EQUIPMENT PERFORMANCE SPECS

A NEW METHOD FOR PREDICTING THE ADJACENT-CHANNEL PERFORMANCE OF MOBILE RADIO EQUIPMENTS BY GRAPHICAL ANALYSIS — *By* H. H. Davids *

DURING the past few years, with rapid increase in radio communications systems especially in the 152 to 174-mc. band, there has been more and more emphasis on adjacent-channel operation. As a result, receiver IF systems have been made more and more selective, approaching virtually vertical slope as a goal. A specification often quoted as necessary for adequate adjacent-channel operation is that the selectivity should be 100 db at ±30 kc. That is, with signals of a maximum deviation of 15 kc., and channels 60 kc. apart, the attenuation at 30 kc. off resonance should be 100 db to give satisfactory rejection of signals 60 kc. off.

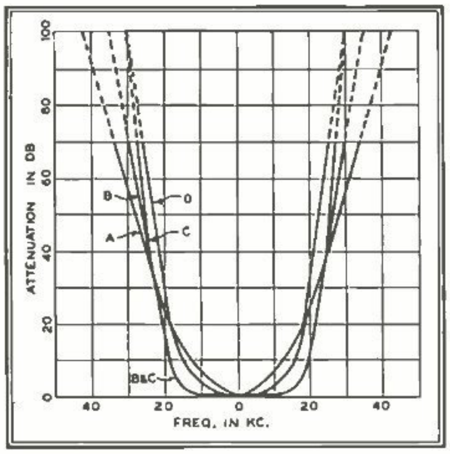

FIG. 1. SELECTIVITY OF 4 TYPICAL RECEIVERS

Selectivity Measurement Methods:

How is this attenuation or selectivity measured? There has been two accepted methods. One is that of measuring the overall IF gain versus frequency off resonance for a constant output, usually a fixed value of 2nd limiter current.

The other method is the 20-db quieting measurement. This has the advantage of using a signal fed through the front end of the set and is, therefore, an overall measurement. A convenient means of determining the relative sensitivity of an FM receiver is to measure the on-frequency unmodulated signal that will give 20 db reduction of noise output of the receiver. This method has been extended to get a measure of selectivity by shifting the signal off frequency, and measuring the increase of signal necessary to maintain 20 db quieting.

The selectivity curve, when expressed in db with reference to the on-frequency 20-db quieting sensitivity, agrees very closely to the overall IF selectivity and, therefore, it was taken as a measure of overall receiver selectivity.

Fig. 1 shows the selectivity of four receivers as measured by the 20-db quieting method. It will be seen that the upper portions of the curves are shown in dashed lines. The last point that can be actually measured falls between 60 db and 80 db, depending on the receiver in question. This occurs because desensitization of the receiver has started. The signal reaches a level such that some grid prior to the limiters starts to draw grid current and biases itself. Reduction of gain with resultant reduction of quieting begins. When this point is reached, no matter how much the signal is increased, 20-db quieting cannot be produced. Beyond that point, the curves are extrapolated by projecting them as indicated by the dashed lines. No one knows exactly what form the curves should take above this point, or what the bandwidth is at 100-db attenuation. The same limitation also occurs with an overall IF selectivity curve.

Field tests of these receivers showed that in adjacent-channel operation equipment represented by curve A, Fig. 1, was equal to or slightly better than other types of receivers which had considerably greater IF selectivity, such as curve B or curve C. However, when it is realized that the 20-db quieting selectivity measurement is a single-signal measurement, and discloses just one element of the set's performance (the response of the IF system to a single signal) it is easy to see that this method does not give a true picture of adjacent-channel operation.

In determining actual adjacent-channel performance not only the IF selectivity, but also the desensitizing effect of the interfering signal and the transmitter noise spectrum are important.

As we have already seen with the 20-db quieting method of measurement, the curve ceases to be significant when desensitization starts. Even in the range in which desensitization does not come into play, the 20-db quieting curve merely serves to show that one receiver has more IF selectivity than another. In itself, it cannot answer the question of whether two systems must be 60, 80, or 100 db down at 30 kc. off resonance for adjacent-channel operation.

