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NRL REPORT NO. R-3232

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COMPARISON OF AM AND NARROW-BAND FM UHF COMMUNICATION SYSTEMS

APPENDIX C

DESIGN AND PERFORMANCE CHARACTERISTICS OF EQUIPMENT EMPLOYED

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COMPARISON OF AM AND NARROW-BAND FM UHF COMMUNICATION SYSTEMS

APPENDIX C

DESIGN AND PERFORMANCE CHARACTERISTICS OF EQUIPMENT EMPLOYED

W. E. W. Howe and A. R. Rumble

March 11, 1948

Approved by:

T. McL. Davis, Head, Radio Techniques Section
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ABSTRACT

A description is provided of the principal design and performance characteristics of the receivers, transmitters, and recording equipment used in the comparison of am with narrow-band fm in the uhf range. Comparison of a-m with f-m characteristics is made wherever possible. Such measurements as selectivity, resonant overload, signal-to-noise ratios, sensitivity, discriminator response, capture effect, overall frequency response, and modulation characteristics are described. In addition, deficiencies observed during the course of the a-m and f-m systems' evaluation are outlined.

It is shown that the Model X-TDZ-2 f-m transmitter provides freedom from the undesirable carrier power change during modulation obtained with the Model TDZ a-m transmitters, and that the Model X-RDZ-2 f-m receivers provide lower distortion when exactly tuned. The a-m receivers (as compared to f-m with 7 kc maximum deviation) provide superior signal-to-noise ratios when weak, marginal signals are received. The performance of the f-m receiver is largely dependent upon the following factors: accurate alignment of a single (discriminator) transformer and its stability after alignment; centering of the signal at or near the "center" of the frequency detector's response characteristic, and the frequency stability of that signal. These strict requirements make the f-m receiver more critical than the equivalent a-m version. From other general performance characteristics described in this report, there seems little choice between modulation systems.

PROBLEM STATUS

This report completes this phase of Problem No. R01-12 (S-1388). Other reports are in preparation which discuss other aspects of the comparison between am and fm.

AUTHORIZATION

NRL Problem No. R01-12 (BuShips Problem S-1388).

COMPARISON OF AMPLITUDE-MODULATED AND NARROW-BAND FREQUENCY-MODULATED UHF COMMUNICATION SYSTEMS
Appendix C: Design and Performance Characteristics

INTRODUCTION

This report is one of several separate appendices which describe the investigation authorized by Problem No. 39R01-12 (S-1388).[1] It was essential in the required comparison of a-m and f-m communication systems to be informed fully of the characteristics of the transmitting and receiving equipment used. The capabilities and limitations of all equipments employed had to be considered to permit a fair appraisal of the two types of modulation. Much of the data included in this report must therefore be considered as supplementary to the overall system tests in final evaluation of the results.

A description of a standard Model RDZ receiver is given with stress on those characteristics which are considered important in the comparison of a.m. and f.m. A short description of the modifications effected in the Model RDZ to convert to f-m detection is included, followed by an analysis of performance characteristics of the Model X-RDZ-2 f-m receiver. A similar description is given for the Model X-TDZ-2 transmitter, followed by measured performance characteristics. During the laboratory and field trials, a number of both these transmitting and receiving equipments were observed under operating conditions. This gave the Laboratory an excellent opportunity to observe any equipment shortcomings pertinent to the a-m vs f-m comparison, as well as any defects which may bear upon operational performance of the Model RDZ and TDZ equipments now in service. A description of such equipment deficiencies has therefore been included in this report.

DESCRIPTION OF MODEL RDZ A-M RECEIVER

General

The Model RDZ is the standard Navy shipboard receiver for general communications in the 200 - 400 Mc frequency range. The receiver may be manually operated or remotely

[1] BuShips ltr. 3653(925B) of 18 November 1946. NRL reports R-3230 through R-3235 inclusive, entitled Comparison of Amplitude-Modulated and Narrow-Band Frequency-Modulated Ultra-High-Frequency Communication Systems; as follows:
- Appendix A - Report R-3230, Final Summary Report and History of Problem
- Appendix B - Report R-3231, Theoretical Considerations
- Appendix D - Report R-3233, Laboratory Studies and Investigations
- Appendix E - Report R-3234, Shipboard Studies and Investigations
- Appendix F - Report R-3235, Airborne Studies and Investigations.

controlled to tune to any one of ten pre-set channel frequencies in this range. The receiver is of the superheterodyne type and the heterodyne oscillator is crystal-controlled. The receiver is designed primarily for voice reception, although provisions for connection to panoramic and video accessories have been made, and teletype or tone-keying reception would be feasible.

Preselection

The input impedance of the receiver is designed to match 50 ohms. This is the impedance of the auxiliary transmission line and the approximate free-space impedance of the antenna. Two tuned circuits precede the first r-f amplifier, and these provide maximum feasible selectivity ahead of the first tube, consistent with practical tracking or tolerable loss of antenna input power. The r-f amplifier tube is a Type 956, which is an "acorn" pentode with remote cut-off. AVC potential is applied to the grid of the r-f amplifier (with AVC "on"). The design of this stage minimizes cross-modulation and overload effects in the first amplifier.

Coupling between the plate of the r-f amplifier and the grid of the mixer or first detector is provided by a continuously variable gang-tuned circuit. There is only one r-f amplifier stage in the receiver. The use of more tuned circuits in the preselector, together with a higher center frequency for the i-f amplifier, would result in better image rejection and a reduction in other spurious responses.

Conversion

The heterodyning frequency is produced by a crystal oscillator and a chain of frequency multipliers, the tuned circuits of which are ganged with those of the signal frequency circuits. The converter tube is a Type 6F4 "acorn" triode. The oscillator and the various multiplier stages utilize one Type 6F4, two Type 6AK5 and two Type 6AC7 tubes. The crystal fundamental frequencies are between 4480 and 7100 kc. The final multiplier is designed to tune to the 48th harmonic of the crystal oscillator at frequencies between 200 and 325.7 Mc, employing a multiplier sequence of 3 x 2 x 2 x 2 x 2. Above this frequency the 64th harmonic is used, with a sequence of 4 x 2 x 2 x 2 x 2. The intermediate center frequency of the Model RDZ is 15.1 Mc. The shifting of multiplier sequence in the middle of the band not only saves crystals but also reduces the number of "blocked areas" to one. The so-called "blocked area" of the Model RDZ centers around 226.5 Mc, and is caused by third-harmonic voltages from the crystal saturating the i-f amplifier.

Another undesirable consequence of the use of fundamental crystals of these relatively low frequencies has been the generation of a relatively large number of spurious receiver responses close to desired signal resonance, where u-h-f receiver preselection is normally not particularly effective. A fuller discussion of these responses is found elsewhere,[2] but the presence of these responses should be remembered in analyzing data in other appendices of this report series. The signal frequency almost exclusively employed for the a-m vs f-m evaluations, 328.2 Mc, was chosen because, compared to other standard channels, it is relatively free from both receiver spurious responses and Model TDZ spurious emissions.[3]

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[2] NRL Report R-2667, dated 23 October 1945, entitled Test of Model CXHY (RDZ) Radio Receiving Equipment; NRL Report R-2929, dated 19 August 1946, entitled Test of Model RDZ-1 Radio Receiving Equipment, by W. E. W. Howe; NRL Report R-2967, dated 6 December 1946, entitled Interference Analysis of 100 Primary Communication Channels, 225-400 Mc (TDZ-RDZ Equipments), by A. W. Walters.

[3] NRL Report R-2967, *op. cit.*

I-F Amplification

There are five stages of intermediate-frequency amplification at 15.1 Mc in the receiver. All five tubes used are Type 6AB7 amplifiers. There is a single tuned circuit between the converter plate and the first i-f amplifier grid. The rest of the i-f transformers are conventional double-tuned circuits between stages, except that the third, fourth, and fifth transformers are of a variable-selectivity type. Selectivity is varied by mechanically changing the coupling between primary and secondary.

The six-db overall bandwidth of the i-f amplifier is designed to be 125 kc in the narrow and 250 kc in the broad selectivity conditions. This amplifier is considered to be more stable than the 18.6- and 30.2-Mc amplifiers found in other Navy 200-400-Mc communication equipments.[4] The "one-signal" selectivity characteristic (often called "weak-signal" selectivity) of the Model RDZ is superior to that of both the Models RED and RDR-MAR in performance at high-signal levels, as well as in stability.

AVC voltage is applied to the grid return circuits of the first three i-f amplifiers. The fourth i-f amplifier grid return is connected to a tap on a voltage divider across the AVC potential source. No AVC voltage is applied to the last i-f amplifier.

Demodulation

The second-detector used in the Model RDZ for a-m demodulation utilizes one section of a Type 6H6 diode rectifier. AVC voltage is obtained from the plate of the same section of the diode used for detection.

Noise Limiting

The other section of the Type 6H6 diode is used as a noise limiter. The circuit employed is of the simple series diode type, and is considered characteristic of modern a-m Navy communication receivers. An improved noise limiter circuit was devised for use in the a-m vs f-m tests, but it was never found necessary during the course of the tests to use any but the noise limiter circuit originally provided. A hum-bridge circuit is employed in the Model RDZ noise limiter circuit to reduce the hum fed from the limiter cathode into the following a-f circuits.

Audio Amplification

The first a-f amplifier is a triode-connected Type 6AB7 pentode. The amplifier stage is of conventional design, except for the application of partial AVC voltage to its control grid circuit. This amplifier is followed by the audio filter circuits which may be used or switched out of the circuit. These circuits consist of a high-pass followed by a low-pass network, giving a pass-band of between 350 and 3500 cps. Following this filter is a Type 6SN7 duo-triode operating as a d-c amplifier and series-diode silencer. A second Type 6AB7 pentode audio amplifier follows, which is resistance-coupled to the Type 6V6 tetrode used as an output tube. A relatively high degree of inverse feedback is provided from the

[4] NRL Report R-2667, op. cit., p. 4; NRL Report R-2929, op. cit., p. 3; NRL Report R-2960, dated 25 October 1946, entitled Analysis and Evaluation of Model RDR Radio Receiving Equipment Characteristics for Naval Service, by W. E. W. Howe, p. 5-7, p. 17; NRL Conf. ltr. C-1220-78/47 of 7 August 1947, concerning Model RED receiver.

plate of the output tube to the cathode of the preceding amplifier, which allows the output load to be varied from 600 to 30 ohms with less than 30 percent decrease of output voltage.

Other Features

The Model RDZ provides a number of features which are not important in a-m to f-m comparison, such as scanning provisions, video output, a silencer, and remote control. An r-f filter is provided for all circuits entering or leaving the receiver, except the antenna input and video and scanning output. An improved r-f filter assembly has been developed for the Model RDZ equipment.[5] It is feasible to provide the receiver with even greater protection than is now available against introduction of interference by paths other than the antenna, should experience with fleet installations indicate the need for greater protection.

The power consumption of the receiver is around 160 to 200 watts, without the Autotune operating. Space and performance factors make the internal operating temperatures of the equipment excessive, unless precautions are taken to provide adequate movement of ambient air.

Summary

The Model RDZ receiver has some undesirable characteristics such as high internal temperature rise, high hum level, and a multiplicity of spurious responses due mainly to crystal limitations. This receiver is considered comparable or superior to other crystal-controlled equipments in this frequency range. Hence, it was utilized for the a-m vs f-m evaluation as being characteristic of contemporary design in this frequency range.

DESCRIPTION OF MODEL X-RDZ-2 F-M RECEIVER

It was considered essential, for obtaining any valid comparisons of a m with f m to have the receivers for both types of modulation as nearly identical as possible. Hence, the f-m receivers used were modified Model RDZ's, designed as Models X-RDZ-2, and differing from the a-m model only in the demodulator (second-detector) stage. The National Company converted 12 Model RDZ receivers into Model X-RDZ-2 equipments under contract NObsr-39107. These 12 receivers were all used for various portions of the Laboratory analysis and comparison.

Consideration was given to the installation of a conventional Foster-Seeley type of phase discriminator, preceded by saturation limiting, in the Model X-RDZ-2. It soon became apparent that such a conversion was not practical with the Model RDZ equipment, due to the extremely high i-f gain (over 1,000,000 times amplification) required.[6] To obtain a less complex conversion with improved stability, a ratio-type of f-m detector was employed. The use of the ratio detector, a circuit now very commonly used in broadcast f-m equipment, gave several advantages for the evaluation. It was possible to convert from

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[5] NRL Report R-3127 dated 12 May, 1947, entitled Development of an Improved Radio-Frequency-Filter System for Model RDA/RDZ-1 Receiving Equipment, by W. C. Whitmer and E. L. Powell.

[6] National Company Interim Development Report for Navy Model X-RDZ-2 Radio Receiving Equipment, pp. 1-1, 2-1.

a-m to f-m reception with no circuit changes outside of the second-detector stage itself. This enabled the f-m and a-m receivers to be identical except for the last i-f transformer and the detector-diode circuits. No preceding limiter stages were required, since the ratio discriminator itself provided amplitude limiting. Problems of gain and stability which would have resulted from the addition of an i-f amplifier stage to provide low-level limiting preceding the second-detector were thus avoided. The ratio detector also provided a good source of AVC voltage as well as requiring a minimum of circuit modifications.

The conversion of the Model RDZ for f-m detection required the replacement of the last i-f transformer, Z-205, by a discriminator transformer, Z-206. It also required rewiring of the Type 6H6 detector and noise limiter circuit as a balanced demodulator employing both sections of the 6H6 diode. Figure 1 is the circuit diagram of the resulting conversion. The only other changes made in the original circuitry of the Model RDZ receiver were in the fourth i-f amplifier, where additional r-f by-passing was required on the filament leads and the grid return.[7] The additional by-passing was required to reduce a parasitic oscillation described elsewhere[8] and also later in this report.

Theoretical descriptions of the ratio detector may be found elsewhere.[9] This type of detector has its two diodes arranged to provide an output current balance, in contrast with the Foster-Seeley type, which depends on an output voltage balance. The ratio detector is

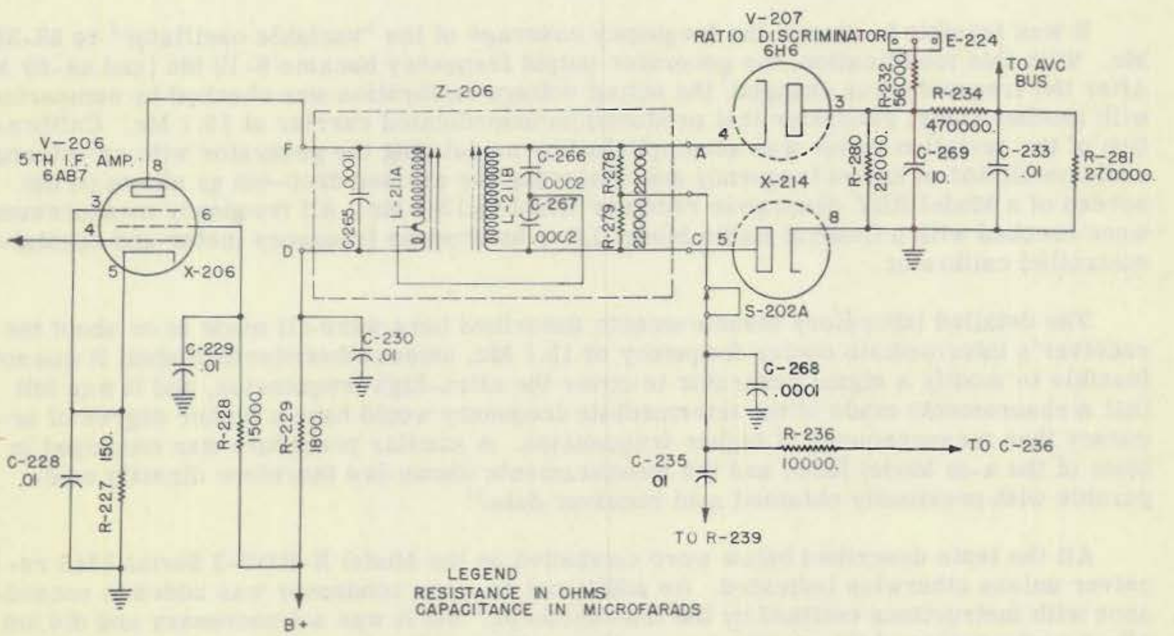

Fig. 1 - Schematic Circuit Diagram of Ratio Detector in IF/AF Amplifier of Model X-RDZ-2 Receiver

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[7] Model X-RDZ-2 Instruction Book (Navy Dept. and Bureau of Ships NAVSHIPS 900, 617).

[8] BuShips ltr. 2803(925Ca) dated 28 February 1947.

[9] NRL Report R-3194, dated November 1947, entitled Development and Performance of a Ratio Type FM Detector as Applied to the Model RDO Receiving Equipment, by D.R. Maxson. RCA Industrial Service Laboratory Reports: LB-645, dated 15 September 1945, entitled Ratio Detectors for FM Receivers, and LB-666, dated 1 March 1946, both by S. W. Seeley; LB-710, dated 26 May 1947, entitled The Ratio Detector, by J. Avins; Hazeltine Report No. 7028-R, dated 4 April 1947, entitled FM Detector System.

essentially a phase detector combined with a shunt limiter, the diodes serving both for detection and limiting.

PERFORMANCE CHARACTERISTICS OF MODEL X-RDZ-2

Introduction

Analysis and evaluation of the a-m version of the Model RDZ receivers have already been reported elsewhere,[10] and the characteristics of those equipments can be found in the references given. The characteristics of the f-m version are discussed in this report.

The f-m signal generator used in these tests was a modified Boonton Model 150-A. This signal generator produces its output frequency by the mixing of two oscillators. One oscillator, the so-called "fixed oscillator" is frequency-modulated by an internal a-f oscillator (or an external source) through a reactance tube. Thus a modulated output is provided, independent of the mean frequency of the selected mixer output. The center frequency of the "fixed oscillator" is 20 Mc; the original range of the other oscillator, the so-called "variable", was 21-30 Mc. The output frequency range of the generator before modification was 1-10, and 41-50 Mc.

It was feasible to change the frequency coverage of the "variable oscillator" to 28-39 Mc. With this modification, the generator output frequency became 8-19 Mc (and 48-59 Mc). After the frequency was changed, the output voltage calibration was checked by comparison with another signal generator that produced an unmodulated carrier at 15.1 Mc. Calibration of the deviation meter was accomplished by modulating the generator with an external audio oscillator of known frequency and observing the carrier drop-out as shown on the screen of a Model RBY panoramic receiver tuned to 15.1 Mc. All frequency measurements were checked with a General Radio Model LR-1 heterodyne frequency meter and crystal-controlled calibrator.

