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N R L REPORT NO. R-3190

INVESTIGATION AND STUDY OF THE AM REDUCTION AND DOWNWARD AM CHARACTERISTICS OF THREE FORMS OF RATIO-TYPE FM DETECTOR

FR-3190

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Date: 21 DEC 2016
Reviewer's name(s): [redacted]
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Declassification authority: NAVY DECLASS GUIDE/ NAVY DECLASS MANUAL, 11 DEC 2012
S8 SERIES

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N R L REPORT NO. R-3

INVESTIGATION AND STUDY OF THE AM REDUCTION AND DOWNWARD AM CHARACTERISTICS OF THREE FORMS OF RATIO-TYPE FM DETECTOR

D. R. Maxson

Approved by:

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Problem No. 39R01-12 October 28, 1947

DEPARTMENT OF THE NAVY OFFICE OF NAVAL RESEARCH

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ABSTRACT

The balanced and unbalanced amplitude-modulation reduction properties of frequency-modulation detectors are defined. Methods of measurement for these characteristics and the downward A-M capability of such detectors are outlined. The results of comparative measurements made on the Model X-RDZ-2 receiver's F-M detector and with two other forms of ratio-type detector are discussed, and the performance graphs correlated with the overall X-RDZ-2 receiver sensitivity.

PROBLEM STATUS

This is an interim report on this problem; work is continuing.

INVESTIGATION AND STUDY OF THE AM REDUCTION AND DOWNWARD AM CHARACTERISTICS OF THREE FORMS OF RATIO-TYPE FM DETECTOR

INTRODUCTION

In accordance with arrangements made by the Bureau of Ships in connection with the current A-M to F-M comparison project at NRL (BuShips Problem S1388), a Model X-RDZ-2 Receiver, Serial 3245, was sent to the laboratories of the Hazeltine Electronics Corporation at Little Neck, Long Island, for the purpose of determining some performance characteristics of the receiver's F-M detector in comparison with two other possible circuit arrangements. The A-M rejection properties and other characteristics of the ratio-detector in this receiver were measured by the methods described in Hazeltine Report No. 7029.* Similar measurements were made on another ratio-detector circuit and on a shunt limiter plus ratio-detector combination, both of which had been designed and constructed at the Hazeltine laboratories. The measurements were performed by Mr. M. Aron under the direction of Mr. B. D. Loughlin, both being engineers of the Hazeltine Electronics Corporation. Some of these tests were observed by Mr. D. R. Maxson of the Naval Research Laboratory, who was present in the capacity of a technical representative of the Laboratory to provide any needed information regarding the X-RDZ-2 receiver and to obtain information about the methods employed by the Hazeltine Corporation in the design and measurement of ratio-detector circuits.

A-M REDUCTION FACTORS

In evaluating the A-M rejection capabilities of an F-M detector system such as a ratio-detector circuit, the Hazeltine laboratories employ a measurement procedure whereby an i-f signal which is simultaneously frequency and amplitude modulated is applied to the input of the detector circuit. The audio output vs frequency characteristic, as observed on an oscilloscope, is modified by the input A-M to an extent determined by the A-M rejection capabilities of the detector. By resolving the output pattern obtained into components resulting from the input F-M and A-M respectively, the immunity of the circuit to amplitude-modulation can be expressed in terms of "A-M reduction factors".

If an F-M signal containing no A-M were applied to the input of a ratio-detector circuit, the output voltage vs frequency characteristic might appear as in Figure 1 (a). This pattern could be observed on an oscilloscope by applying the detector's audio output to the vertical axis and the audio modulating signal to the horizontal axis. If the frequency deviation were confined to the linear portion of the characteristic, the pattern obtained would consist merely of a diagonal line, (Figure 1 (a)). The pattern could be extended to reveal the peaks of the characteristic if a wider deviation were used, as indicated by the dotted portion of the curve. For the following discussion, it will be assumed that the signal-frequency deviation is less than one-half of the discriminator peak separation.

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* Hazeltine Electronics Corporation Report No. 7029, "Design and Measurement of Ratio Detectors," 12 May 1947.

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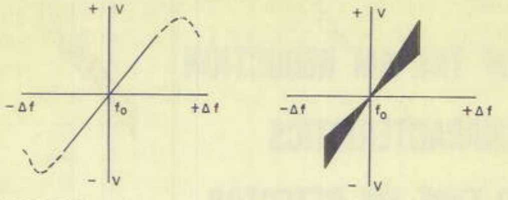
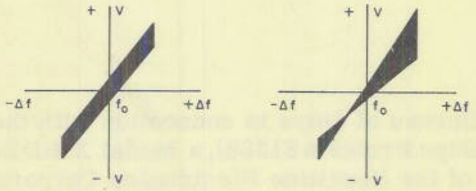


