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A PERCENTAGE MODULATION INDICATOR

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by

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SUMMARY

This report describes the development and testing of an instrument for measuring percentage of modulation of radio communication and air navigation facilities while such facilities are in normal operation. The precision of measurements is well within the tolerances specified in the Civil Aeronautics Administration Office of Air Navigation Facilities Manual of Operations The procedures used in calibrating the instrument, using commercially available test equipment, are described

It is concluded that with the percentage modulation indicator, an oscilloscope, and an a-c vacuum tube voltmeter, modulation levels of VOR, and localizer and communication facilities can be accurately measured at the ground stations, at remote locations on the ground, or in flight.

INTRODUCTION

A major problem in the operation and maintenance of Civil Aeronautics Administration (CAA) radio navigation and communication facilities is the accurate measurement of the percentage of amplitude modulation without interrupting the normal operations of these facilities The Manual of Operations of the Office of Air Navigation Facilities (OANF) requires that modulation percentages be set to definite levels and maintained within certain close tolerances. Typical modulation levels specified in the Manual of Operations are listed in Table I

TABLE I

Equipment		Modulation Level (per cent)
VOR	Reference signal	28 to 30
	Variable signal	28 to 30
	1020 cps*	6 to 10
	Voice communications (peaks)	26 to 30
Localizer— (on-course)	90 cps	18 to 22
	150 cps	18 to 22
	1020 cps voice and tone	4 to 6
	Voice communications (peaks)	40 to 55
Radio Communications (peaks)		90 to 95

* cycles per second

The method presently in use for measuring these percentages of modulation requires the removal of the facility from normal operation. In order to reduce the number of these "outages," the OANF requested the Technical Development Center (TDC) to develop an instrument by means of which accurate measurements of the percentage of modulation could be made without interrupting the normal operation of the facility. The instrument must be capable of selecting a specific radio frequency (r-f) channel within the very-high-frequency (VHF) band 108 to 136 Mc and have sufficient sensitivity for the measurement of modulation levels of r-f signals received from facilities located within a 3-mile radius. Also, it must be capable of operating in strong r-f fields such as those encountered within transmitter buildings. This report describes such an instrument which operates in conjunction with a cathode ray oscilloscope (CRO) and/or a-c vacuum tube voltmeter (VTVM).

PRINCIPLES OF OPERATION

The equipment described in this report can be used for the measurement of modulation percentages by either of two well-known methods. The first is called the trapezoidal method because a geometric shape of a trapezoid is displayed on an oscilloscope. To determine the percentage modulation by this method, the modulated carrier wave is applied to the vertical plates of an oscilloscope, and the modulating voltage wave is applied to the horizontal plates of the oscilloscope, resulting in a trapezoidal pattern. See Fig. 1A Modulation percentage is then calculated from the formula

$$\text{Per cent Modulation} \qquad \frac{A - B}{A - B} \times 100,$$

where the dimensions A and B are proportional to the crest and trough amplitudes of the modulated carrier wave, respectively.[1] This method is particularly suitable for measurements of short bursts of modulation where meter response would be too slow for accurate indications. It is possible in such cases to form a mental image of the trapezoidal pattern and determine the percentage modulation very closely. This method also is desirable for the determination of the combined peak modulation percentage when more than one audio frequency is impressed simultaneously on a single carrier.

The second method is termed the a-c/d-c method. This name is derived from the fact that direct current is established as a reference of r-f level and the level of the demodulated a-c voltage is related to percentage modulation as indicated, in Fig. 1B. This method has an advantage in that percentage of modulation is derived from the readings of precision instruments and is not materially affected by noise signals. However, this method is valid only for audio wave shapes possessing a symmetry such

[1] Radio Amateurs Handbook, Chapter 10, 1957 Edition.

that the positive half-cycle time integral is equal to the negative half-cycle time integral, impressed on the carrier by linear modulating circuits. If these conditions are not met, some inaccuracy may result.

DESCRIPTION

A block diagram of the percentage modulation indicator is shown in Fig. 2. The accessories to the basic measuring equipment are shown in dotted lines. An r-f tuner provides continuous tuning through the 108- to 135-Mc band. The 3.15-Mc intermediate frequency (i-f) derived from the tuner is amplified and divided into two branch circuits. Part of the signal is fed to a demodulator and part to a 45-kc converter. The output of the 45-kc converter is applied to the vertical amplifier of an oscilloscope. The d-c portion of the demodulated signal is metered for a tuning indication and to establish a reference for the r-f amplitude in the a-c/d-c method of determining percentage of modulation The audio signal from the demodulator may be switched to selective filters as desired. After appropriate filtering, the signal is applied to the horizontal amplifier of the oscilloscope and to a VTVM. Figure 3 is a photograph of the instrument with associated transistorized power supply The interior of the unit is displayed in Fig. 4. Figure 5 is a schematic wiring diagram of the basic instrument.

Tuner and Frequency Converter

The r-f tuner and frequency converter unit of an Aircraft Radio Corp. Type 15D VHF navigation receiver were selected for use in this instrument. It was modified to provide a manual r-f gain control, which is inserted in the cathode circuits of the two r-f stages, which controls the bias of the tubes. The sensitivity of the instrument is shown in Fig. 6, Curve A The oscillator frequency was changed to provide a 3 15-Mc i-f. A resistance-capacitor (r-c) amplifier stage following the mixer circuit feeds a 3.15-Mc i-f amplifier. The secondary of the i-f transformer is shunted with a 22K resistor to extend the width of the reponse curve. The bandwidth is 60 kc at the 3-db level and 510 kc at the 60-db level. The converter consists of a Pierce-type crystal oscillator operating at a frequency of 3105-kc and link-coupled to a pentagrid mixer stage The 3.15-Mc intermediate and the 3105-kc local oscillator frequencies are converted to a 45-kc signal. The 45-kc conversion was selected in order to be within the linear operating frequency range of most oscilloscopes Low-capacity cable was used to couple the output of the converter to the vertical amplifier of the oscilloscope.

Demodulator and Audio Circuits

A 1N75 crystal diode operating as a high-level detector is used for the demodulator. The linearity of the detector is illustrated in Fig. 7, which shows the input in microvolts versus detector current. The output of the detector is connected to a direct-coupled cathode follower which is coupled to a headphone amplifier and a filter-switching circuit The switching circuit is provided for selecting individual filters, the combination of VOR filters, or the combination of localizer filters. Low-pass and high-pass filters separate the 30- and 9960 cps VOR signals and a 1020-cps inductive filter is used to separate the identification signal from the composite modulated wave transmitted by VOR or localizer facilities. Tandem inductive filters separate the 90- and 150-cps localizer signals The outputs of both the localizer and VOR filters are fed to centering or balance controls. These controls permit compensation for the inequalities in insertion loss of the filters, and are set in the laboratory. These filters are located externally to the basic unit to eliminate magnetic coupling to the power transformer. The output of the filter switching circuit is connected to a direct-coupled cathode follower which feeds the audio signals to the oscilloscope and VTVM

CALIBRATION

In order to prepare accurate curves of percentage modulation versus a-c voltage for the a-c/d-c method of measuring modulation, and to gauge the accuracy of the percentage modulation indicator, it was necessary to know the percentage of modulation of a test signal To accomplish this, a test setup as shown in Fig 8 was used. It consisted of two units of a Boonton Model 211-A signal generator (A and B) and r-f amplifier, an a-c voltmeter, d-c voltmeter, audio signal generator, detector, and wave analyzer. With both signal generators operating on crystal-controlled frequencies near 110 1 Mc, a beat frequency of approximately 2000 cps was obtained. Modulating the low-level 211-A signal generator A with 1000 cps from the audio signal generator resulted in a signal at the detector output containing a 2000-cps carrier, a 1000-cps lower sideband, and a 3000-cps upper sideband. The gain of the wave analyzer was adjusted so that it indicated 100 per cent of the 2000-cps carrier. The sum obtained by adding the percentage reading from the wave analyzer of the upper and lower sidebands represented the percentage modulation of the 211-A signal generator (A). A d-c voltmeter and an a-c voltmeter were connected permanently in parallel across the screen grid and ground of the 6AK5 output tube in the low-level 211-A signal generator (A) With the screen grid operating at 140 volts d-c, recording the a-c voltage for various percentages of modulation as measured by the wave analyzer provided data from which the 211-A signal generator (A) could be modulated to a known level. From these data the 211-A signal generator (A) could be modulated accurately from 0 to 100 per cent with any audio frequency to provide a test signal for calibrating the percentage modulation indicator.

Using this method to provide known percentage modulation inputs, and obtaining a-c voltage readings from the demodulated output of the modulation indicator, curves were drawn for a-c volts versus percentage modulation for VOR and localizer signals. These are shown in Figs 9 and 10 No appreciable change in the calibration curves was noted during a period of six months of bench testing

With this same signal input to an oscilloscope, to obtain a trapezoidal pattern, another curve of percentage modulation versus divisions of beam deflection was drawn, as shown in Fig. 11. With a 40-division deflection for the maximum, and reading the minimum deflection, the curve shows the percentage modulation It is important that the oscilloscope and VTVM used with this equipment be accurate and reliable in order to obtain precise measurements A Dumont Type 2559 oscilloscope and a Ballentine Type 643 VTVM were used for all tests described in this report An i-f filter is required at the input of the VTVM in order to reduce spurious r-f pickup The filter consisted of a series choke of 1.8 microhenry and a 100-micromicrofarad capacitor shunted across the VTVM input terminals.

ACCESSORIES

Antenna

Normally, a horizontal dipole, a Yagi, or a V-type antenna will provide satisfactory signal pickup when the equipment is operated at remote locations The antenna impedance should be suitable for operation into a 52-ohm transmission line.

Tunable R-F Amplifiers.

The need for additional r-f amplification was desirable in low signal areas. A second tuner of a Type-15D Aircraft Radio Corp. VHF navigation receiver was modified to provide manual r-f gain control. This was accomplished by varying the cathode bias of the two r-f amplifiers The oscillator tube and the mixer circuit were converted to a cathode follower, as shown in Fig. 12. The output of the cathode follower is coupled to the basic instrument with low-capacity cable Figure 6, Curve B, shows the increase in sensitivity with the addition of the tunable r-f amplifier section.

Crystal-Controlled Receiver.

Provisions also were made to couple a broadbanded Collins 51R-3 navigation receiver to the basic instrument which increases the sensitivity to 5 microvolts. The receiver is desirable for measurements of modulation percentage of communication facilities because of the difficulty in adjusting a manual tuner to the center frequency on transmissions of short duration However, the continuous tuner is satisfactory where continuous transmission occurs, such as on navigation facilities

Antenna-Converter Unit.

Figure 13 shows an antenna-converter unit which was developed to reduce interference caused by transmitter leakage when the measuring equipment is located within the transmitter building. A schematic diagram of the unit is shown in Fig. 14 A 6.4-Mc crystal was selected for the oscillator, however, this frequency is not critical Since the r-f tuner does not tune below 108 Mc, it is necessary to tune the percentage modulation indicator to 6.4 Mc above the station frequency Tuning the percentage modulation indicator to 6 4 Mc above the station frequency eliminates all stray r-f pickup

TESTS

VOR Field Tests

The first of these tests was conducted on a four-loop VOR with the percentage modulation indicator CRO and VTVM installed in an instrument truck The antenna used in these tests was a V-type, mounted on a 10-foot mast. Measurements of percentage modulation were made at a number of locations between 30 and 800 feet from the VOR The results showed uniform indications of percentage modulation at all distances beyond 100 feet These data are shown in Fig. 15.