The detailed laboratory measurements described here were all made at or about the receiver's intermediate center frequency of 15.1 Mc, unless otherwise indicated. It was not feasible to modify a signal generator to cover the ultra-high frequencies, and it was felt that measurements made at the intermediate frequency would have a higher degree of accuracy than measurements at higher frequencies. A similar procedure was employed in tests of the a-m Model RDZ, and the measurements shown are therefore directly comparable with previously obtained a-m receiver data.[11]

All the tests described below were conducted on the Model X-RDZ-2 Serial 3243 receiver unless otherwise indicated. An additional by-pass condenser was added in accordance with instructions outlined by the manufacturer,[12] but it was not necessary and did not affect performance of this particular receiver. No re-alignment of the i-f or discriminator transformers was attempted or found necessary during the tests. The alignment of this receiver was maintained in the state in which it left the manufacturer.

All measurements were made with 115-volt, 60-cps power input, and at ambient temperatures between 20° and 25° C, with relative humidity generally below 50 percent. The

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[10] NRL Reports R-2667 and R-2929, op. cit.

[11] Ibid.

[12] BuShips ltr. 2803, loc. cit.

receiver was in a test position outside of the cabinet to facilitate measurements. This provided maximum ventilation and was doubtless a factor in obviating the need of re-alignment during tests. All measurements, unless otherwise indicated, were completed within a two-week period. The output was measured at the audio-output receptacle located at the rear of the receiver. The panoramic output connections were terminated with a 0.01-microfarad condenser and a 50-ohm resistor in series.

The frequency deviation used at all times was 6 kc, unless otherwise indicated. The results using this deviation do not differ greatly from those using a 7 kc deviation, and a correction from a curve included in this report can be applied if desired. (When frequency deviation values are mentioned in this report, symmetrical modulation is assumed, and the total frequency excursion is plus and minus the indicated frequency). At the time these measurements were made, the deviation to be used for the field and laboratory tests was believed to be 6 kc. The f-m generator was always modulated externally during these tests by a Hewlett-Packard Type 200-C audio oscillator in order to provide the best possible audio wave-form (lowest distortion). A Ballantine vacuum-tube voltmeter was used as an audio-output indicator across a 600-ohm non-inductive load.

Selectivity

The bandwidth of the entire i-f amplifier system of the Model X-RDZ-2 is designed to be approximately 120 kc at the points of 6-db attenuation. Measurements of i-f amplifier selectivity in the f-m receiver were made by a conventional method, i.e. by using an unmodulated signal from a standard a-m generator and a constant value of rectified (d-c) voltage developed at the demodulator output as the output reference level. The modified receiver is designed to be used with the receiver i-f bandwidth switch in the narrow position only. A conventional family of selectivity curves is shown in Figure 2, at maximum and reduced r-f gain conditions.

The measured bandwidth of the Model X-RDZ-2 i-f amplifier was as follows:

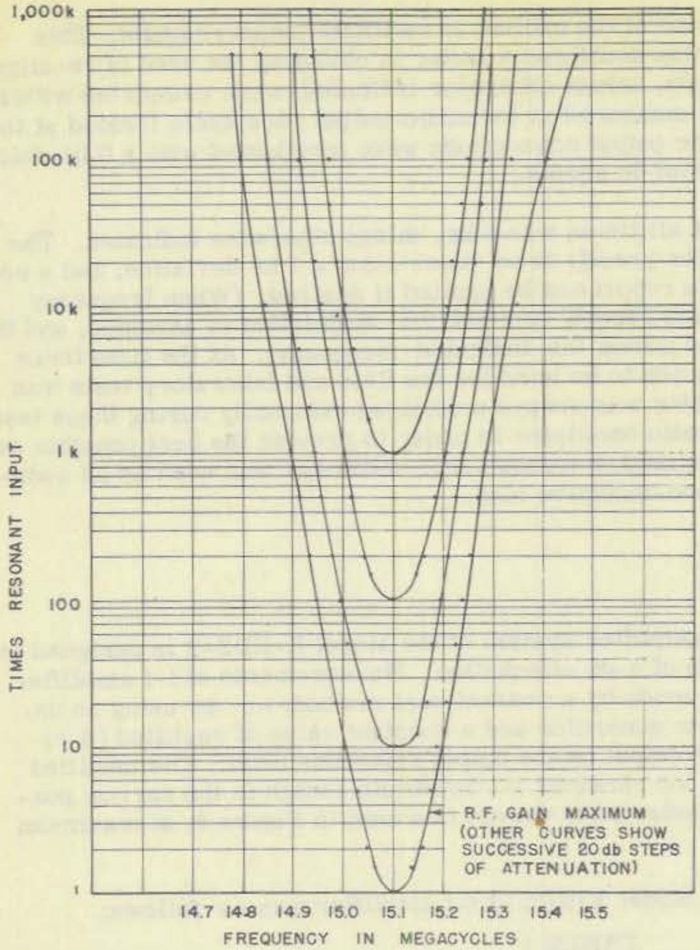
TABLE I

BANDWIDTH AT 6 DB DOWN FROM MAXIMUM RESPONSE		BANDWIDTH AT 60 DB DOWN FROM MAXIMUM RESPONSE	
R-F Gain Reduced (db)	Bandwidth (kc)	R-F Gain Reduced (db)	Bandwidth (kc)
0	110	0	390
20	115	20	390
40	120	40	370
60	115	60	345

This selectivity is closely comparable to that of the Model RDZ, and is well within specification requirements for the a-m receiver.[13] No evidence of regeneration in this particular f-m receiver was observed during these measurements.

The pre-selector in a Model RDZ or X-RDZ-2 receiver will contribute very little to the overall "one-signal" selectivity, since it is intended for the reduction of cross-modulation and other strong signal effects. Hence, the selectivity curve shown in Figure 2 will be substantially representative of the overall one-signal selectivity of an a-m receiver with the characteristics of the Model RDZ series. It will also be essentially the one-signal

[13] BuShips Specification RE-16R64, dated 1 August 1945, p. 17.



C-w input from Measurements 65B, Ser. 369, Sig. Gen. introduced at 6F4 converter grid through .01 μf condenser. Output measured with RCA Volt-Ohmyst Jr. Ser. 12832 between E-224 and ground. AVC off. I-f selectivity narrow. I-f sensitivity approx. 4 μv. Resonant input at full gain 4 μv. Frequencies checked with LR-1 heterodyne frequency meter and crystal calibrator.

Fig. 2 - I-F Selectivity for Model X-RDZ-2 Receiver Measured with C-W Signal

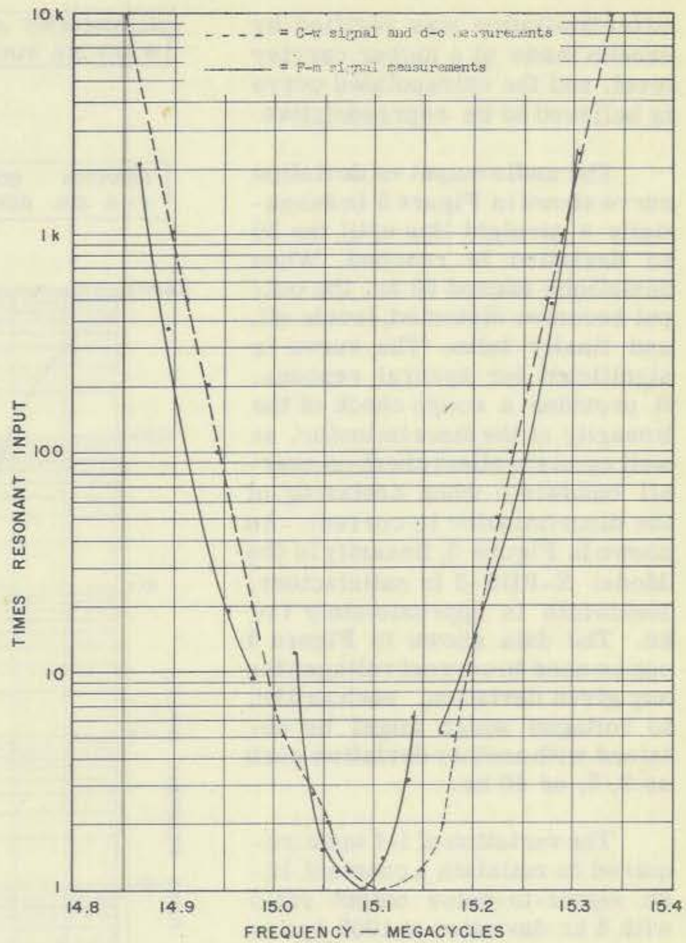
selectivity as measured with a frequency-modulated signal for an f-m receiver with the same i-f amplifier at frequencies outside the "re-entrant portion" of the discriminator characteristic. The results of such a measurement are shown in Figure 3.

The solid-line curve in Figure 3 shows the selectivity as measured with an f-m generator deviated 6 kc at 1000 cps, with the audio output maintained constant as the reference parameter. The dotted line is the comparable d-c measurement previously shown in Figure 2. The discontinuity in the f-m selectivity measurement is due to the high distortion and low output obtained at frequencies corresponding to the discriminator "re-entrant points." Data obtained in the "re-entrant" regions are not trustworthy and have not been plotted. As shown in Figure 3, at frequencies outside the "re-entrant" regions, the f-m selectivity values follow the d-c measurements quite closely. It is evident that the a-m and f-m one-signal selectivity curves will be closely comparable outside the "re-entrant" regions. This is significant in appraising f-m and a-m systems in vulnerability to direct adjacent-frequency interference or "breakthrough".

Vulnerability of the f-m receiver to c-w adjacent-frequency interference was also measured by a method similar to that customarily used for a-m overload tests. The results of this off-resonant two-signal test is shown in Figure 4. The desired resonant signal was fixed in frequency at 15.100 Mc and frequency-modulated 6 kc at 1000 cps. The c-w interference was adjusted to produce a 3-db decrease in desired signal at each off-resonant frequency. This characteristic was also measured with a greater deviation (40 kc) of the resonant signal, but the results were about the same, since the effect is primarily a function of selectivity, and not of the desired signal deviation. The characteristic was also measured with AVC on and was found to be very similar.

Since more than 3 db of output decrease ("capture") is obtained where the two signals are on the same frequency at the same voltage level, complete closing of the selectivity curve at the zero-db attenuation point is not shown. It is apparent, however, in comparing this data with Figure 2, that this interference curve is almost identical to the ordinary receiver selectivity curve. At very high input levels, some flattening of the characteristic on the low-frequency side is observed, probably due to overload in an i-f amplifier stage caused by AVC being off. Nonsymmetrical distortion of the characteristic below 10 times resonant input may be due to off-centering of the discriminator relative to the other i-f transformers.

Other two-signal measurements of adjacent frequency interference were made, but they added very little to the general conclusion. From the discriminator "re-entrant" level up to very strong interference levels the a-m and f-m receiver performances with adjacent frequency interferences were essentially equal. An investigation of very strong signal effects, such as overall cross-modulation and overload, was made with TDZ transmitters, and is discussed in the separate reports on the laboratory operational trials.[14]



D-c data same as shown in Fig. 2. F-m signal from Boonton 150-A F-M Sig. Gen. (modified for problem S-1388) fed into signal grid of 6F4 converter through .01-μf condenser. I-f narrow. AVC off. R-f gain -20 db from max. A-f narrow. NL, OM, Sil. off. A-f gain max. F-m signal deviated 6 kc at 1000 cps. Ballantine Model 300, Ser. 1187, Output Voltmeter and 600-ohm non-inductive output load. Resonant input 9 μv.

Fig. 3 - I-F Selectivity for Model X-RDZ-2 Receiver Measured with F-M Signal

Signal-to-Noise Ratio

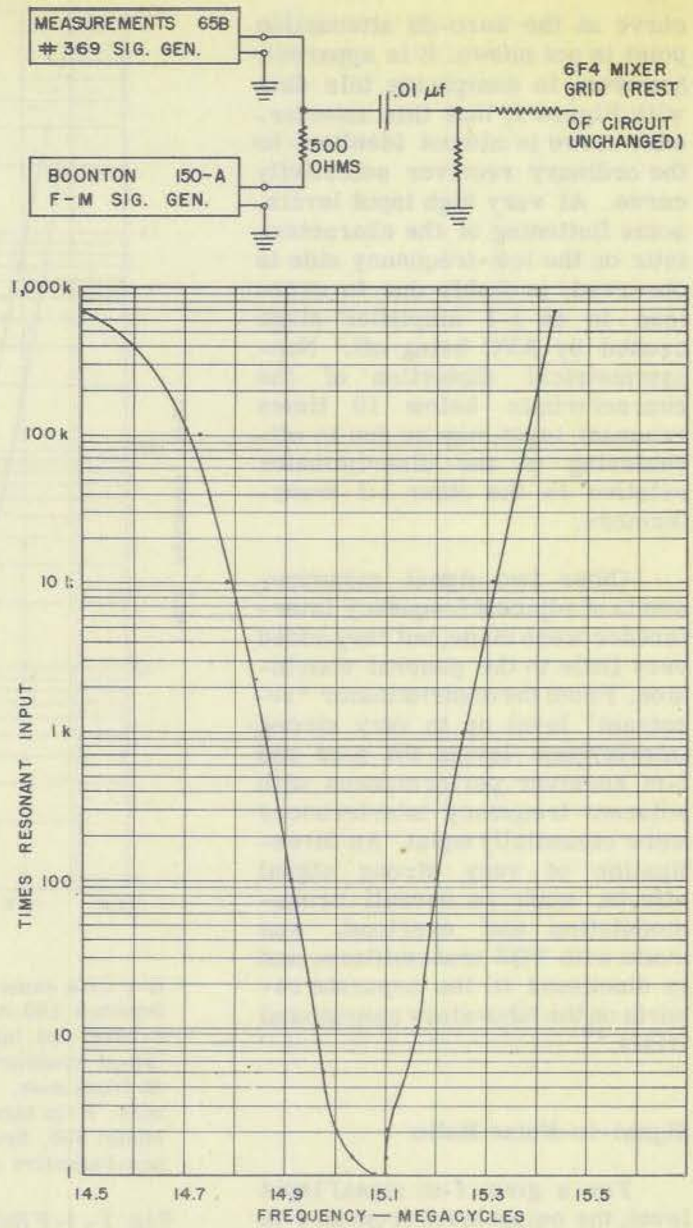
For a given f-m signal input level, the output level from an f-m receiver will depend on the frequency deviation of the received signal and also on where the signal frequency falls relative to the overall selectivity and discriminator frequency characteristics. Figure 5 is a plot of receiver audio output as a function of carrier deviation for the Model X-RDZ-2 equipment. This data was measured with the carrier centered at 15,100 kc, the approximate center frequency of the discriminator. The values measured below 4 kc deviation are not considered reliable and the curve has therefore been extrapolated as a straight line below 4 kc. Aside from the difficulty of reading the deviation meter for very low values, noise obscured the results below 4 or 5 kc deviation. This

[14] NRL Report R-3233, op. cit.

latter limitation was verified by checks made at a higher carrier level, and the extrapolated curve is believed to be representative.

The audio output vs deviation curve shown in Figure 5 is essentially a straight line until the 20 kc deviation is reached. When deviations exceed 50 kc, the output becomes distorted, levels off, and finally falls. The curve is significant for several reasons. It provides a rough check of the linearity of the discriminator, as well as an excellent check on over-all bandwidth when centering of the discriminator is correct. As shown in Figure 5, linearity in the Model X-RDZ-2 is satisfactory; bandwidth is approximately 110 kc. The data shown in Figure 5 can be used to correct voltages for any given deviation, such as 6 kc, to voltages which might be obtained with another deviation such as 2, 7, or 40 kc.

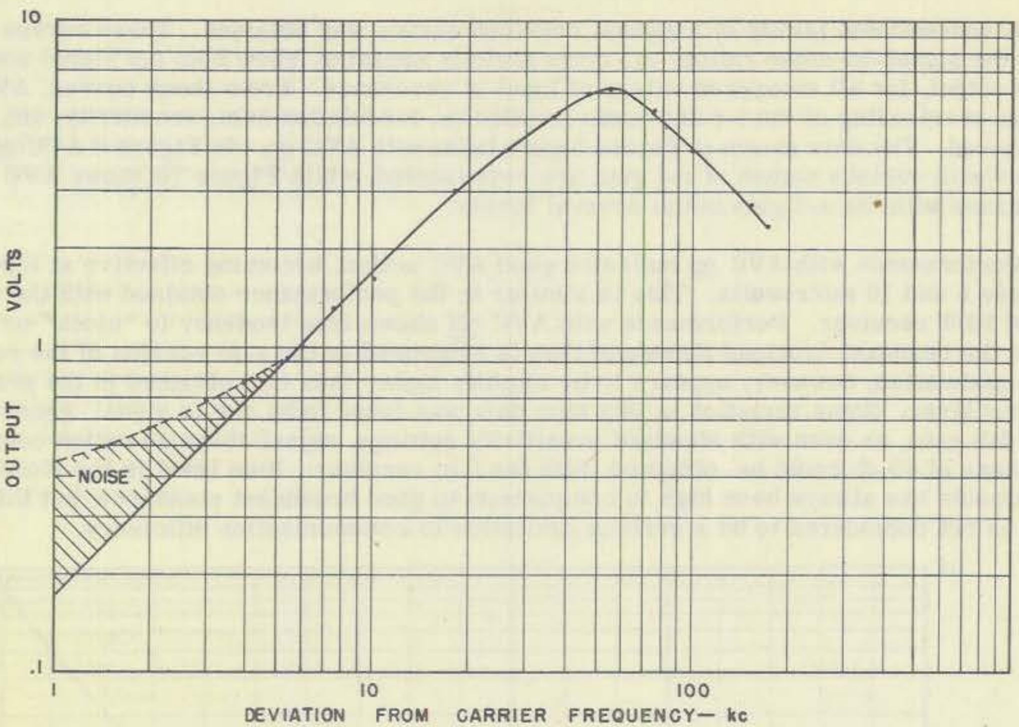
The variation of i-f input required to maintain a constant 10-db signal-to-noise output ratio with 6 kc deviation at 1000 cps is shown in Figure 6 as a function of i-f input frequency. The total signal output was held constant with modulation on, and the corresponding noise output was determined with modulation off. As discussed elsewhere,[15] at low signal levels when the noise peaks equal or exceed the carrier peaks, the receiver output noise level with fm may differ for the modulated and unmodulated conditions of the carrier. Since, however, the deviation with respect to bandwidth, prior to detection, is small in the system studies here, this error is unlikely to be a serious factor. The values shown in Figure 6 can be corrected, to any other deviation employed with the



F-m signal from Boonton Modified 150-A Sig. Gen., deviated 6 kc at 1000 cps. Carrier center frequency 15,100 kc, held constant. Unmodulated "undesired" carrier measurements from Model 65B off resonance - adjusted level to reduce desired modulated output level 3 db. AVC off. R-f gain max. I-f narrow. A-f narrow. NL, OM, Sil. off. Resonant input (actual) 3μv.