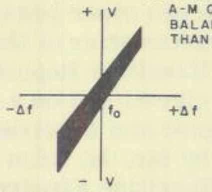
(a) PERFECT A-M REJECTION

(b) BALANCED A-M COMPONENT IN OUTPUT



(c) UNBALANCED A-M COMPONENT IN OUTPUT

(d) BALANCED AND UNBALANCED A-M COMPONENTS IN OUTPUT; BALANCED COMPONENT GREATER THAN UNBALANCED COMPONENT



(e) BALANCED AND UNBALANCED A-M COMPONENTS IN OUTPUT; UNBALANCED COMPONENT GREATER THAN BALANCED COMPONENT

Fig. 1. Oscilloscope Patterns for Various Degrees of A-M Rejection

Assume that the i-f signal applied to the discriminator were frequency modulated as before, and simultaneously amplitude-modulated at another audio frequency not harmonically related to the F-M modulating signal. If the detector were completely insensitive to A-M, the output would be unaffected and the pattern would remain a diagonal line, as shown in Figure 1 (a). If the A-M rejection were not perfect, however, the output characteristic might appear as in Figure 1 (b), 1 (c), 1 (d), or 1 (e). A pattern such as that shown in Figure 1 (b) would indicate the slope of the discriminator characteristic to be a function of the instantaneous input signal amplitude in which case the output is said to contain a "balanced A-M component." A characteristic similar to that of Figure 1 (c) would result from a detuning of the discriminator transformer and consequent frequency shift of the output characteristic as as function of the instantaneous signal amplitude. In this case the output is said to contain an "unbalanced A-M component." If both the slope and the center frequency of the discriminator characteristic are functions of the instantaneous signal amplitude, both balanced and unbalanced A-M components will appear in the output, resulting in patterns similar to those shown in Figures 1 (d) and 1 (e).

The "balanced component A-M reduction factor" P_b is a parameter employed to designate the magnitude of the balanced A-M component in the output relative to the percentage amplitude-modulation of the input signal. With reference to Figure 2 (a), the balanced A-M component B is the equal to the vertical width of the pattern at the specified frequency deviation. The balanced A-M modulation factor M_b is equal to the ratio B/Z, where Z is the vertical height of the pattern which would result from F-M alone. The balanced component A-M reduction factor, P_b, is defined as the ratio of M_b to the A-M modulation factor of the input signal, i. e.,

$$P_b = \frac{M_b}{M_I} \qquad (1)$$

where $M_b = \dfrac{B}{Z}$

and 100 M_I = percent amplitude-modulation of input signal. Note that a balanced A-M reduction factor of unity indicates no A-M rejection, whereas a reduction factor of zero indicates perfect A-M rejection, considering only the balanced component. The factor P_b is defined as positive when an increase in input signal amplitude causes the slope of the discriminator characteristic to increase, and negative when the slope decreases for increasing signal amplitude. The sign of P_b can be inferred from the fact that it is generally positive when the mean signal amplitude is small. For ratio-detectors, P_b is normally large for small signal inputs, decreasing and ultimately becoming negative as the input signal is increased.

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The "unbalanced component A-M reduction factor" P_u is a measure of the amount of dynamic frequency shift, or the magnitude of the unbalanced A-M component, relative to the percent input A-M. With reference to Figure 2 (b), the unbalanced A-M component U is the vertical width of the pattern, the unbalanced A-M modulation factor M_u is the ratio U/Z as measured with the specified deviation, and the unbalanced A-M reduction factor, P_u, is

$$P_u = \frac{M_u}{M_I} \tag{2}$$

The sign of P_u is arbitrarily considered positive when an increase in input signal amplitude causes the discriminator center frequency to shift higher in frequency, and negative when the discriminator characteristic shifts lower in frequency as the input amplitude is increased.

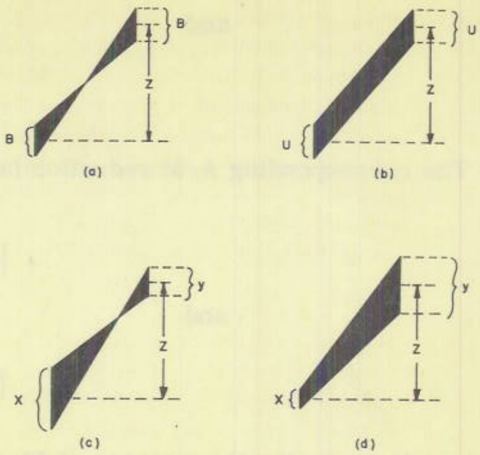


Fig. 2. Geometry of A-M Rejection Computations

Patterns such as those illustrated in Figures 1 (d) and 1 (e) can be measured, and the balanced and unbalanced components computed by the use of simple equations which follow directly from the geometry of the figures. When the balanced component is greater than the unbalanced component, the A-M response null, or "crossover", occurs at some frequency between the end frequencies corresponding to the specified deviation. This condition is illustrated in Figures 1 (d) and 2 (c). With reference to Figure 2 (c), the magnitudes of the balanced and unbalanced components are

$$|B| = \left|\frac{x + y}{2}\right| \tag{3}$$

and

$$|U| = \left|\frac{x - y}{2}\right| \tag{4}$$

If the input signal is 30-percent amplitude-modulated, the corresponding A-M reduction factors are

$$|P_b| = \frac{3.33}{Z}|B| = \frac{1.67}{Z}|x + y| \tag{5}$$

and

$$|P_u| = \frac{3.33}{Z}|U| = \frac{1.67}{Z}|x - y|. \tag{6}$$

When the unbalanced component is greater than the balanced component, the A-M response null does not appear on the pattern. The output characteristic then appears as in Figure 1 (e) or Figure 2 (d). Referring to Figure 2 (d), the magnitudes of B and U for this condition are