Two-Signal Measurements:

The method of selectivity measurement incorporated in the IRE railroad and vehicular communication specifications

FIG. 2. SETUP FOR TESTING RECEIVER SELECTIVITY BY THE IRE 2-SIGNAL SPECIFICATIONS

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as approved January 13, 1949, provides a factual measurement of selectivity.

It consists of feeding two modulated FM signals into the receiver. The first is modulated with a standard IRE test modulation, 1,000 cycles with 70% of maximum rated system deviation (10.5 kc.) with an input sufficient to produce 12 db ratio of signal + noise + distortion to noise + distortion, as measured with a standard distortion analyzer. The interfering signal is modulated at 400 cycles with 70% of maximum rated system deviation, and the level increased until the ratio of signal + noise + distortion to noise + distortion drops to 6 db. This level expressed in db with reference to the 12 db S+N+D/N+D level is plotted against frequency to form a selectivity curve. Fig. 2 shows the test setup, while Fig. 3 presents the block diagram. The squelch should be disabled for these measurements.

A selectivity curve produced in this manner is shown in Fig. 4. This curve is an actual measure of the level of an interfering signal required to produce a 6 db reduction in the signal to noise ratio of a weak signal.

The selection of reference level and the deviation are arbitrary. but represent reasonable approximations to operating conditions. The 12 db S+N+D/N+D signal level is the IRE and RTMA sensitivity standard. and represents a little less than the input required for 20 db quieting. The 10-kc. deviation has already been selected for RTMA standard test signals, and is somewhat greater than the average deviation on speech with the peaks limited to 15 kc. The IRE test signal of 10.5 kc. is essentially the same.

An analysis of the audio ouput is shown on the lower part of the chart. This shows that at first the reduction in signal-to-noise ratio is due to break-through of 400 cycles modulation, and is governed by IF selectivity. Then desensitization starts, causing the IF gain to decrease, reducing the signal and consequently increasing the noise through loss of quieting.

Fig. 5 shows the selectivity of three receivers that correspond to the 20-db quieting curves A, B, and D. The figure of 100 db at ±30 kc. has disappeared. The curves bear out the field test results.

The top curve, for receiver D, is a further proof that extreme IF selectivity is of relatively little value. Measured by the 20 db quieting method, this receiver indicated 100 db at ±33 kc. At 60 kc. off frequency, however, it is essentially the same as indicated in curve A. Improvement in performance at 60 kc. off frequency can only be achieved by improvement in desensitization, and further improvement in desensitization is hard to realize.

Further field tests were made with receivers A and B with the desired signal and the interfering signal 45 kc. apart, representing the minimum spacing possible for adjacent channels under FCC Rules on frequency tolerance of transmitters. Both signals were voice-modulated, with peaks causing limiting in modulation-limiters set for 15 kc. deviation. Receiver A proved to be a little better than receiver B, whereas the curves in Fig. 5 would indicate receiver B should have been 6 db better than A.

This discrepancy is due to the second factor mentioned in discussing the shortcomings of the 20-db quieting selectivity measurement: that is, the noise spectrum of the transmitter producing the interference.

The noise spectrum of a typical transmitter is given in Fig. 6. It will be seen that at resonance the noise input is 75 db below the transmitter signal output. For several hundred kc. away from the