Fig. 4 - Two-Signal I-F Selectivity of Model X-RDZ-2 Receiver

[15] NBC Frequency Modulation Field Test by Raymond F. Guy and Robert M. Morris; published in V. 5; pp. 190-225; RCA Review, October 1940.



Signal center frequency at 15.1 Mc. Constant 3-μv input. 1000 cps modulation. AVC on. R-f gain max. A-f gain adjusted for 1.0-v output with 6-kc deviation. 600-ohm non-inductive output load. A-f bandwidth narrow. I-f bandwidth narrow. NL, OM, Sil. off. A-f gain fixed after initial setting.

Fig. 5 - Modulation Characteristics of Model X-RDZ-2 Receiver

Model X-RDZ-2 by use of the data shown in Figure 5.

Maximum sensitivity, as shown in Figure 6, is obtained at the discriminator (and i-f) center frequency, 15.100 Mc. When the carrier center frequency shifts 40 kc lower or 33 kc higher, the sensitivity drops 6 db, falling more rapidly as the carrier frequency approaches the "re-entrant" area. The comparable 3-db points are plus and minus 24 kc. The curve is shown to be discontinuous in the discriminator "re-entrant" regions, where the fundamental modulation frequency substantially disappears. The side responses are shown beyond this region. It should be noted that the side responses with the ratio detector are lower than those with a grid-bias limiter and Foster-Seeley type balanced detector.[16] The data shown in Figure 6 indicate better than average suppression of side responses in an f-m system. The problem of side response is one which should not be disregarded in appraising f-m systems as compared to a-m systems.

A curve similar to Figure 6, but showing the overall gain variation vs carrier center frequency (for constant output voltage only instead of for constant output S/N ratio), is shown in Figure 7. An attempt was made to obtain useful points in the "re-entrant" area, and this portion of the characteristic is dotted in Figure 7. The shape of the curve is very similar to the one for constant signal-to-noise ratio curve shown in Figure 6. No significant change in performance was observed with AVC on or off. Reserve gain was adequate at and near the discriminator center frequency.

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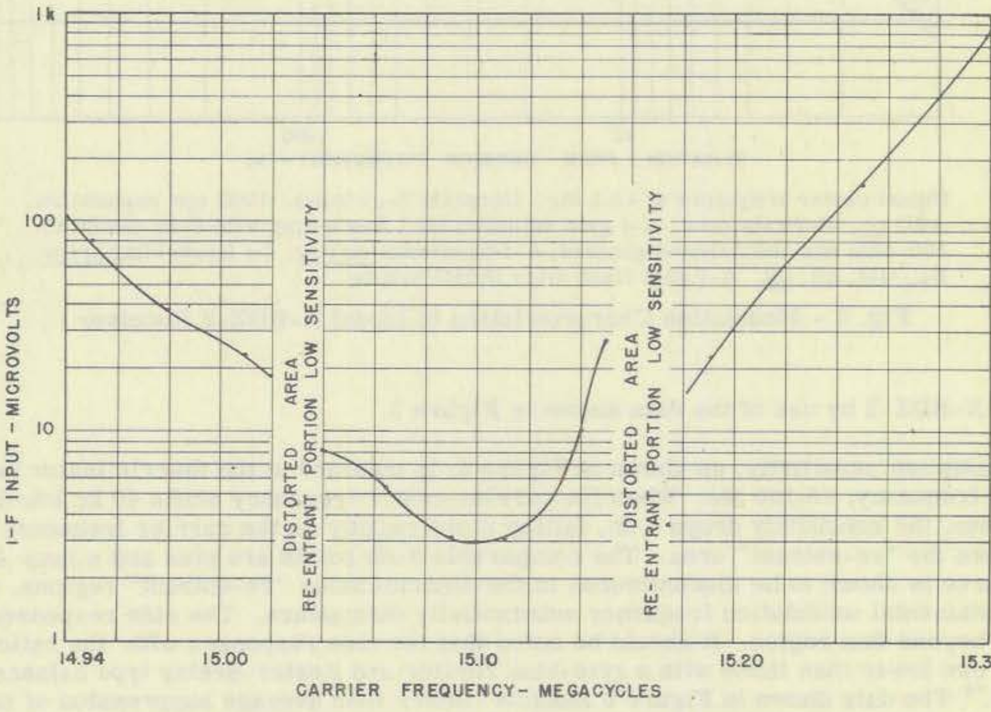
[16] Hazeltine Report No. 7028-R, op. cit., pp. 5-10.

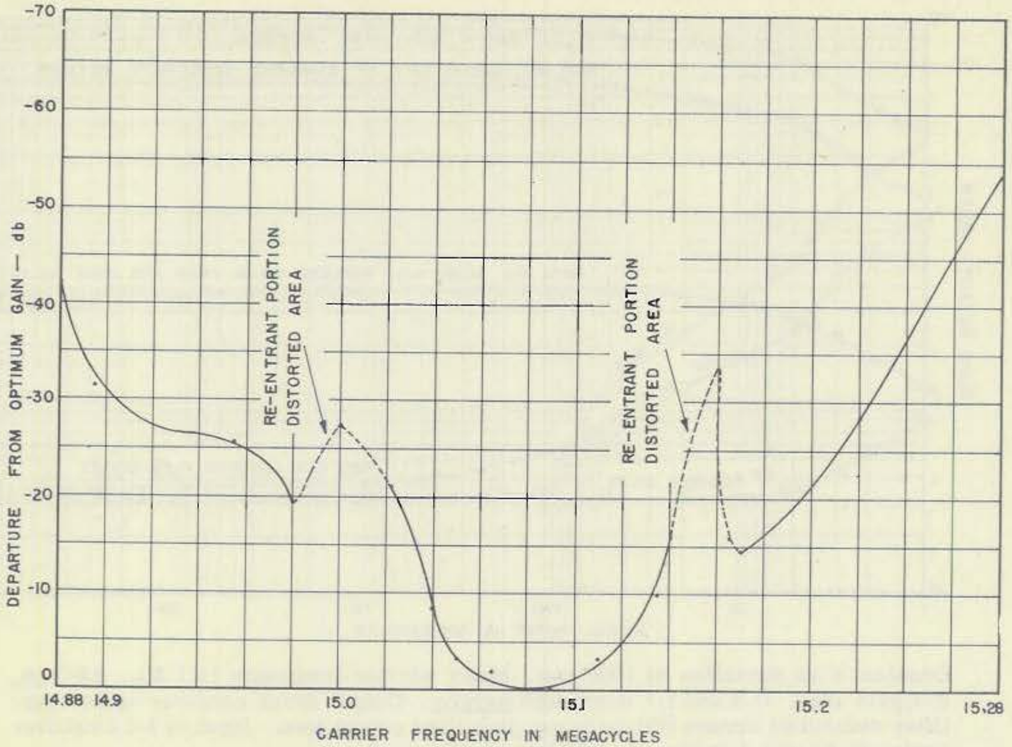
A conventional family of resonant overload curves was obtained. These curves also show the signal-to-noise ratios, or, more strictly speaking, show both the signal and the noise output, for all measured values of input at resonance. From these curves, AVC action, overloading of the i-f and audio amplifiers, modulation hum, sensitivity, etc., can be derived. The data shown in Figure 8 were taken with AVC on. In Figure 9 AVC off conditions with various values of r-f gain are represented, while Figure 10 shows AVC off conditions with the a-f gain set at several levels.

Performance with AVC on indicates good AVC action, becoming effective at input levels between 5 and 10 microvolts. This is similar to the performance obtained with the a-m Model RDZ receiver. Performance with AVC off shows less tendency to "block" or distort above the resonant overload threshold than is evidenced in the a-m version of the receiver. Hum modulation, however, appears to be slightly higher than that obtained in the production a-m receiver. Some variation in this hum data was found to be due to signal generators. With full gain, or even with standard sensitivity settings, signal-to-noise ratios considerably in excess of 40 db could be obtained with the f-m receiver. Hum level in the Model RDZ equipments has always been high in comparison to good broadcast standards, but this hum level is not considered to be a serious limitation to communication efficiency.



AVC on. Data with AVC off almost identical. Measured i-f input needed to produce constant value of signal-to-noise ratio at the output, 10 db, at a constant value of output voltage. Receiver a-f gain adjusted so that output with modulation on was 6 mw (1.9 v). Since signal-to-noise ratio was a constant 10 db, the noise level (carrier present, but modulation off) was 600 μw (.60 v). Constant carrier deviation 6 kc. Modulation frequency 1000 cps. Audio output load 600 ohms. Input at mixer grid as in other tests. Input from Boonton 150-A, Ser. 144, F-M Sig. Gen. (modified and calibrated) modulated externally with Hewlett-Packard 200-C, Ser. 6717, Audio Oscillator. Output measured with Ballantine Model 300, Ser. 1187, Output Voltmeter.

Fig. 6 - I-F Sensitivity vs I-F Input Frequency for Model X-RDZ-2 Receiver



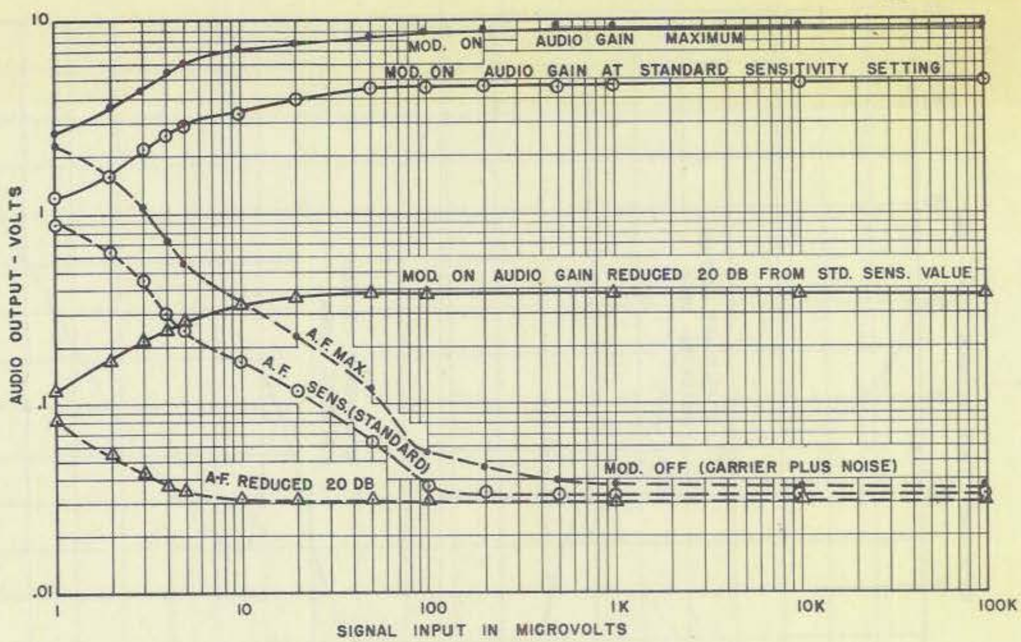
AVC off. Input level varied to obtain a constant value of output with fixed gain control settings, regardless of output signal-to-noise ratio. R-f gain reduced 20 db from max. gain. A-f gain max. Constant value of output 1.9 v across 600-ohm non-inductive load at audio amplifier output. Constant 6-kc deviation at 1000 cps. Other details similar to Fig. 6.

Fig. 7 - I-F Gain Variation vs I-F Input Frequency for Model X-RDZ-2 Receiver

Data shown in Figures 11, 12, and 13 are included to provide direct comparison with measurements made under essentially identical conditions on the a-m Models CXHY (RDZ) and RDZ-1. They show performance with AVC on and off for various gain control settings. Although the data taken on the a-m RDZ receivers were measured with broad i-f bandwidth and the data on the X-RDZ-2 receivers were of necessity measured with narrow i-f bandwidth, the curves are directly comparable, since the change of bandwidth has little effect on resonant overload performance. It should be noted that all the Model X-RDZ-2 curves show excellent overload performance even with AVC off, although Figures 8 and 11 indicate that AVC on is, in general, preferable from the operational point of view.

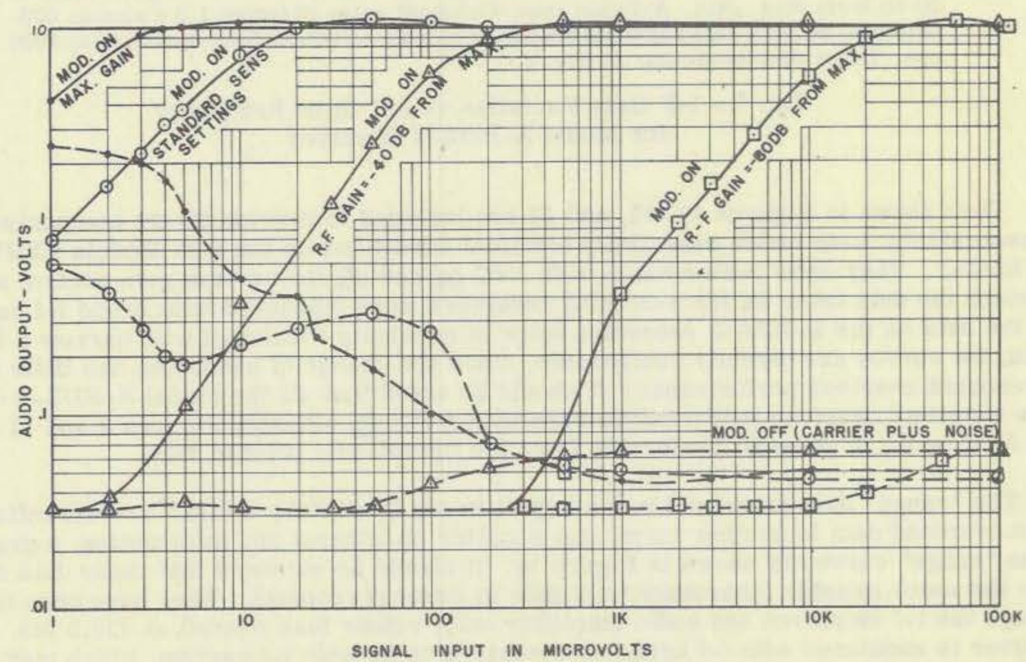
The "range" data discussed in the report in the laboratory trials,[17] are essentially resonant overload data in another form. As a matter of interest and information, a graph similar to the "range" curves is shown in Figure 14. It should be stressed that these data differ from the more reliable laboratory trial data in several respects. They have been obtained through the i-f amplifier and audio amplifier only, rather than overall at 328.2 Mc. The a-m receiver is measured with i-f broad as compared to fm with i-f narrow, which may tend to somewhat favor fm on an output signal-to-noise ratio basis. The curves shown have been

[17] NRL Report R-3233, op. cit.



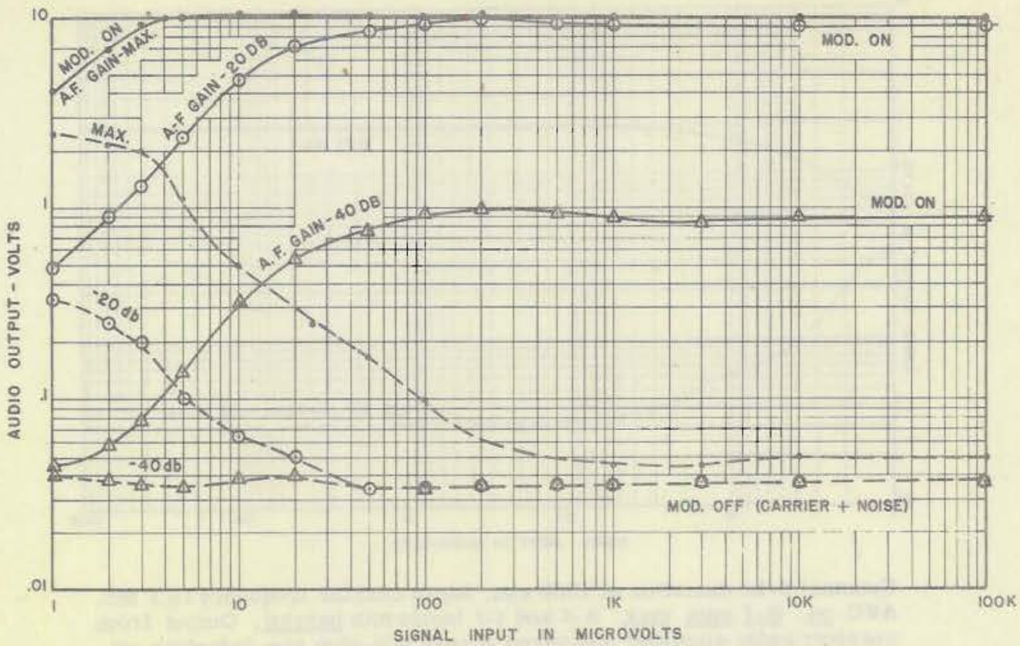
Constant 6-kc deviation at 1000 cps. Mean carrier frequency 15.1 Mc. AVC on. R-f gain max. A-f and i-f bandwidth narrow. Output from receiver audio amplifier measured across 600-ohm non-inductive output load. Input at i-f amplifier center frequency introduced at 6F4 converter grid.

Fig. 8 - Audio-Channel Resonant Overload for Model X-RDZ-2 Receiver



Constant 6-kc deviation at 1000 cps. Mean carrier frequency 15.1 Mc. AVC off. A-f gain max. A-f and i-f bandwidth narrow. Output from receiver audio amplifier measured across 600-ohm non-inductive output load. Input signal introduced to i-f amplifier at 6F4 converter grid.

