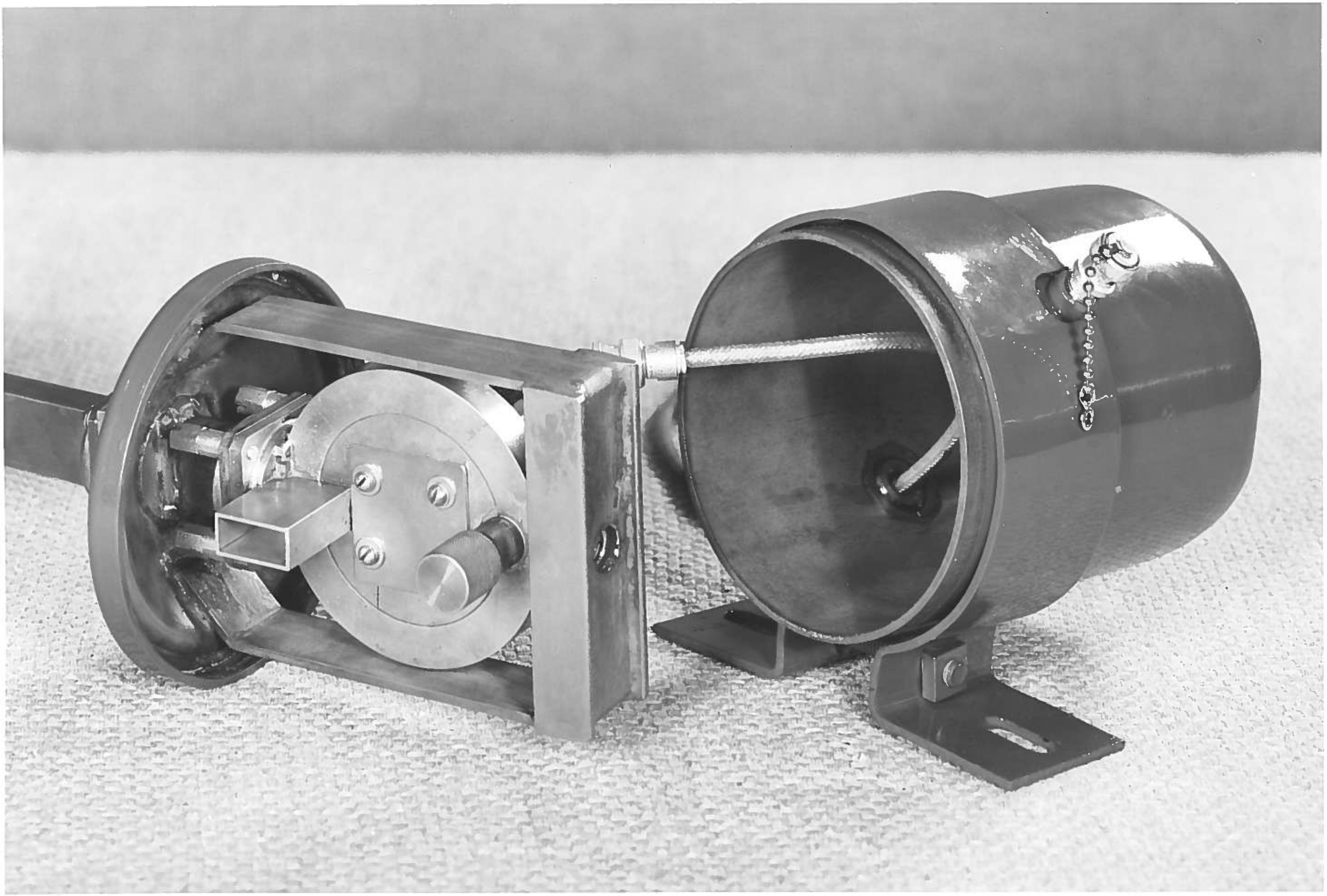

PHOTO 5
CRYSTAL MOUNT–WEATHERPROOF COVER REMOVED
SHOWING MAGIC T JUNCTION

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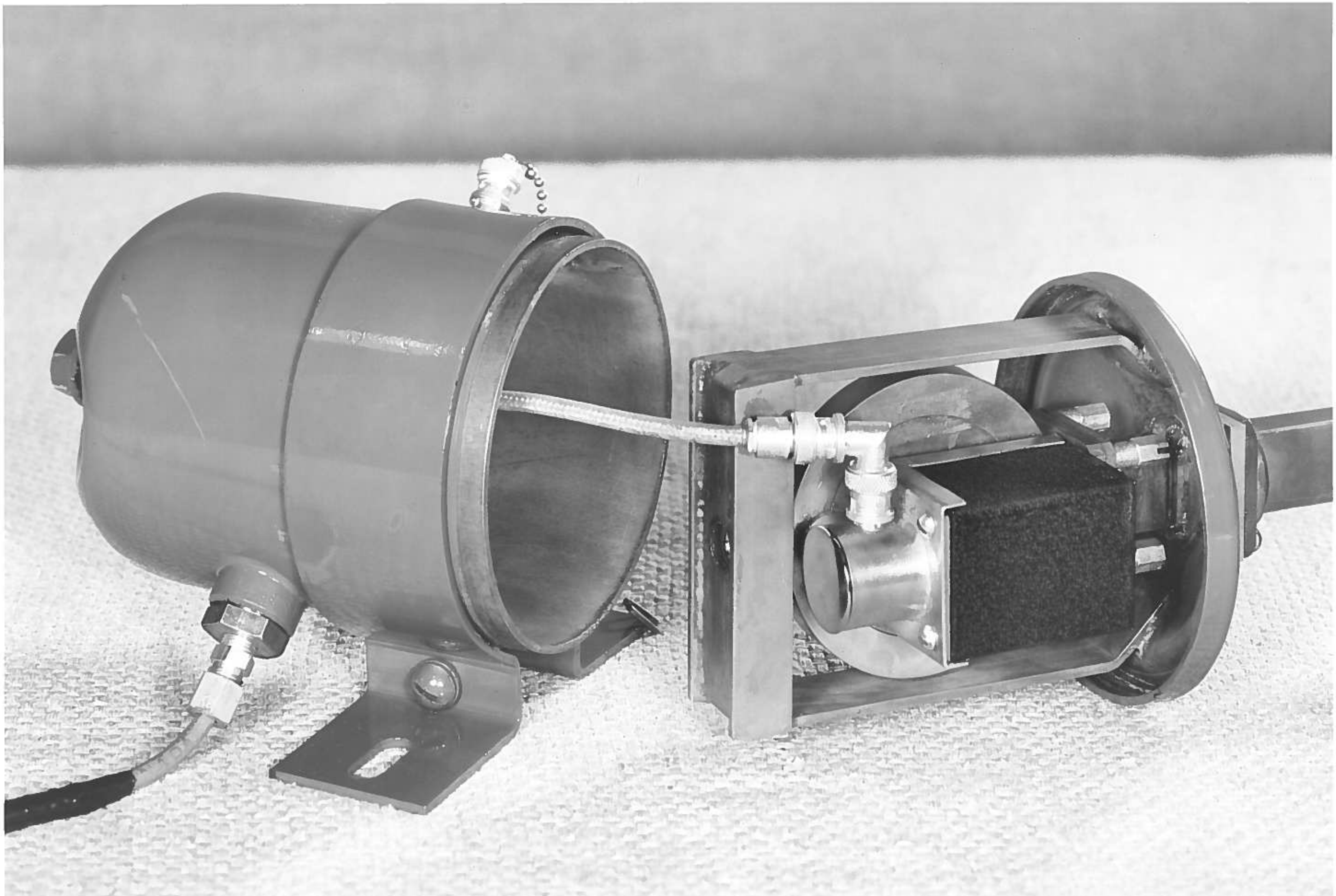

