

CHAPTER 37

RECEIVER AND AMPLIFIER TESTS AND MEASUREMENTS

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SECTION 1 : A-M RECEIVERS

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(i) Introduction

Few of the results of measurements made on radio receivers can be expressed as the difference between an ideal receiver and the receiver under test. For this reason it is desirable to adopt standard methods of measuring the performance characteristics of receivers and of presenting the results of those measurements. When this is done direct comparisons between receivers are possible, whereas if for instance one manufacturer expresses noise as the percentage of output voltage remaining when the 400 c/s 30% modulation is removed from the modulated carrier required to give standard output, and another follows the English R.M.A.* recommendation and expresses it as the unmodulated r-f input carrier for which the output is equal to the output given by a 10% modulation of that carrier at 1500 c/s, then it is not easy to form any opinion of the relative merits of receivers measured under the two systems.

Unfortunately there is no standard international method of measuring receiver performance and the two series of tests due to the American I.R.E. (Ref. 1) and the English R.M.A.* (Ref. 2) differ in important details. The main requirements of the two testing specifications are given in this chapter.

(ii) Definitions

(A) **Standard input voltages** (I.R.E.) "Four standard input voltages are specified for the purpose of certain tests, as follows :

- (1) A "distant-signal voltage" is taken as 86 decibels below one volt, or 50 microvolts.
- (2) A "mean-signal voltage" is taken as 46 decibels below one volt, or 5000 microvolts.
- (3) A "local-signal voltage" is taken as 20 decibels below one volt, or 100 000 microvolts.
- (4) A "strong-signal voltage" is taken as one volt.

(B) **Antenna sensitivity-test input** (I.R.E.) "The sensitivity input is the least signal-input voltage of a specified carrier frequency, modulated 30 per cent at 400 cycles and applied to the receiver through a standard dummy antenna, which results

*This standard is now obsolete and it is understood that a new R.I.C. standard is in course of preparation. References to the old standard have been included where it appears that they convey useful information or follow current practice.

in normal test output when all controls are adjusted for greatest sensitivity. It is expressed in decibels below 1 volt, or in microvolts."

(C) Normal test output (I.R.E.) "For receivers capable of delivering at least 1 watt maximum undistorted output, the normal test output is an audio-frequency power of 0.5 watt delivered to a standard dummy load.

For receivers capable of delivering 0.1 but less than 1 watt maximum undistorted output, the normal test output is 0.05 watt audio-frequency power delivered to a standard dummy load. When this value is used, it should be so specified. Otherwise, the 0.5-watt value is assumed.

For receivers capable of delivering less than 0.1 watt maximum undistorted output, the normal test output is 0.005 watt audio-frequency power delivered to a standard dummy load. When this value is used, it should be so specified.

For automobile receivers, normal test output is 1.0 watt audio-frequency power delivered to a standard dummy load."

The English R.M.A. recommends a standard output of 50 milliwatts measured across a non-inductive resistance connected in place of the speaker voice-coil and with an impedance equal to the modulus of the voice-coil impedance at 400 c/s.

A level of 1 mW has been suggested (Ref. 3) for communication receivers intended for phone operation or for connection to a land line. An alternative of 0.1 mW is suggested in Ref. 4 for special conditions.

The use of 500 mW for large receivers has the advantage of decreasing the effects of hum and noise on the standard output, but when simple a.v.c. is used the sensitivity may be affected by the a.v.c. before the standard output is reached, so that sensitivity and the a.v.c. characteristic both affect the results obtained.

(D) Maximum undistorted output (I.R.E.) "The so-called maximum undistorted output is arbitrarily taken as the least power output which contains, under given operating conditions, a total power at harmonic frequencies equal to 1 per cent of the apparent power at the fundamental frequency. This corresponds to a root-sum-square total voltage at harmonic frequencies equal to 10 per cent of the root-sum-square voltage at the fundamental frequency, if measured across a pure resistance. (The root-sum-square voltage of a complex wave is the square root of the sum of the squares of the component voltages.)"

(E) Bandwidth (I.R.E.) "As applied to the selectivity of a radio receiver, the bandwidth is the width of a selectivity graph at a specified level on the scale of ordinates."

(F) Standard antenna (I.R.E.) "A standard antenna is taken as an open single-wire antenna (including the lead-in wire) having an effective height of 4 meters."

(iii) Equipment required

(A) Standard signal generator (English R.M.A.) "Signal generators shall give readings of microvolts to $\pm 10\%$ up to 10 megacycles per sec. and to $\pm 25\%$ above 10 megacycles. Their frequency calibration shall be within 1% or within 10 kc. whichever is the greater and incremental frequencies shall be within 0.5 kc; the modulation shall be accurate to within 1/10 of the nominal percentage."