Operation of the equipment within the transmitter building and with the V-antenna located at the edge of the counterpoise resulted in erratic operation of the indicator due to spurious r-f pickup in the transmission line connecting the V antenna to the equipment. It was this test that led to the development of the antenna-converter unit. With this unit at the edge of the counterpoise, it was possible to locate the modulation indicator inside the building, and obtain repeatable readings within plus or minus 0.3 per cent regardless of the location of the incoming r-f lead with respect to the transmitter The curves in Fig. 16 show a comparison of the percentage modulation measurements made by the two methods.

Measurements of percentage modulation with respect to azimuth at the counterpoise edge of an experimental four-loop VOR produced some interesting data which are shown in Fig. 17 Of particular interest in this test was the uniform radiation of the 9.96-kc signal as compared to variations of the 30-cps space modulated signal It is believed that the variation of the 30-cps signal is caused by misalignment of the VOR antenna array. These data were taken with the antenna-converter unit mounted on the edge of the counterpoise and the measuring equipment located in the transmitter building

Localizer Field Tests.

With the percentage modulation indicator installed in an instrument truck, data were obtained from a normal commissioned localizer at a distance of 1,200 feet A symmetrical pattern of modulation existed as shown in Fig. 18. The difference in percentage modulation, due to sideband antenna lobes, is plotted in decibels versus angle off-course, and also difference in depth of modulation (DDM) versus angle off-course in Fig. 19

Trapezoidal Patterns.

Several examples of trapezoidal modulation patterns, photographed directly from a cathode ray oscilloscope for different types of transmissions are shown in Fig. 20A, 20B, 20C, and 20D

Flight Tests

Flight tests were conducted with the equipment installed in a DC-3 aircraft using a Collins 51R-3 crystal-controlled receiver coupled to the basic instrument. Measurements of percentage modulation using both the CRO and the VTVM were made These flight tests indicated that some precautions are necessary to prevent propeller modulation interference. The aircraft used for these tests was equipped with three V-antennas One antenna was located well forward on the fuselage, one near the middle, and one on top of the vertical stabilizer. Measurements made on the tail V-antenna were identical with those made in the laboratory on the same facility with no noticeable propeller modulation This was true regardless of the direction of the station with respect to the aircraft's heading. Some propeller modulation was evident when the middle V-antenna was used and when the transmitting station was in the direction of the aircraft's heading. The forward V-antenna was not satisfactory for reception of any station because of propeller modulation, regardless of aircraft heading

CONCLUSIONS

It is concluded that the percentage modulation indicator operating in conjunction with an oscilloscope and VTVM, as described in this report, is sufficiently accurate and reliable for the measurement of modulation levels of VOR, localizer, and communication facilities while they are in normal operation

For accurate measurements within the VOR transmitter building, it is essential to use the antenna-converter unit When using an antenna which does not have a converter, a distance of 100 feet or greater should be maintained from the facility.

Satisfactory measurement can be made with an r f signal level as low as 300 microvolts when using the basic unit, 18 microvolts when using the r-f amplifier, and 5 microvolts when using the 51R-3 receiver.