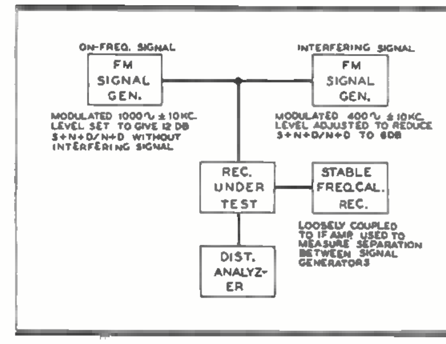


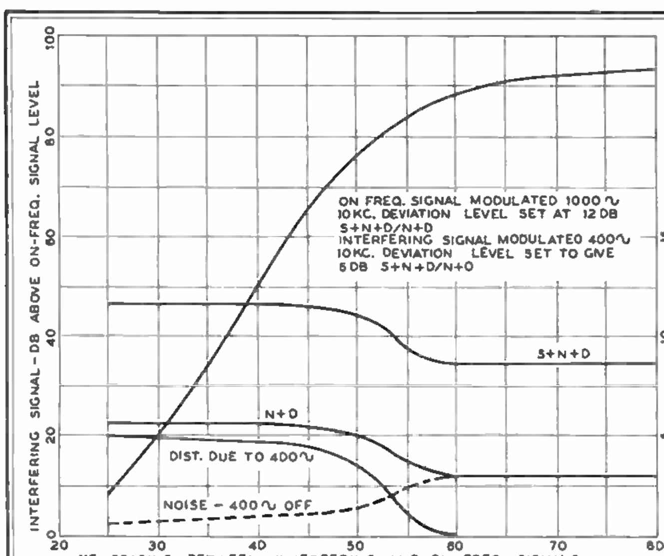
FIG. 3. SELECTIVITY TESTING BY IRE METHOD

signal frequency, the noise output decreases very little. Therefore, an adjacent-channel transmitter will produce noise-modulated sidebands on the desired frequency whose level is about 80 db below the adjacent-channel signal being received on the antenna. The question to be resolved is whether break-through of adjacent-channel modulation, desensitization produced by the adjacent-channel carrier, or on-frequency noise produced by the adjacent-channel transmitter will first cause interference in a given receiver. This can be determined by field tests, but it is desirable to have a laboratory method of predicting the performance of receivers. Such a method has been developed. It consists of three steps:

1. Preparation of sideband distribution curves for voice-modulated transmitters.

2. Preparation of receiver interference characteristics.

3. Graphical application of these curves to each other to determine the source of adjacent channel interference.



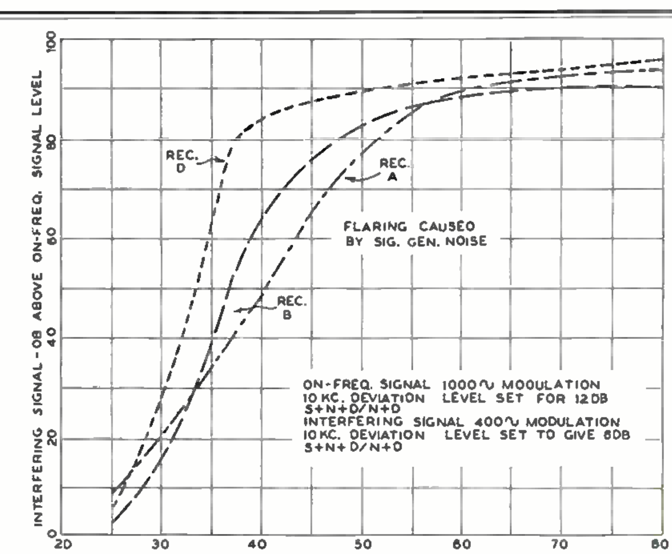


FIG. 4. INTERFERING SIGNAL LEVEL REQUIRED TO REDUCE THE SIGNAL-TO-NOISE RATIO BY 6 DB. FIG. 5. IRE SELECTIVITY OF 3 RECEIVERS

Sideband Distribution Curves:

For a noise-free FM transmitter with no modulation limiting and sine wave modulation, sideband distribution can be calculated by means of Bessel Functions

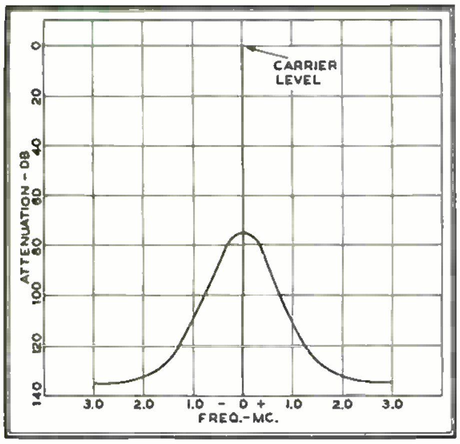


FIG. 6. TYPICAL TRANSMITTER NOISE CHART

and plotted in db with reference to the unmodulated carrier level against frequency in kc. from the carrier frequency. Fig. 7 gives such a curve for 360 cycles modulation and 10-kc. swing. For a practical transmitter this curve would be modified on the skirts due to the noise output.