$$|B| = \frac{|x - y|}{2} \tag{7}$$

and

$$|U| = \frac{|x + y|}{2}. \tag{8}$$

The corresponding A-M reduction factors for 30-percent input amplitude-modulation are

$$|P_b| = \frac{1.67}{z}\,|x - y| \tag{9}$$

and

$$|P_u| = \frac{1.67}{z}\,|x + y| \tag{10}$$

In analyzing the patterns of Figures 1 and 2, the signs of U and P_u can be determined from the position of the A-M response null, provided that the sign of B is known. The sign of B can generally be inferred from the fact that it is positive for low input signal amplitudes.

When B and U are of like sign, the A-M response null occurs at a frequency which is higher than the discriminator F-M center frequency f_0; conversely, the null occurs below f_0 when B and U are of unlike sign. In this connection, it should be clearly understood that the presence of an unbalanced component causes the A-M response null to occur at some frequency other than the midpoint between the peaks of the discriminator characteristic, and that the position of the null will generally change as a function of the mean input signal amplitude. The null will shift with respect to the peaks of the characteristic of the relative amplitudes of B and U vary, regardless of whether or not the discriminator center frequency is dependent upon the average input signal level. In performing a series of A-M rejection measurements, it is therefore desirable that the center frequency of the input signal be adjusted by a method which does not involve observations of the position of the A-M response null. The correct center frequency can be determined either by d-c voltage measurements, using an unmodulated signal, or by using an F-M signal of deviation at least equal to one-half of the peak separation for adjusting the frequency of the signal generator output, reducing the deviation to the specified or desired deviation for the A-M rejection measurements.

The "composite A-M reduction factor" P_c is a figure of merit defined as the rms sum of the balanced and unbalanced component A-M reduction factors, i. e.

$$|P_c| = \sqrt{P_b^2 + P_u^2} \tag{11}$$

This factor is, as discussed in Hazeltine Electronics Corp. Report No. 7029, useful in "evaluating the objectionableness of the harmonic distortion in the output of a ratio detector being subjected to F-M and synchronous A-M sinultaneously." The term "synchronous A-M" refers to any amplitude-modulation of the desired signal which is directly related to the rate of frequency deviation, such as that caused by the selectivity characteristic of the i-f amplifier.

DOWNWARD A-M CAPABILITY

The "downward A-M capability" of a ratio-detector is a measure of the amount by which the input signal can be reduced dynamically without causing the diodes to cease conducting. It is expressed in terms of the maximum percent "downward" amplitude-modulation for which the diodes do not become cut off during any part of the A-M cycle.

MEASUREMENT SET-UP AND PROCEDURE

The measurement set-up used at the Hazeltine laboratories is shown in the block diagram of Figure.3. A Boonton F-M Generator Type 150-A was used to provide a frequency-modulated signal at 46 Mc. The output of this generator was fed into a converter unit to reduce the carrier frequency to 15.1 Mc, which is the i-f center frequency of the Model X-RDZ-2 receiver. The 400 cps output of an audio oscillator was fed into the converter unit to provide for amplitude-modulation of the converter output signal. The output of the converter unit consisted of a 15.1 Mc signal, frequency-modulated at approximately 100 cps and amplitude-modulated at about 400 cps. The frequency setting of the audio oscillator was adjusted so that the two modulating frequencies were not harmonically related. The converter was provided with a calibrated dial for adjusting the percent A-M, and a meter which was calibrated to indicate the rms volts output. The Boonton generator was equipped with a deviation meter, which had been calibrated previously. The 15.1-Mc signal from the converter unit was applied to the grid of the i-f amplifier tube driving the detector circuit under investigation, V-206 in the case of the Model X-RDZ-2 ratio detector. The audio output of the detector was applied to the vertical-axis amplifier of a Dumont Type 208 oscilloscope, while the 100-cps modulating signal from the F-M generator was applied to the horizontal axis via a resistance-capacity phase shifter. The peak-to-peak audio output voltage for each signal level used in the A-M rejection tests was measured by a substitution method, whereby the output of a Hazeltine square-wave voltmeter was applied to the vertical axis of the oscilloscope and adjusted for the same deflection as that produced by the detector output, the meter then indicating the peak-to-peak voltage directly. The AVC voltage developed by the detector was measured for each signal level using an RCA Volt-Ohmyst Jr. The downward A-M capability was measured by increasing the percent amplitude-modulation of the input signal and recording the minimum percent modulation for which the diodes could be seen to stop conducting momentarily for all frequencies within the pattern.