I.R.E. recommendations include the following three points:—

(1) At broadcast frequencies an output voltage indication accuracy within 10% is usually adequate. At higher frequencies an accuracy of indication within 25% is satisfactory.

(2) A frequency indication accuracy of 1% is generally sufficient, but for selectivity or interfering-signal tests the radio frequency should be adjustable in small increments about the desired frequencies and adjustment and indication to within 0.1 per cent of the carrier frequency are desirable.

(3) Frequency modulation should be kept as low as possible. The maximum permissible frequency modulation in cycles is given by $(50 f_c + 100)m$, in which f_c is the carrier frequency expressed in megacycles and m is the modulation factor.

Built-in 400 c/s modulation facilities are usually provided, at least for 30% modulation and sometimes for varying depths. The 400 c/s source should have low distortion (not greater than 1%). It is desirable for modulation depths between 0 and

90% to be available and modulation distortion should be small. There should be provision for the connection of an external a-f generator so that the modulation frequency can be varied between the limits of 30 and 10 000 c/s.

The r-f output should be variable at least between one microvolt and one volt, but a maximum output of two volts is useful.

A smooth, backlash-free drive is necessary, with a movement slow enough and scale large enough for small increments of frequency to be accurately recorded when selectivity curves are being taken.

Fig. 37.1. Standard dummy antenna and method of connection (from Ref. 1).

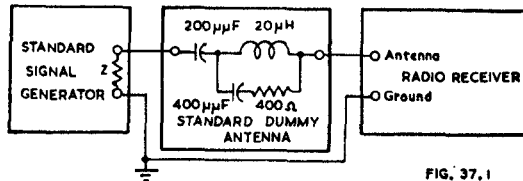


FIG. 37.1

(B) Standard dummy antenna (I.R.E.) "The elements of the standard dummy antenna are capacitors (C_1 and C_2) of 200 and 400 micromicrofarads, respectively, an inductor L of 20 microhenrys, and a resistor R of 400 ohms, connected as shown in Fig. 37.1. The effective values of R , L , and C should be within 10% of the nominal values. The stray capacitance between any two points must be so small as to be negligible at operating frequencies, and the dummy antenna must be so devised as to avoid coupling to other equipment. If the output impedance of the attenuator of the signal generator is not negligible with respect to that of the dummy antenna, this impedance should be deducted from the respective constants thereof.

The leads used in connecting the standard-signal generator through the dummy antenna to the receiver should be so short as to introduce negligible voltage drop. They should be shielded to reduce external fields."

(C) Output-power-measuring device (I.R.E.) "The standard dummy load is a pure resistance which should be of sufficient power capacity to carry the maximum power output of the receiver without change in its resistance. If provided with taps, these should be sufficiently numerous to allow adjustment to within 10% of the proper value. The precise value of the resistance of each step should be known.

Dry-rectifier-type voltmeters, vacuum-tube voltmeters, or thermocouple-type ammeters are suitable for measuring the power delivered to the standard dummy load. They may read root-sum-square values and be calibrated in current, voltage, power, or directly in decibels, the former units being more commonly used. While dry-rectifier-type voltmeters are subject to temperature and frequency errors these are usually not of sufficient magnitude to affect the measurements seriously, so long as distortion is not high."

(D) Audio-frequency generator The output of the a-f generator should be sufficient to modulate the r-f signal generator to 100% from 30 to 10 000 c/s, and to drive the output valve of the receiver to full output when connected to its grid circuit. The maximum harmonic distortion should not exceed 1%.

(E) Audio-frequency attenuator An attenuator is desirable which gives known a-f output voltages continuously variable between 1 V and 1 mV when supplied with a 1 V (or larger) input. Commercial types are available with an output range of 1 V to 1 μ V. The calibration should be accurate (or the correction known) over the range of frequencies to be used.

(F) Wave analyser A wave analyser is required to measure the relative magnitudes of harmonics and inter-modulation products. The I.R.E. requirements for such an instrument are "the accuracy of measurement of each frequency should be within 5% of the indicated harmonic amplitude, and sufficient selectivity should be available to prevent adjacent harmonics at any measured frequency from influencing the results. In this type of analysis it is, of course, necessary that the signal-generator harmonics be small in comparison with the harmonic distortion being measured."

A **distortion-factor meter** can be used to measure total distortion* i.e. the receiver output at all frequencies except the fundamental of the signal source. It is worth noting that the English R.M.A. definition of "distortion factor" is

$$\frac{1}{2} \sqrt{\frac{\sum_{n=2}^{\infty} n^2 V_n^2}{\sum_{n=1}^{\infty} V_n^2}}$$

where n represents the order of an individual harmonic. This expression† loads the higher harmonics in proportion to their order.

An I.R.E. recommendation is "If an instrument is used which makes a lumped measurement of all distortion, by elimination of the fundamental, a high-pass filter should be used, in order to eliminate hum and similar low-frequency noise from the result."