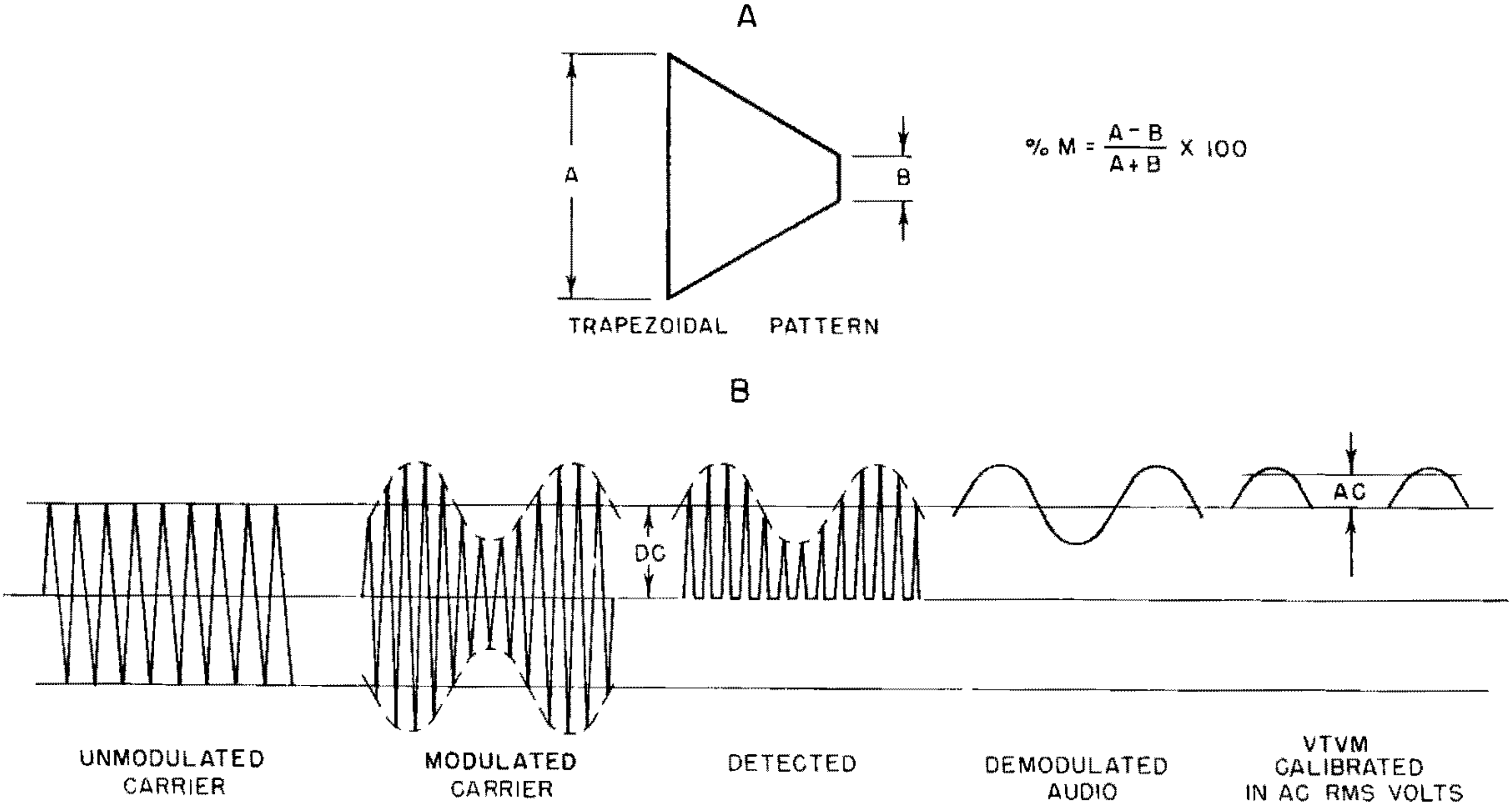


FIG I WAVE FORMS AND TRAPEZOIDAL PATTERN ASSOCIATED WITH AMPLITUDE MODULATION

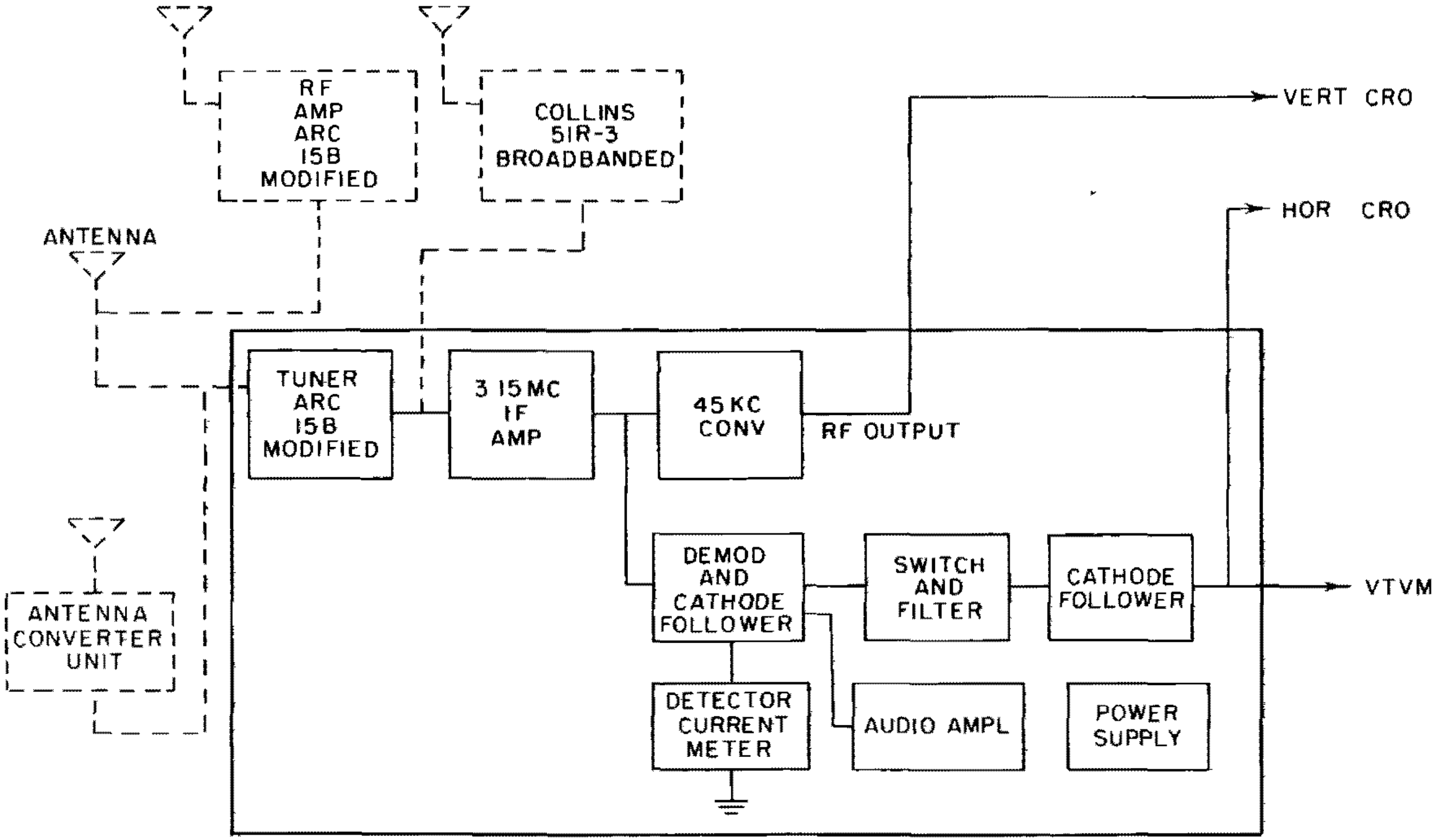


FIG 2 BLOCK DIAGRAM OF PERCENTAGE MODULATION INDICATOR AND ACCESSORIES

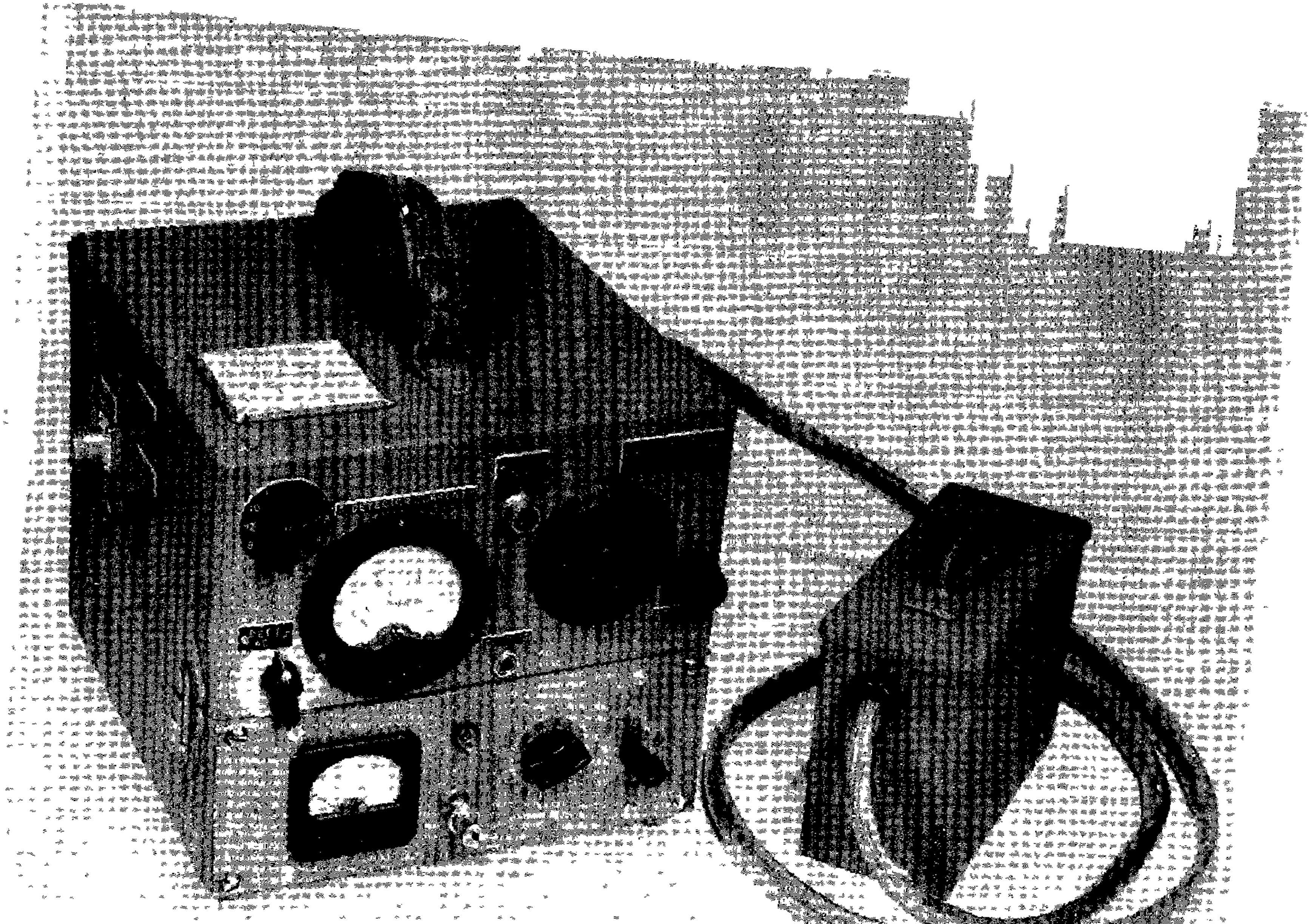


FIG. 3 PERCENTAGE MODULATION INDICATOR

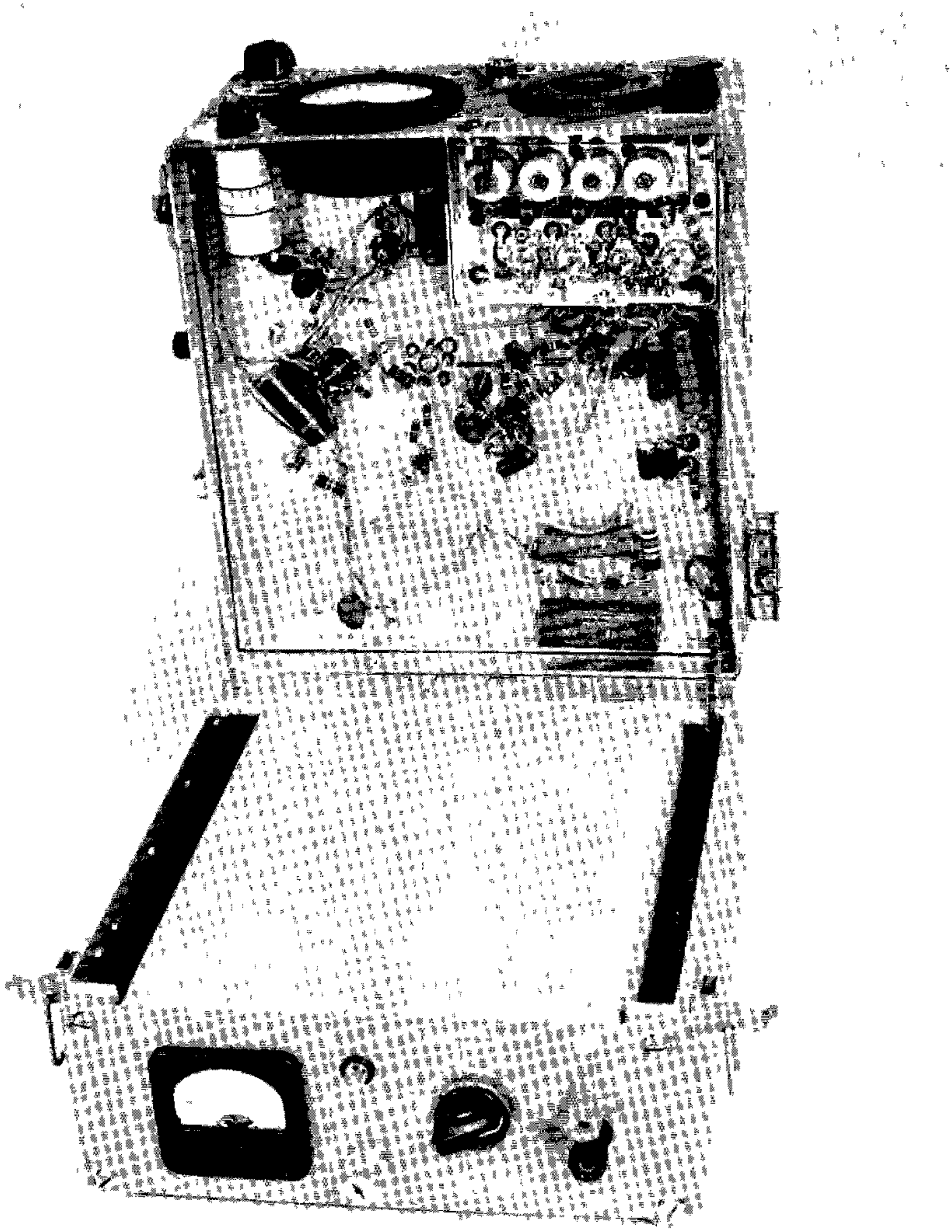


FIG 4 PERCENTAGE MODULATION INDICATOR (INTERNAL VIEW)