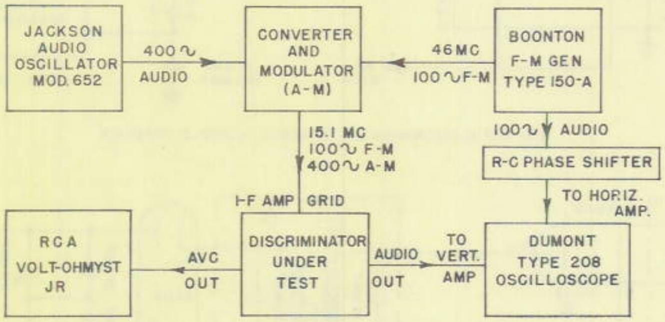
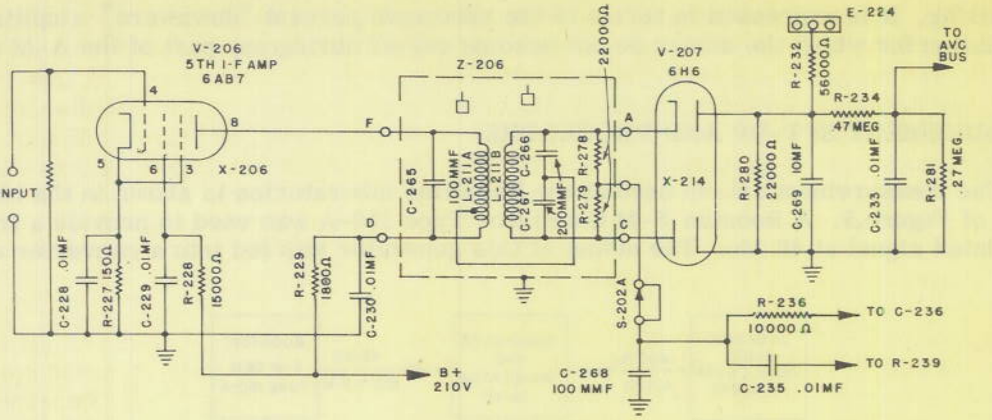


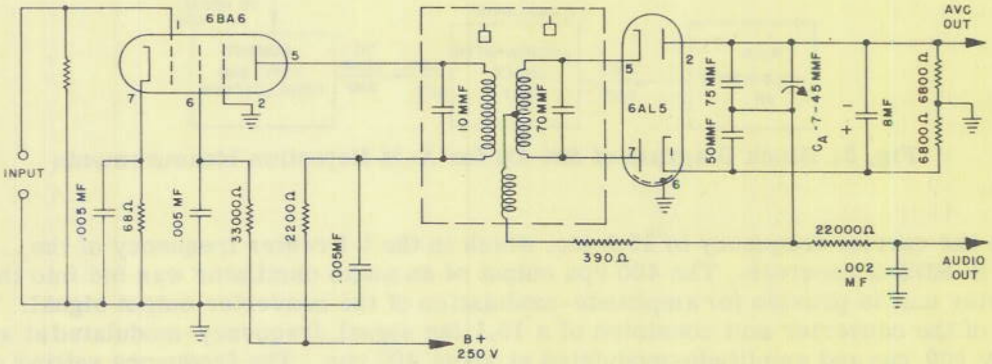
Fig. 3. Block Diagram of Set-Up for A-M Rejection Measurements

EXPERIMENTAL RESULTS

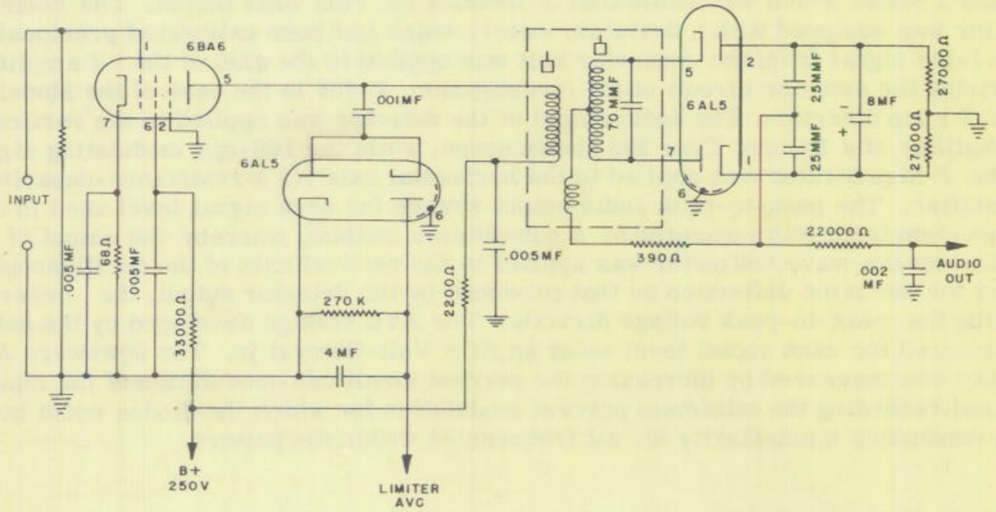
The ratio-detector incorporated in the Model X-RDZ-2 receiver is shown in Figure 4 (a). The A-M reduction factors for this circuit were first measured using a deviation



(A) RATIO-DISCRIMINATOR IN MODEL X-RDZ-2 RECEIVER



(B) HAZELTINE RATIO-DISCRIMINATOR



(C) HAZELTINE LIMITER PLUS RATIO-DISCRIMINATOR COMBINATION

Fig. 4. Ratio-Detector Circuit Diagrams

of ± 75 Kc. The audio output and AVC voltage were also measured with this deviation. With an input of 1.0 volt rms, the downward A-M capability was found to be about 45 percent. It was observed, however, that cutoff of the diodes occurred near the low-frequency end of the characteristic for amplitude-modulation percentages in excess of about 28 percent. With an input of 0.1 volt rms, cutoff occurred along the full trace at 55 percent, while the downward A-M capability was virtually 100 percent for inputs of less than .03 volt to the last i-f amplifier (less than 1 µv input to the receiver). Downward A-M capability is not, however, in itself an indication of good A-M rejection at low input levels, as can be seen from Figure 5, which shows the balanced A-M reduction factor to be about 0.7 at .03-volt input to the last i-f amplifier.