(G) Meters. Meters are required to cover the range of voltages and currents to be measured. Valve voltmeters are useful for measuring small a.c. voltages and currents and for making measurements in which a minimum of circuit loading is necessary (e.g. a.v.c. bias voltages).

(H) Equipment for acoustical tests A number of I.R.E. and English R.M.A. tests are of an acoustical nature. For information on the equipment required and the testing conditions, Refs. 1 and 2 should be consulted.

(iv) Measurements and operating conditions

(A) Output measurements The I.R.E. requirement is that output measurements are to be made in terms of the power delivered to a standard dummy load, which is a pure resistance of a value equal to the 400 c/s impedance of the loudspeaker to be used with the receiver. Where an output transformer is connected between the radio receiver and the loudspeaker, the output transformer is to be treated as part of the radio receiver.

There are special requirements when power output is to be measured in the presence of background noise. If the background noise power is smaller than the output power being measured, the incremental reading of output power may be used. With a thermocouple output meter the incremental output power is equal to the observed total power minus the observed noise power. If another type of output meter is used, a calibration should be made in terms of incremental power.

If the background noise is greater than the output power being measured, it is desirable to use a band-pass filter tuned to the test audio frequency to remove the background noise wholly or partially from the output meter. This filter should be connected between the load and the output meter.

Alternatively an electro-dynamometer with its field synchronously excited from the original source of modulation can be used.

(B) Summary of additional I.R.E. requirements "The operating voltage applied to a radio receiver should be held constant at the specified value during measurements of receiver characteristics. Certain receiver characteristics may be desired at other than normal test voltage, or over a range of operating voltages, in which case a statement of the voltages used should be included in the test data. In any case, tests should be made to check whether the receiver operates satisfactorily over the full range of operating voltage that is liable to be encountered in practice. A.C., A.C./D.C., or D.C. receivers should be tested with 117 volts r.m.s. A.C. or 117 volts D.C. applied, unless some other operating voltage is stated.

Automobile receivers should be tested with 6.6 volts at the receiver-battery terminals. The voltage should be obtained from a battery being charged at the required rate and not by the use of a dropping resistor. 32-volt farm-lighting-plant receivers are tested with 36 volts.

*Total harmonic distortion, see Chapter 14 Sect. 2 (iv) p. 609.

†This is the same as the Weighted Distortion Factor described in Chapter 14 Sect. 2(v) p. 610.

Other battery-operated receivers are tested with batteries of the type and voltage specified. The batteries used should not have abnormally high internal resistance.

The valves used should be selected to have the rated values of those characteristics which most affect the performance of the receiver."

(C) Summary of English R.M.A. requirements The receiver is to operate in its cabinet for at least half an hour before tests begin.

All batteries are to be at their normal operating voltages. The internal resistance of the H.T. battery is to be increased by adding, in the H.T. negative lead, a resistance equal to 1 ohm per cell. Care should be taken to see that the added resistance does not affect the grid bias.

Where the receiver carries a mains tapping device and a number of marked ranges, the applied voltage should fall in the middle of one of these ranges, the midpoint being calculated as a geometric mean.

(v) Measurements

Tests are applied to receivers for various reasons ; as an aid to design, to compare different designs, to compare a mass-produced receiver with a laboratory prototype and as a preliminary to repairs. Appropriate tests should be selected from the following sections to suit the required object, or perhaps the available equipment. An arbitrary distinction has been drawn between measurements (carried out with voltmeters and ammeters) and tests, which in general need more equipment.

For normal **voltage and current measurements** receivers and amplifiers should be operated without input or output, and bias-controlling volume controls should be turned to maximum.

If all voltages are to be checked it is necessary to use a high impedance meter (20 000 ohm/volt or more) but most important checks can be made with 1000 ohm/volt meters. In any case allowance must be made for meter resistance in all high impedance circuits and it is useful to know the actual value of resistance for any particular range in use.

Measurements of grid bias should normally be made either across the cathode bias resistor (if any), or between the cathode and the earthy end of the grid resistor. This will give the grid-cathode voltage unless current is flowing in the grid resistor. The latter may be checked by short-circuiting the grid resistor with a suitable current meter in the plate circuit, and noting any change in reading.

There are two methods which can be used to determine plate and screen voltages when high values of series resistors are used. The first is the direct method, noting the reading on a high impedance voltmeter and making allowance for the meter resistance. If a suitable two range voltmeter is available, the method described by Lafferty may be used to determine the correct voltage—see Chapter 4 Sect. 7(iii) pages 163-164, and eqns. (10) and (11). Alternatively, the series resistor in the voltmeter may be shunted by an external resistor of equal value, with a switch to remove the shunt when required. This gives a scale ratio of 2, and enables eqn. (11) on page 164 to be used. The shunt resistor may well take the form of a decade box, accurately adjusted to the internal voltmeter resistance. Other methods of making allowance for meter resistance may introduce serious errors.