Fig. 9 - Audio-Channel Resonant Overload for Model X-RDZ-2 Receiver



Constant 6-kc deviation at 1000 cps. Mean carrier frequency 15.1 Mc. AVC off. R-f gain max. A-f and i-f bandwidth narrow. Output from receiver audio amplifier measured across 600-ohm non-inductive output load. Input introduced to i-f amplifier at 6F4 converter grid.

Fig. 10 - Audio-Channel Resonant Overload for Model X-RDZ -2 Receiver

derived from the resonant overload curves of this and the Model RDZ-1 report.[18] The f-m curve has been corrected by use of the data shown in Figure 5 from 6 to 7 kc deviation; the a-m data have been corrected from 30- to 100-percent modulation by adding a factor of 10 db to the signal-to-noise output ratio.

The curve shown in Figure 14 resembles those obtained in the laboratory trials. The so-called "cross-over" occurs at 16 db signal-to-noise ratio. Cross-over in the laboratory trials occurred between 15 and 20 db. Beyond 1,000 microvolts, both curves would be "flattened" by the hum level. The input signal level producing cross-over on an overall basis would be shifted by the r-f gain or loss in the preselector.

It is apparent from Figure 14 that the difference between the two types of modulation is not tremendous in regard to output signal-to-noise ratio. Operational changes in frequency deviation in the f-m transmitter or deterioration of receiver performance could produce more difference than that obtained between the a-m and f-m curves shown in Figure 14.

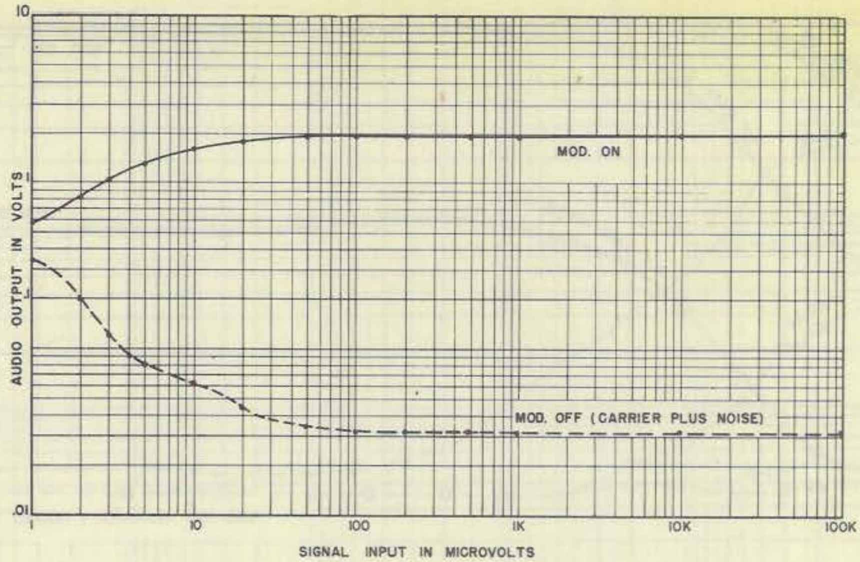
The output hum level chargeable to the ratio detector and audio amplifier of the Model X-RDZ-2 was measured. With all controls adjusted for maximum hum level, the total (rms) hum measured across 600 ohms was 0.029 volts or 1.4 microwatts. This compares closely with 1.2 microwatts for the Model RDZ-1,[19] 3.3 microwatts for the Model CXHY,[20] and the specification requirement for these equipments of 2.0 microwatts.[21]

[18] NRL Report R-2929, op. cit.

[19] Ibid., p. 6.

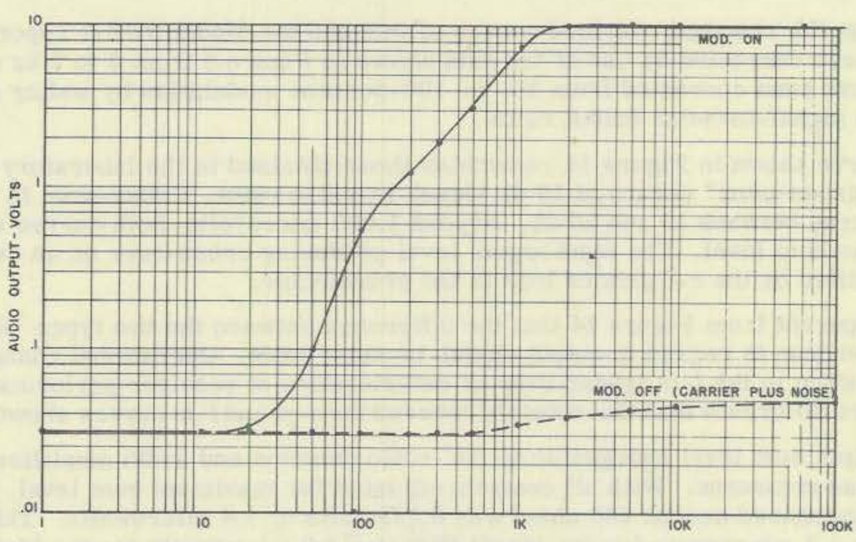
[20] NRL Report R-2667, op. cit., p. 10.

[21] BuShips Specifications RE-16R64, op. cit., p. 21.



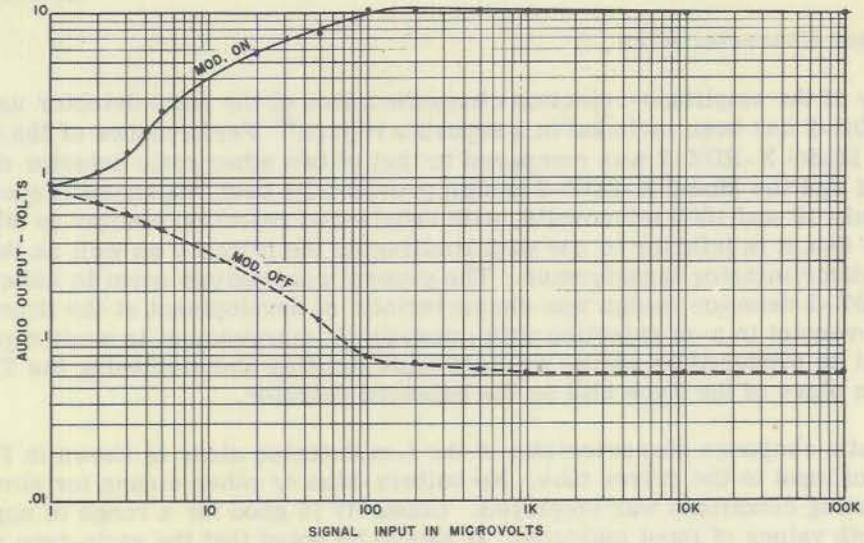
Constant 6-kc deviation at 1000 cps. Mean carrier frequency 15.1 Mc. AVC on. R-f gain max. A-f and i-f bandwidth narrow. Output from receiver audio amplifier measured across 600-ohm non-inductive output load. A-f gain adjusted for 1.9-v output with 300-μv input. Input introduced to i-f amplifier at 6F4 converter grid.

Fig. 11 - Audio-Channel Resonant Overload for Model X-RDZ-2 Receiver



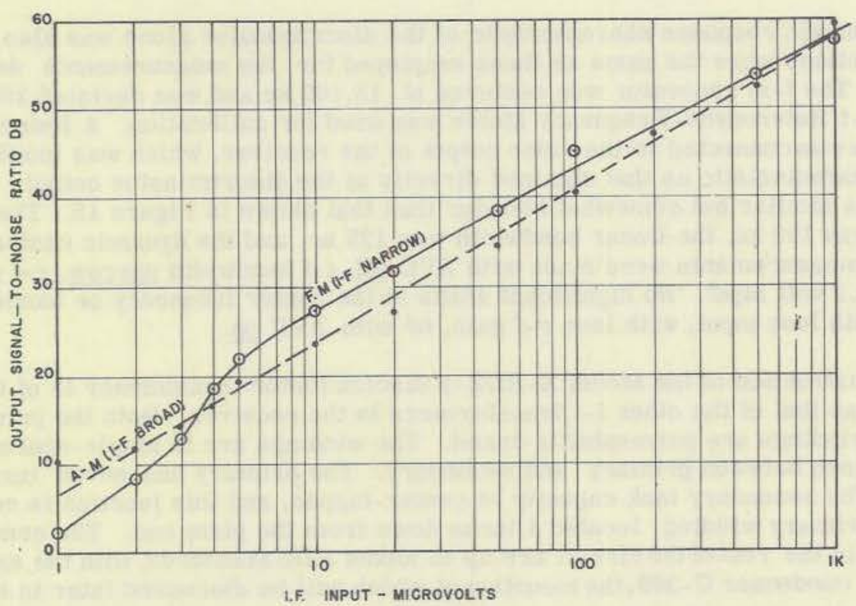
Constant 6-kc deviation at 1000 cps. Mean carrier frequency 15.1 Mc. AVC off. A-f gain max. R-f gain adjusted to give 1.9-v output with 300-μv input (r-f gain reduced approx. 60 db). A-f and i-f bandwidth narrow. Output from receiver audio amplifier measured across 600-ohm non-inductive output load. Input introduced to i-f amplifier at 6F4 converter grid (across R-115).

Fig. 12 - Audio-Channel Resonant Overload for Model X-RDZ-2 Receiver



Constant 6-kc deviation at 1000 cps. Mean carrier frequency 15.1 Mc. AVC off. R-f gain max. A-f gain adjusted to give 1.9-v output with 3-μv input. A-f and i-f bandwidth narrow. Output from receiver audio amplifier measured across 600-ohm non-inductive output load. Input to i-f amplifier introduced at 6F4 converter grid (across R-115).

Fig. 13 - Audio-Channel Resonant Overload for Model X-RDZ-2 Receiver



RDZ-1, Ser. 1, a-m receiver. X-RDZ-2, Ser. 3243, f-m receiver. Measured through i-f amplifier. Data compares 100% am with 7-kc deviation fm. AVC on. A-f bandwidth narrow. 1000 cps tone modulation. NL, OM, Sil. off. Input carrier frequency 15.1 Mc.

Fig. 14 - "Range" - A M vs F M

Discriminator Characteristics

A study of the amplitude-rejection characteristics of the ratio detector used in the Model X-RDZ-2 has been included in a separate report.[22] Performance of the detector used in the Model X-RDZ-2 was compared to that of two other ratio detector designs. It was found that the Model X-RDZ-2 design provides its best "balanced" rejection between approximately 10 and 1000 microvolts, with unbalanced rejection similar to other ratio detectors; but that it is inferior to one with limiting on the primary as well as the secondary side of the discriminator transformer. The general conclusions seem to indicate that the Model X-RDZ-2 detector design was characteristic of development at the time, but that some improvement in a-m rejection with consequent improvement in weak signal-to-noise ratios might be produced by adding primary-side limiting and employing the Type 6AL5 duo-diode in place of the Type 6H6 as the balanced detector.

The static response characteristic of the f-m detector alone is shown in Figure 15 for two values of input to the driver tube. No battery-bias or other means for simulating dynamic operating conditions was employed. Linearity is good for a range of approximately 70 kc for both values of input indicated. It should be noted that the ratio-type of f-m detector yields static characteristics which differ in output-voltage amplitudes and absolute voltage values from characteristics measured by "dynamic" methods. The static curves shown, however, are valuable for indicating linearity, etc.

Figure 16 shows similar static characteristics, measured through the entire i-f amplifier. The effect of the added selectivity upon the skirts or outer slopes of the characteristic is immediately apparent. The general shape and linearity of the curve is similar to that of Figure 15. About 70 kc of linear bandwidth is available and the slope does not change to any appreciable extent beyond the 200-microvolt level. Center shift is on the order of 3 kc. Data shown are with AVC off. Data were also recorded with AVC on, but were almost identical to those obtained with AVC off.

The dynamic response characteristic of the discriminator alone was also measured. Input connections were the same as those employed for the measurements described in Figure 15. The f-m generator was centered at 15,100 kc and was deviated 200 kc at 100 cps. A Type LR-1 Heterodyne-Frequency Meter was used for calibration. A Reiner Model 556 oscilloscope was connected to the video output of the receiver, which was found to produce the same characteristic as that obtained directly at the discriminator output. The curve obtained was similar but somewhat broader than that shown in Figure 15. The peak-to-peak bandwidth was 190 kc, the linear bandwidth was 125 kc, and the dynamic center was 15,104 kc. These measurements were made with AVC off, i-f bandwidth narrow, r-f gain at maximum, and 0.1 volt input. No significant shifts in the center frequency or bandwidth were observed with less input, with less r-f gain, or with AVC on.

The construction of the Model X-RDZ-2 discriminator transformer is of the same type and quality as that of the other i-f transformers in the receiver. Both the primary and secondary windings are permeability-tuned. The windings are in single-spaced grooves, with 11/16 inch between primary and secondary. The primary has seven turns; the secondary six. The secondary tank capacity is center-tapped, and this junction is connected to a tap on the primary winding located 4 turns down from the plate end. The components and layout used in the rest of the circuit are up to Model RDZ standards, with the exception of the electrolytic condenser C-269, the mounting of which will be discussed later in this report.

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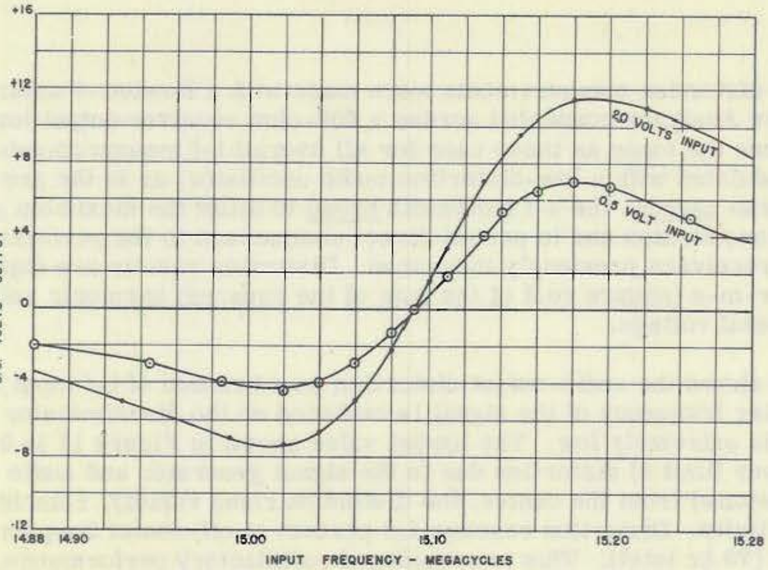
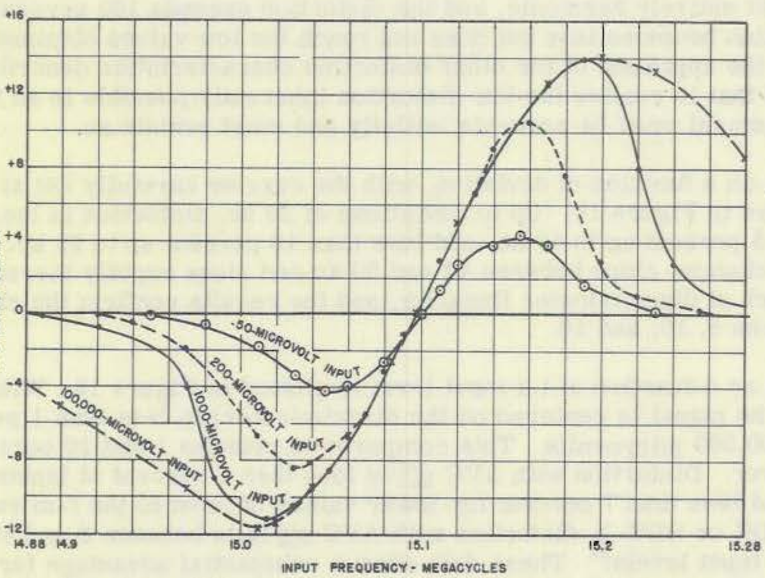
[22] NRL Report R-3190, dated November, 1947, entitled Investigation and Study of the AM Reduction and Downward AM Characteristics of Three Forms of the Ratio-Type FM Detector, by D. R. Maxon.



Input to grid of V-206 (6AB7 5th i-f amplifier), input lead from transformer Z-204 removed. C-w signal from Measurements 65B, Ser. 369, Sig. Gen. Output between discriminator a-f output and AVC resistor center tap measured with RCA Volt-Ohmyst Jr., Ser. 12832. AVC off.

Fig. 15 - Static Discriminator Characteristics (Discriminator Alone) for Model X-RDZ-2 Receiver



Input to mixer grid (across R-115) from Measurements 65B, Ser. 369, Sig. Gen. Unmodulated c-w signal. I-f bandwidth narrow. Output measured with RCA Volt-Ohmyst Jr., Ser. 12832, between discriminator a-f output and center tap of AVC resistor. (AVC resistor, R-280, 22,000 ohms, replaced by two 11,000-ohm resistors in series.) A-f output point at junction of R-278 and R-279. AVC off.

Fig. 16 - Static Discriminator Characteristics (through I-F Amplifier) for Model X-RDZ-2 Receiver

Distortion

All output distortion measurements were made with a Hewlett-Packard Type 300-A Harmonic-Wave Analyzer connected across a 600-ohm receiver output load. The input connections were the same as those used for all overall i-f measurements, and the fm generator was modulated with a low-distortion audio oscillator, as in the previous tests. The i-f bandwidth was <u>narrow</u>, the a-f bandwidth <u>broad</u> to allow the maximum possible range of harmonic transmission and to permit direct comparison to the performance obtained with the a-m receivers previously measured. Distortion results are expressed as the percentage of r-m-s (square root of the sum of the squares) harmonic voltage compared to the fundamental voltage.

Figure 17 shows the audio-output distortion as a function of i-f input frequency. When the mean carrier frequency of the signal is centered on the discriminator center frequency, the distortion is extremely low. The lowest value shown in Figure 17 is 0.3 percent, which may be the lower limit of distortion due to the signal generator and audio oscillator. As the signal is detuned from the center, the distortion rises rapidly, coinciding with decreasing sensitivity. Distortion reaches 1.8 percent at off-center frequencies of minus 45 and plus 25 kc (70 kc total). This is considered satisfactory performance, but it must be stressed that the f-m advantage of lower output distortion is dependent to a great extent on proper centering of the received signal carrier on the discriminator characteristic. If such centering cannot be realized and maintained, the inherent f-m advantage of low receiver distortion may be abrogated.