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PHOTO 6
CRYSTAL MOUNT – COVER REMOVED
SHOWING OUTPUT TRANSFORMER

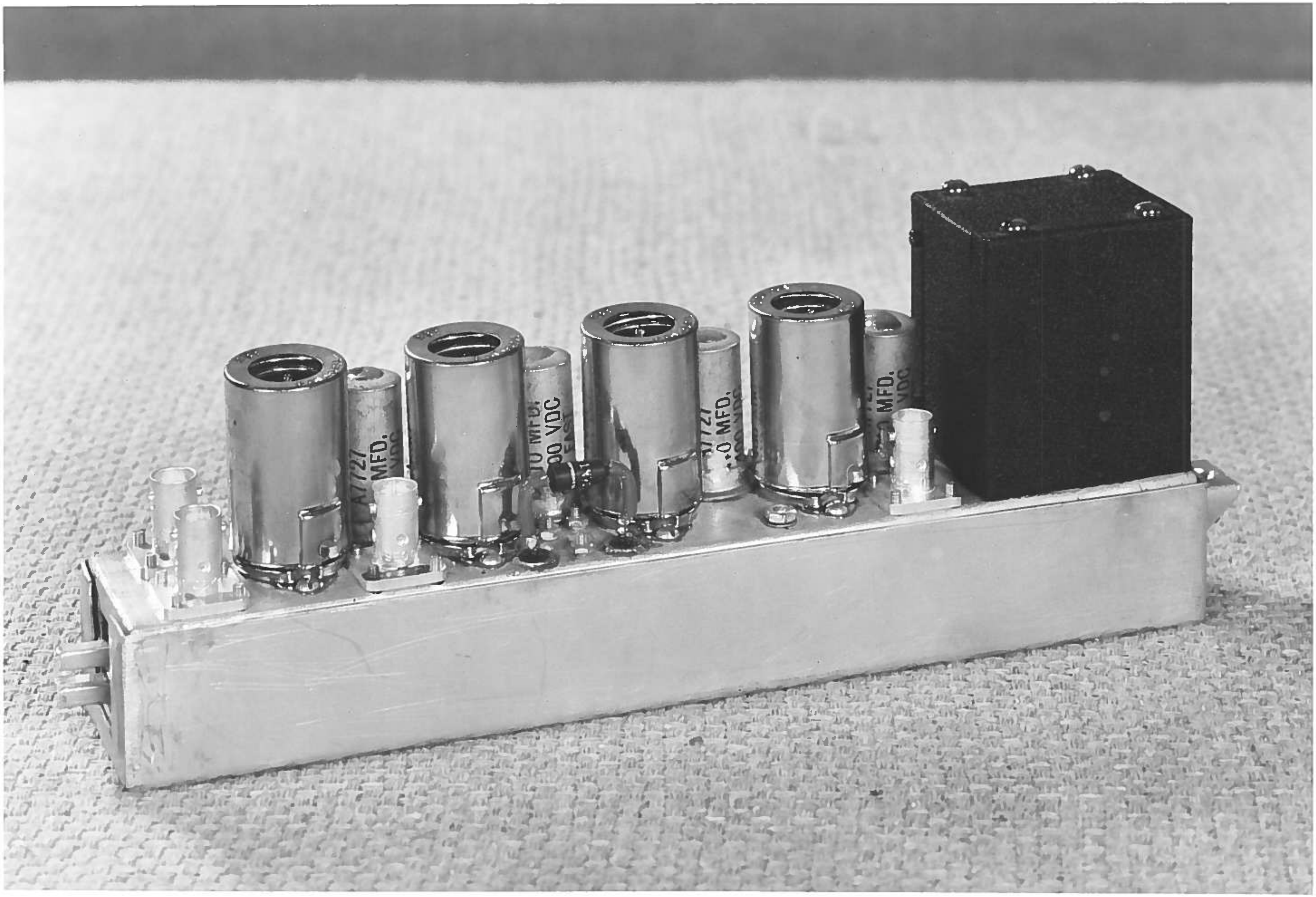

PHOTO 7

VIDEO AMPLIFIER CHASSIS