Similar sets of data were obtained for this ratio-detector, as well as for the Hazeltine ratio-detector of Figure 4 (b) and for the Hazeltine limiter plus ratio-detector combination of Figure 4 (c), using a deviation of ± 24 Kc. This deviation was used because of the difficulty of obtaining large enough patterns on the oscilloscope when a deviation of ± 6 Kc was employed. The data, however, is plotted in Figures 5 through 9 for a deviation of ± 6 Kc. It was possible to refer the measurements of ± 6 Kc for plotting without serious error because of the fact that the discriminator characteristic was practically linear over a range of more than 48 Kc. The balanced A-M reduction factor P_b and the AVC voltage should be practically the same for either deviation. The unbalanced A-M reduction factor for ± 6 Kc, however, was obtained by multiplying the value measured at ± 24 Kc by four, whereas the audio output for ± 6 Kc deviation was obtained by dividing the value measured at ± 24 Kc by four. As can be seen from the curves of Figures 5, 6, and 7, the Hazeltine ratio-detector was superior to the Model X-RDZ-2 detector from the standpoint of balanced A-M rejection for signals equivalent to less than 10 microvolts input to the X-RDZ-2 receivers, and performed about equally well insofar as unbalanced A-M rejection was concerned.

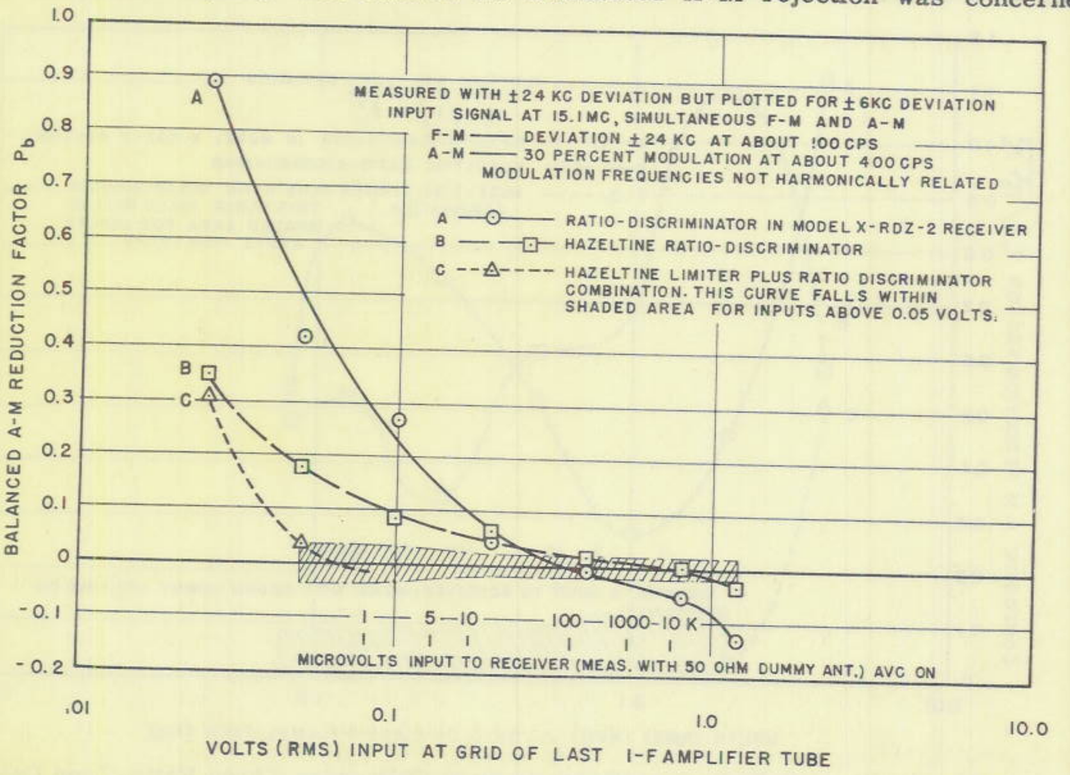


Fig. 5. Balanced A-M Reduction Factor vs Input Voltage for Three Ratio-Type Detectors