When a signal becomes detuned enough to fall near the "re-entrant" portion of the discriminator characteristic, the distortion becomes very high. At off-center frequencies of minus 71 and plus 48 kc, the distortion reaches 10 percent. At the worst points, the output is almost entirely harmonic, and the distortion exceeds 100 percent. On the outer slopes, distortion becomes less but does not reach the low values obtained at the center frequency. In the appraisal of the other distortion characteristics described below, it must be emphasized that to realize the low distortion inherently possible in an f-m receiver, tuning and alignment must be accurate initially and must remain so.

Distortion as a function of deviation, with the carrier carefully set at the discriminator center, is shown in Figure 18. Up to deviations of 25 kc, distortion is less than 1 percent; it is less than 5 percent up to 45 kc, and less than 10 percent up to 52 kc. The distortion curve rapidly changes slope between 40 and 50 kc and rises rapidly thereafter. The curve is another check of discriminator linearity, and the results confirm the characteristics shown in Figures 5, 15, and 16.

Distortion as a function of i-f input level is plotted in Figure 19. With AVC <u>on</u>, distortion (when the signal is centered on the discriminator) is less than 1 percent for input values up to 100,000 microvolts. This compares to between 1 and 10 percent measured on the a-m receiver. Distortion with AVC <u>off</u> is less than 1 percent at inputs greater than 50 microvolts, and less than 7 percent for lower values of input to the f-m receiver. With the a-m Models RDZ or RDZ-1, distortion with AVC <u>off</u> falls between 3 and 80 percent over the same range of input levels.[23] These data show a substantial advantage for fm, particularly with AVC <u>off</u>; but, as mentioned before, accurate tuning is required on fm to obtain this advantage. Equipment instabilities and crystal tolerances all tend to reduce this marked improvement.

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[23] NRL Report R-2929, <u>op. cit.</u>, Plate 25.
NRL Report R-2667, <u>op. cit.</u>, Plate 21.

Constant 1000-μv input; 6-kc deviation at 1000 cps. A-f level set to constant 1.9 v with AGC. 600-ohm non-inductive output load. A-f bandwidth broad. I-f bandwidth narrow. NL, OM, Sil. off. AVC on.

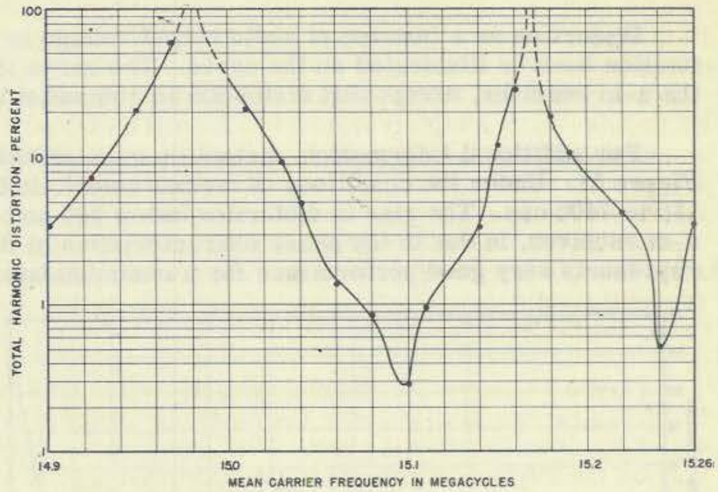


Fig. 17 - Audio Output Distortion vs I-F Input Frequency for Model X-RDZ-2 Receiver

Constant 1000-μv input at 1000 cps. Carrier input at 15.1 Mc. A-f gain adjusted at all deviations to obtain 1.9 v output across 600-ohm non-inductive output load. AVC on. NL, OM, Sil. off. A-f bandwidth broad. I-f bandwidth narrow.

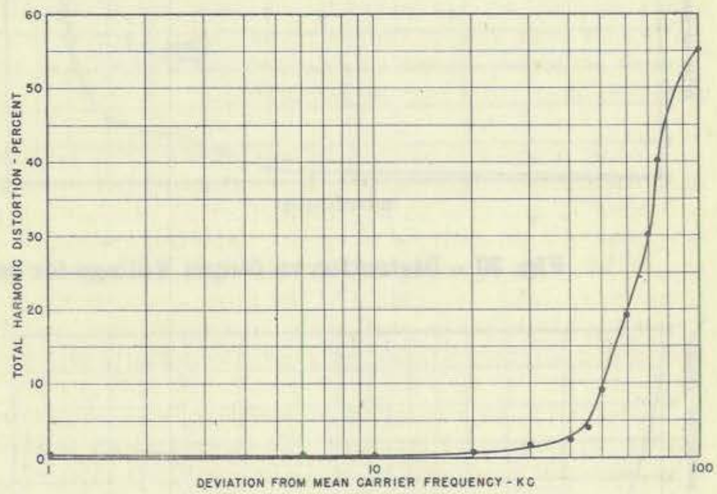


Fig. 18 - Distortion vs Deviation for Model X-RDZ-2 Receiver

Constant 6-kc deviation at 1000 cps. A-f bandwidth broad. I-f bandwidth narrow. R-f gain max. A-f gain adjusted at each level for 1.9 v output across 600-ohm non-inductive load. NL, OM, Sil. off. Input at i-f center frequency 15.1 Mc. Hewlett-Packard 300-A Harmonic Wave Analyzer. Boonton Modified 150-A, Ser. 144 F-M Sig. Gen. modulated externally with Hewlett-Packard 200-C, Ser. 6717 Audio Oscillator.

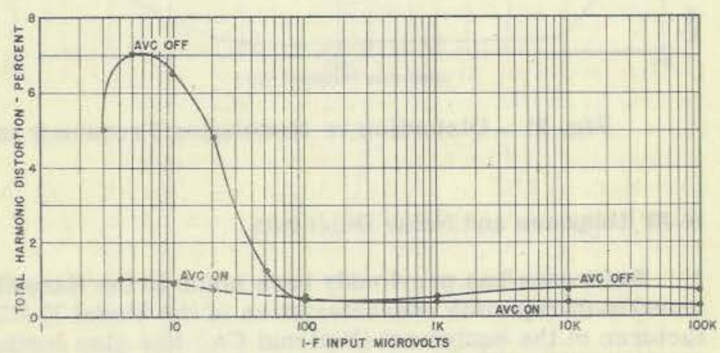
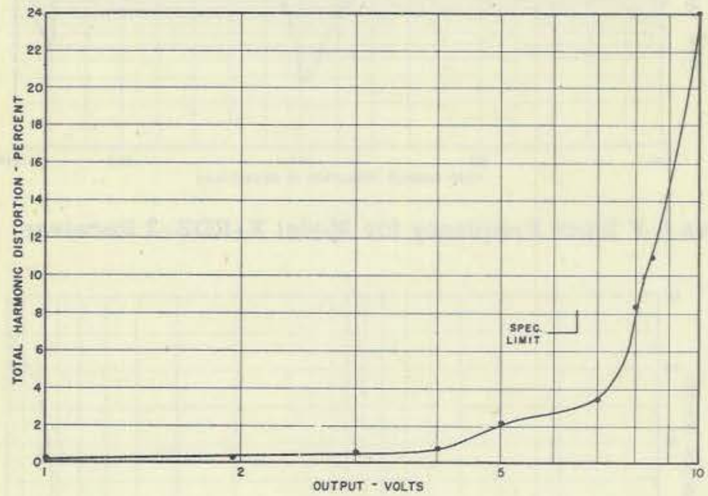


Fig. 19 - Distortion vs I-F Input for Model X-RDZ-2 Receiver

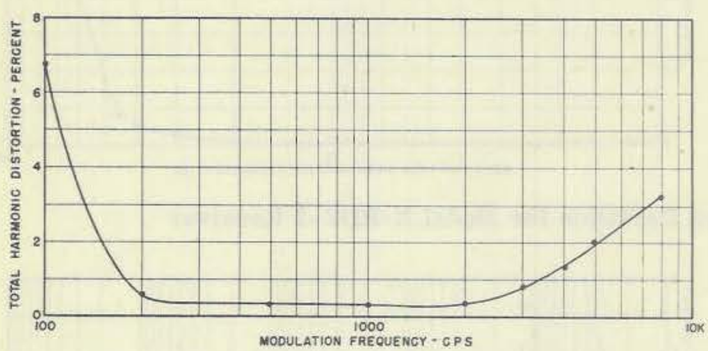
Distortion as a function of audio output voltage is shown in Figure 20. The a-m specification limit is illustrated on the curve. The curve is very similar to those obtained with the a-m receiver, except that distortion is somewhat lower at low output levels.

For additional information, distortion vs modulation frequency has been included in Figure 21. Under the conditions of measurement, distortion was less than 3 percent from 130 to 7400 cps. The rise in distortion below 200 and above 3000 cps, as in the case of the a-m receiver, is due to the phase characteristics of the audio amplifier system. The curve represents very good performance for a communications-type receiver.



1000-μv signal input at mean carrier frequency of 15.1 Mc, deviated 6 kc at 1000 cps. AVC on. Output set with a-f gain control. A-f bandwidth broad. I-f bandwidth narrow. R-f gain max. 600-ohm non-inductive output load.

Fig. 20 - Distortion vs Output Voltage for Model X-RDZ-2 Receiver



Constant 6-kc deviation. Carrier input center frequency 15.1 Mc. 1000-μv input. Audio output set to constant 1.9 v at all frequencies by means of the a-f gain control. 600-ohm non-inductive output load. AVC on. A-f bandwidth broad. NL. OM. Sil. off.

Fig. 21 - Distortion vs Modulation Frequency for Model X-RDZ-2 Receiver

A-M Response and Noise Rejection

Reference has previously been made to the Hazeltine test data on balanced and unbalanced a-m rejection characteristics of the Model X-RDZ-2 second-detector. [24] The manufacturer of the equipment (National Co.) has also conducted some comparative noise and

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[24] NRL Report R-2193, op. cit.

a-m rejection tests on the Model X-RDZ-2 and Model RDZ receivers.[25] In the report on the laboratory trials[26] measurements with radar interference and other external noise are discussed. In the initial receiver measurements described in this report, it was not practicable to inject enough noise energy into the antenna input to produce interference. Noise was introduced into the i-f amplifier, but the results with the Strobotac source employed were inconclusive and unsatisfactory, and are therefore not included .

Resonant overload data were obtained comparing the f-m receiver's response to an a-m signal to its response to an f-m signal. Such data are shown in Figures 22 and 23, with AVC off and AVC on. The AVC off measurement was obtained with r-f gain reduced

A-m source - Measurements 65B, Ser. 369 Sig. Gen., modulated 1000 cps at 30%. F-m source - Boonton Modified 150-A, Ser. 144, Sig. Gen., deviated 6 kc at 1000 cps. AVC off. R-f gain reduced 20 db from max. I-f and a-f bandwidths narrow. Signal introduced at i-f center frequency of 15.1 Mc. Input to 6F4 converter grid.

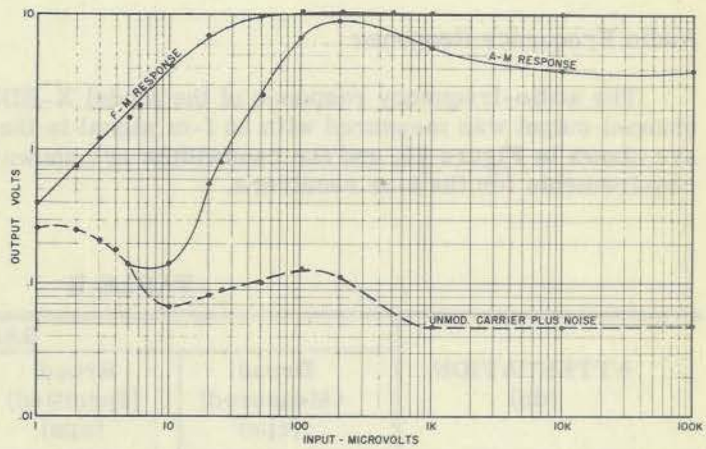


Fig. 22 - Amplitude-Modulation Response for Model X-RDZ-2 Receiver

A-m source - Measurements 65B, Ser. 369, Sig. Gen., modulated 1000 cps at 30%. F-m source - Boonton Modified 150-A, Ser. 144 Sig. Gen., deviated 6 kc at 1000 cps. AVC on. Standard sensitivity settings of controls. No retuning at any time during measurements. I-f and a-f bandwidths narrow. Signal introduced at 15.1 Mc through i-f amplifier at converter grid.

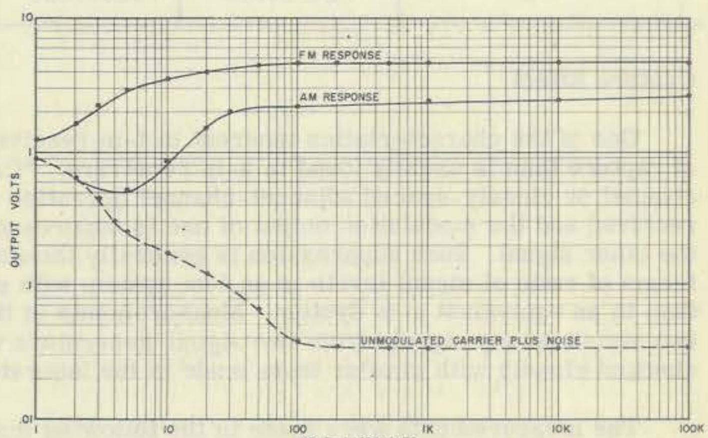


Fig. 23 - Amplitude-Modulation Response for Model X-RDZ-2 Receiver

[25] National Company Interim Development Report, op. cit., pp. 2-3.

[26] NRL Report R-3233, op. cit.

20 db. The data were later checked with another a-m generator, a Ferris Model 16-C, the output of which should have been more free of frequency modulation than the Measurement Corp. generator, but the results were almost identical. During the measurement, there was no retuning of the generator. Further investigation indicated that the a-m minimum (whether through the entire i-f or the discriminator alone) shifted substantially with high inputs. It should be noted that the a-m rejection with AVC off is good at the input levels used in the Laboratory "range runs" (less than 40 microvolts with full gain).

The normal procedure employing the a-m minimum for alignment of the secondary of the discriminator must be applied with considerable caution. Satisfactory results were obtained with the Model X-RDZ-2 only when low input levels (less than 10 microvolts) were used for such adjustment.

Audio Frequency Response

The audio-frequency response of the Model X-RDZ-2 between i-f input and audio-channel output was measured with an f-m signal in the customary manner. The results are shown in Figure 24, and the bandwidths are shown in Table II, with the specification requirements for the a-m receivers.

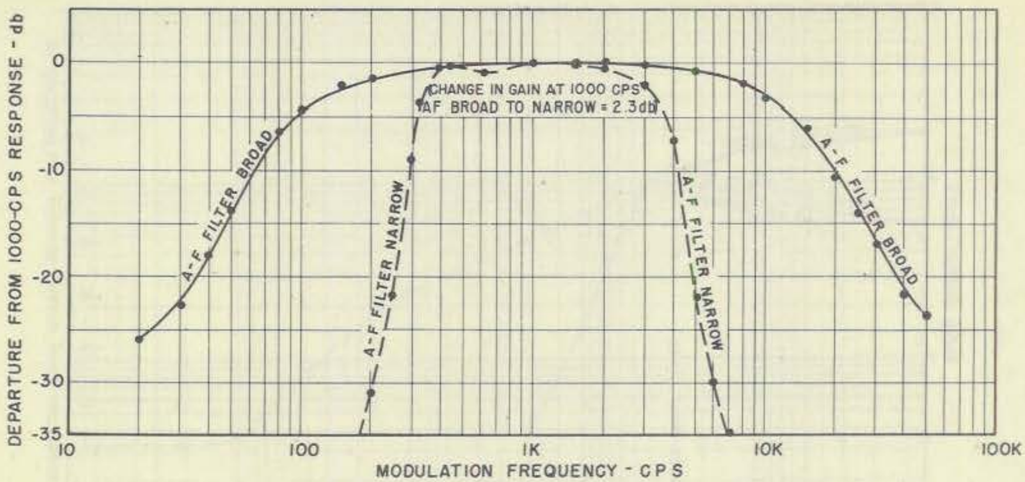
TABLE II

ATTENUATION (db)	BANDWIDTH			
	Broad (Measured) (cps)	Broad (Specified) (cps)	Narrow (Measured) (cps)	Narrow (Specified) (cps)
2	180-8200	--------	350-1800	400-2000
4	110-11000	200-4000	330-3400	--------
6	84-15000	125-7000	315-3800	350-3500

Capture Effect

One of the characteristics inherent in f-m receivers with limiters is a greater amount of capture than is usually found in a-m receivers. "Capture" refers to an effect in common-channel or closely-spaced adjacent-channel operation when two or more signals are being received and the modulation output of one is suppressed or eliminated by the presence of the other signal. Such suppression is generally thought to be greater and more abrupt in terms of ratio of signal levels in an f-m system with good limiters and a linear demodulator than in an equivalent a-m system. Measurements of this effect in the Model X-RDZ-2 with two simultaneous signals from two signal-generators were made, and the data obtained checked closely with similar tests made in the laboratory trials.

The measurements were made in the following manner. The two signal generators were connected in the same way as for two-signal selectivity tests. Both signals were fed across resistor R-115 (at the mixer grid) through an 0.01-mfd. blocking capacitor. The two signal generators were parallel, but the Boonton f-m generator was isolated with a 500-ohm resistor. Its effective input was calculated by substitution for the other generator on a c-w signal. The second generator, used for the undesired signal, was a Measurements Model 65B. The frequency used for the tests was the i-f center of 15,100 kc. It was found impossible to maintain the heterodyne frequency below audibility during a run; hence the beat



Constant 6-kc deviation. 500-μv input. AVC on. R-f gain max. A-f gain set to 2.0 v with 1000 cps modulation and a-f broad. NL, OM, Sil. off. Carrier center frequency 15.1 Mc. Audio output across 600-ohm non-inductive load measured with Ballantine Model 300, Ser. 1187, Output Voltmeter.