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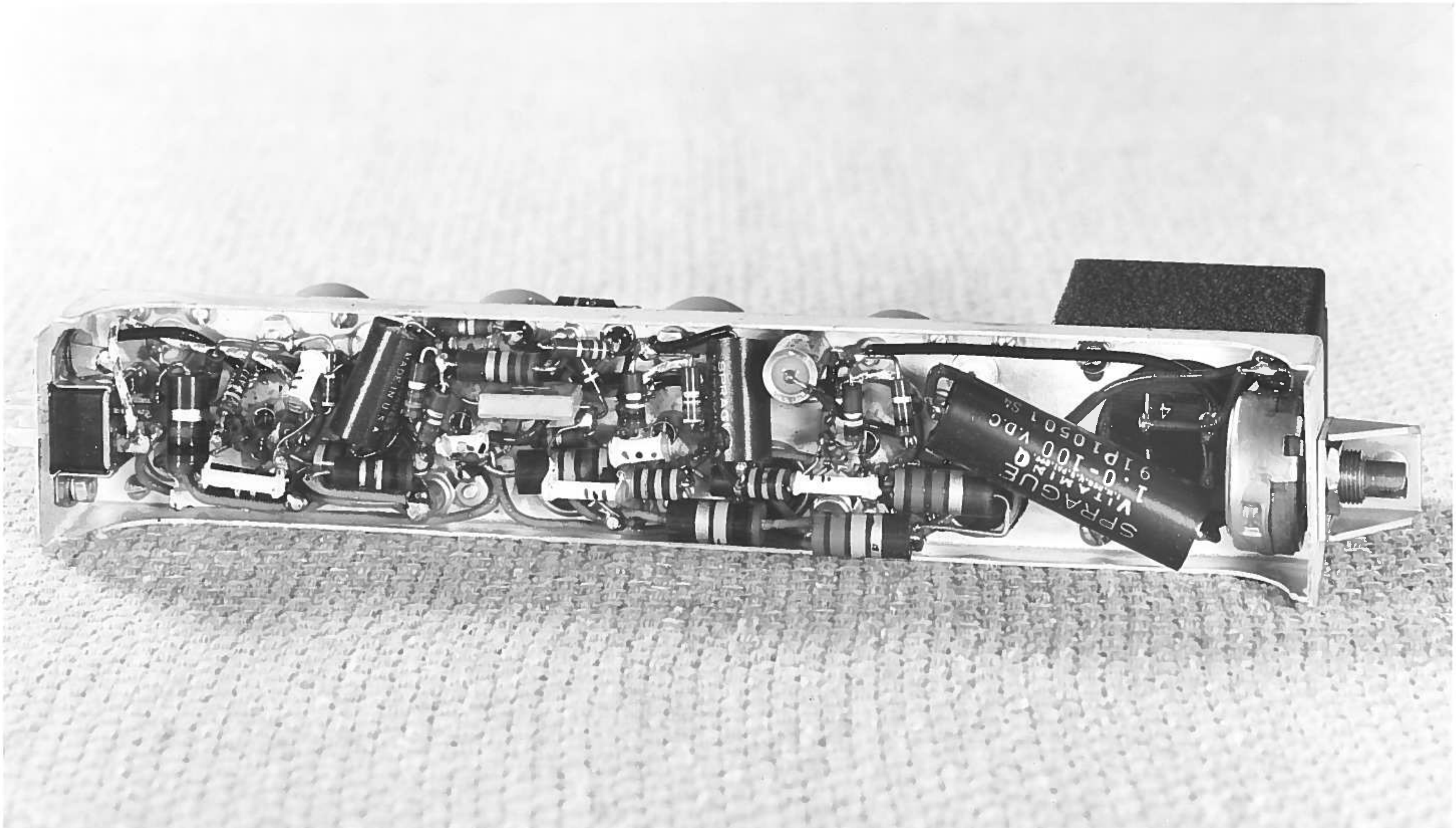

PHOTO 8
VIDEO AMPLIFIER CHASSIS
BOTTOM VIEW

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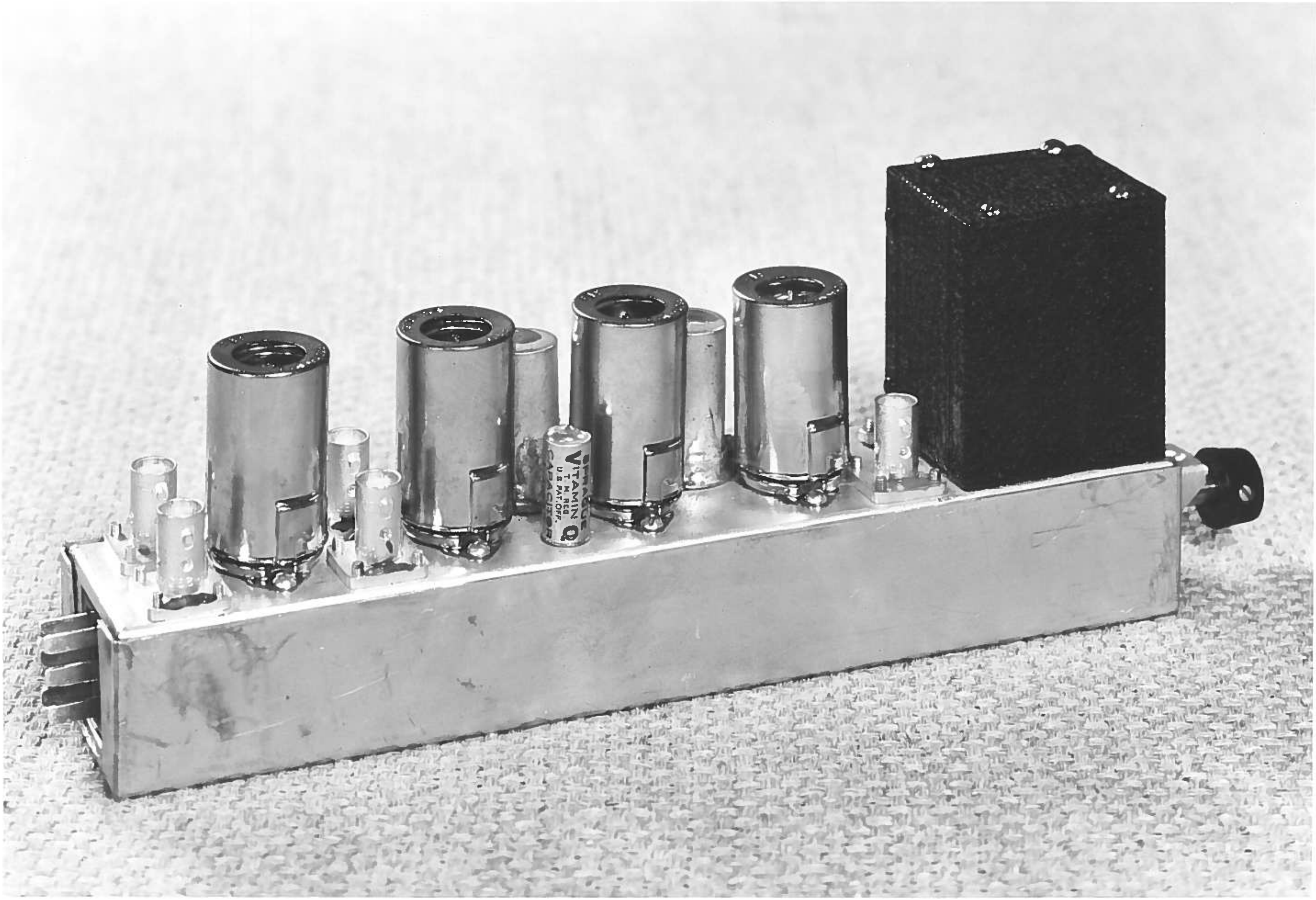