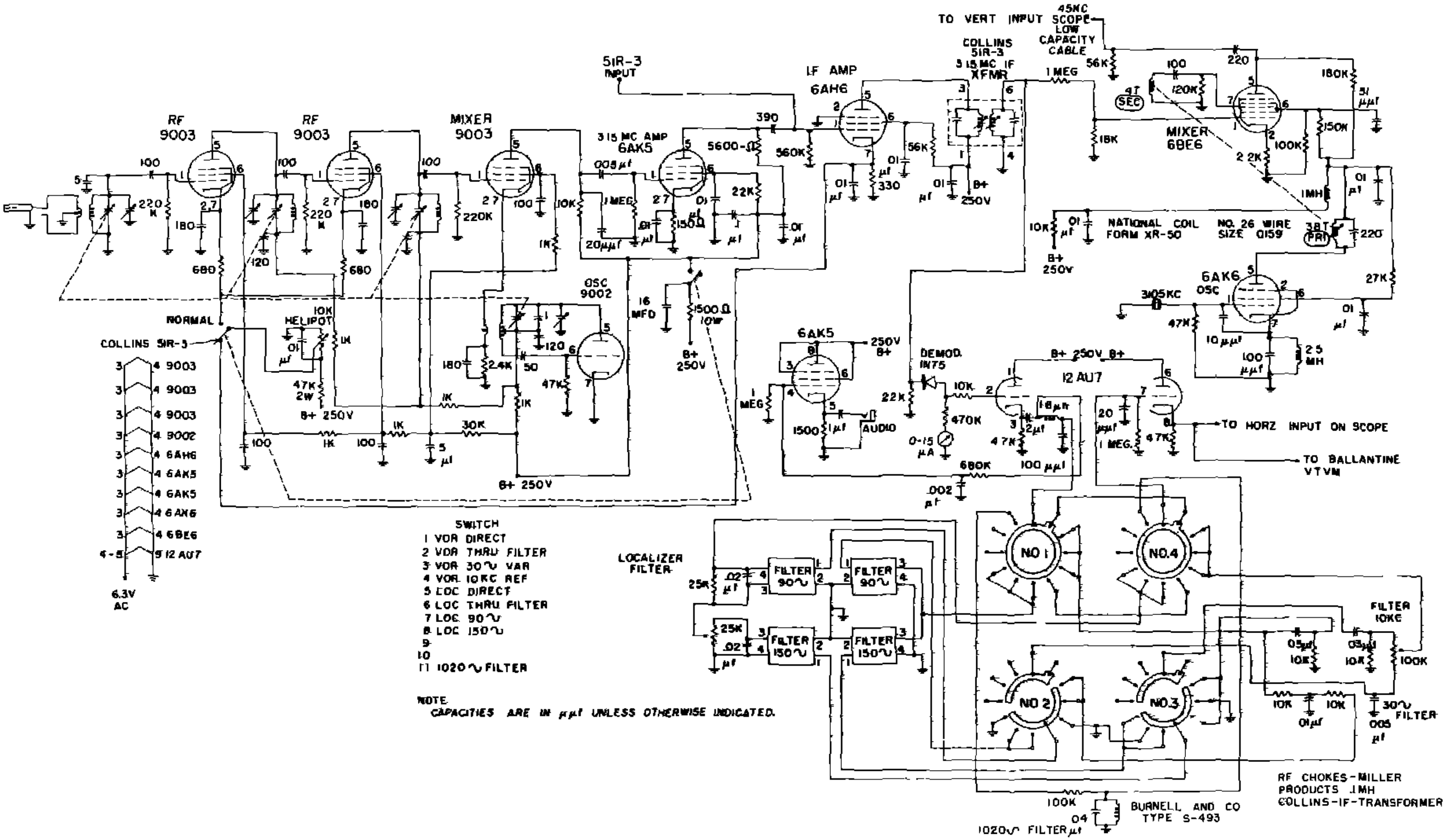


FIG 5 SCHEMATIC DIAGRAM OF PERCENTAGE MODULATION INDICATOR

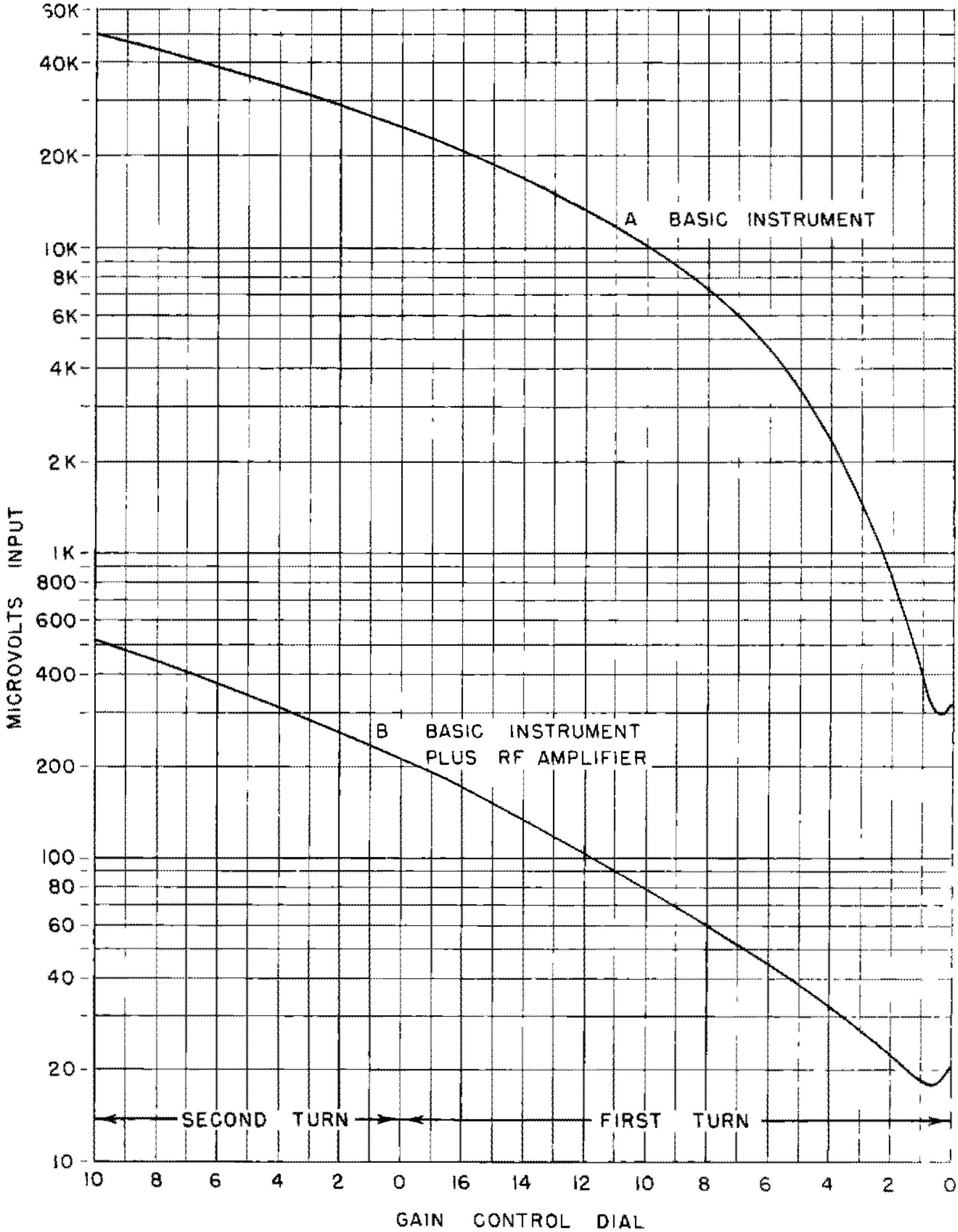


FIG. 6 RF SENSITIVITY VERSUS GAIN CONTROL DIAL FOR 9 MICROAMPS DETECTOR CURRENT

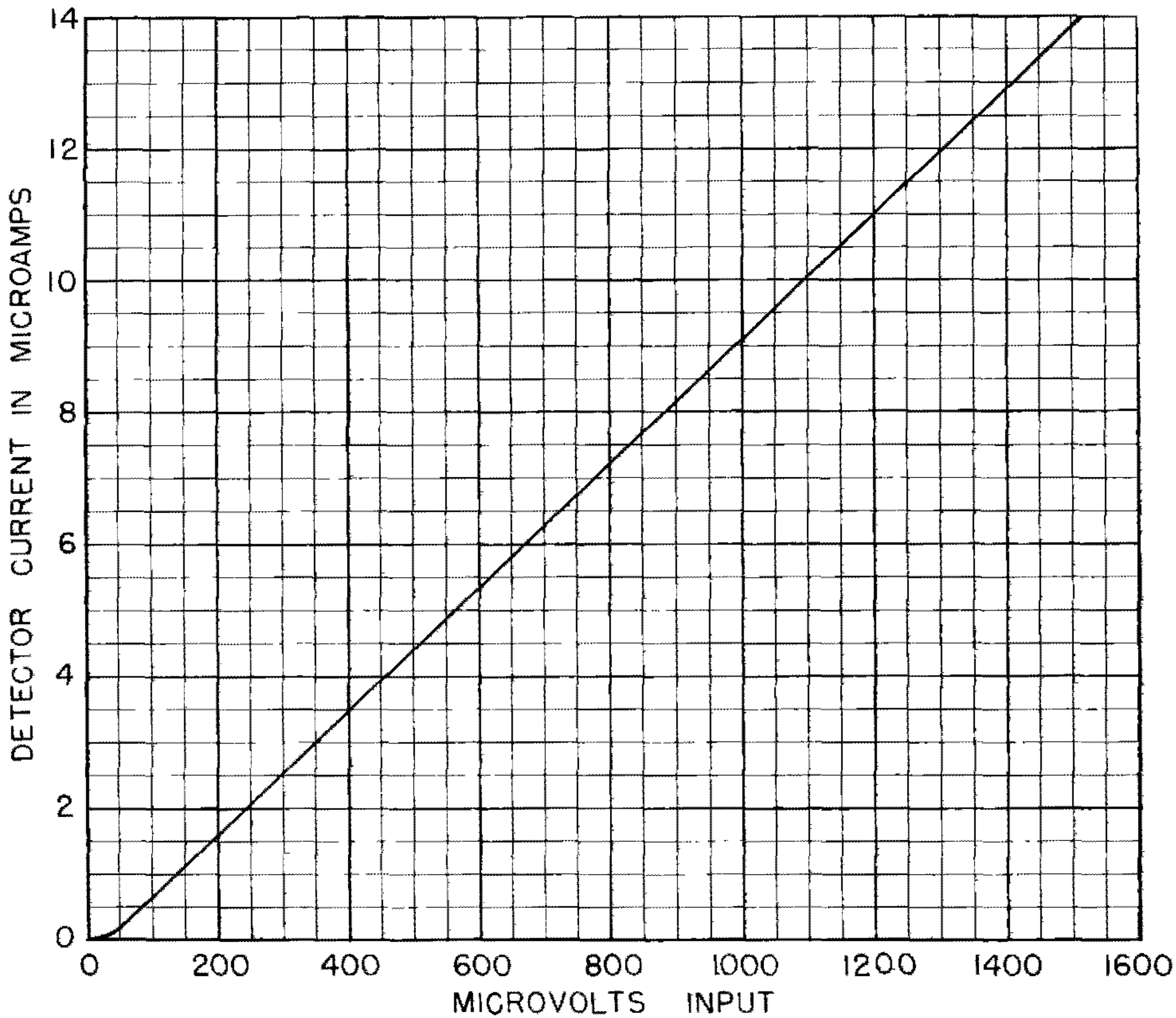


FIG 7 D-C DETECTOR CURRENT VS RF INPUT LEVEL

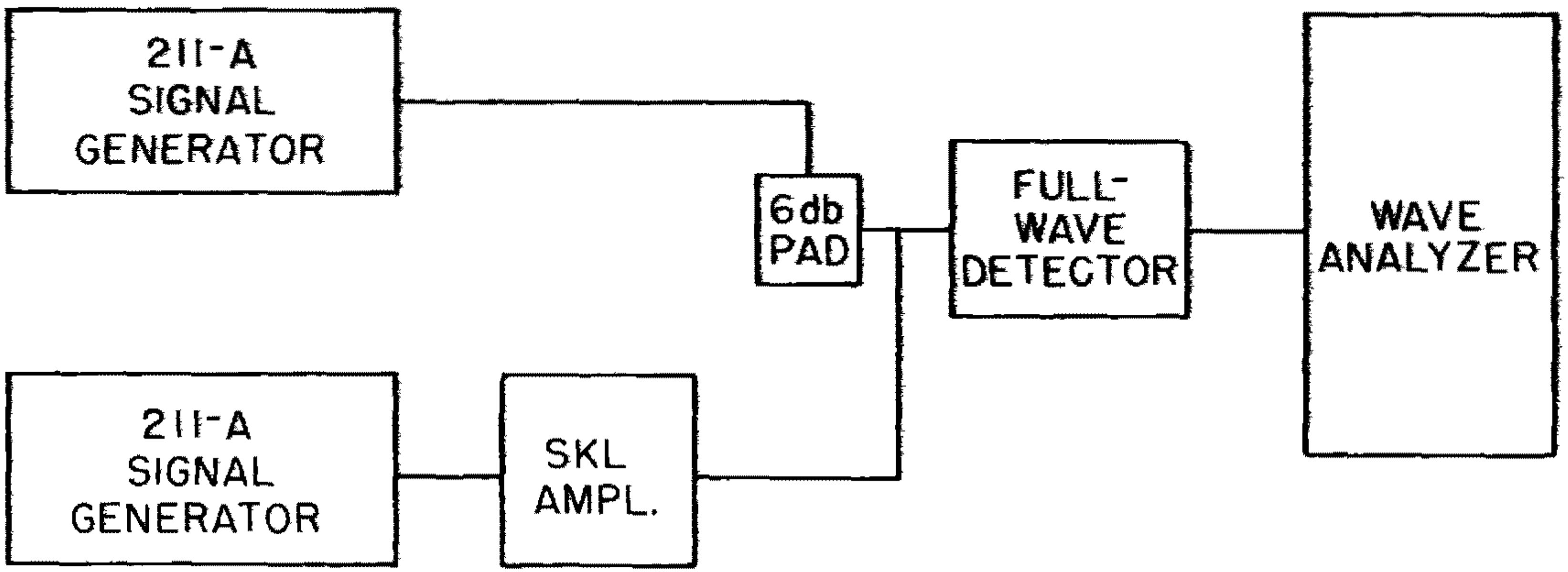


FIG. 8 BLOCK DIAGRAM OF TEST SET-UP