Fig. 24 - Audio-Frequency Response through I-F Amplifier for Model X-RDZ-2 Receiver

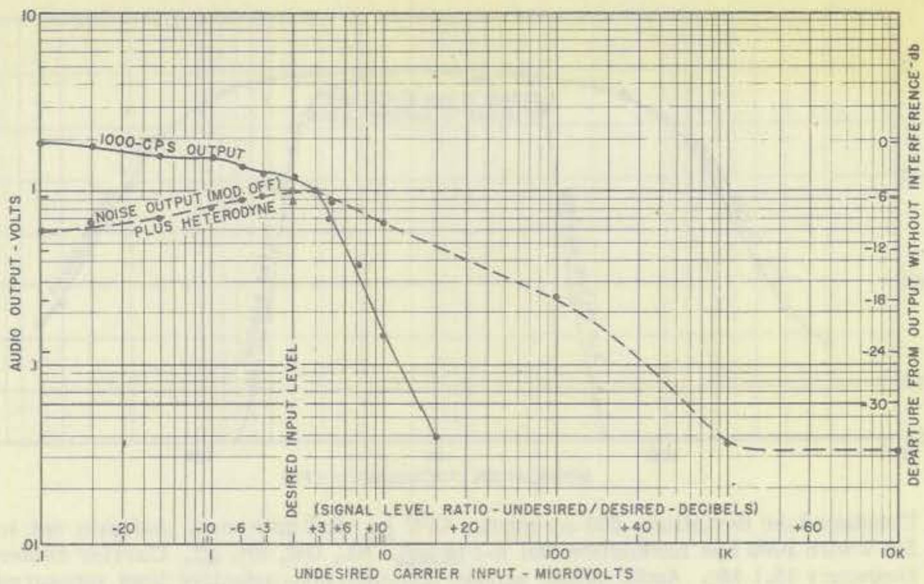
was adjusted to a value between 1500 and 3000 cps. The f-m source (the desired signal) was modulated 6 kc at 1000 cps; the other signal was unmodulated. Measurements were made with AVC on and off but very little difference in performance was observed between these two conditions. The data shown in the included curves are therefore with AVC on only. The "noise" curve shown includes both noise and the output due to the audible heterodyne between the two signals. The measurements of 1000-cps output obtained near, at, or below the output noise level were made with a General Radio Type 736-A Selective Wave Analyzer tuned to 1000 cps.

Figure 25 shows the characteristic obtained with a 6-kc deviation and a desired f-m signal input level of 3 microvolts. The decrease in desired signal tone output is 4 db under these conditions, when the two signals are equal in level. A depression of 6 db is obtained when the interfering signal is only approximately 3 db greater than the desired signal. When the undesired carrier is 15 db stronger than the desired one, a depression of 30 db has been effected.

During the laboratory trials, discussed in a separate report[27], all "capture" measurements were obtained with desired signal levels of less than 100 microvolts. Additional measurements with signal generators were obtained with 1000 microvolts input in the performance tests reported herein. Capture data with this input level, but with conditions otherwise similar to those of Figure 25, are shown in Figure 26. Results are closely comparable, and a slightly greater degree of capture is apparent with the stronger desired signal level. When the two signals are equal in level, the decrease in desired signal output is 5.5 or almost 6 db. When the undesired carrier is 8.5 db stronger than the desired signal, a depression of 30 db is attained.

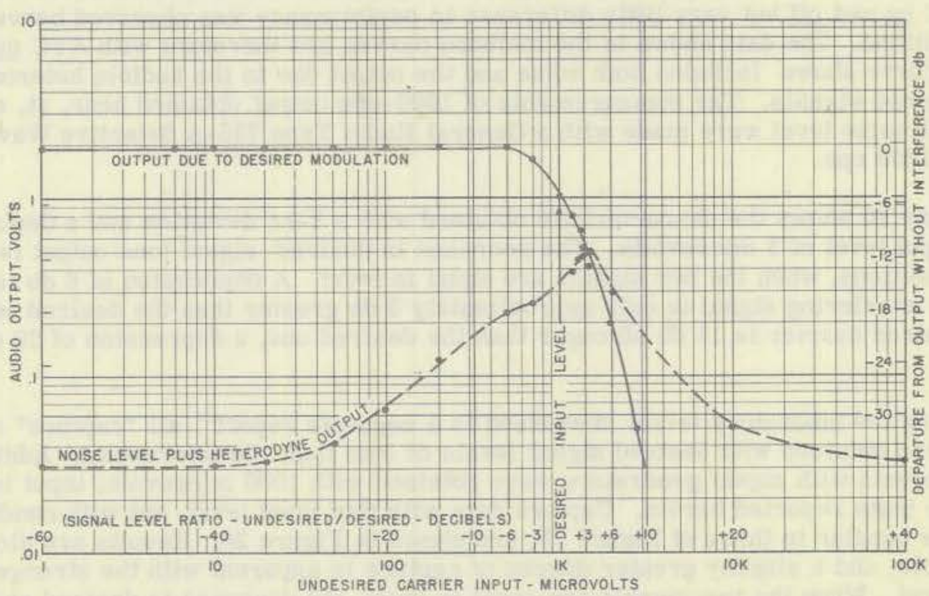
Additional information was also obtained with greater deviation and the same bandwidth.

[27] NRL Report R-3233, op. cit.



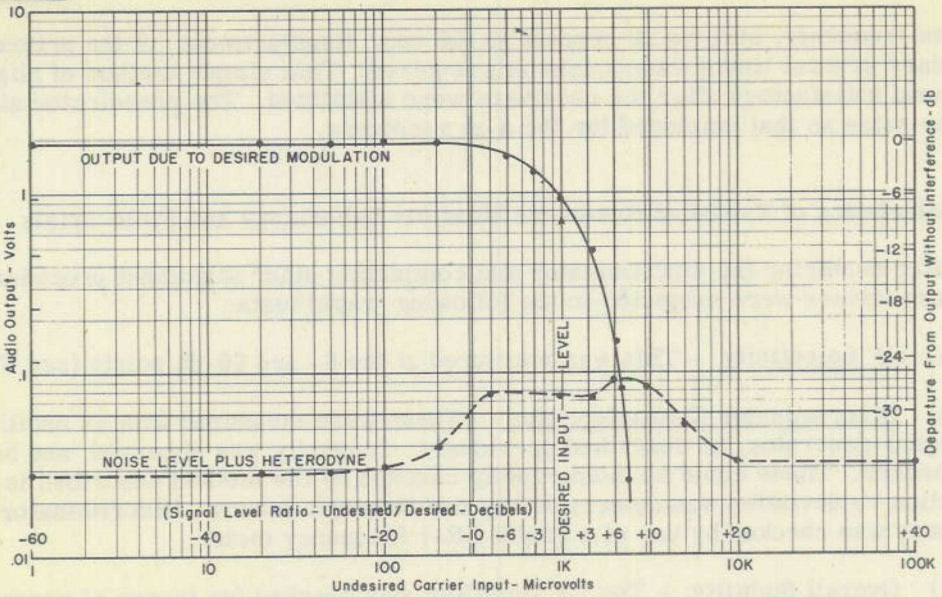
Two-signal measurement. Both signals at 15.1 Mc. F-m signal deviated 6 kc at 1000 cps with 3-μv input level. Level of "undesired" unmodulated carrier (c-w) signal varied as indicated. AVC on. Audio heterodyne above 2000 cps. I-f and a-f bandwidths narrow.

Fig. 25 - "Capture Effect" Characteristics for Model X-RDZ-2 Receiver



Two-signal measurement. Both signals at 15.1 Mc. "Desired" f-m signal deviated 6 kc at 1000 cps with 1000-μv input level. Level of "undesired" unmodulated carrier (c-w) signal varied as indicated. AVC on. Audio heterodyne above 2000 cps. I-f and a-f bandwidths narrow.

Fig. 26 - "Capture Effect" Characteristics for Model X-RDZ-2 Receiver



Two-signal measurement. Both signals at 15.1 Mc. "Desired" f-m signal deviated 40 kc at 1000 cps with 1000-μv input level. Level of "undesired" unmodulated carrier (c-w) signal varied as indicated. AVC on. Audio heterodyne above 2000 cps. I-f and a-f bandwidths narrow.

Fig. 27 - "Capture Effect" Characteristics for Model X-RDZ-2 Receiver

Figure 27 shows performance with 40 kc deviation at the 1000-microvolt level of desired signal. Comparison of Figure 27 with Figure 26 shows very little difference, and slightly more capture is evident with the greater deviation. When the signals are equal, desired-signal depression is 6.4 db. The undesired carrier is 7.2 db stronger than the desired carrier at the 30-db depression point. Figure 27 also shows the improved signal-to-noise ratio obtained in the capture region with the greater deviation.

Receiver Alignment Procedures

All the other (11) Model X-RDZ-2 f-m receivers were carefully aligned before any of the laboratory or field trials were begun. The i-f amplifier alignment procedure followed was similar to that employed for the a-m Model RDZ receiver, except that selectivity in the broad condition was not checked. The normal alignment procedure for the Model RDZ utilizes the broad selectivity condition only, but due to the mechanical construction of the transformers, it was not feasible to align the variable transformers in the narrow bandwidth condition which would have been desirable in view of the "narrow" bandwidth of the discriminator. Hence, i-f alignment of the variable bandwidth transformers was accomplished in the broad condition, as with the a-m receivers. It is possible that a somewhat more symmetrical selectivity characteristic might have been obtained, had it been possible to align all stages in the narrow bandwidth condition, but the characteristic obtained with alignment partly in the broad and partly in the narrow condition was considered adequate.

The discriminator transformer was aligned, utilizing an a-m signal generator, by the procedure outlined in the instruction book. The primary was adjusted for maximum AVC voltage (detector d-c output) with a low-level unmodulated signal. The secondary was adjusted for minimum a-m output. The a-m generator was used, modulated to low percentage at a low frequency, such as 20 percent at 100 cps. Readjustment of the primary and secondary several times was occasionally required. This simple method of alignment was found satisfactory after the receivers were stabilized. The preselector alignment was the same as that employed for the a-m receivers.

Characteristics of X-RDZ-2 Receivers Used for Laboratory and Field Trials

After centering the discriminator and completing other alignment procedures, the eleven receivers were subjected to the following rapid tests:

(a) <u>I-F Selectivity</u> - This was measured at the 6- and 60-db points (see Figure 2).

(b) <u>Discriminator Characteristics</u> - These were measured with an oscilloscope and f-m signal-generator, as described previously. Linearity was observed, and bandwidth was checked. These could be most rapidly checked by the method described in Figure 5. Distortion vs deviation was determined by oscilloscopic means. Discriminator center frequency was checked by use of a Model LR-1 frequency meter.

(c) <u>Overall Stability</u> - The i-f amplifier was checked for traces of regeneration, and care was taken to prevent parasitic oscillation when the crystal oven was inserted with any of the ten standard channels (including 328.2 Mc) and with any tuning adjustment. More details are given on this aspect of the problem in ensuing paragraphs.

(d) <u>Overall Sensitivity</u> - This was measured by a substitution method at 328.2 Mc, using a procedure similar to that employed for the a-m receiver.[28] The output utilized as a reference was the d-c output voltage of the ratio detector. The crystal oven was in place during both the i-f and the overall measurements. To obtain the i-f reference level, an f-m signal generator deviated 6 kc at 1000 cps was employed.

The results of such measurements upon the majority of the eleven receivers indicated satisfactory performance, comparable to that of Serial 3243, the performance of which has been previously described. The later failures of these eleven receivers will be discussed elsewhere, but the initial failures were due largely to i-f or overall regeneration. When the receivers were finally repaired and stabilized, their performance was as follows:

(a) <u>I-F Bandwidth</u> - (<u>narrow</u> only) at 6 db down: average, 125 kc; limits, 110 to 140 kc; specified production limits, 115-135 kc. At 60 db down: average, 390 kc; limits, 380 to 414 kc; specified, 325-425 kc.

(b) <u>Discriminator Characteristics</u> - could be made satisfactory with all receivers.

(c) <u>Stability</u> - See "Instability Due to Excessive Heating" (p. 30 of this report).

(d) <u>Overall Sensitivity</u>- average, 4.8 microvolts (measured with a Measurements Model 80 Signal Generator); limits, 3.6 to 7.2 microvolts; specified limit, 10 microvolts or less.[29] The specification limits mentioned above are those for the Model RDZ a-m receiver.

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[28] NRL Report R-2667, pp. 1-2.
NRL Report R-2929, p. 1 and Plate 1.

[29] BuShips Specifications Re-16R64, <u>op. cit.</u>, p. 17.

STANDARDIZATION OF F-M WITH A-M RECEIVERS

The receivers, when adjusted as described above, gave satisfactory performance for many of the system measurements. It soon became apparent that better correlation between the f-m and a-m receivers for many of the laboratory and field tests, particularly "range trials", was required. As noted in the previous paragraph, the overall sensitivity variation between "aligned" f-m receivers was 6 db. It was expected that the a-m receivers used in the comparisons would be likely to show even greater variations, since the majority of them had low-production serial numbers, and many had been in service for some time. To prevent the equipment variations from obscuring the differences due to type of modulation, a procedure of standardization was employed.

Each receiver (both a-m and f-m) was aligned according to the usual procedures. The i-f bandwidths were then measured on each receiver. With this accomplished, the main problem was to determine that the "noise-figure" of each receiver was comparable to that of the others up to the output terminals of the last i-f amplifier tube. To measure the "noise-figure", a crystal diode was connected to the plate of the last i-f amplifier through a blocking capacitor, with a suitable decoupling resistor to prevent any considerable transformer loading effects. A Leeds-Northrup Type 2420C sensitive galvanometer was connected in series with the crystal-diode load to measure the rectified current. A Measurements Model 80 signal generator with its accessory 6-db pad (50-ohm output impedance) was used as a signal source.

Each receiver was allowed to warm up and stabilize (under normal ambient conditions). The peaking of every trimmer in the preselector as well as those in the i-f amplifier was checked. Then the carrier-to-noise ratio at the plate of the last i-f amplifier was measured. The carrier value was the galvanometer reading obtained with the unmodulated signal generator tuned to receiver resonance and the noise value was the reading obtained in the absence of the carrier. The carrier-to-noise ratios for several values of carrier input were measured. Receivers were then paired or matched, a-m with f-m, each pair having an identical or almost identical carrier-to-noise ratio, as measured above, for the same input.

Over a dozen receivers were thus measured and paired, as far as possible, for use in the sea and airborne tests and for the several phases of the laboratory system analysis. The alignment, standardization, servicing, and operation of approximately 20 receivers, at the Laboratory, at Chesapeake Bay Annex, and at sea, gave an excellent opportunity for appraising the operational performance and shortcomings of the Model RDZ receiver. These procedures also provided a good basis for comparing the reliability of a-m and f-m receivers in Naval Service.

RECEIVER DEFECTS ENCOUNTERED

Regeneration

Two general types of receiver regeneration were observed. One was instability of the i-f amplifier alone. The other was only evidenced when the crystal oven (with appropriate crystals) was inserted and the preselector tuned to various channels. The contractor has mentioned a parasitic oscillation found in the Model X-RDZ-2 and his method of correcting it.[30]

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[30] National Company Interim Development Report, op. cit., p. 3-1.

It was not always possible, however, to eliminate this defect with the by-passing procedure he described.

Both overall and i-f regeneration were found in some of the a-m and f-m receivers. Two of the original 12 f-m receivers were regenerative in initial tests, and another subsequently developed evidence of regeneration. Three a-m receivers were likewise found to be faulty during the tests. The overall regeneration, evidenced when the preselector was adjusted as described in the preceding paragraph, produced "motorboating". The i-f regeneration was generally recognized by dissymmetry and narrowing of the selectivity characteristic and some increase in noise level. In all cases, most of the trouble could be remedied in the i-f amplifier. The output or high-gain end of the amplifier was naturally the worst section. There was already over 100 db of gain in the i-f amplifier at a single frequency. The f-m receivers tended to be somewhat more regenerative. Possibly this was due to the ungrounded or "balanced" transformer secondary at the output of the amplifier but it was probably because of "gain" of the last i-f stage. There is no substantial evidence, however, to support the opinion that the f-m receivers were uniformly worse than the a-m in regard to regeneration. No difficulties due to regeneration were encountered during the laboratory or shipboard tests.

No single means for the reduction of regeneration was found. Each receiver had to be treated separately, and often the trouble was remedied by different means. One or more of the following modifications may be applied to the receivers to eliminate regeneration.

1) Installation of a shielded panoramic load: This never entirely eliminated the trouble, but it reduced regeneration in most cases. A number of such dummy loads were constructed and installed on all receivers during the comparison trials.

2) Grounding and shields: In modifying the a-m receiver to fm, the contractor had removed a supporting bracket which was bolted to the bottom cover plate. This bracket was located near the second detector, and was replaced by the electrolytic capacitor (C-269) and its support. By extending the second-detector support to the shield plate and by bolting this shield to the bracket, the grounding was restored to similarity with the a-m receiver. Other shields and ground straps around the discriminator were found useful in the f-m receiver.

3) Installation of additional by-passing in vacuum-tube heater circuits: A value of a few hundred $\mu\mu$f was found most useful. Location of such by-passing varied with receivers, but it was always placed in the i-f amplifier or at the filament input to the pre-selector.

4) Rewiring (and sometimes shielding) of i-f amplifier heater leads: This was done in two receivers. At present, the path of the filament leads in the i-f amplifier is extremely circuitous.

5) Installation of interstage shields near the output (detector) end of the i-f amplifier.

6) Placing small r-f "chokes" (resistors of low value) and AVC by-pass capacitors (low-capacity mica) across or in the output circuit of the discriminator. The contractor did not provide any r-f by-passing across capacitor C-269 (the electrolytic condenser) in the f-m receiver. The addition of such by-passing was at times useful.

Instability Due to Excessive Heating

Previous laboratory reports have called attention to the excessive heating of receiver components by the B-supply rectifier.[31] During the laboratory trials, an additional over-all metal shield was placed around the receiver to reduce r-f leakage in the added measuring system. This naturally aggravated the problem of heat dissipation, even though the enclosures were later provided with fans. As a result, the receivers used in the laboratory trials required frequent re-alignment during the course of these trials. Similar difficulty was experienced to a lesser extent in the aircraft trials. The sea trials were not so seriously affected.

Both a-m and f-m receivers were affected by this internal heating. The f-m receivers were more vulnerable to high temperatures. Typical symptoms of drift due to heating were lower sensitivity on either type of receiver and higher distortion on the f-m receiver. The preselector seldom needed much re-alignment, but the i-f stages were often considerably affected.