Moreover, for complex wave forms of speech, the sideband distribution cannot be calculated. Since, in the practical case, an adjacent-channel signal would be speech-modulated, an empirical means of measuring the sidebands is necessary.

This was accomplished as shown in Fig. 8. The signal from the transmitter was fed into a shielded room through an attenuator and thence into a communication receiver modified to give a 100-kc. output from the second mixer. This was applied to a highly selective receiver through a second attenuator. The receiver was operated without regeneration, and the output from the plate of the detector was fed through an integrating network to a vacuum tube voltmeter. By this means, the RF level of the carrier, or of a narrow segment of the sidebands, can be measured as a DC voltage. In practice, the first attenuator was used to keep the signal from overloading the communication receiver. The second attenuator was used to maintain a constant output level and the relative levels of the sidebands determined by the attenuator readings.

To check the method of measurement, a signal generator modulated with 1,000, 2,200 and 3,000 cycles at ±10-kc. swing was connected in place of the transmitter. The measured sideband distributions checked the curves calculated from Bessel's functions within 2 db.

A tape recording of a test phrase was then prepared and fed into the microphone circuit of the transmitter. The modulation limiter was set for 15 kc. deviation, while the audio output level was set to give limiting on peaks of modulation. The resulting sideband distribution curve for normal speech is shown in Fig. 9. It will be noted that the skirts run off virtually horizontally at the 78-db level due to the transmitter noise.

Interference Curves:

To use the transmitter sideband curve, a suitable receiver characteristic curve was prepared for each receiver to be investigated. The setup was made exactly the same as for the two-signal selectivity measurement, using the same desired-signal modulation and input level. For the interfering signal, a modulation of about 400 cycles per second was required to give a very sharp slope to the signal generator sideband distribution curve. The frequency of 360 cycles was chosen because it could be checked very accurately by comparison to 60 cycles. The deviation was set for 10 kc. A curve of interfering signal level in db. referred to the signal level for 12-db ratio of signal + noise + distortion to noise + distortion, versus frequency separation between desired and interfering signals was taken, using just perceptible audio interference as a criterion.

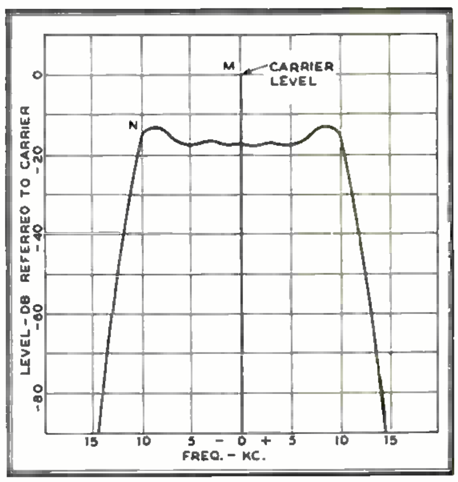


FIG. 7. CALCULATED SIDEBAND DISTRIBUTION

The 360-cycle sideband curve, Fig. 7, was then applied with its carrier center frequency set at some frequency such as 60 kc. The curve was raised until the point M marking the level of the unmodulated carrier just touched the previously-drawn curve. A small section of the arc on the knee of the sideband curve N was drawn. This was repeated for a number of points along the curve. By trial and error a curve could be drawn through the arcs representing the position of the knee of the sideband curve, such that, as the point M was moved up and down the original curve, N would just make contact with the new curve which can be called the Receiver Interference Characteristic. Such curves for receivers A, B, and D are shown in Fig. 10.

It will be noted that the curves have not been extended beyond the 60-db level. The curves are limited at this point because the threshold of just perceptible audio interference was masked by noise for higher input levels.

This noise interference was due to the noise output of the signal generator which, although considerably lower, relative to signal, than for a transmitter, still causes interference in the receiver under test before desensitization takes effect. If the noise was not present, the curves would level off at a value above 70 db.

Use of the Curves:

The Receiver Interference Characteristics are basic receiver characteristics against which the sideband distribution curves can be applied for any transmitter at any given separation from the desired signal, with any sine wave or complex modulation such as voice with any desired deviation, to determine the nature of the interference produced and the level necessary to give just perceptible interference.