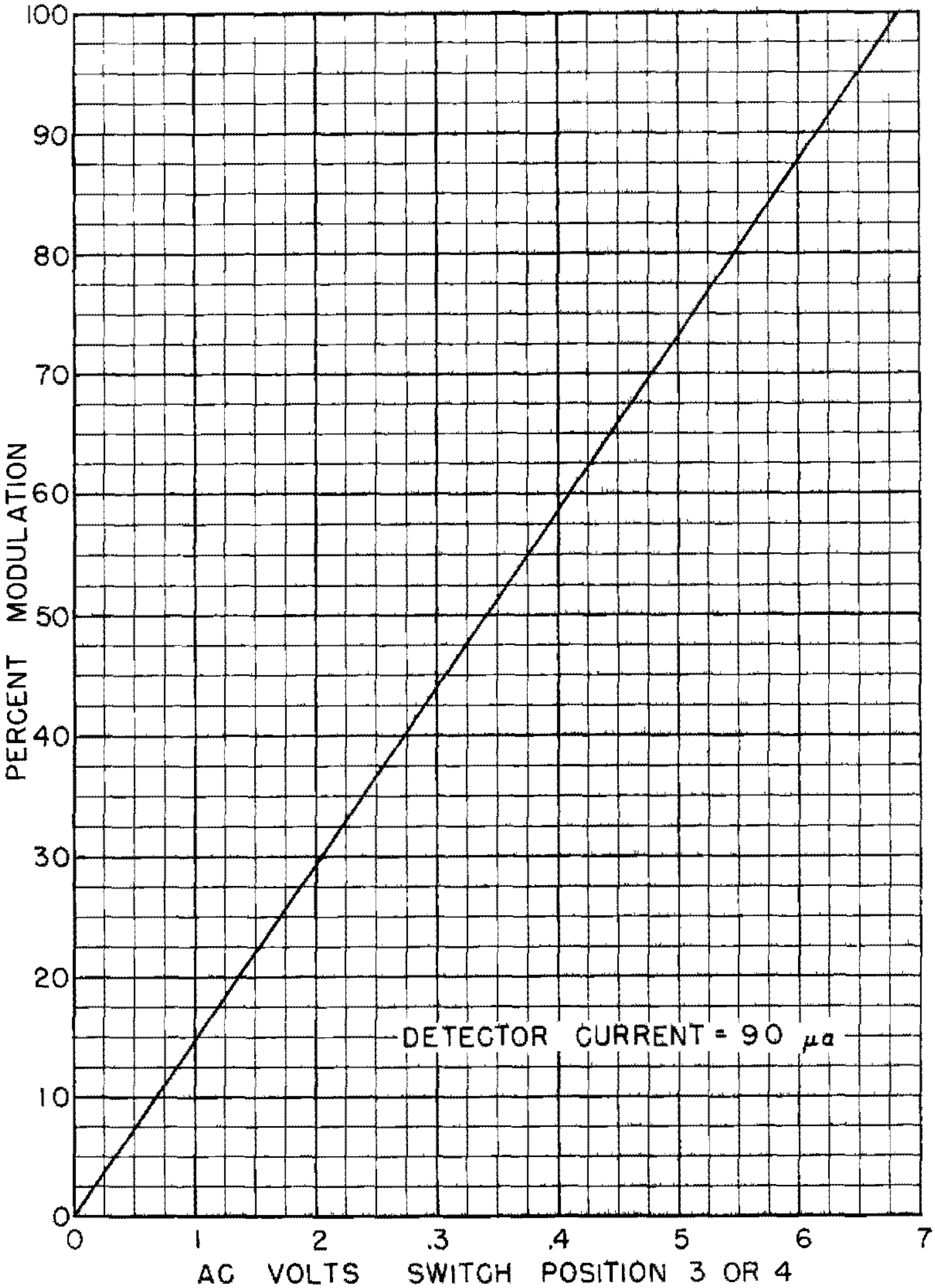


FIG 9 DEMODULATED AC VOLTS VERSUS PERCENT MODULATION FOR VOR SIGNALS

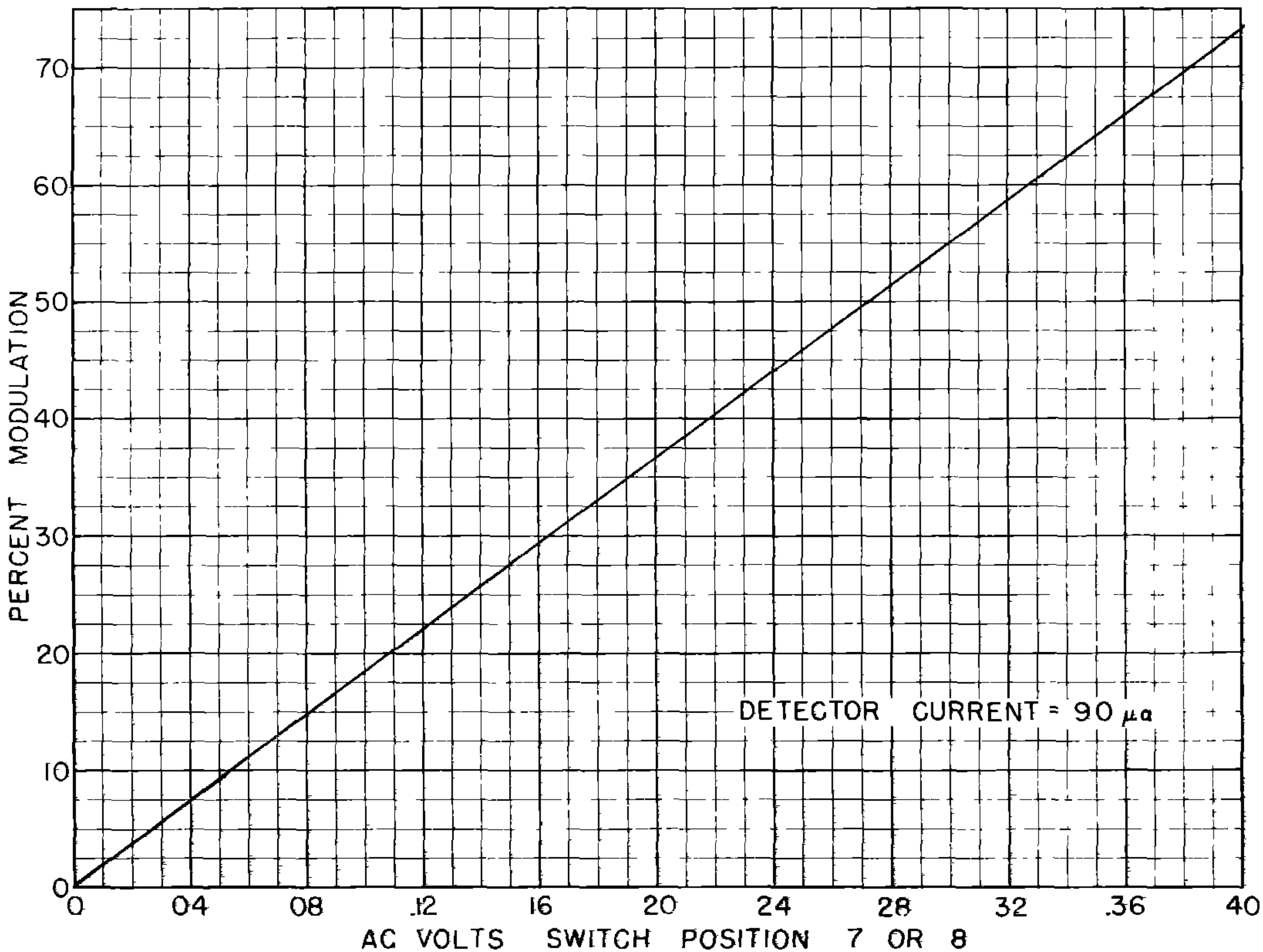


FIG 10 DEMODULATED AC VOLTS VERSUS PERCENT MODULATION
FOR LOCALIZER SIGNALS

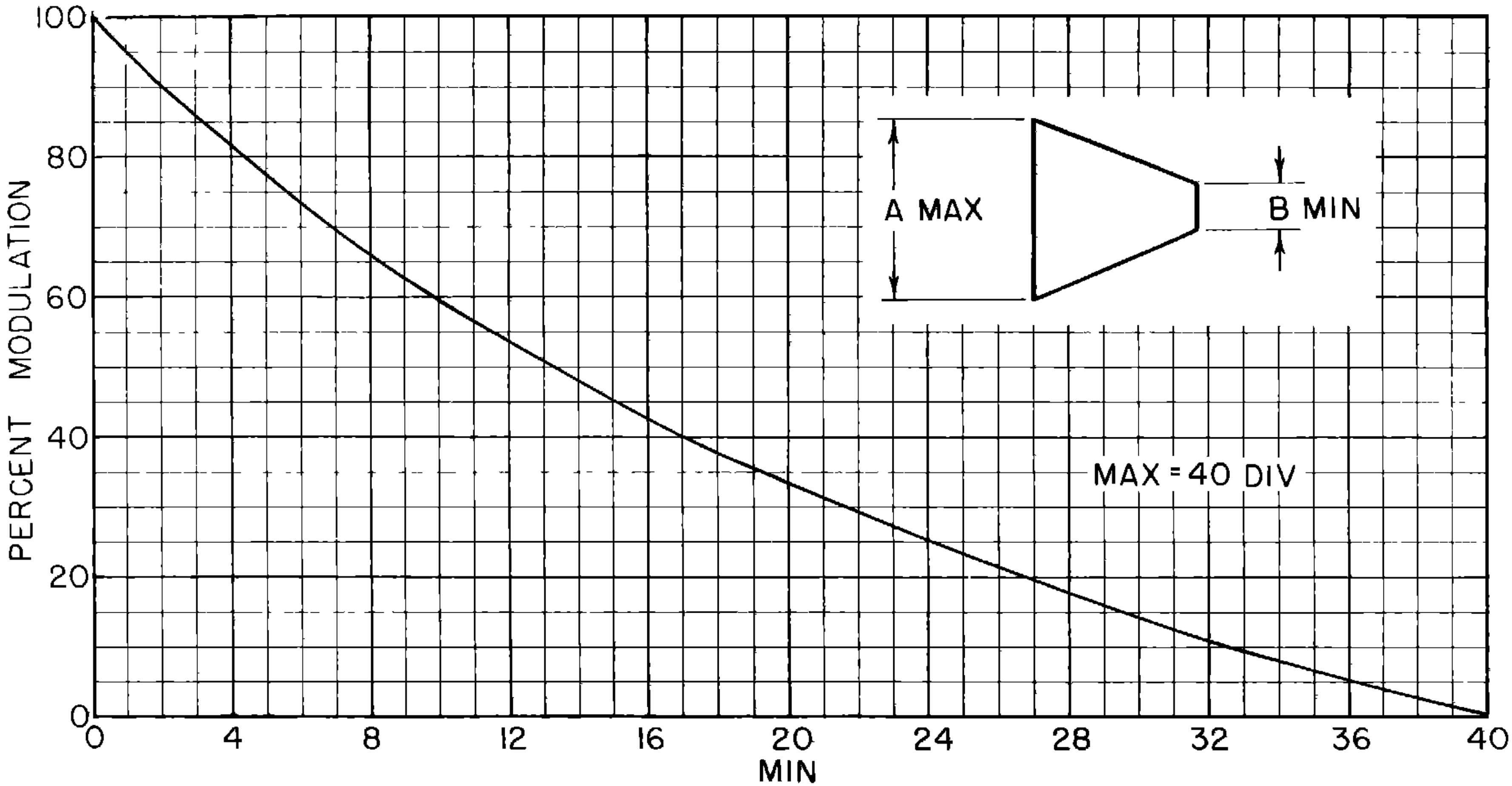


FIG. 11 CURVE FOR CONVERSION OF OSCILLOSCOPE DEFLECTION TO PERCENT MODULATION