PHOTO 9
MIXER AND BRIGHTENING PULSE GENERATOR

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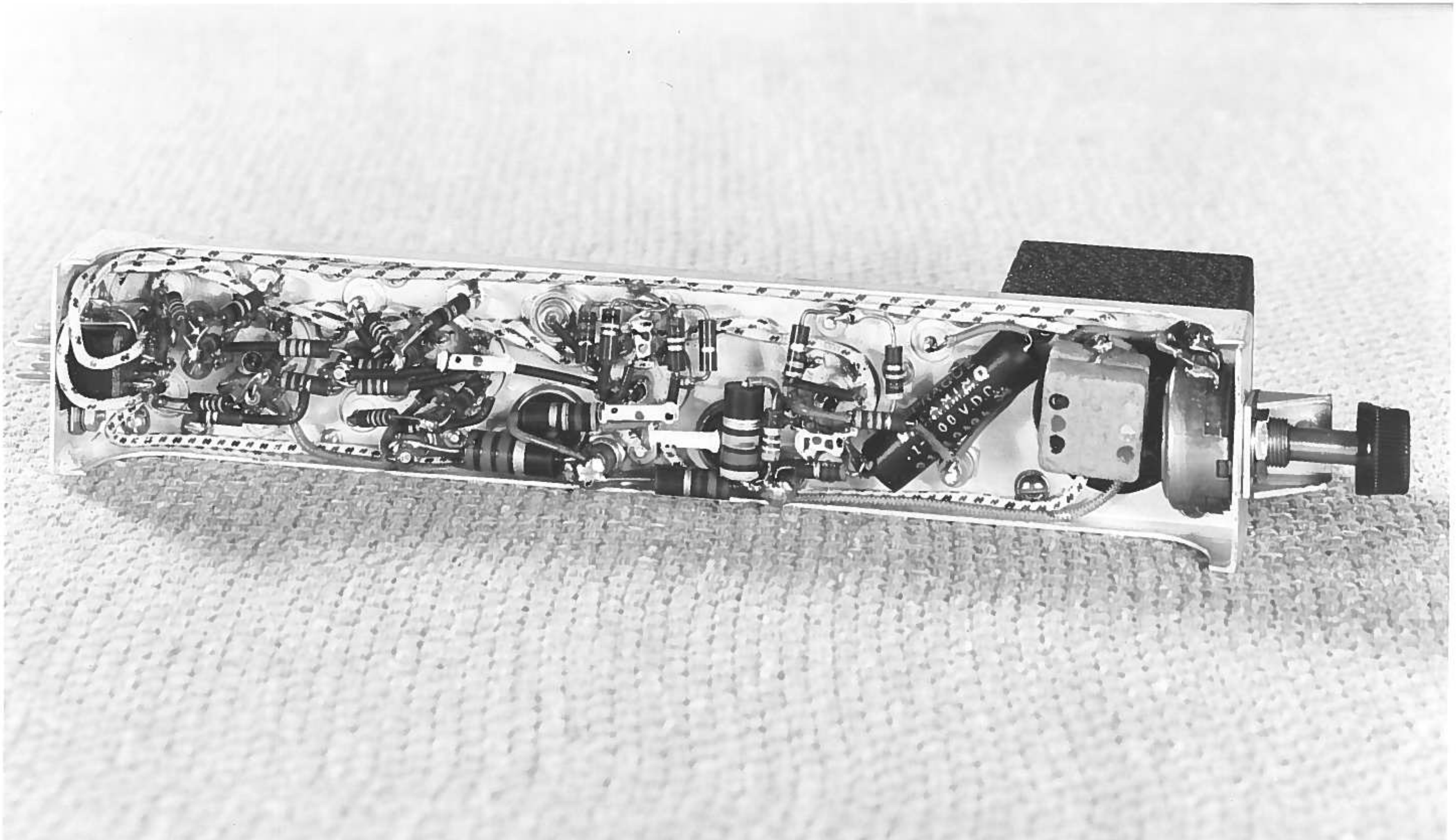