The second method of measuring plate and screen voltages, which may be called the indirect method, is to measure the voltage from B+ to cathode and also the current to the electrode. The value of the series resistor should then be measured, and the voltage drop across it may be calculated by Ohm's Law.

An example of the error which may be introduced by other methods is given below. Suppose that a 20 000 ohm/volt meter on the 25 volt range is used to measure the bias voltage (from grid to cathode) on an output valve which has back bias and a 0.5 megohm grid resistor.

Although the meter resistance is equal to the resistance of the grid leak so that half of the bias voltage appears across the meter, only one half of the generated bias voltage is applied to the grid of the valve, its plate current is increased, and a larger voltage is developed across the back-biasing resistor. The indicated bias voltage is thus more than half the working bias voltage.

When voltages and currents are being measured to check valve electrode dissipation or component ratings it may be necessary to modify receiver operating conditions to obtain the worst conditions for the component in question. For example tuning a strong signal with a back-biased receiver will decrease the bias on the output valve and may cause the plate dissipation to exceed the limit. The effect of component tolerances must also be taken into account.

A measurement of, say, oscillator grid current at low voltages as part of a type test in a battery receiver at low voltages would not be considered finished until many valves had been measured to determine the average and minimum values, or unless valves with bogie and limit characteristics were available.

The maximum **temperature rise** allowed in radio power transformers by R.M.A. specification M4-541 is 65°C (core or windings whichever is greater) when operated continuously with the specified load, at the specified frequency, under standard conditions and at a voltage 10% above that of the standard line voltage.

The standard conditions are set out in M4-546 and require a specially constructed asbestos box. The core temperature is measured with an all-glass mercury bulb thermometer brought into good contact with the surface of the core by means of glazier's putty.

The temperature of the primary and secondary windings are determined by the resistance method using the following formula : (A.I.E.E. Rule 13-207)

t = reference temperature of winding

T = temperature of winding to be calculated

r = resistance at reference temperature t

R = observed resistance at temperature T

$$T = \frac{R}{r} (234.5 + t) - 234.5.$$

The observed resistance R is to be measured within one minute from the completion of the test run, that of the highest voltage secondary winding being measured first and that of the primary winding being measured second.

The temperature rise of the transformer is determined by subtracting the temperature of the ambient air within the enclosure at the end of the test from the temperature of the core or windings (whichever is highest) at the end of the tests.

In determining the ultimate temperature of the core and windings, the operation of the transformer is continued until temperatures within the enclosure show constancy for three successive readings at intervals of at least 15 minutes.

An ambient temperature of 40°C is maintained within the enclosure throughout the test.

(vi) Performance tests

(A) Sensitivity

All measurements, including sensitivity, which are made with the signal generator output applied to the aerial terminal of a receiver require a standard dummy antenna to be connected between the two, except that in the case of a receiver designed for use with a special aerial, a dummy aerial is required with constants giving an impedance characteristic similar to the special aerial. The sensitivity is expressed as the input required to give standard output from the receiver. The input referred to is the open circuit voltage from the signal generator, modulated 30% at 400 c/s.

For purposes of recording results sensitivity is usually measured at or near the three tracking points on each wave range, but when curves are to be drawn additional points are required.

With sensitive receivers noise forms a large part (or all) of the output in sensitivity measurements, and alternative methods of measurement which specify the input required to give a minimum signal-to-noise ratio are becoming increasingly popular. One method is to specify the input required to give equal signal and noise outputs i.e. when the modulation is switched off the output power is halved. A signal-to-noise ratio of 15 db is more commonly used for communication work in England, this ratio being taken as providing satisfactory intelligibility.

When the signal-to-noise ratio method of measurement is used for all types of receivers it is necessary to make provision for insensitive receivers by defining sensitivity as the input required to give a certain signal-to-noise ratio, or the input required to give standard output, whichever is the greater.

Sensitivity measurements on telegraphy receivers are carried out by adjusting the beat note to the peak of the a-f response.

To check the gain of individual stages in a receiver, a measurement is made of the input to successive grids required to give standard output from the receiver. The generator is coupled to the receiver by means of a large capacitor (say $0.1 \mu\text{F}$) and the normal connections to the grid are not disturbed.

Measurements made in this way are liable to errors at high frequencies and when regeneration is present. At high frequencies the inductance of the generator output leads and the input capacitance of the stage being measured may seriously affect the results.

During measurement, regenerative effects may be eliminated by the low impedance of the signal generator connected between grid and ground but when the gain from the previous grid is measured the regeneration will re-appear so that the apparent gain of the earlier stage is its true gain multiplied by the gain due to regeneration in the subsequent stage.