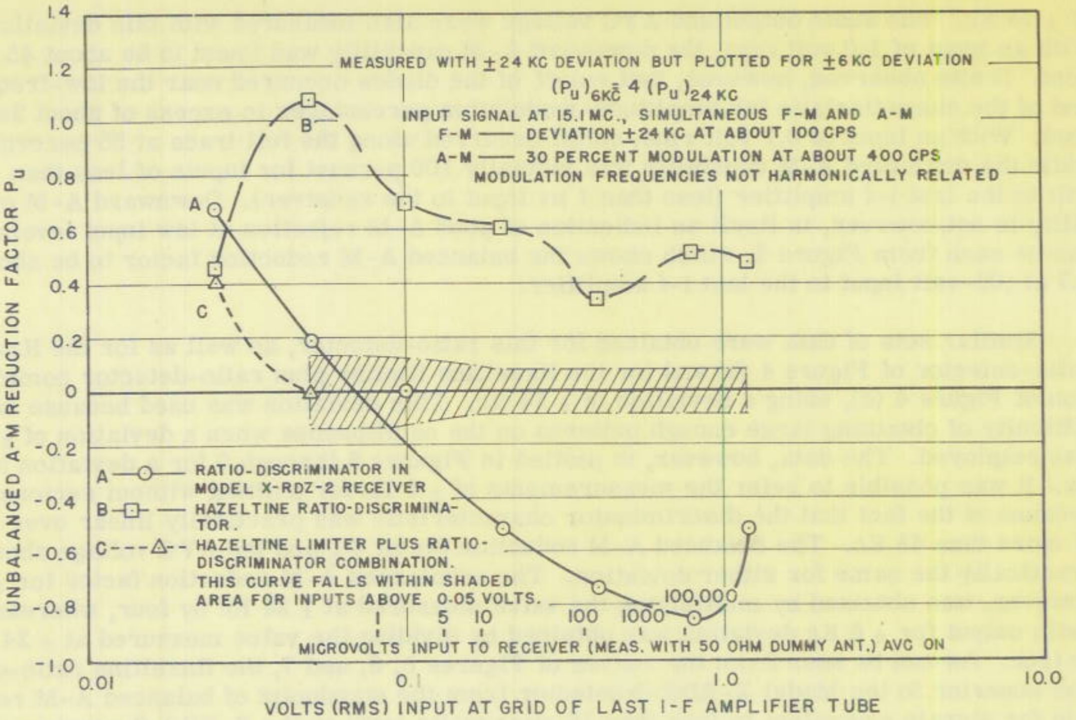


Fig. 6. Unbalanced A-M Reduction Factor vs Input Voltage for Three Ratio-Type Detectors

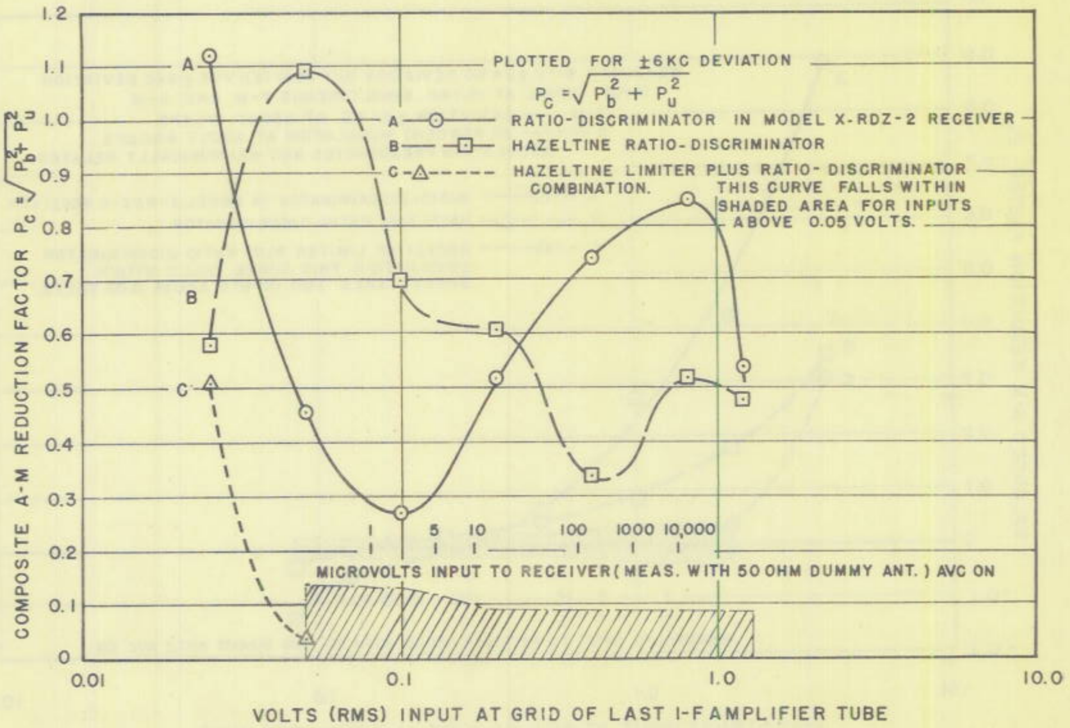


Fig. 7. Composite A-M Reduction Factor vs Input Voltage for Three Ratio-Type Detectors

The A-M rejection of the limiter plus ratio-detector combination was markedly superior to that of either form of ratio-detector alone. The audio outputs of the two ratio-detectors were almost exactly equal and were greater than that of the limiter plus ratio-detector combination by more than 30 percent for all signal levels. The detector in the Model X-RDZ-2 receiver developed about 65 percent more AVC voltage than the Hazeltine ratio-detector, and about 230 percent more than the limiter plus ratio-detector combination. The downward A-M capability of the Model X-RDZ-2 ratio-detector, as measured at inputs of 0.1 and 1.2 volts rms to the last i-f amplifier (equivalent to about 3 and over 100,000 microvolts input to the receiver with AVC on) was about 45 percent, as compared to 70 percent for the limiter plus ratio detector combination.