PHOTO 10
MIXER AND BRIGHTENING PULSE GENERATOR
BOTTOM VIEW-COVER REMOVED

SECRET

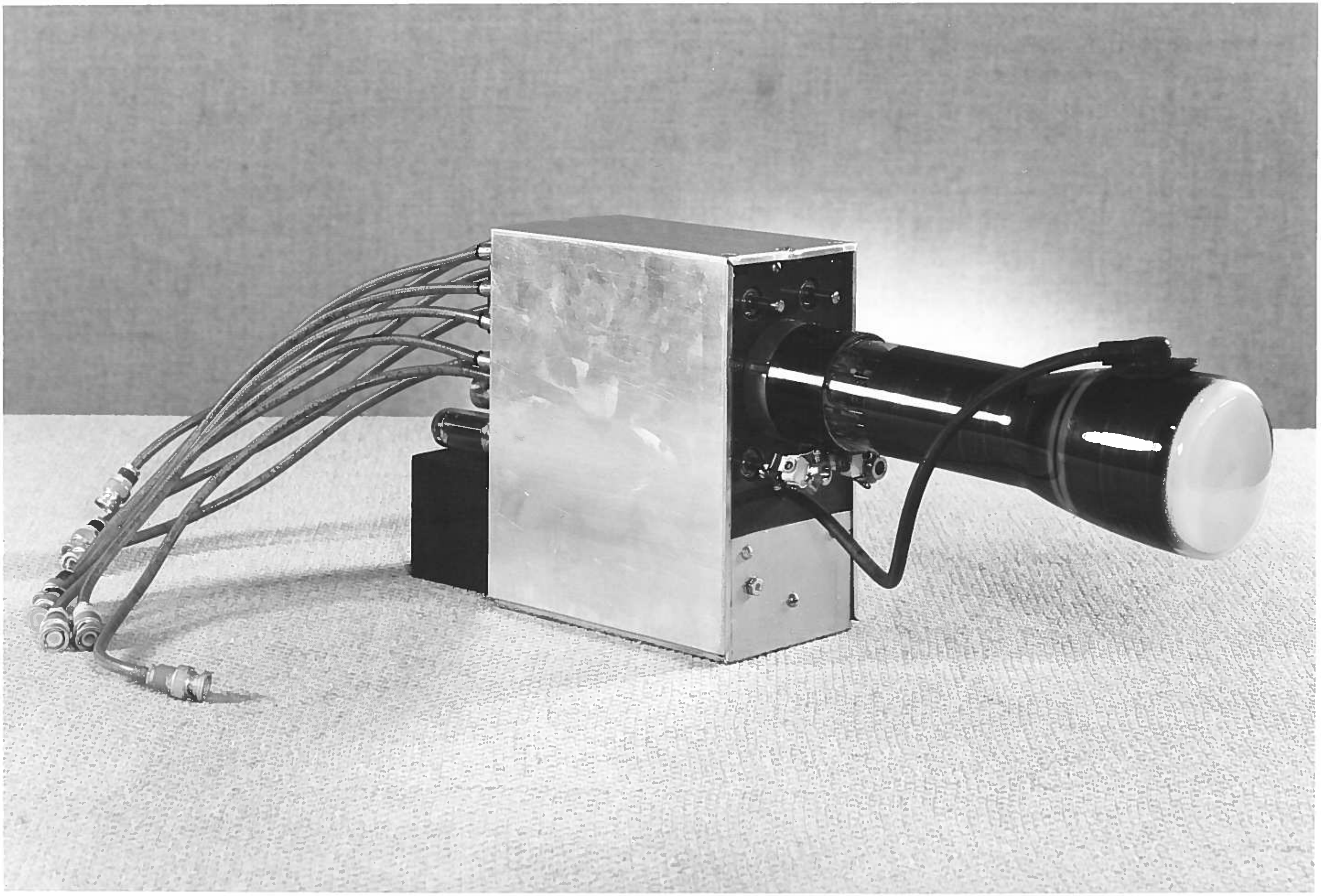

PHOTO II
H.V. POWER SUPPLY AND CATHODE-RAY TUBE

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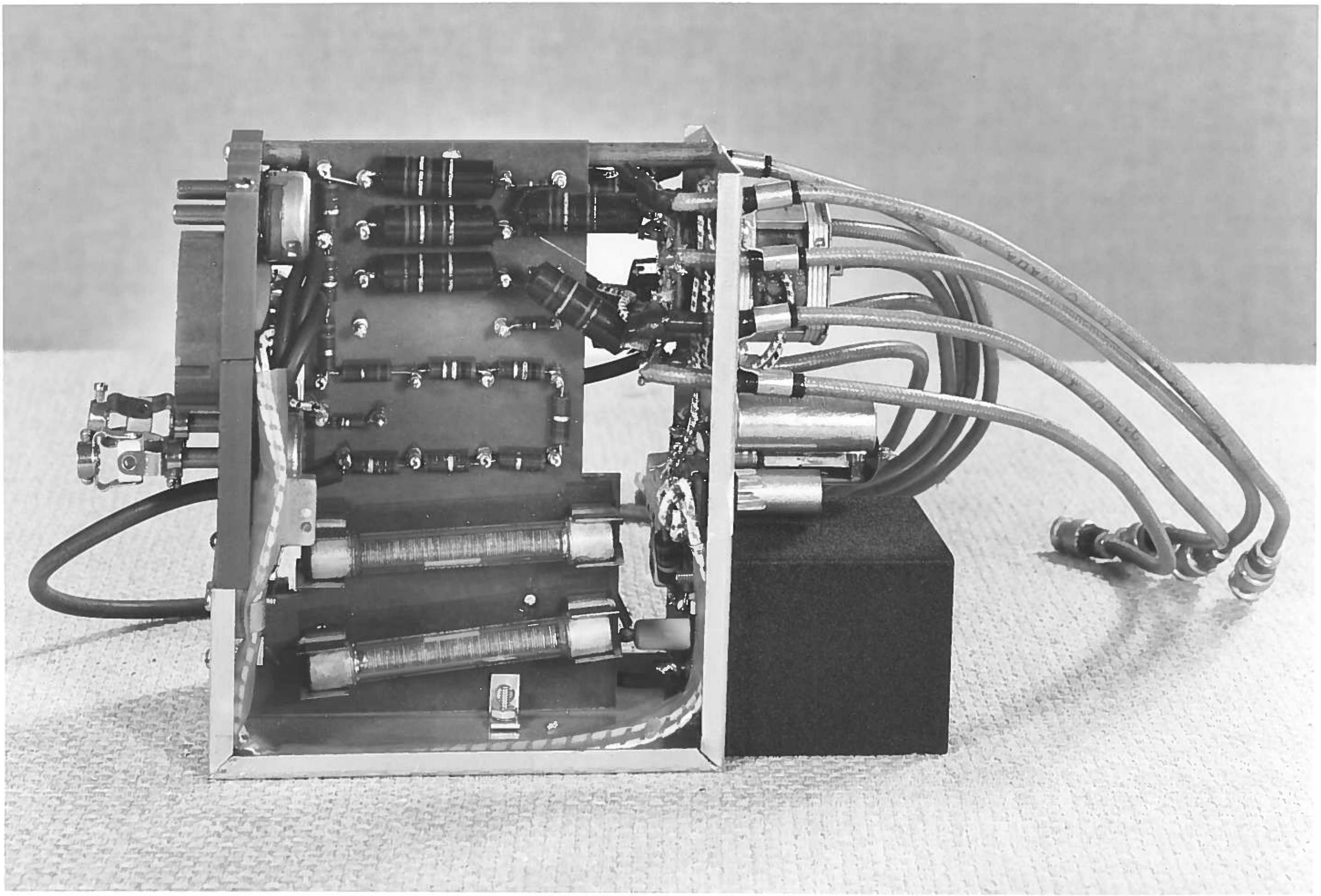

PHOTO 12
INTERNAL VIEW OF H.V. POWER SUPPLY
SHOWING SELENIUM RECTIFIERS

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PHOTO 13
LOW VOLTAGE POWER SUPPLY