The regeneration may be from causes such as feedback due to the plate-grid capacitance of an i-f amplifier, or in the case of a converter it may be due to oscillator voltages on the signal grid. For the latter reason, measurements of conversion gain and r-f gain (or aerial coil gain if no r-f stage is used), particularly at high frequencies, should be treated with reserve unless it is known that these effects were not present.

(B) Selectivity

Selectivity measurements are made with the object of determining the frequency separation necessary to eliminate interference between a desired signal and a stronger undesired signal.

It is not possible to specify one selectivity test the results of which will be a measure of the interference to be expected, because there are several ways in which interference can occur.

These are :—

(1) Because of inadequate selectivity the two modulated carriers may both be present at the second detector, and although no noticeable interaction occurs between the signals, they are both heard.

(2) The desired carrier may be modulated by the modulating frequencies of the undesired carrier (cross-modulation).

(3) A reduction of the a-f output from the desired carrier may be caused by a.v.c. voltages developed by the undesired carrier, or by demodulation by the undesired carrier.

(4) When the frequency separation between adjacent carriers is an audible frequency a continuous heterodyne is heard. This effect is very noticeable in receivers with a good high frequency response as they are capable of reproducing frequencies of 9 or 10 Kc/s by which medium wave broadcasting stations are separated.

(5) Intermodulation may occur between two stations of which the frequency difference or frequency sum is the same (or nearly the same) as the frequency of a desired station. An intermodulation product can then interfere with a desired signal.

(6) Distortion in the receiver may produce harmonics of an undesired signal which interfere with a desired signal.

(7) "Monkey chatter" may occur due to the sidebands of the undesired carrier being detected, with frequency inversion, as sidebands of the desired carrier. For example, if the desired carrier is separated by 20 Kc/s from the undesired carrier, which is lower in frequency and which is modulated by frequencies of 7 and 12 Kc/s, the higher sidebands of the undesired carrier become respectively 13 and 8 Kc/s lower sidebands of the desired signal.

Sturley (Ref. 3) points out a less commonly recognised extension of this effect. The presence of small percentages of a-f harmonics may greatly extend the carrier

frequency separation across which monkey chatter may occur. For example, suppose a strong local station on 1000 Kc/s induces 1 volt 50% modulated at 7 Kc/s in the aerial of a receiver tuned to 1030 Kc/s. If there is a fourth harmonic sideband percentage of 0.1% the amplitude of the upper frequency harmonic sideband (1024 Kc/s) is 500 μ V. A station on 1030 Kc/s would thus have added to it a 6 Kc/s sideband of ample power to cause over-modulation at low signal levels.

An investigation into the poor agreement between selectivity as measured by the one or two signal generator methods and actual performance on the air is detailed in Ref. 13.

The I.R.E. recommendation for a single signal selectivity test is that the receiver be tuned to the test frequency as in the sensitivity test. The signal generator is then detuned each side of resonance, the radio-frequency input voltage which results in normal test output is observed, and its ratio to the sensitivity-test input is computed. If this test is made at only one frequency in superheterodyne receivers it is recommended that this be 1000 Kc/s.

When the selectivity of the a.v.c. circuit is the same as that of the signal circuit no special precautions are necessary. However if there is any appreciable difference between the two selectivities it is recommended that the a.v.c. voltage be maintained at the value obtained at centre frequency. This method provides an indication of the circuit selectivity rather than of discrimination against interference.

Errors may occur in very selective receivers because the receiver output is the result of applying a band of frequencies (carrier and upper and lower sidebands) to a sloping characteristic. To avoid this effect an unmodulated carrier can be used and diode current in the second detector circuit taken as the output indication.

Another point which may give trouble is that with very sensitive receivers the majority of the standard output at full sensitivity is noise. A different signal-to-noise ratio at standard output will be experienced when tuning towards a strong carrier and a faulty reading will be obtained. To overcome this a reference input is often selected to give a good signal-to-noise ratio while still leaving the a.v.c. inoperative—10 μ V is a suitable input in many cases.

Two-signal tests are specified by the I.R.E. for cross-talk, whistle and blocking interference. The signal generators are preferably connected in series but parallel connection is possible with special dummy aerials. The radio receiver is tuned to the desired signal at one of the standard test frequencies and at one of the standard input voltages. The receiver volume control is adjusted to give normal test output when the signal is modulated 30% at 400 c/s, after which the modulation is switched off.

An interfering-signal input voltage is applied to the receiver, in addition to the desired signal which remains unchanged. The interfering signal is modulated 30% at 400 c/s. The interfering signal is tuned through a wide frequency range and the interference-test input voltage which gives interference-test output at 400 c/s (30 db below standard output) is observed wherever its value is less than one volt. Readings are not taken for carrier spacings so close that beat note interference is more severe than cross-talk interference.