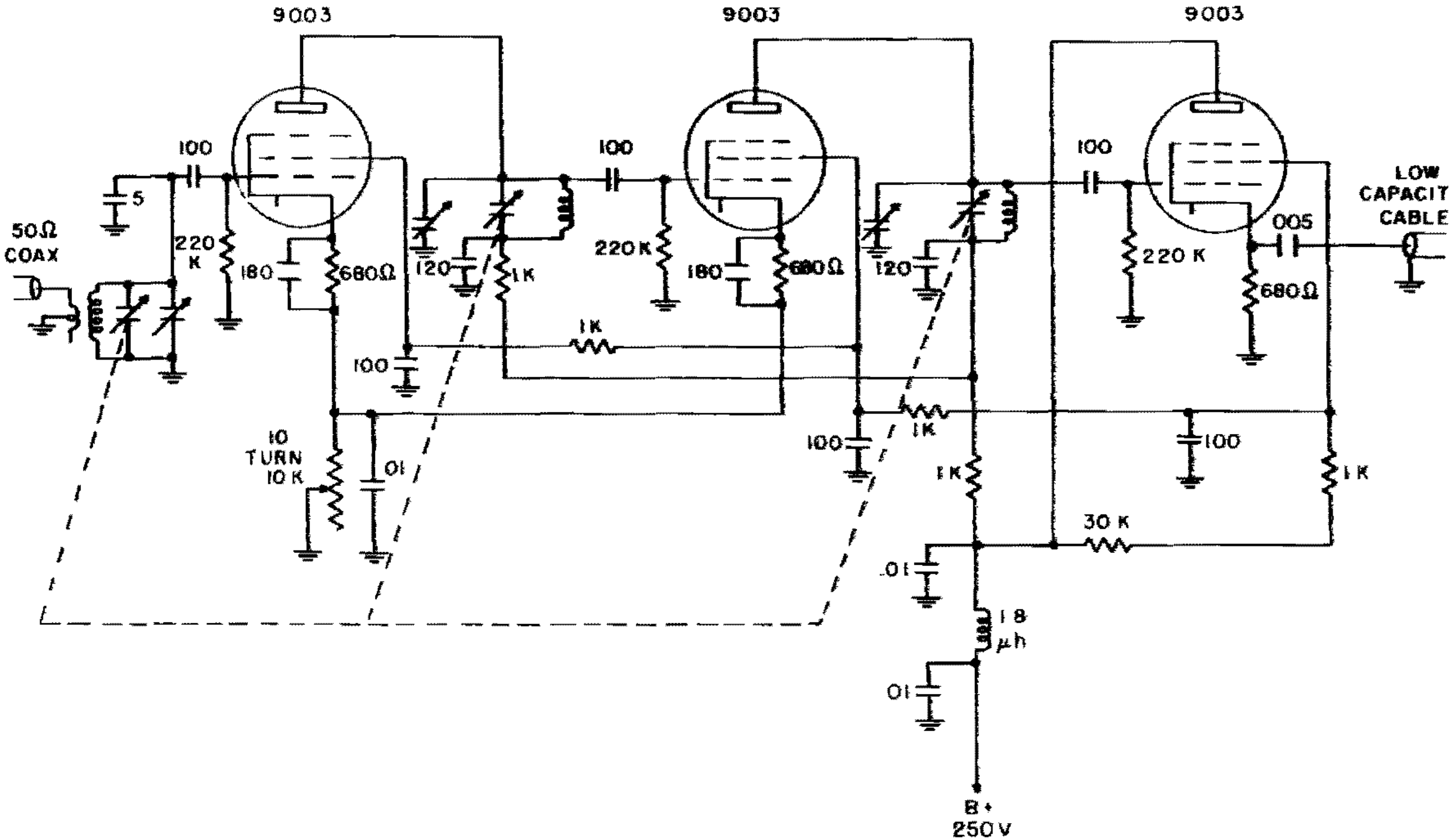


FIG 12 SCHEMATIC DIAGRAM OF TUNABLE RF AMPLIFIER UNIT

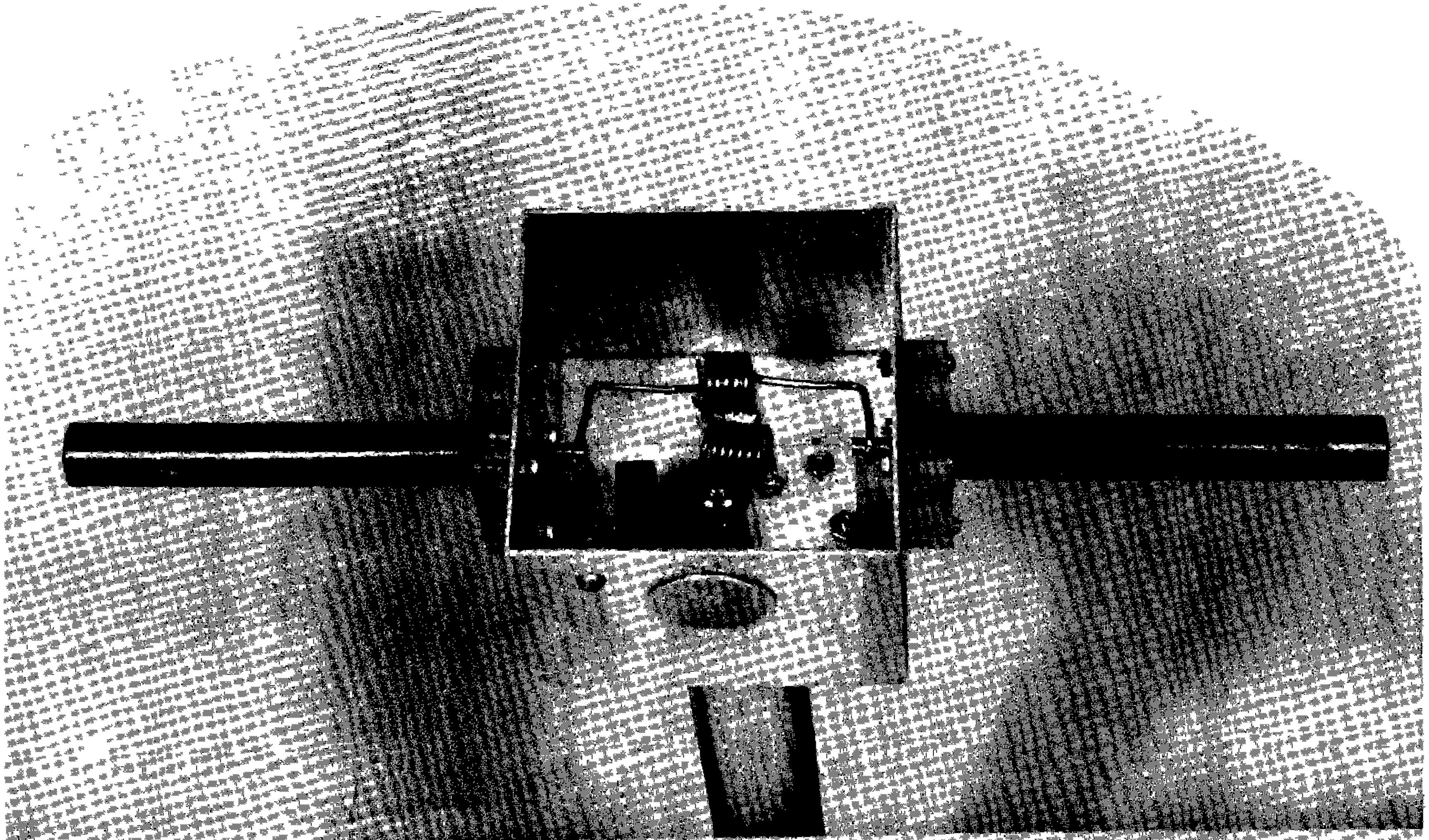


FIG. 13 ANTENNA–CONVERTER

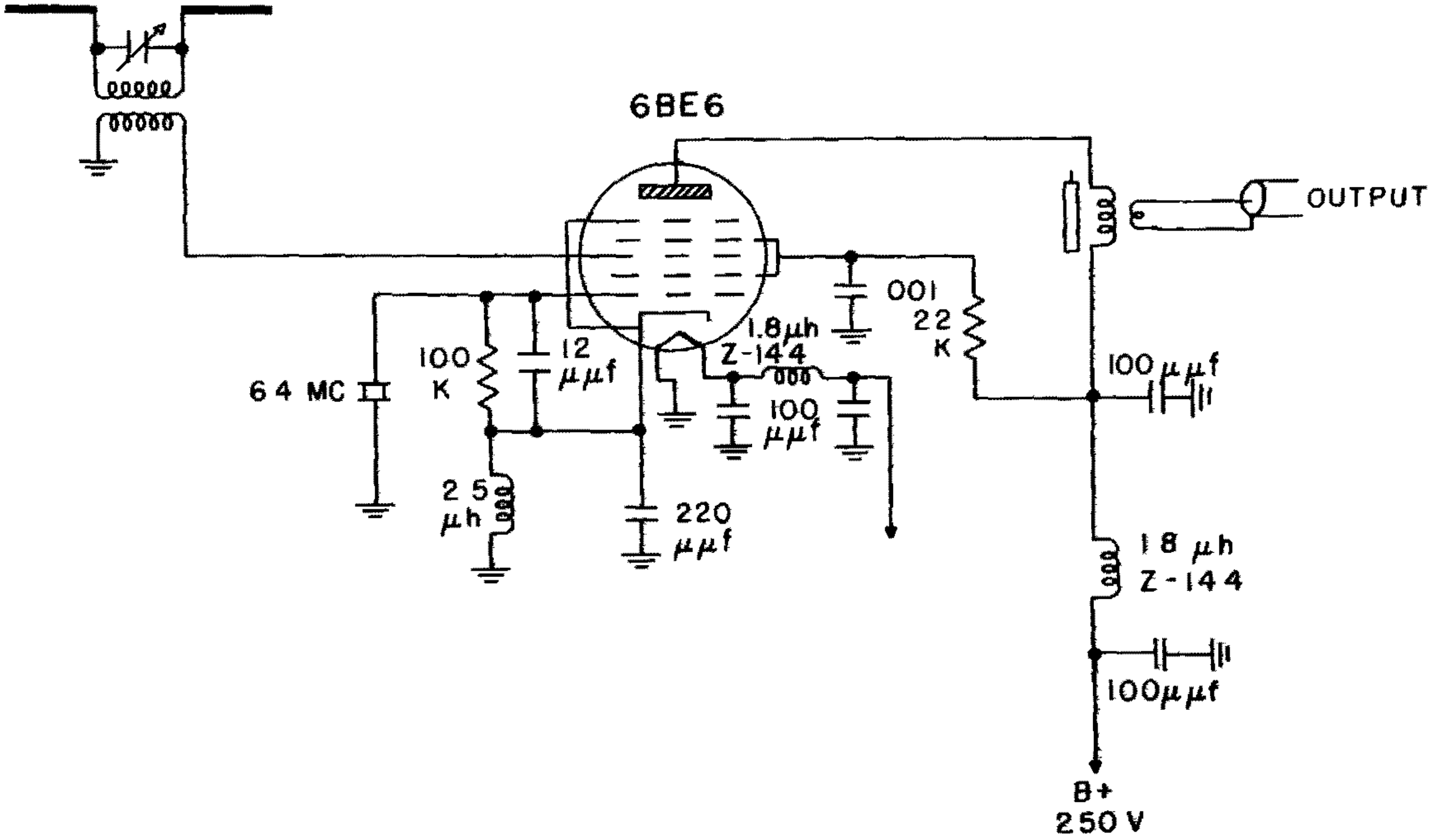


FIG 14 SCHEMATIC DIAGRAM OF ANTENNA-CONVERTER UNIT

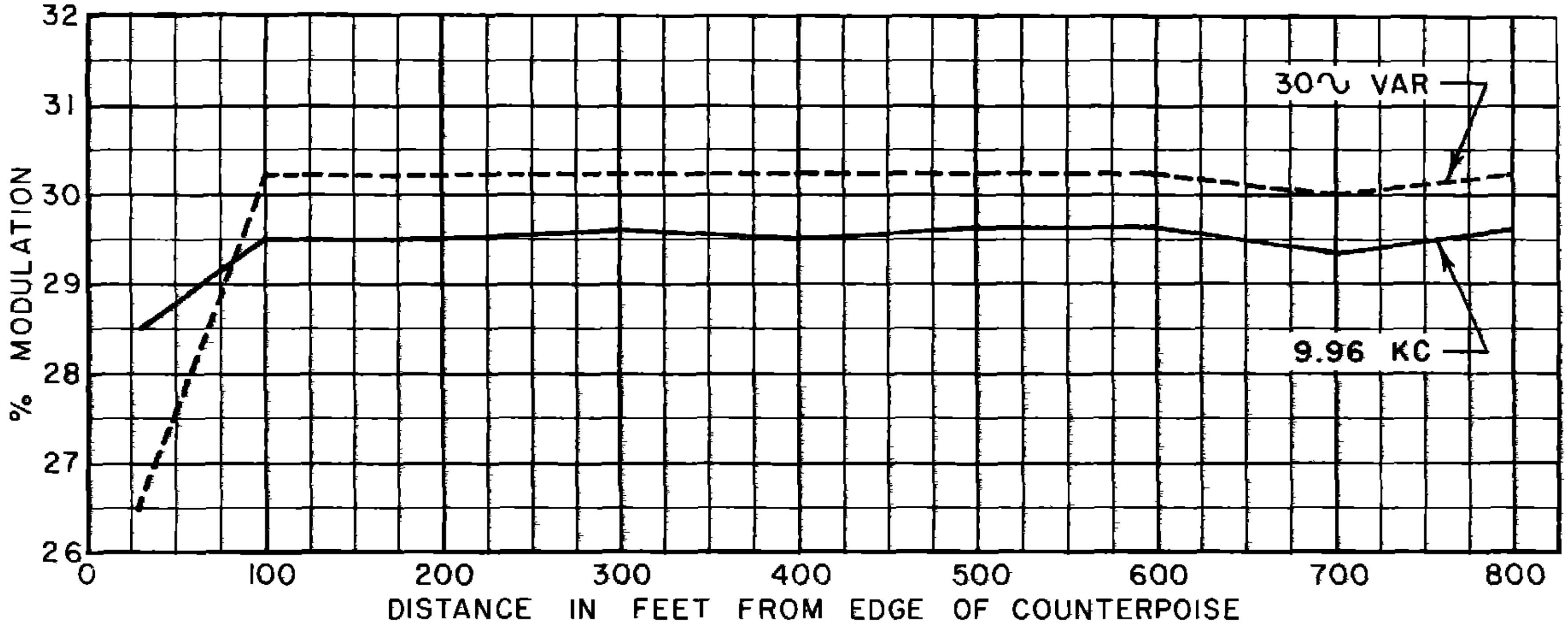


FIG 15 VOR PERCENT MODULATION VERSUS DISTANCE IN FEET

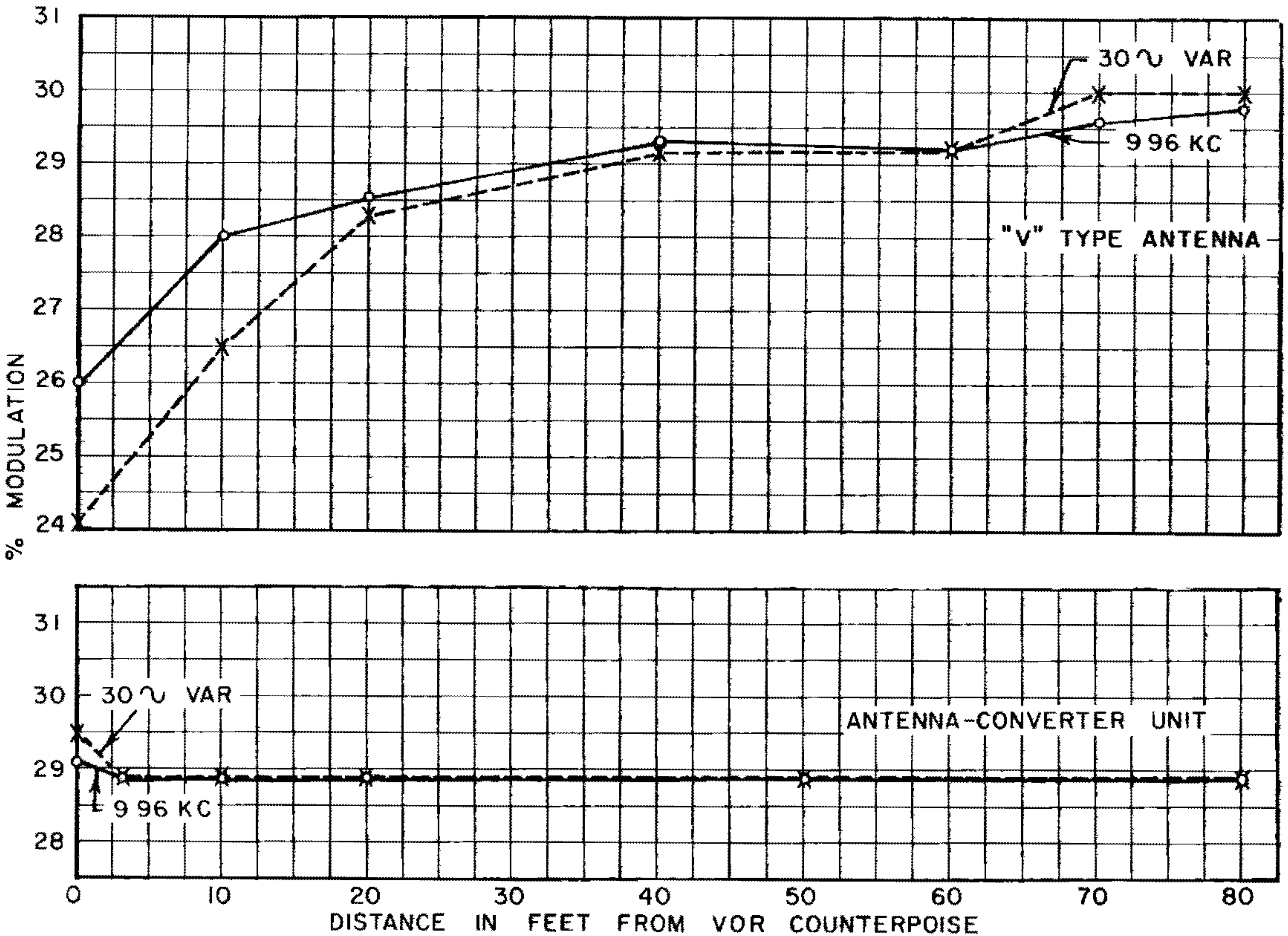