The f-m receivers were much more critical to temperature changes than were the a-m receivers. The main difference between the equipments in this regard was the alignment of the secondary of the last i-f transformer. Tuning of the i-f output or detector transformer in the a-m receivers is not particularly critical. On the other hand, the frequency alignment of the f-m discriminator secondary was extremely critical, since it was the prime factor in providing the discriminator balance essential for optimum performance. It is felt that the need for such accuracy of tuning (within a few kc at 15.10 Mc) in f-m receivers is an inherent disadvantage for that system of modulation. The "tuning" of the single discriminator transformer secondary is as important as the net tuning of the ten other tuned circuits in the i-f amplifier combined.

During laboratory and airborne trials frequent re-alignment of the receiver i-f amplifiers was required to insure optimum performance of both modulation systems. In the laboratory range trials a discriminator transformer in one f-m receiver became defective after several heating cycles. Examination of the transformer indicated that the polystrene coil form had become distorted to a considerable degree. No other transformers in this receiver were similarly distorted. Initially the receiver provided normal performance, which suggests that the transformer failure was largely due to excessive heating during the trials.

Previous and subsequent investigations have shown that inside temperatures around the i-f transformers in the Model RDZ with normal outside ambient temperatures vary between 75° and 82° C. This is extremely high and rather close to the temperature at which polystrene weakens and deforms. Although no failures were observed during the tests previously conducted in an ambient of 50° C, it now appears that the equipments may be subjected to more severe heating in service. It is therefore recommended that attention be given to reducing the internal heat in the Model RDZ receivers as well as in all similar equipments now in service or likely to be procured in the future. Provision of circulating air around the receiver cabinet is desirable in all installations of the Model RDZ receiver.

Defective Switch Contacts

Failure of a variable i-f bandwidth (broad-narrow) switch in one i-f amplifier has been previously reported.[32] Similar contact failures developed in this switch on three receivers

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[31] NRL Report R-2667, op. cit., pp. 15-16; NRL Report R-2929, op. cit., p. 15.

[32] NRL Report R-2929, op. cit., p. 9.

in the laboratory trials and one during the sea trials (both a-m and f-m). A bad contact also developed in the AVC "on-off" switch in one receiver during the sea trials. Repair of such failures is readily effected, but the failures are most annoying and undesirable. It is recommended that reliable contact be provided on all similar switches in future equipment, possibly by use of multiple parallel contacts.

Inadequate Audio Response

One receiver had defective audio response. It was found that an excessively long screw had been used to secure side braces to the i-f chassis, and that one end of the screw grounded on one end of the audio feedback resistor, R-266. Substitution of a smaller screw corrected the defect, which was a production defect not found in the other 11 f-m receivers.

Defective Potentiometer

The control used for adjusting the input meter, R-257, is a 500-ohm wire-wound potentiometer. The windings of this control opened in two receivers during the tests.

Tube Failures

A number of tube failures was experienced during the tests. The most common, in approximate order of frequency of failure, were the following:

1. Type 6F4 (mixer)
2. Type 956 (r-f amplifier)
3. Type 6SN7 (silencer - a "ruggedized" tube)
4. Type 6F4 (last multiplier)
5. Type 6AC7 (first oscillator)

DESCRIPTION OF TRANSMITTERS

A-M Transmitter

The a-m transmitters used during the comparison of a-m and f-m communication systems were standard Navy Model TDZ equipments. A photograph of this transmitter is shown in Figure 28. The transmitter is provided with an Autotune system whereby any one of ten preselected and pretuned channels may be chosen by dialing. Amplitude modulation of the transmitter is accomplished in the power amplifier stage, which utilizes a push-pull grounded-grid amplifier circuit. No frequency multiplication occurs in this stage. The power amplifier is plate modulated by two Type 807 tubes in push-pull through a modulating transformer. A separate winding on the modulation transformer supplies audio voltage to a pair of push-pull diodes, the rectified output of which is used as a bias on the first speech amplifier stage. This circuit arrangement is provided to permit automatic gain control of speech signals, and may or may not be used, as desired. The following is a list of the principal characteristics of the transmitter:

Carrier Frequency Range	225-400 Mc
Frequency Control Means	Quartz Crystal
Frequency Stability	0.01 percent
Crystal Circuit Frequency Range	4.16 - 7.4 Mc
Frequency Multiplication Factor	54
Nominal Carrier Power	30 Watts
Types of Emission	A-2 and A-3
Power Amplifier Tubes	Two Type 2C39, in Push-Pull

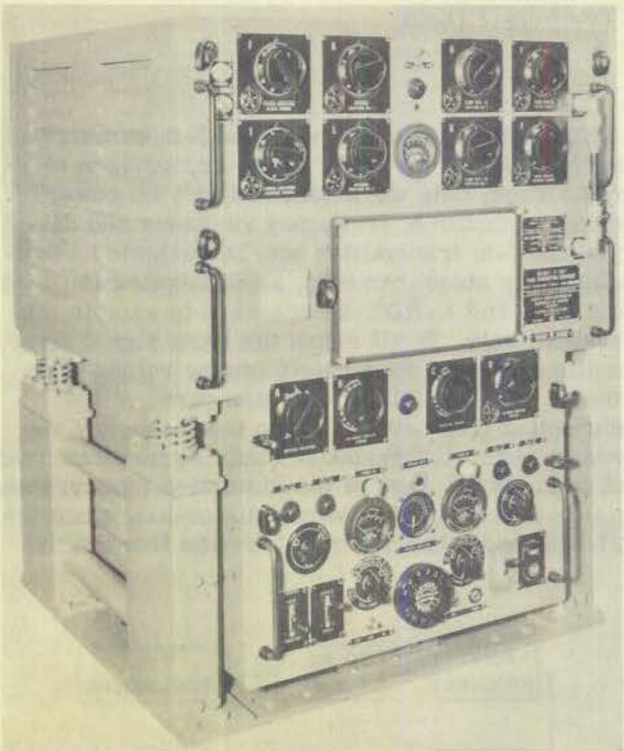

Fig. 28 - Model TDZ Transmitter
(This photo was Enclosure B to NRL letter R-S67/43(1210: JAE) R-1210-172/46)

F-M Transmitter

The f-m transmitters were modified Model TDZ equipments, and were designated as Model X-TDZ-2 units. The modifications were made by the General Electric Company, manfuacturer of the Model TDZ transmitter. At both the General Electric Company and the Laboratory, initial attempts were made to frequency-modulate the transmitter crystal oscillator circuit directly. Reactance-tube modulators, Miller-effect modulators, and various other types of frequency modulators were tried. Due to the excellent frequency stability characteristics of the crystal-controlled oscillator, however, little frequency modulation resulted. Consequently, it was decided to use phase modulation of the crystal oscillator output to obtain a frequency-modulated emission from the transmitter. The phase modulator was inserted between the crystal oscillator and the first amplifier stage, and an audio frequency filter was inserted between the input circuit of the phase modulator and the output circuit of the speech amplifier. The filter was directly proportional to the audio frequency applied. This proportionality in drive to the phase modulator input controlled the phase modulator so that phase modulation of the oscillator output frequency accorded with speech frequencies. Thus, after the output of the oscillator circuit had passed through succeeding r-f transmitter stages a frequency-modulated signal was emitted. The circuit used for this purpose was suggested by the General Electric Company and is essentially the arrangement described in a recently published article.[33]

The audio-frequency excitation voltage for the phase modulator, which is supplied through the previously mentioned filter, is taken from the output of a speech amplifier circuit. The latter is identical with that used as a modulating circuit in the a-m version of transmitter. Thus, audio-frequency characteristics for the f-m transmitters are obtained which are approximately equivalent to those of the a-m transmitter. In the f-m transmitter the audio-frequency output of the speech amplifier is largely dissipated in a resistive load instead of being supplied to the final transmitter power amplifier as in the a-m transmitter. The amplifier in the f-m transmitter thus serves only as a means for driving the phase modulator. Only a small portion of the available power output is used for this purpose, and the remainder is delivered to the dissipative load.

[33] Mobile FM Communications Equipment From 30 to 44 Megacycles, by R. B. Hoffman and E. W. Markow; published in Communications, v. 27, pp. 34-35, August, 1947.

PERFORMANCE CHARACTERISTICS OF TRANSMITTERS

Introduction

In preparation for the laboratory and shipboard trials of the a-m and f-m communication systems, only those performance characteristics pertinent to the comparison of two communication systems were considered. Thus, data were obtained only on power output under both the modulated and unmodulated condition, frequency response and distortion. In addition, the deviation linearity of the f-m transmitter was investigated. Frequency response, distortion, and deviation linearity measurements, as illustrated in Figures 29 and 30, were made, using Models RDZ and X-RDZ-2 receivers to sample the outputs of the a-m and f-m transmitters, respectively. In all cases the input signal level from the transmitter to the receiver was maintained at a moderately strong value. This kept the background noise in the receiver output at a negligible level compared to the receiver fundamental or low order harmonic output tone level. Since the frequency response of each receiver employed was known, transmitter response could be deduced from the overall transmitter-receiver measurements. In the case of the distortion measurements, the transmitter distortion comprised the major portion of the overall distortion, since the receiver distortion, illustrated in Figure 21, was less than 1 percent for the frequencies covered by these measurements.

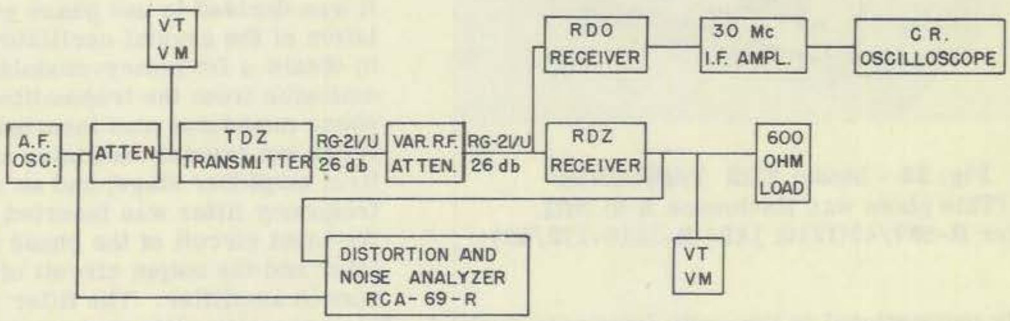

Fig. 29 - Block Diagram of Equipment Used for A-M System Measurements Utilizing Model TDZ-RDZ Performance Characteristics

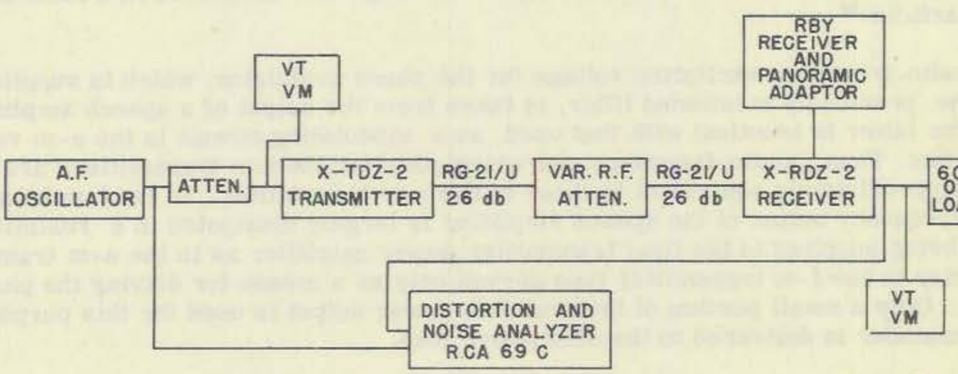

Fig. 30 - Block Diagram of Equipment Used for F-M System Measurements Utilizing Model X-TDZ-2 - X-RDZ-2 Performance Characteristics

Power Output

The power output of both a-m and f-m transmitters was measured with a Bird "Termaline" radio-frequency Wattmeter, Model 750-2. The unmodulated power output of the various transmitters varied from 23 to 30 watts, with the representative average values as shown below. This table indicates the a-m transmitter carrier reduction, or carrier shift, resulting from modulation. Where values with modulation are shown, the modulating frequency was 1000 cps.

TABLE III

CONDITION	POWER (watts)	OUTPUT POWER REDUCTION BELOW THAT OF UNMODULATED CARRIER	
	A-m Transmitter	(Percentage)	db
Carrier, unmodulated	26	0	-
Carrier plus side bands - 100% Modulation	23	17.5	-0.5
Carrier only; 100% Modulation (2/3 of carrier plus side-band power)	15.3	41	-2.2
	F-m Transmitter		
Carrier, unmodulated	26	0	-
Carrier plus side frequencies at 7 kc deviation	25.5	2	-0.1

In the above tabulation it should be noted that the "carrier only" power for the a-m modulated case is based upon the assumption of symmetrical modulation. Under these conditions the carrier power is two-thirds the total power. This assumption is considered valid, in view of the fact that distortion, as measured at 1000 cps, was generally below 6 percent. The downward carrier shift with modulation is one of the shortcomings of the a-m transmitter. Carrier reduction varies with the depth of modulation, but since voice modulation produces only approximately 30 percent average modulation, the average carrier power reduction during voice modulation probably would not exceed one decibel. Carrier shift apparently occurs in the grounded-grid amplifier stage since the input and output circuits of such an amplifier are effectively in series. This condition results in modulation characteristics which depart somewhat from the ideal.[34]

Frequency Response

A block diagram of the equipment used to measure the overall audio-frequency response of the a-m system is shown in Figure 29. In order to reduce the receiver input to a suitable working value, sections of Type RG-21/U lossy cable, together with a variable r-f attenuator,

[34] Grounded Grid Power Amplifiers, by E. E. Spitzer, published in Electronics, v. 19, April 1946, pp. 138-141.

were used between the transmitter and receiver, the total attenuation being on the order of 80 to 100 db. The Model RDO receiver, used for checking the percentage of modulation, had been modified previously to provide a 30-Mc intermediate-frequency output. This output was insufficient to apply directly to the deflection plates of an oscilloscope, so an additional single-stage 30-Mc amplifier was included. The coaxial input and output cables for the amplifier were adjusted to lengths of approximately a quarter-wave, which gave maximum deflection of the oscilloscope beam. By this means it was possible to amplify the carrier voltage sufficiently to produce a vertical deflection of two inches on the oscilloscope without overloading the receiver. Since this portion of the circuit arrangement was used primarily for checking the point at which negative modulation peaks of the transmitter reached 100 percent, linearity in the system was not essential. Nevertheless, no serious distortion in the Model RDO receiver or in the amplifier was apparent. The use of the remainder of the units employed for measurement of the audio frequency response (shown in Figure 29) was conventional. Frequency response characteristics were determined in terms of the receiver output variation, with the reference or zero level taken as the receiver output at 1000 cps.

Figure 30 is a block diagram of the equipment used for the f-m response measurements. Before measurements were undertaken, the transmitter modulating circuit was adjusted to give a 7-kc deviation. Deviation was determined by use of the carrier drop-out method, hereafter described. When the deviation of an f-m steady-tone modulated signal is increased continuously from zero, the amplitude of the carrier component steadily decreases and disappears at a ratio between deviation and modulation frequencies of 2.405. All the signal energy then appears in the side bands. As the deviation is increased further, the carrier re-appears and passes through similar cycles periodically. With a modulation frequency of 2910 cps, the ratio between 7 kc and the factor 2.405, the first carrier drop-out would occur when the deviation reached 7 kc. This procedure, using a 2910-cps modulating frequency, was employed in adjusting the transmitter deviation to the prescribed value. The carrier-drop-out condition was determined both audibly and visually on a selective receiver connected to the scanning output of the Model X-RDZ-2 receiver. The selective receiver thus employed was a Model RBY equipment which included a local oscillator and a panoramic adaptor. The beat note due to the carrier could be distinguished readily from the beat notes of the various side frequencies, and the point of carrier disappearance could be aurally determined. The carrier also appeared distinct from the side-bands on the panoramic adaptor and the drop-out point could thus be visually observed. The audible and visual methods of determining "carrier drop-out" were used as cross-checks on one another. After the transmitter deviation had been correctly adjusted, transmitter audio response measurements were undertaken. As in the a-m case, response was determined from the f-m receiver audio output as the transmitter tone modulation input level was held constant and the modulating frequency was varied.

Curves showing the a-m system audio-frequency response, as determined by the overall receiver and transmitter characteristics, are shown in Figure 31. By comparing these data with those of the a-m receiver for the broad audio bandwidth conditions,[35] it is apparent that the transmitter response at frequencies above 3000 cps is somewhat deficient. For the purpose of comparison of the a-m and f-m systems, however, this condition was not highly significant, since the various investigations were made with the narrow receiver audio bandwidth condition. Table IV is a comparison of a-m receiver and the overall system response characteristics.

Audio-frequency response characteristics for the f-m system are shown in Figure 32. The high-frequency response of the f-m transmitter is superior to that of the a-m

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35 NRL Report R-2929, op. cit., p. 4 and Plate 11.

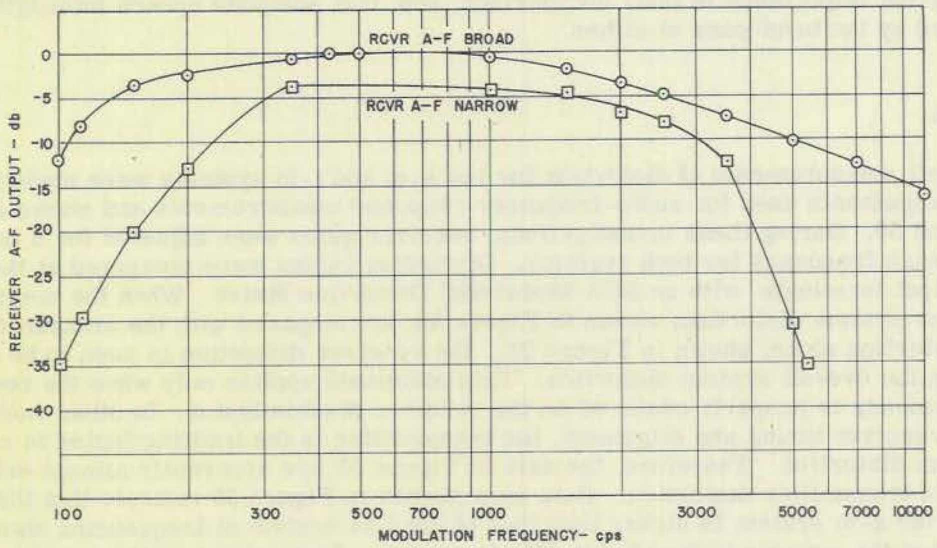
TABLE IV

Receiver Audio Bandwidth Condition	Bandwidth at 6 db below 1000 cps Response	
	Receiver (cps)	Receiver and Transmitter (cps)
Narrow	325-4000	230-3000
Broad	125-11,000	120-3150

transmitter, but with the receiver audio band in the "narrow" position, the condition ordinarily used, the resultant overall differences are not very great. For the purpose of comparison of the communication systems, therefore, the overall performance of each system can be considered similar. The f-m system band-pass measured 305 to 3650 cps, compared to 230-3000 cps for the a-m system. Receiver and overall responses for the f-m system are shown in Table V.