Such a test is the only type of selectivity test which shows correctly the selectivity curve, at reduced sensitivity, of a receiver having a.v.c. It is also the only method by which the selectivity of a receiver having automatic selectivity control can be tested directly.

The interfering signal may also reduce the desired-signal output by a.v.c. action or overloading. Blocking interference tests can be carried out for this effect (as specified by the I.R.E.) by modulating the desired signal and measuring the change in output with varying signal strength and frequency of the unmodulated signal. The results of blocking signal tests can be plotted on the same sheet as the results of the two-signal cross-talk tests.

The two-signal whistle interference test specified by the I.R.E. indicates the greatest interference input permitted without the output exceeding the equivalent of approximately 1% modulation of the desired signal. If the desired signal is modulated 30%, the permitted interference output power is 0.001 of the desired-modulation output power.

The signals are the same as for the cross-talk test, except that the interfering signal is unmodulated. The interfering signal is tuned through a wide frequency range, and the interference-test input voltage, which gives interference-test output at 400 c/s, is observed wherever its value is less than one volt. No reading is made with the desired and undesired signals separated by 400 c/s.

The English R.M.A. selectivity test is similar to the I.R.E. cross-talk interference test but a 400 c/s bandpass filter is used between receiver and output meter to eliminate the effect of the heterodyne between carriers. The desired signal is 1 mV, 30% modulated at 400 c/s and the receiver volume control is adjusted to give one quarter of the rated maximum output. Modulation is removed from the desired signal and the input required to give an output 40 db below the previous output is noted for various off-tune frequencies of the 400 c/s 30% modulated undesired carrier.

In Ref. 40 a test for r-f intermodulation is given. A "wanted" signal 30 db above 1 μ V is applied to a receiver, the sensitivity control is adjusted for standard output (a.v.c. switched off) and the signal is then removed.

Two interfering signals are then applied to the receiver with a frequency difference or frequency sum equal to the frequency of the wanted signal. The interfering signals are each 110 db above 1 μ V and neither is of such a frequency as to give an appreciable output when applied alone. Under these conditions the receiver is not to produce an output exceeding the standard output.

When this test is used care should be taken to see that intermodulation does not occur outside the receiver, for instance in measuring diode circuits of signal generators.

A test for r-f harmonic generation in the receiver is also given in Ref. 40. Standard output is obtained from a wanted signal as above, and then the wanted signal is replaced by an unwanted signal of half the frequency and at a level of 116 db above 1 μ V. The output from the receiver should not exceed the standard output. The effect of signal generator harmonics must not be overlooked when this test is being performed.

Sturley (Ref. 3) gives additional tests whereby the effects of heterodyne whistles, monkey chatter and a receiver whistle filter can all be shown on a set of curves.

(C) Electric fidelity (frequency response)

The electric fidelity test specified by the I.R.E. shows the manner in which the electric output of a receiver depends on the frequency of the a-f modulation. The radiation characteristics of the loud speaker are not taken into consideration and this minimizes the value of the test.

30% modulation of a 1000 Kc/s 5000 μ V signal is used, and the receiver is tuned to it in the following manner. Firstly the receiver is tuned to the carrier with 400 c/s modulation, and then the modulating frequency is increased until the receiver output has fallen to one fifth. The receiver tuning is then readjusted slightly for **minimum** output.

The receiver output is measured in terms of current or voltage in a standard dummy load, or in terms of the voltage across or of the current in the voice coil of the loud speaker. In the latter case, the loud speaker should be located in its baffle or cabinet, with the receiver chassis in place. The data should include a statement of which load is used. The receiver volume control is adjusted to give normal test output. The modulation frequency is then varied continuously from 30 to 10 000 cycles while maintaining 30% modulation and the output variation is observed.

If the electric-fidelity curve has decided peaks, there is abnormal tendency towards overloading, and the observations may have to be repeated with less output.

It is frequently unnecessary to make or plot these observations below -20 db, but further observations may be desirable, particularly if a large amount of negative feedback is used.

Suitable precautions must be taken to prevent hum or noise, if present, from affecting the accuracy of the results.

If electric-fidelity varies appreciably with the signal frequency, the input level, the volume or tone control settings or any other parameter, additional tests should be made to show the effect of these changes.

(D) Harmonic distortion (I.R.E.)

This test is intended to evaluate the spurious a-f harmonics which appear in the electric output of the radio receiver during normal operation. Care should be taken to avoid appreciable harmonic distortion occurring in any part of the signal-generating equipment, or in the output-measuring circuit. The required harmonic-measuring equipment in the output circuit should not appreciably affect the output load conditions. This equipment may measure each harmonic individually or may measure all harmonics collectively. The proper tuning of the receiver is important in making distortion tests.