Fig. 9 represents the sideband distribution with the modulation of most practical interest, that is, normal voice modulation into a transmitter with the modulation limiting correctly set for 15 kc. If this is applied to the Receiver Interference Characteristics, Fig. 10, at the ordinate representing 60 kc. from the desired signal and raised vertically, it can

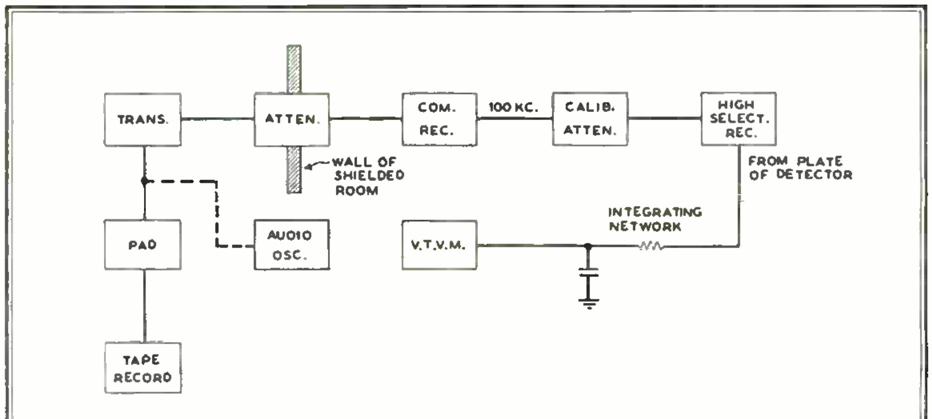


FIG. 8. SETUP FOR MEASURING TRANSMITTER SIDEBAND DISTRIBUTION WITH SPEECH AS INPUT

be determined whether desensitization due to the carrier of an adjacent channel signal, audio breakthrough due to its modulation, or noise due to its on-frequency noise spectrum will first occur. This can best be done by cutting out a transparent plastic template of the sideband distribution. If point M touches the Receiver Interference Characteristic, desensitization results; if any portion of the curve between N and O intersects, the interference characteristic there will be modulation breakthrough; and if the portion between O and P intersects the nose of the interference characteristic, noise will result.

First, the portion O-P intersects the nose of receiver D and then shortly after the nose of receiver B, but since the latter is broader, the area of interception on it increases rapidly, so that both receivers suffer perceptible interference at about the same level.

Finally, the nose of receiver A is intercepted. The slope O-N does not intercept any of the curves until the noise interference caused by section O-P has completely blanketed the receivers. Similarly, the carrier level, M, has not produced appreciable desensitization. Refer to dashed curves E and F on Fig. 10.

This graphical analysis predicts that receivers B and D will experience measurable interference at virtually the same interfering signal level, and that for receiver A it will take a somewhat higher level. Moreover, it indicates that the interference will be in the form of increase of noise and not modulation breakthrough. This was exactly the results that field test revealed.

Now let this technique be applied to the case of two transmitters operating at the extremes of the FCC frequency tolerance: that is, only 45 kc. apart.

We shift the carrier center line of Fig. 9 to the 45-kc. ordinate of Fig. 10, and repeat the procedure. It will be seen that noise and modulation interference will first appear on receiver B; then for a level of interference 6 to 8 db higher, modulation will occur in receiver A. Noise due to section O-P appears on receiver D. All the receivers will experience strong interference from noise and modulation before desensitization becomes appreciable. Here again these conclusions were borne out by field tests.

By these graphical means, therefore, a powerful means is available for determining the relative adjacent-channel performance of receivers.

Design Criteria:

From this graphical study of selectivity, we can set down the following design criteria:

1. At the present stage of the development transmitter noise is the limiting factor in adjacent channel operation.

2. If means to reduce transmitter noise are found, receiver desensitization would then be the limiting factor.

3. With the above factors eliminated, a Receiver Interference Characteristic slope greater than that of the normal voice-modulation sideband curve results in no increase in adjacent-channel rejection. Since this slope of Interference Characteristic is determined by the IF selectivity, even if means of greatly reducing transmitter noise and receiver desensitization were found, there would be no value in increasing the IF selectivity of a receiver appreciably over that of receiver A with the present 60-kc. channel spacing unless means are found to increase the slope of the transmitter sideband distribution.