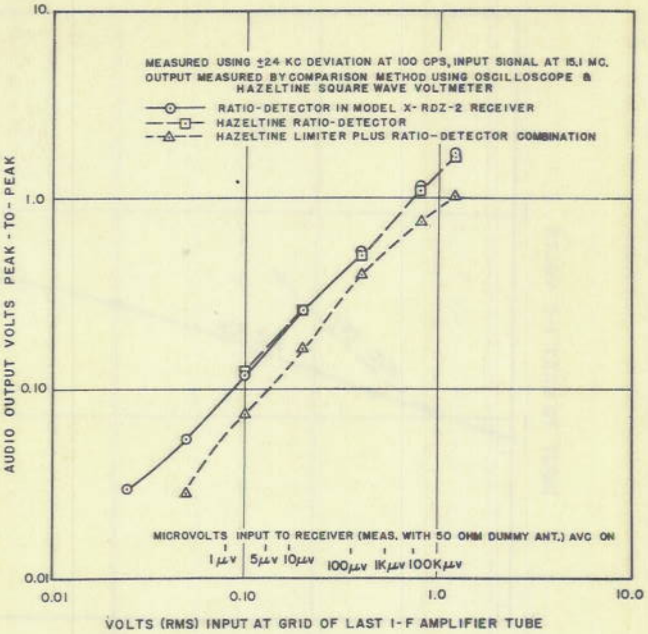


Fig. 8. Detector Audio Output vs Input Voltage for ± 6 Kc Deviation

The grid-to-plate gain of the last i-f amplifier (V-206) in the Model X-RDZ-2 receiver was measured in the following manner. An unmodulated signal of 0.1 volt was applied to the grid of the tube, and the AVC voltage was measured and found to be 2.85 volts. An r-f vacuum tube voltmeter was then connected to the plate of V-206, and the input signal increased to bring the AVC voltage back to 2.85 volts. The reading of the r-f voltmeter was 3.85 volts rms, indicating the grid-to-plate voltage amplification to be 38.5, which is considered to be a satisfactory value. The purpose of this gain measurement was primarily to determine if the gain was sufficiently low to insure stability. (See Haz. Report 7029, Page 22)

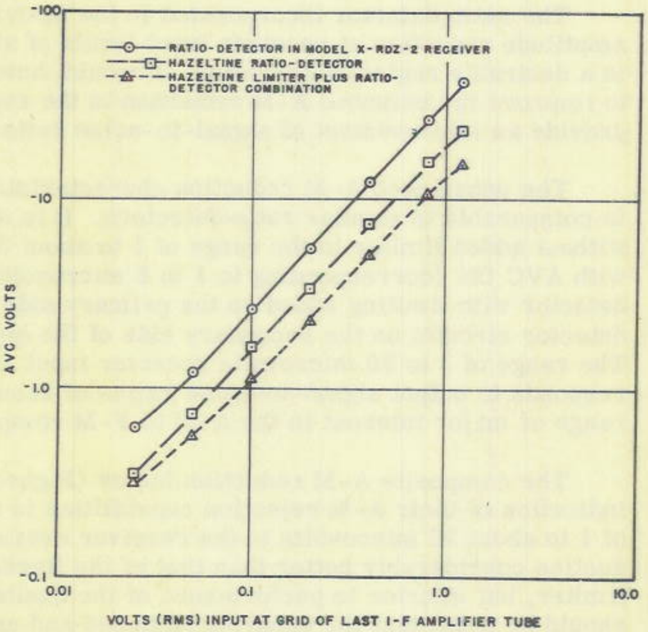


Fig. 9. AVC Voltage vs Input Voltage

Figure 10 shows the variation of input voltage appearing at the grid of the last i-f amplifier against the r-f input voltage applied at the input to the X-RDZ-2 receiver.