No one complete set of conditions can be prescribed for this test, because harmonic distortion depends on so many details of radio receiver design and operating conditions. Harmonic distortion is caused by overloading and many other phenomena, and is present under various operating conditions, especially at high degrees of modulation. The following series of tests is intended to show the effect of operating parameters on distortion.

Variation of output. The receiver is tuned to 1000 kilocycles and a "mean-signal" input, modulated 30% at 400 cycles, is applied. The distortion is noted as the output of the receiver is varied by means of the volume control.

Variation of modulation. With a "mean-signal" 1000-kilocycle, 400-cycle-modulated input, the modulation is varied from 10 to 100% and the distortion observed. The output is maintained at normal test output by the volume control for this test, or as near this value as possible.

Variation of input signal level. With a 1000-kilocycle signal, modulated at 400 cycles, the distortion at normal test output is noted as the input signal voltage is varied. This test is to be performed at both 30% and 80% modulation. It is usually sufficient to take distortion at the standard input levels which fall within the limits of the receiver. When a standard-signal level exceeds the limit of the receiver, a measurement should be made at that limit.

Variation of modulation frequency. To disclose the effect of the modulation frequency on distortion, tests on variation of output and variation of modulation should be repeated at several modulation frequencies throughout the a-f range. The maximum modulation frequency at which harmonic distortion can be measured is one-half the maximum frequency which can produce any appreciable output.

The harmonic distortion is measured across a standard dummy load and may be measured as either root-sum-square total harmonic distortion or each harmonic may be measured separately. It is expressed as the ratio of the harmonic voltage to the fundamental voltage either in per cent or decibels.

Intermodulation measurements. Owing to the lack of signal generators suitable for r-f intermodulation work, these measurements are normally carried out only on the a-f end of radio receivers. See Sect. 3(ii)A of this chapter for details.

(E) Maximum undistorted output (I.R.E.)

"This test is intended to indicate the maximum power output which the receiver will deliver under given conditions, before appreciable overloading or other forms of distortion occur. The maximum undistorted output may be determined under given conditions by observing the total harmonic distortion, and continuously increasing the output from zero up to the least value which contains a total harmonic distortion of 10% (root-sum-square voltage). This value is designated the maximum undistorted output under the given conditions.

The data should include a statement of the operating conditions, including which condition was varied in order to increase the output during this test. It is suggested that the volume control of the radio receiver be varied, the other conditions being unchanged during a single test and being chosen as suggested for the harmonic-distortion test. Freedom from distortion depends on the r-f input voltage and on the frequency and percentage of modulation.

It is understood that there is no sharp dividing line between appreciable and negligible distortion. The figure of 10% has been chosen somewhat arbitrarily as a reasonable basis for the definition of maximum undistorted output as affected by all operations in the receiver."

(F) Automatic volume control

The I.R.E. recommendation is to tune the receiver to a mean-signal input voltage 400 c/s 30% modulated at 1000 Kc/s and to adjust the volume control so that with one volt input to the receiver the output is one half of the maximum power output. The output is then read as the input is varied from one microvolt to one volt.

A disadvantage of this method is that the output readings for low inputs, from which much valuable information can be obtained, are carried out at very low levels (perhaps below 1 mW) and hum in the receiver output may be troublesome.

Scroggie (Ref. 6) suggests beginning the a.v.c. curve with the volume control set at maximum and with the minimum input. Output readings are taken with increasing input until the output reaches one quarter of the maximum. It is then reduced to one tenth of this value by means of the volume control and the input is further increased. This procedure is repeated until the maximum input is applied to the receiver. The sections of the curve are made continuous by the use of appropriate multiplying factors. This method has many advantages—Chapter 27 Sect. 3(xiv).

Useful information can also be obtained from a noise curve plotted on the same sheet. The same procedure is adopted as for drawing the a.v.c. curve but the input carrier is unmodulated.

Other information sometimes added to a.v.c. curves includes graphs of distortion, a.v.c. bias voltage and electrode current and dissipation for the controlled valves vs. input voltage, and it may be useful to draw a horizontal line across the a.v.c. curve (when drawn by Scroggie's method) at a level representing the nominal output of the receiver. Alternatively the maximum output of the receiver may be plotted.

When the converter valve has a.v.c. applied to it, detuning of the signal may occur as the signal input is varied. This should be remedied by retuning the receiver with each input level change if necessary.

(G) Noise

The I.R.E. recommendation is that noise should be expressed as the equivalent-noise-sideband-input (ensi). An unmodulated input carrier of suitable strength, E_s , is applied to the receiver, and the noise output power P_n is measured on a R.M.S.-reading instrument. A 400 c/s bandpass filter is connected between receiver and output meter, the carrier is 30% modulated at 400 c/s and the signal power output P_s is measured. Then

$$\text{ensi} = 0.3 E_s \sqrt{P_n/P_s}.$$

E_s should be at least three times and preferably ten times greater than the computed noise voltage.