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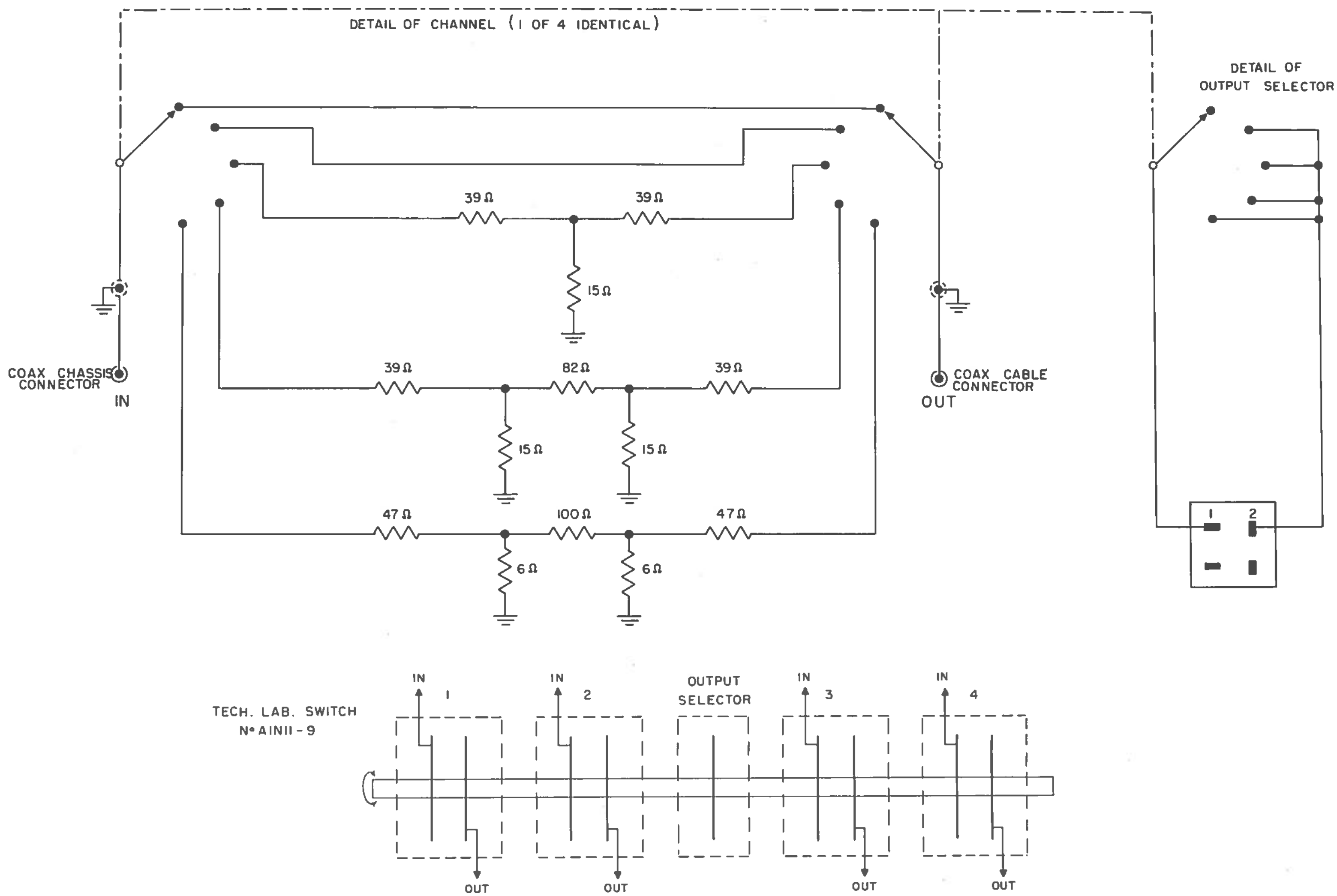

NOTE:
All resistors $\frac{1}{2}$w 5%

SCHEMATIC DIAGRAM N° 1
ATTENUATOR

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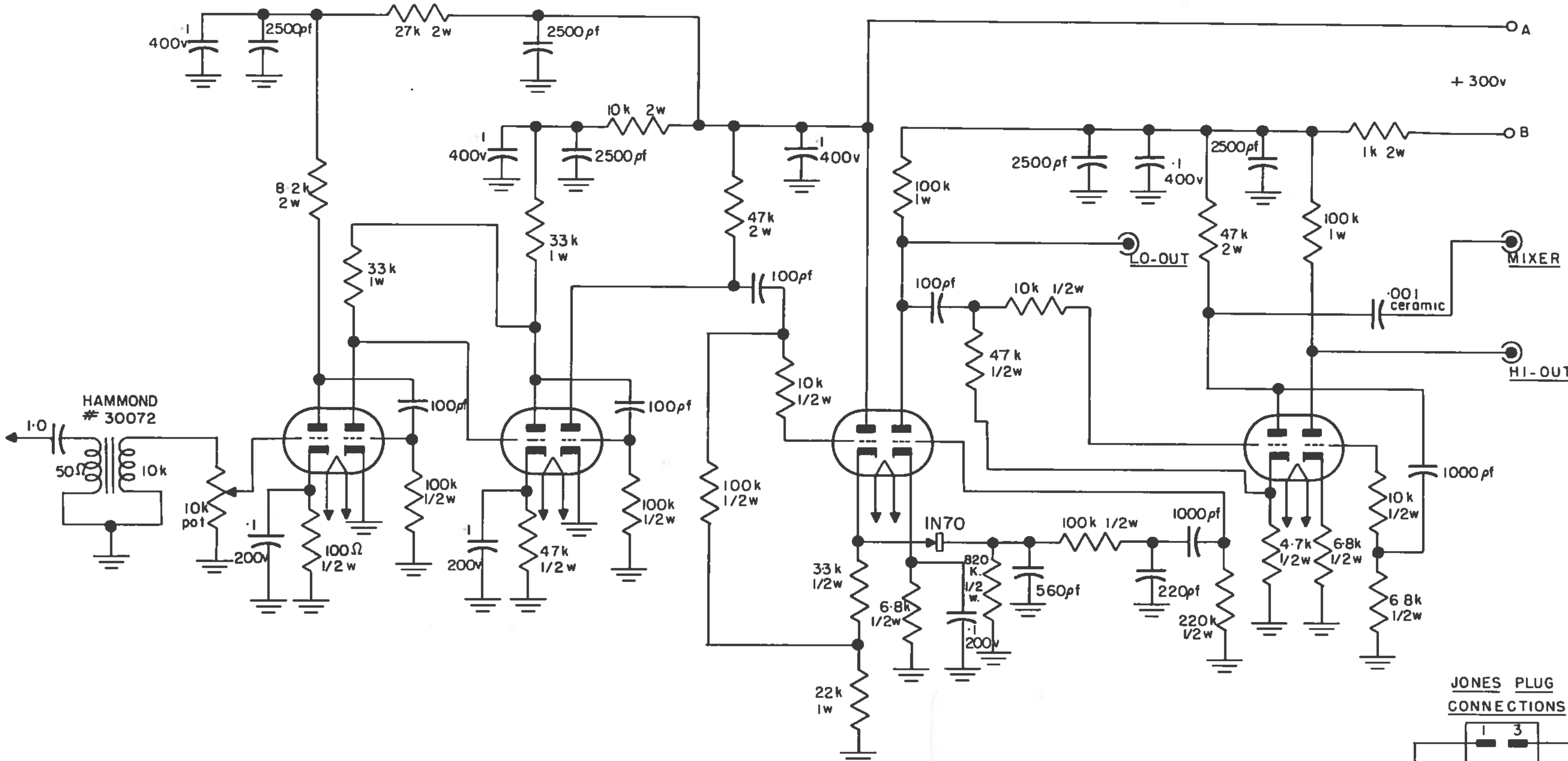