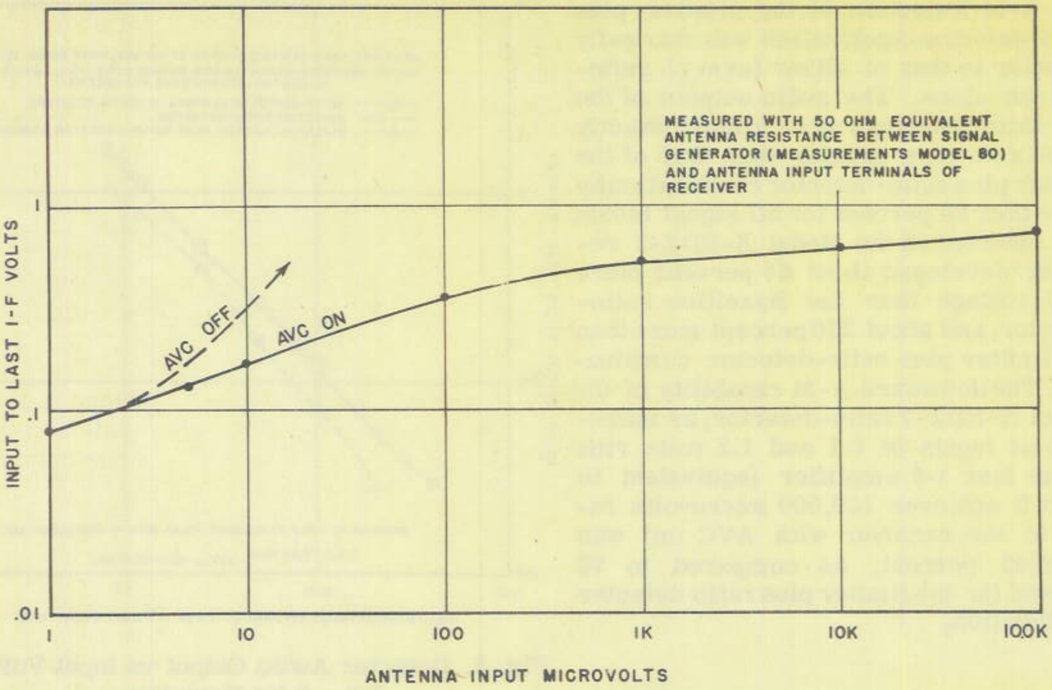


Fig. 10. 15.1 Mc Input to Last I-F Amplifier vs Antenna Input at 328.2 Mc

CONCLUSIONS

The ratio detector incorporated in the Model X-RDZ-2 provided its optimum balanced amplitude reduction at receiver input levels of about 10 to 1000 microvolts (Figure 5) which is a desirable region of operation. It would, however, be helpful for weak-signal operation to improve the balanced A-M reduction in the region below 10 microvolts, since this might provide an improvement of signal-to-noise ratio on the order of 6 db.

The unbalanced A-M reduction characteristic of the Model X-RDZ-2 detector (Figure 6) is comparable to similar ratio-detectors. It is superior to the Hazeltine ratio-discriminator without added limiter in the range of 1 to about 30 microvolts signal input to the receiver with AVC ON (corresponding to 1 to 8 microvolts with AVC OFF) but is inferior to a ratio-detector with limiting added on the primary side to supplement the limiting action of the detector circuits on the secondary side of the discriminator transformer (Figure 4 (c)). The range of 1 to 30 microvolts receiver input AVC ON (1 to 8 microvolts AVC OFF) corresponds to output signal-to-noise ratios of about +1 to over +30 db. This is the S/N ratio range of major interest in the A-M to F-M comparison trials.

The composite A-M reduction factor (Figure 7) of the various detector circuits is an indication of their A-M rejection capabilities in actual operation. Over a signal input range of 1 to about 30 microvolts to the receiver overall (AVC ON), the X-RDZ-2 shows A-M reduction considerably better than that of the Hazeltine ratio-detector without an added limiter, but inferior to performance of the limiter-plus-ratio-detector combination. It should be noted that the separate balanced and unbalanced A-M reduction factors are essentially of analytical rather than operational interest.

The Hazeltine version of the straight ratio detector has provision for adjusting the balanced A-M reduction factor (condenser C_A, Figure 4 (b)), together with grounding of the AVC resistor center, and utilizes the higher perveance Type 6AL5 duo-diode for better weak-signal A-M limiting, in place of the Type 6H6 used in the X-RDZ-2. These are desirable differences to consider for future ratio-detector applications.

Best general performance in these tests has been obtained with limiting on both primary and secondary sides of the discriminator transformer (Figure 4 (c)). Addition of a primary-side limiter would, however, result in some insertion loss (3 to 6 db) and reduction in reserve gain. By using germanium-type crystals for the primary-side limiter, relatively small additional space would be required to incorporate the added circuits in equipment such as the Model X-RDZ-2.

The A-M reduction factors in this report are measures of the performance of the various detectors studied in the presence of simultaneous sinusoidal amplitude and frequency modulation of a single carrier. They are not definite indications of the output signal-to-noise ratios encountered with a simple frequency-modulated carrier in the presence of fluctuation noise, as in the A-M to F-M comparison range trials.

The downward A-M capability of the various detectors is mainly of concern in the reception of rapidly fading or fluctuating input signal levels. This condition was not a factor of importance in those A-M to F-M comparison trials whose results have been used in evaluating the relative performance of the two types of modulation in BuShips Problem S1388. It is, however, desirable that, for service use, the downward A-M capability of F-M detectors be as great as feasible.

RECOMMENDATIONS

The problems of A-M reduction and downward A-M capability should be studied further, including all the important types of F-M detectors, and with particular attention given to the importance of these characteristics in naval radio applications.

The addition of primary-side limiting should be considered in all future applications of ratio-type F-M detectors.

ACKNOWLEDGEMENT

The courtesy and cooperation of the Hazeltine Electronics Corporation and its engineers in providing the facilities and techniques for the subject investigation are gratefully acknowledged.