FIG 16 COMPARISON OF PERCENT MODULATION MEASUREMENTS USING ANTENNA-CONVERTER UNIT AND V-TYPE ANTENNA

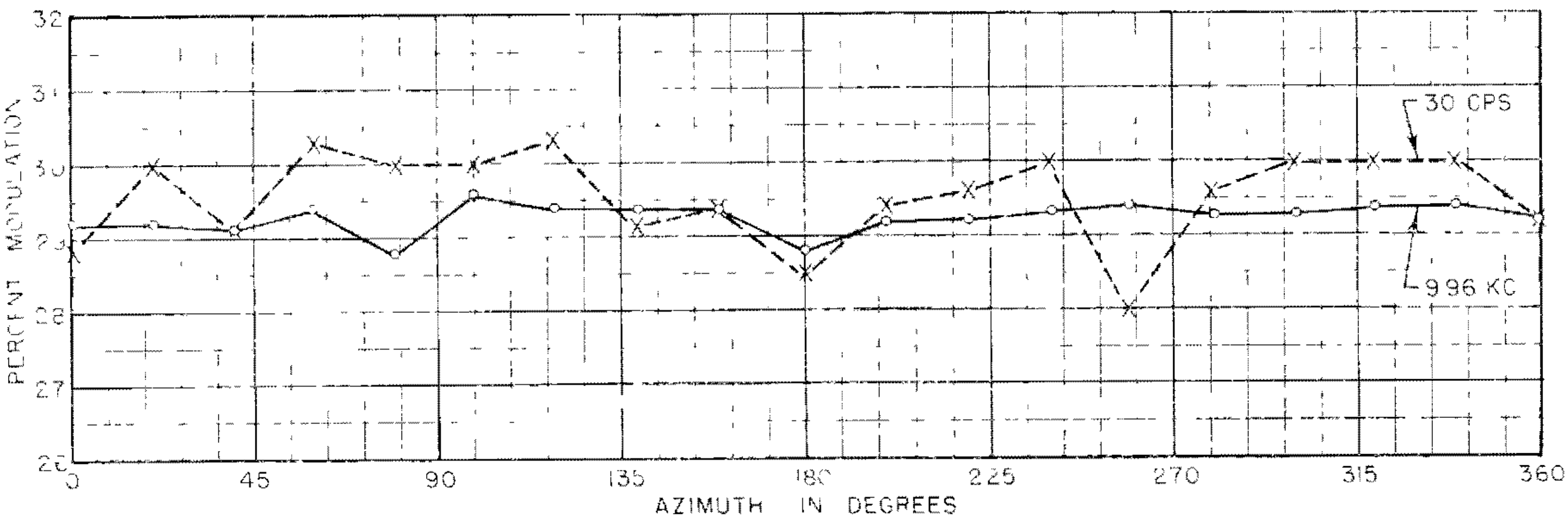


FIG 17 VOR MODULATION VS AZIMUTH

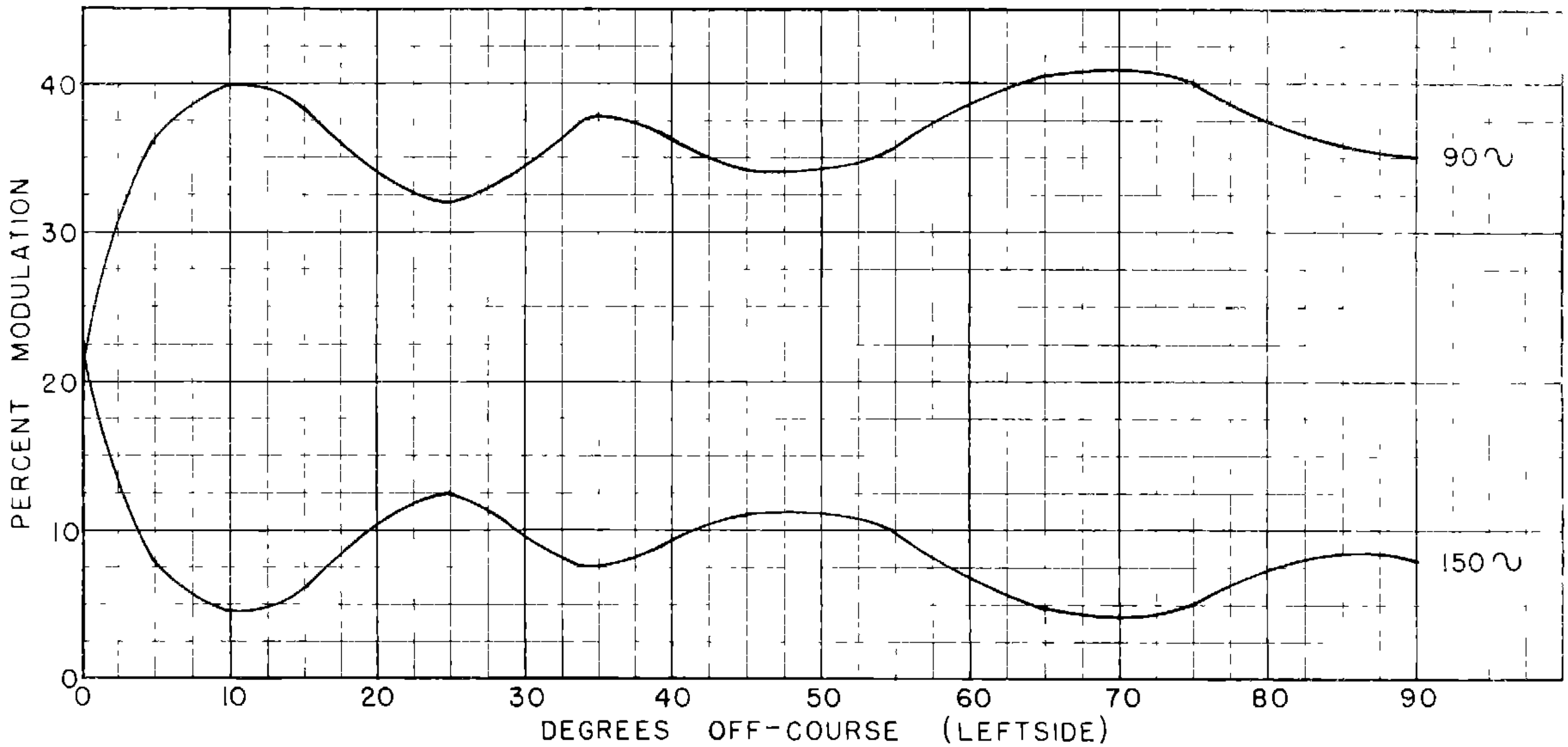


FIG 18 PERCENTAGE MODULATION OF LOCALIZER VERSUS ANGLE OFF-COURSE

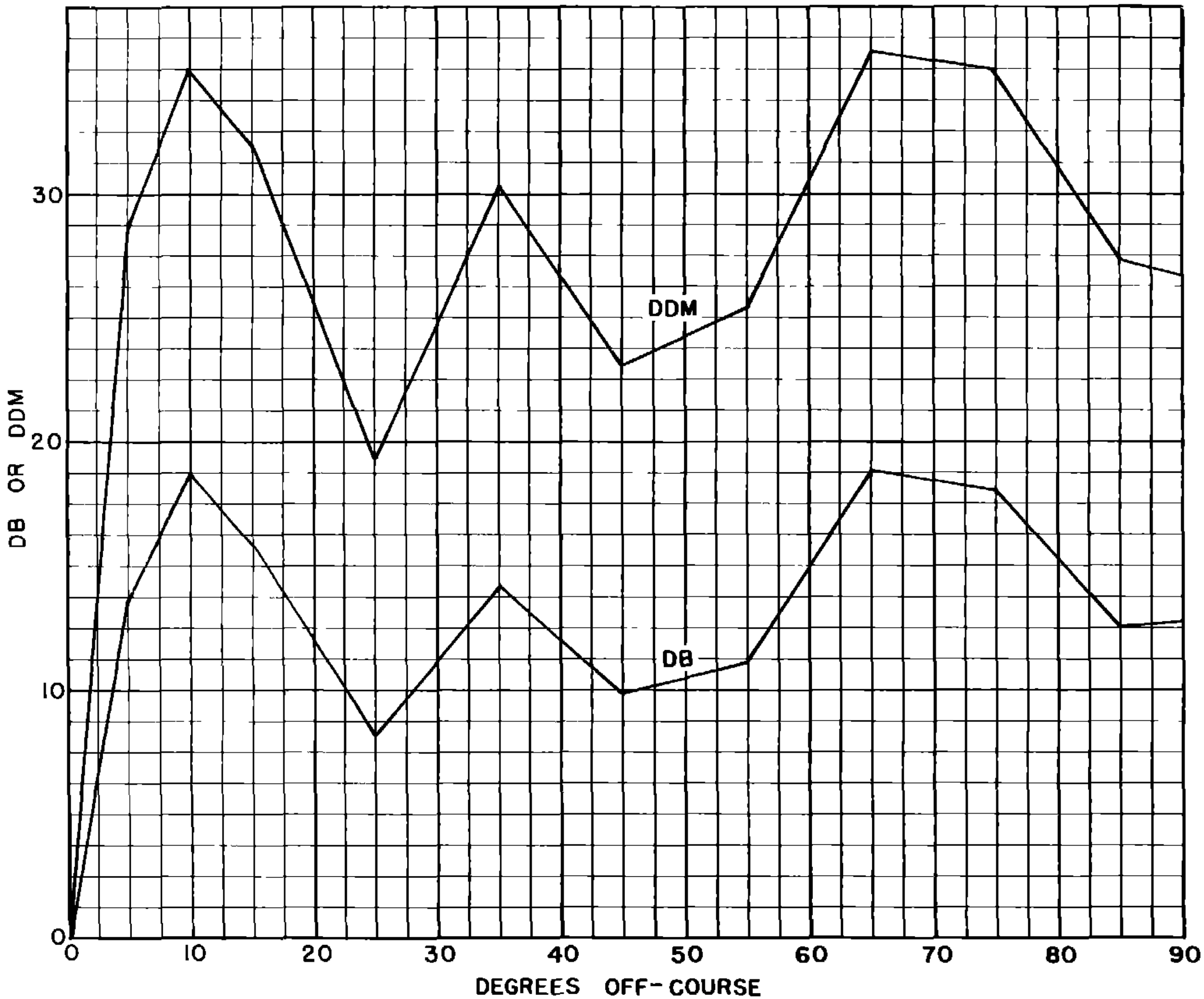
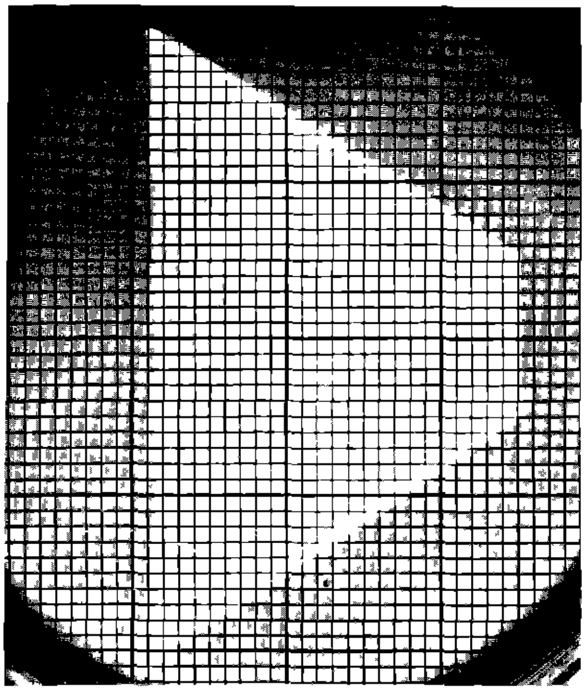