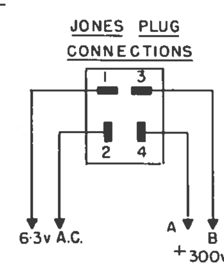

NOTE: 1. ALL CONDENSERS IN M.F.Ds UNLESS OTHERWISE INDICATED

2. ALL TUBES ARE 2C51 OR 5670

3. THE 5 2500PF CONDENSERS MAY BE REPLACED BY INSULATING STAND-OFFS.

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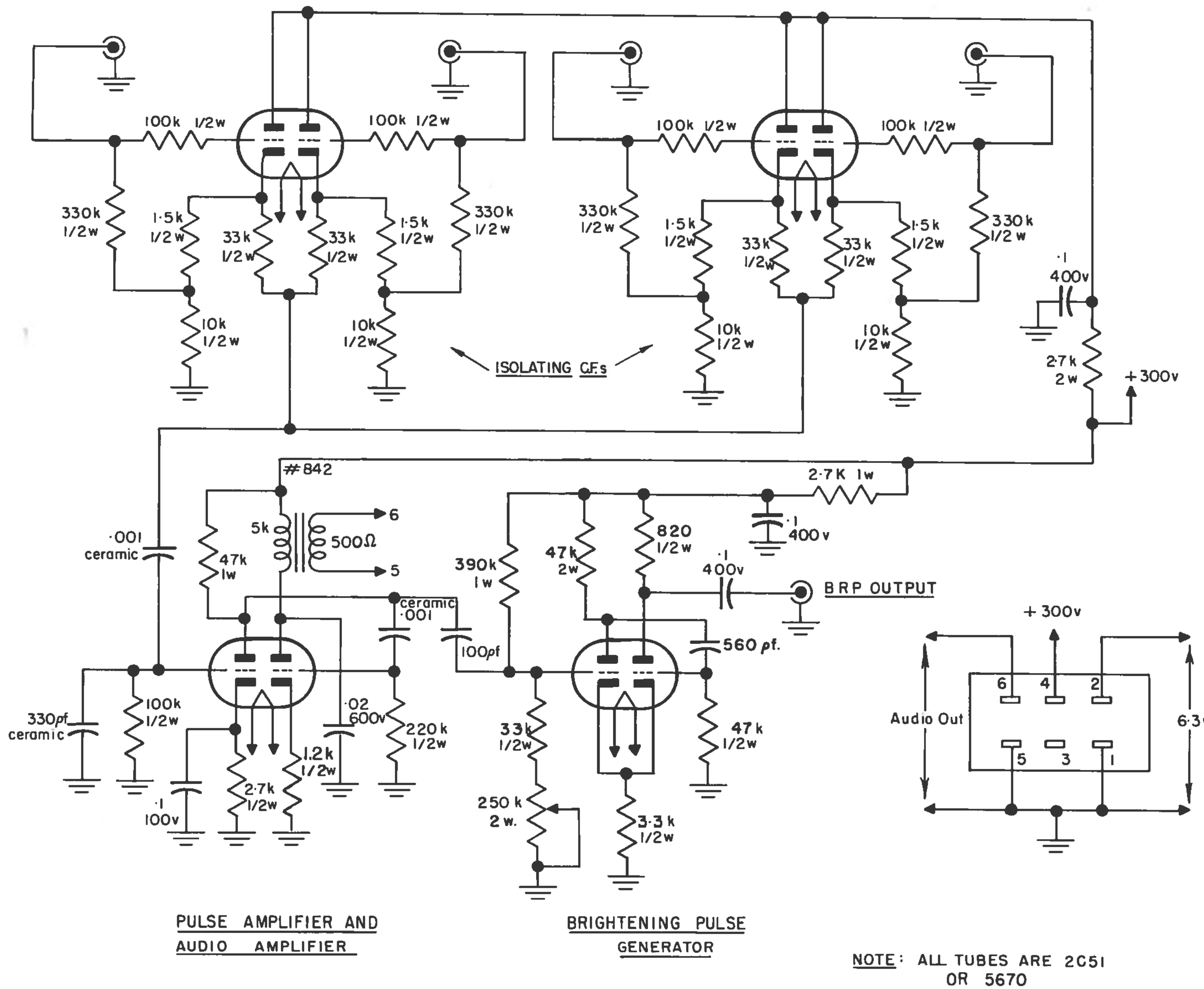
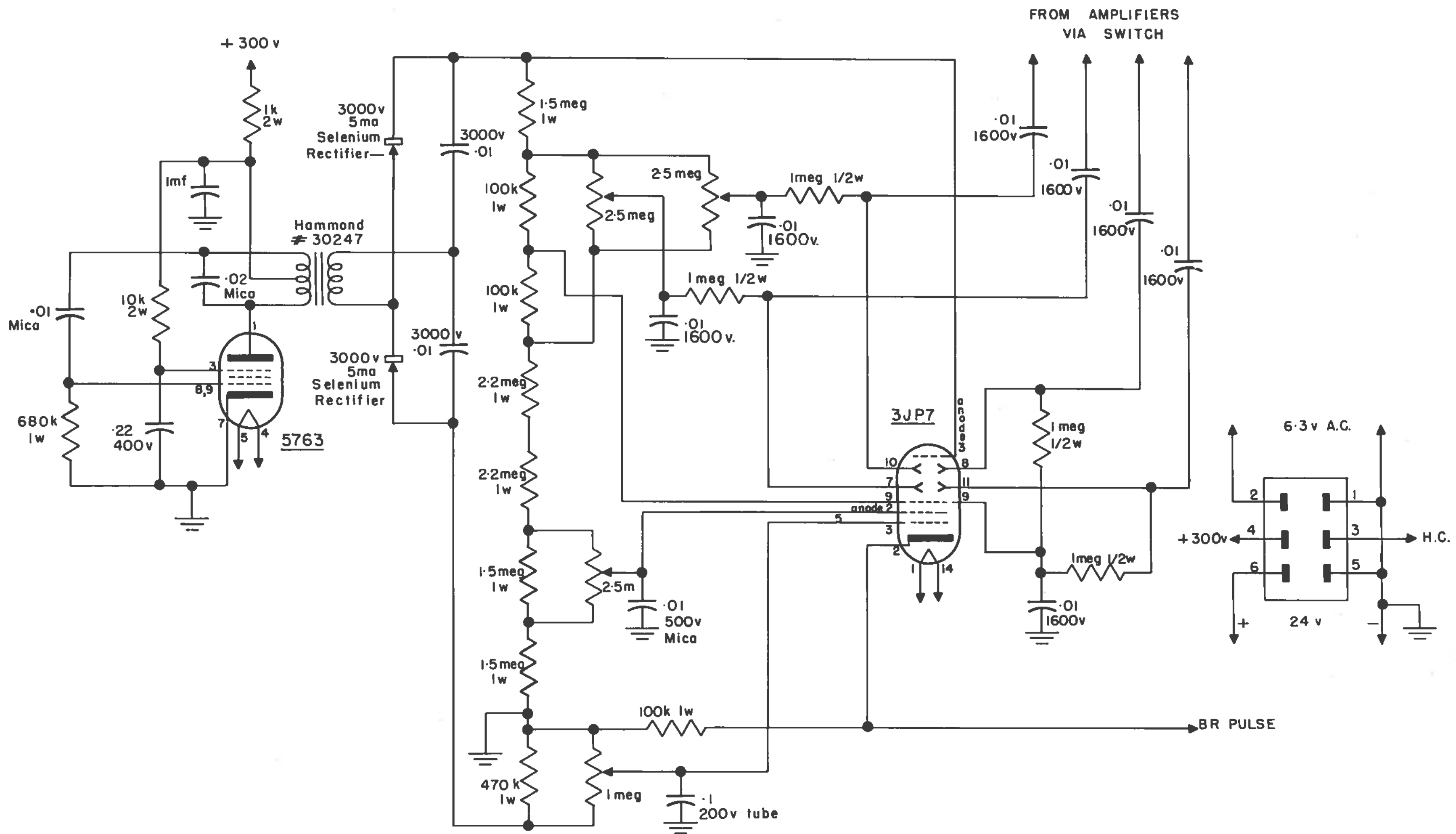
SCHEMATIC DIAGRAM N° 2
VIDEO AMPLIFIER