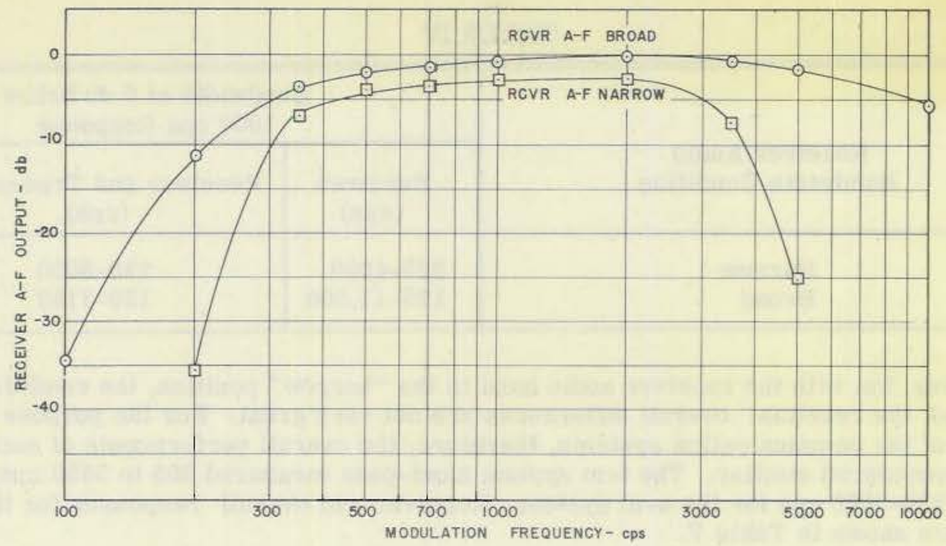
TABLE V

Receiver Audio Bandwidth Condition	Bandwidth at 6 db below 1000 cps Response	
	Receiver (cps)	Receiver and Transmitter (cps)
Narrow	315-3800	305-3650
Broad	84-15,000	280-over 10,000



Transmitter AGC and receiver AVC off. Measuring circuit shown in Fig. 29 used. Receiver output reference level set short of audio overload.

Fig. 31 - Audio-Frequency Response for A-m System from Model TDZ and RDZ Performance Characteristics



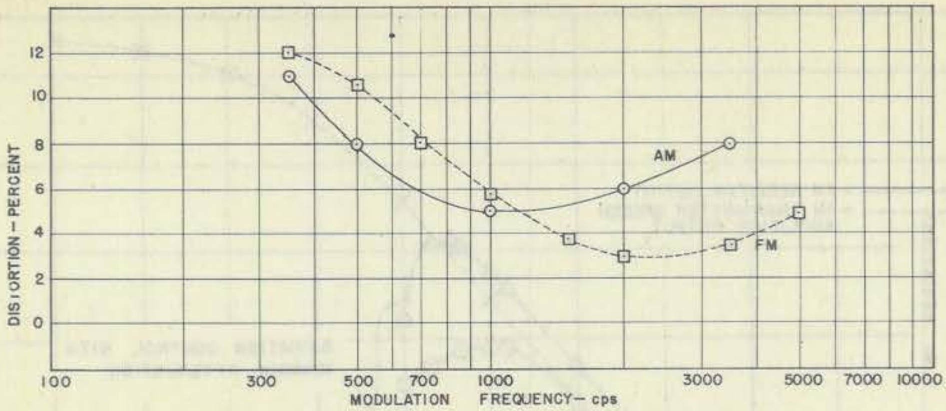
Transmitter AGC and receiver AVC off. Measuring circuit shown in Fig. 30 used. Receiver output reference level set short of audio overload.

Fig. 32 - Audio-Frequency Response of F-M System from Model X-TDZ-2 and X-RDZ-2 Performance Characteristics

From the preceding discussion it is apparent that there is more difference between the a-m and f-m systems in regard to audio-frequency response characteristics of the transmitters than in regard to the receiver response characteristics. In addition, the f-m system band-pass occupies a region in the audio-frequency spectrum somewhat above that of the a-m system. It is believed, however, that the difference between the two systems is not of great importance in their comparison, and that adequate speech intelligibility is provided by the band-pass of either.

Distortion

Overall measurements of distortion for the a-m and f-m systems were made with the same arrangements used for audio-frequency response measurements and shown in Figures 29 and 30. During these investigations, receiver gains were adjusted for 6 milliwatts output at each frequency for both systems. Distortion values were measured at the receiver output terminals with an RCA Model 69C Distortion Meter. When the measured overall f-m system distortion, shown in Figure 33, is compared with the measured receiver distortion alone, shown in Figure 21, the receiver distortion is seen to be much lower than the overall system distortion. This statement applies only when the received signal frequency is properly centered on the receiver discriminator. In other words, given accurate receiver tuning and alignment, the transmittter is the limiting factor in regard to f-m system distortion. Therefore, the data in Figure 33 are apparently almost entirely a measure of transmitter distortion. Data also plotted in Figure 33 indicate that the distortion in the a-m system is higher than that of the f-m system at frequencies above 1,150 cps, and that the reverse is true below this frequency. Distortion in either system is under 10 percent for most of the useful voice range, which indicates that in regard to distortion both systems are acceptable, although not of high quality, for voice communication.



Transmitter AGC and receiver AVC off. Receiver af broad. A-f gain on receiver adjusted to obtain 6 mw output at each frequency (in 600 ohms). R-f gain max. Circuit connections shown in Figs. 29 and 30.

Fig. 33 - System Distortion vs Modulation Frequency Utilizing RDZ and TDZ Performance Characteristics

Linearity of F-M System

In order to determine deviation linearity of the f-m system for deviations of at least 7 kc, measurements were made as to variation of receiver audio output level as a function of the f-m transmitter speech circuit audio input level. The arrangement shown in Figure 30 was used for this purpose. During the measurements the receiver audio gain control was set so that no appreciable overload in the receiver resulted for any received output level experienced. Transmitter automatic gain control was inoperative while these measurements were being made. The results obtained are shown in Figure 34. This graphic illustration has been prepared to give the scale of the abscissa in terms of the decibel value above the transmitter speech circuit input voltage at 1000 cps required for 7-kc deviation with the deviation control at minimum attenuation. Likewise, the ordinate is plotted in terms of decibels above the speech amplifier or the receiver audio output level obtained for the 7-kc deviation condition. The curve labelled "speech amplifier output" indicates the degree of linearity of the audio circuit up to the deviation control. As can be seen, speech amplifier linearity holds for input levels to approximately 21 db. When deviation control was set at minimum attenuation, the receiver output varied with increased transmitter audio input, at three modulating frequencies in the speech-frequency band, in the manner shown by the three left-hand curves in Figure 34. It should be noted that linearity of the system held until the transmitter audio input reached a value of 13 db. Since the output reference level was established at the value which corresponded to a 7-kc transmitter deviation, a receiver output of 6 db above the reference value indicated a deviation of 14 kc. At a 12-db increase of receiver output, the corresponding deviation would be 28 kc. A study of the curves reveals that for modulating frequencies of 1000 and 3500 cps, substantially linear deviations up to a value of 28 kc are possible. At 350 cycles modulation, however, linear deviation begins to be limited at a value between 20 and 25 kc. The right hand set of curves in Figure 34 indicates deviation linearity when 12 db of attenuation is introduced by readjustment of the deviation control. It is evident that loss of linearity then becomes serious only when the input voltage is increased to a value in excess of 21 db. Since the speech amplifier non-linearity starts at an input of 21 db, the deviation control attenuation may be reduced by a similar amount before loss of deviation linearity up to 7 kc would result. Thus, the deviation control attenuation may be increased to a value which reduces the phase modulator input voltage to about one tenth

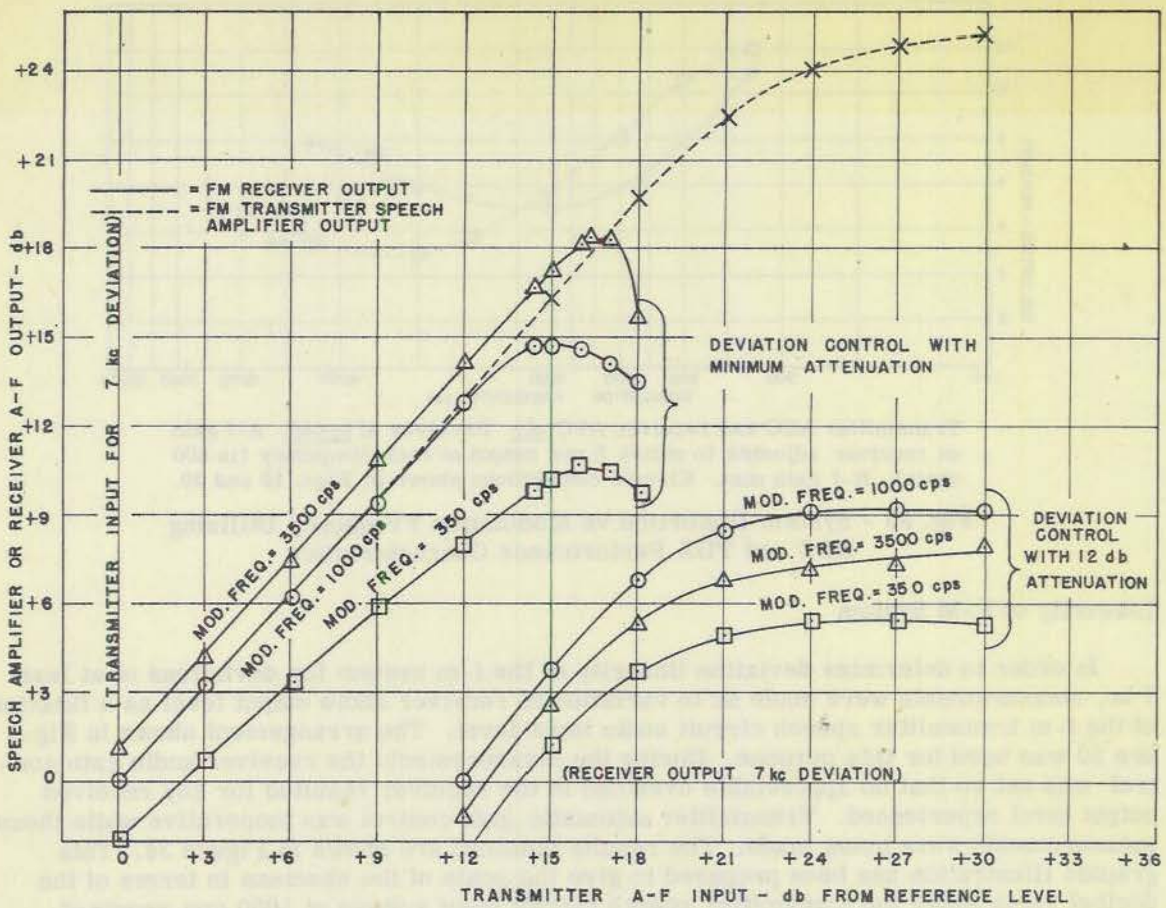


Fig. 34 - Overall Linearity Characteristics of F-M System (Transmitter and Receiver) Utilizing Model X-TDZ-2 and X-RDZ-2 Performance Characteristics

the maximum value, without loss of linearity up to 7 kc deviation. During the work of system comparison, the deviation control was maintained at a setting which introduced only about 9 db of attenuation. Thus, a condition was used which insured deviation linearity.

Transmitter Deficiencies Experienced

During the course of the laboratory and shipboard trials several deficiencies in the Model TDZ series transmitters were observed. Numerous failures of the Type 2C39 tubes occurred. Most failures were experienced in the power amplifier stage. Generally, when the tubes failed they drew excessive plate current with reversed grid current. In some cases the tube, after an inoperative period, performed satisfactorily for a time, but could never again be relied upon to give trouble-free service. Replacement with new tubes always restored normal operation. No attempt was made to determine the cause of tube failures. In many cases the reset accuracy of the tuning controls was poor and the tuning had to be trimmed manually. A considerable amount of rectifier "hash" was observed in the receiver output with the lower serial number Model TDZ transmitters when the transmitters were operated at frequencies between 0.5 and 2.0 Mc removed from receiver resonance. When the higher serial number Model X-TDZ-2 transmitters were used as a-m transmitters, no such difficulty was encountered. For this reason, Model X-TDZ-2 transmitters were used as both a-m and f-m sources during adjacent-channel interference tests. An erratic noise condition was observed while using several of the Model X-TDZ-2 transmitters as f-m sources with an f-m receiver. A full discussion of this condition will be found in the report on the laboratory trials.[36]

RECORDING EQUIPMENT

Sound recorders were used extensively in the laboratory, airborne, and shipboard trials, and were also used for the system intelligibility studies. It was considered that for the service required, magnetic tape recorders would be the most practical. The commercial equipment procured was the type BK-401 "Soundmirror" tape recorder-reproducer, manufactured by the Brush Development Company of Cleveland, Ohio.

These recorders were generally quite satisfactory for the purpose for which they were utilized. They exhibited several defects, however, some of which were remedied by modification at the Laboratory. The hum level was fairly high, though some reduction was effected by rewiring and shielding heater leads. Susceptibility to pulsed radar interference was pronounced, and was successfully reduced by additional shielding and by replacing the wooden cabinet with a metal cabinet. The output was rewired for 600 ohms impedance with volume-control pads. In addition, input pad was provided to avoid recorder-amplifier overloading with 6 milliwatts receiver output. Motor overheating was also encountered and was corrected by use of voltage-dropping resistors.

No measurements were made of frequency response, distortion, or signal-to-noise (or hum) ratios, but it was felt that the characteristics were adequate for reproduction of the narrow-band transmissions employed during the system comparisons. The reproducer unit of the recorder was used for the majority of the analyses of the records made during the trials and appeared satisfactory for the purpose.

CONCLUSIONS

The Model RDZ receiver is believed to be characteristic of the best available Navy receiving equipment in the 200-400-Mc frequency range. The ratio-detector circuit employed in the f-m version of the receiver was the most practical for incorporation into the Model RDZ and is considered to be superior to the conventional grid-bias or saturation limiter and phase discriminator combinations, particularly in regard to adjacent-channel interference response.[37]

Performance characteristics of the Model X-RDZ-2 receiver have been measured with the following principal conclusions. One-signal (or weak-signal) selectivity is closely comparable to that of the a-m receivers. Vulnerability to adjacent-channel interference with f-m and a-m reception is very comparable from the re-entrant region of the discriminator characteristic (60 to 100 kc from resonance) to the region where cross-modulation is observed.

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[36] NRL Report R-3233, op. cit.

[37] Hazeltine Report No. 7035, dated 19 September 1947, entitled Two Signal Performance of Some FM Receiver Systems, pp. 1, 11.

Comparing 7 kc deviation on fm with 100 percent modulation on am in regard to signal-to-noise ratio shows comparable performance, but with a significant advantage for am on very weak signals. Such comparisons are based only upon the given bandwidths of the receiver and discriminator. Strong-signal overload performance with AVC off is better with the f-m than the a-m receiver, due to the effects of i-f amplifier saturation in the a-m case.

Audio frequency response of the f-m receiver is closely comparable to that of the am and in the narrow audio-bandwidth condition is virtually identical for the two. Capture effect measurements indicate very slight differences with deviation, signal level, or AVC condition. Slightly more capture is shown with stronger signals and greater deviations. The f-m receiver is capable of very low distortion, superior to that of the a-m Model RDZ, but such superiority is entirely dependent upon very accurate centering of the signal on the discriminator response characteristic. It is felt that one of the greatest limitations of the f-m receiver is the degree to which its performance is dependent upon the accurate alignment and stability of a single tuned transformer in the i-f chain, namely, the discriminator. The a-m receiver is not similarly limited. Performance difficulties with the Models RDZ and X-RDZ-2 have been discussed in this report. The most serious troubles encountered were frequency instability due to excessive internal temperatures and some regenerative tendencies. The latter were corrected prior to the actual trials. No substantial differences between f-m and a-m receiver performance were established in these respects, except that the f-m receiver tended to be more adversely affected by drifts because of the critical nature of discriminator alignment.

The superiority of the f-m receiver in regard to distortion could not be realized because of transmitter limitations. The overall system distortion was nevertheless adequate for communication purposes. Frequency response was not as uniform between a-m and f-m transmitters as between a-m and f-m receivers, but system response in the narrow band-width condition was comparable between fm and am and was adequate for voice communication.

The most serious service difficulty encountered with the Model TDZ transmitters was numerous Type 2C39 tube failures. Most significant transmitter difference between am and fm was the undesirable negative carrier-amplitude shift encountered with the a-m transmitter. Despite such difficulties, the transmitters, receivers, and recorders all were adequate for the purpose of the comparison. Of the results shown in this appendix of the report, some are favorable to fm and some to am. It is not believed that the net result of tests reported in this appendix supports the superiority of either system of modulation over the other.

RECOMMENDATIONS

It is recommended that:

(a) Reliable contacts be provided on all switches, similar to the receiver i-f bandwidth switch, in future Navy equipment.

(b) In future applications of the ratio-detector, the incorportaion of additional limiting ahead of the discriminator transformer be considered.

(c) In future consideration of fm for naval use, adequate weight be given to the vulnerability of the receiver to frequency drift or misalignment of the demodulator transformer with regard to symmetry and centering of the signal; also that means be developed to reduce such vulnerability without introduction of excessive complexity or undesirable effects.

(d) Consideration be given to reduction of inside temperatures in the Model RDZ receivers by suitable external air circulation or similar means.

(e) Steps be taken to increase the operating life of the Type 2C39 tubes employed in the Model TDZ transmitter.

ACKNOWLEDGMENT

The assistance of all personnel in the review of this report is gratefully acknowledged. R. S. Werner was particularly helpful in assisting with the transmitter portion.

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