4. The bandwidth of the IF system at the nose should be made as narrow as possible consistent with good intelligibility, while maintaining reasonable allowances for drift due to temperature variations and for differences in setting of receiver and transmitter frequencies.

Measuring Receiver Bandpass:

The graphical study of selectivity indicates the desirability of reducing the bandpass of the receiver, but it does not provide a measure of its adequacy in receiving the desired signal. In the past, an attempt to specify this has been made by specifying a minimum bandwidth for the 6-db points on the 20-db quieting selectivity curve.

It can be realized readily that a specification at the nose of the curve has nothing to do with selectivity, which is the ability of the receiver to accept one signal and reject the other. The purpose of such a specification is to insure that the bandpass of the receiver is sufficient to accept the desired signal without distortion, and with sufficient allowance for drift.

Selectivity and bandpass requirements should be stated separately. Obviously, a two-frequency measurement is not necessary, and is not desirable for a band width measurement. However, a modulated signal is necessary to give a true picture of the bandwidth.

As a start, the sensitivity of the receiver should be specified by the RTMA and IRE definition rather than by the 20-db quieting method which uses an unmodulated signal. This defines the sensitivity as a minimum value of a signal modulated with 1,000 cycles and 10-kc. deviation that will produce at least 50% of the receiver's rated audio power output with a ratio of signal + noise + distortion to noise+ distortion that is 12 db or better. This defines sensitivity in terms of a usable signal.

What is being sought with a specification bandwidth at 6 db? It is desired to establish how far the received signal

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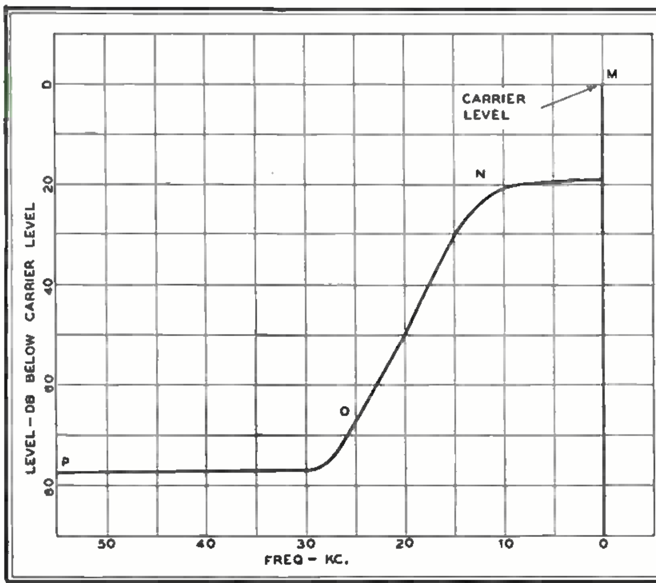

FIG. 9. SIDEBAND DISTRIBUTION CURVE FOR NORMAL SPEECH MODULATION.

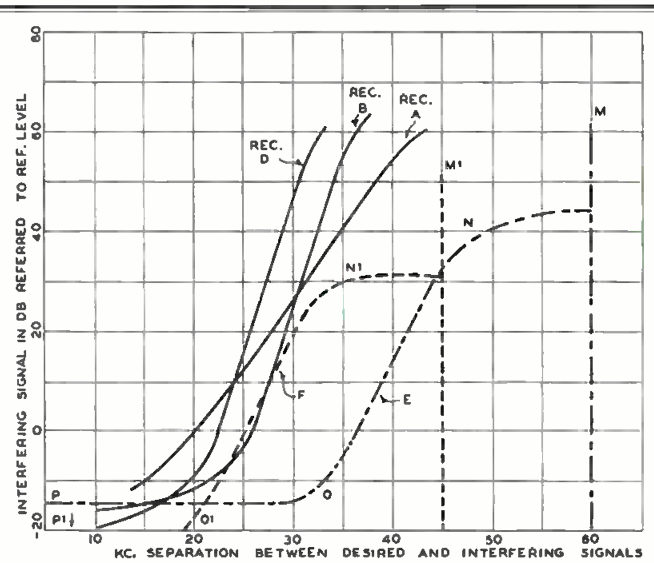

FIG. 10. DETERMINING MINIMUM LEVEL OF INTERFERING SIGNAL

WARNING ALARM

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signal is adjustable by R4A and R4B from 0 to 3 volts RMS. A bridging transformer provides an output impedance of 600 ohms at J1 terminals 3 and 4.