SCHEMATIC DIAGRAM N° 3
MIXER AND BRIGHTENING PULSE GENERATOR

SECRET



SCHEMATIC DIAGRAM N° 4
CRT POWER SUPPLY

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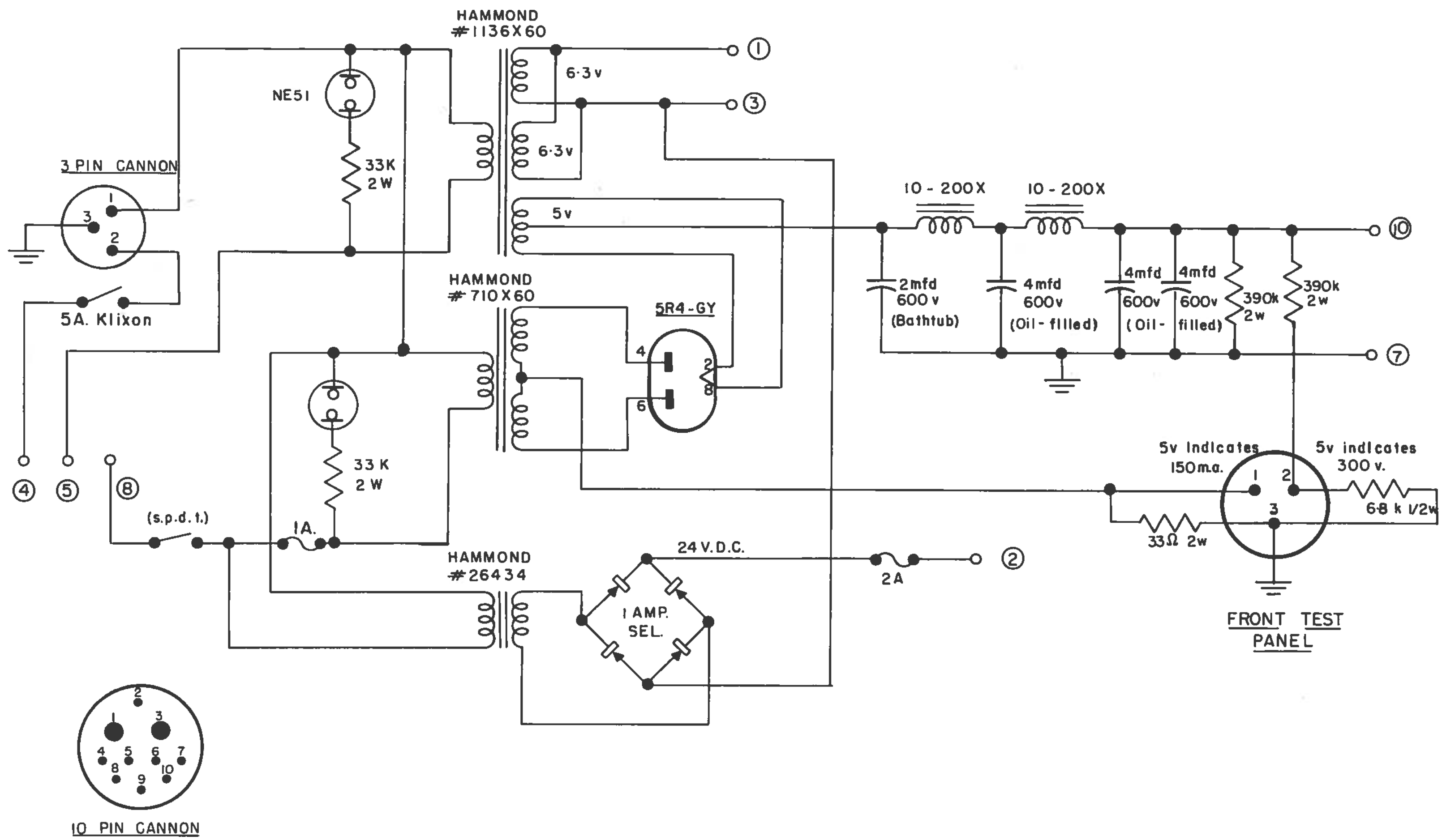

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SCHEMATIC DIAGRAM N° 5
300-VOLT POWER SUPPLY