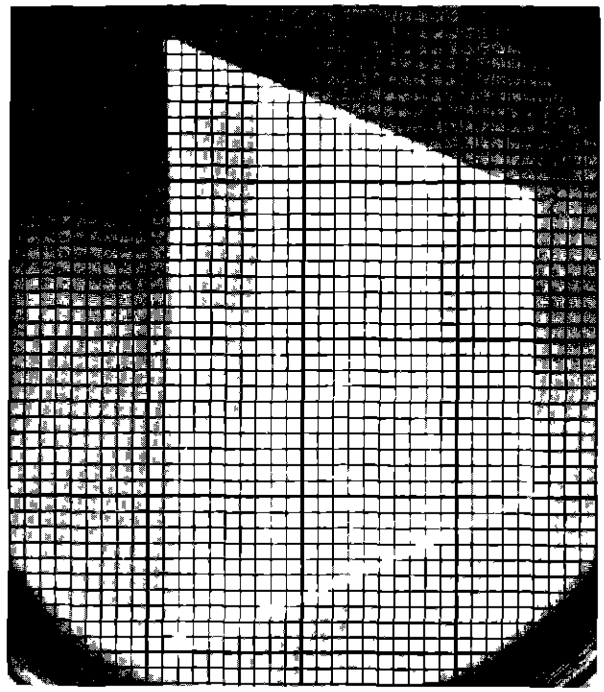


FIG. 19 LOCALIZER DDM AND RATIO VERSUS ANGLE OFF-COURSE



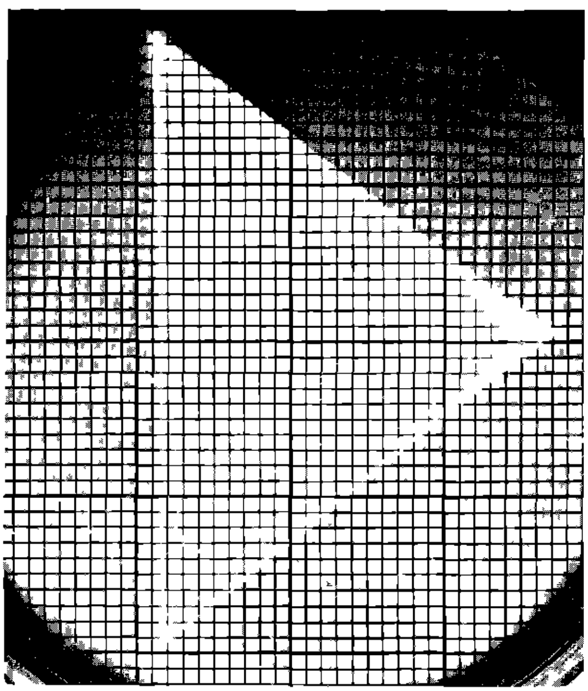
VOR 30% 30 CPS
30% 9 96 KC

A



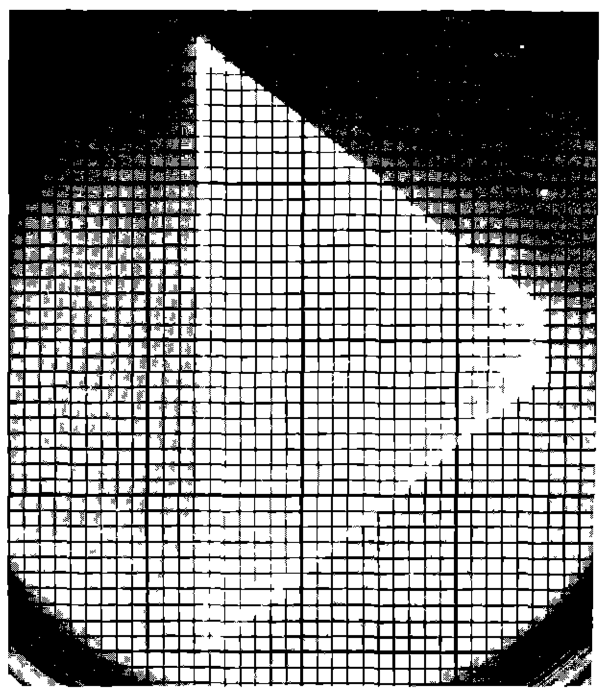
LOCALIZER 20% 90 CPS
20% 150 CPS

B



CONTROL TOWER 100% VOICE

C



VOR WITH VOICE 30% 30 CPS
30% 9 96 KC
20% VOICE

D

FIG 20 TRAPEZOIDAL MODULATION PATTERNS