When the monitored voltage rises to 1 volt above threshold, K1 is reenergized. This removes power from K2, opening the plate circuit for the timer multivibrator. The tone signals are then stopped.

Calibration of K1:

With S1 in the OPERATE position, the voltmeter reads the monitored voltage. When S1 is in the CALIBRATE position, the meter reads the calibration voltage determined by R32. To calibrate, S1 is put into the CALIBRATE position and the threshold adjustment R27 advanced to maximum. Then R32 is rotated clockwise until the neon lamp indicates that K1 is energized. It is then retarded until the lamp is just extinguished, at which time the meter reads the dropout voltage of K1. The settings of R27 and R32 are reduced in steps until the meter reads the desired dropout level as the lamp is extinguished. Then S1 is put back to the OPERATE position for normal monitoring.

Power Requirements:

The warning alarm operates with a single-phase AC input of 105 to 125 volts at 50 to 60 cycles. Power input is less than 50 watts.

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can be off frequency without reducing the sensitivity more than 6 db. The 20-db quieting measurement does not give this. At best, it is a measure of IF selectivity and, as a matter of fact, usually comes out several kc. narrower than this.

If a signal 6 db above the IRE sensitivity level, as defined above, is fed into the receiver and then the deviation is increased until the ratio of signal + noise + distortion to noise + distortion falls to 12 db, the level for the RTMA sensitivity specification, the desired characteristic has been measured. The bandwidth at 6 db will then be twice the deviation. If the receiver selectivity is unsymmetrical, interference will occur at first on the narrower side, and the resultant deviation for 12-db S+N+D/N+D will be less than for a symmetrical characteristic.

This measurement of bandwidth takes into account both the reduction of signal level and the increase in distortion occa-

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sioned by moving off the center frequency of the receiver. If we consider that the RTMA standard test signal of 1,000 cycles and ±10 kc. swing represents normal modulation then ± (bandwidth-20)/2 is the allowance for drift.

The bandwidth is determined not only by the amplitude attenuation which is measured by IF selectivity measurements, but also by the phase shift characteristic. Of two receivers, the one with the wider bandwith as measured by IF selectivity may actually have a narrower bandwidth, due to the shape of its nose, when measured by a method employing a modulated signal and using signal-to-noise ratio as a criterion.

A square nose shape will introduce far more phase shift than a rounded one, and in FM systems abrupt phase shift results in distortion of the modulating signal.

For a practical figure, the bandwidth should not be less than 34 kc. at 6 db for 15 kc. maximum swing. The same method can be used at any other level at which it is desired to measure the bandwidth at the nose.

An alternative method to the one just outlined would be to feed in a signal of the same level, but keep the deviation at a fixed amount and then shift the frequency first to one side and then the other until the S+N+D/N+D is reduced to 12 db. The bandwidth is then twice the sum of the deviation and the smaller of the two shifts in frequency.

This method gives promise of being more precise, but it is somewhat more difficult to make and requires study to set the modulation to be used.

No matter which method is used to specify the minimum bandwidth at the nose for acceptable on-channel signal reception, the nose width should also be examined to determine if it is compatible with good adjacent-channel rejection.

The adjacent-channel performance of a receiver can best be indicated at the present time by use of the two-signal selectivity specification and a minimum nose width specification using the dynamic method of nose-width measurement described above.

To insure the best adjacent-channel performance, the nose width should be held as close as possible to the minimum specified to minimize the interference due to transmitter noise.

The author wishes to acknowledge his indebtedness to a number of his associates, particularly to Messrs. N. H. Shepherd and R. P. Gifford who were, in a large measure, responsible for the graphic selectivity analysis and to C. M. Heiden for his guidance of this project.