Excessive low frequency hum components may usually be filtered out by the use of a 300 cycle high-pass filter without materially affecting the random-noise output.

An alternative method of specifying noise is by comparing the signal-to-noise ratio of a particular receiver with that of an ideal receiver, the difference being called the noise factor of the receiver in question. Ignoring any noise external to the receiving system, the only source of noise which is inseparable from an incoming signal is the thermal agitation noise due to the radiation resistance of the antenna. Thus a signal-to-noise ratio has its highest possible value when the noise due to the antenna radiation resistance is the only noise source in a receiving system.

Where a signal voltage e_{ant} is induced into an antenna of radiation resistance R_{ant} maximum signal power is delivered to a receiver with an input resistance of R_{ant} . This maximum power available from the antenna is

$$\left(\frac{e_{ant}}{2}\right)^2 \times \frac{1}{R_{ant}} = \frac{e_{ant}^2}{4R_{ant}}.$$

Similarly the noise from the antenna available to the receiver is

$$\left(\frac{e_{noise}}{2}\right)^2 \times \frac{1}{R_{ant}} = \frac{4KT\Delta FR_{ant}}{4R_{ant}} = KT\Delta F,$$

where K = Boltzmann's constant = 1.38×10^{-23} joule/degree Kelvin

T = absolute temperature in degrees Kelvin

F = bandwidth of system in cycles per second,

and the signal to noise power ratio of an ideal system is

$$\frac{e_{s,ant}^2}{4KT\Delta FR_{ant}}$$

The noise factor of an ideal receiver can thus be defined as the number of times by which the available signal power from the aerial must exceed $KT\Delta F$ in order to give unity ratio of available signal to noise power.

The noise requirement for such an ideal receiver is that it must contain no internal sources of noise. It must also present an infinite impedance to the antenna so that there will be no loss of signal voltage. If for instance the input impedance of the receiver were to match the antenna impedance the voltage available to the receiver would be one half of the signal voltage induced into the antenna and this would be developed across one half of the antenna impedance due to the parallel connection of the antenna and the matching input circuit. Substitution of these factors in the expression above shows that in such a case the maximum noise factor obtainable is 2, i.e. 3 db.

Since the requirement for maximum power transfer is that the input impedance of the receiver should be equal to the antenna impedance, it is evident that the conditions for maximum gain are in general different from those for minimum noise. The best noise figure in practical receivers is obtained when the input impedance is intermediate between an open circuit and an impedance match with the antenna system.

When noise calculations are being made the value $T = 290^\circ\text{K}$ is commonly used as this gives KT the convenient value of 4×10^{-21} . However, the effective temperature of the radiation resistance is subject to wide variations, and is affected by the surroundings with which the antenna can exchange energy by radiation. For instance, the noise temperature of a highly directional micro-wave radar antenna pointed at the depths of space may be only slightly above absolute zero. On the other hand a directional 7 metre antenna pointed at parts of the Milky Way may have an effective temperature much higher than ambient.

The noise factor of a receiver can be obtained by using a signal generator or a noise diode (see below). With a signal generator, difficulty is experienced in that the characteristic of the detector in the receiver may affect the ratio of signal power to noise power. If the detector is a true power sensitive device such as a thermocouple no error occurs, but with normal detectors error is introduced to a degree dependent on the variation between the assumed and the actual detection characteristic.

On the other hand, if the signal generator is replaced by a noise diode, detector distortion can be ignored since the noise from the diode has the same spectrum as the noise from the antenna.

The signal generator method is to apply the generator output to the receiver through a resistor R_{ant} and to adjust the output until the indication at the receiver detector is twice that from noise alone. The noise factor is then obtained by calculation from the formula

$$\text{noise factor } F = \frac{e_{s,v}^2}{4KT\Delta FR_{ant}}$$

where $e_{s,v}$ = voltage output of signal generator.

Alternatively the anode current of a temperature limited diode (noise diode) can be used as a noise source. The diode is connected with suitable d.c. isolation across the receiver input, which is also shunted by a resistor equal in value to R_{ant} . The d.c. anode current of the diode is then increased until the noise output of the receiver alone is doubled, and under these conditions the noise factor of the receiver is

$$\text{noise factor } F = \frac{2eI_b\Delta FR_{ant}^2}{4KT\Delta FR_{ant}}$$

where e = charge on an electron = 1.59×10^{-19} coulombs

and $I_b =$ diode plate current in amperes.
therefore noise factor $F = 20 I_b R_{ant}$ at 290°K.

A comparison of the two noise factor formulae shows a second advantage of the noise diode method, viz. : the receiver bandwidth need not be known.

Additional information on noise factors will be found in Refs. 7, 8 and 9.

(H) Hum

Hum is a low pitched composite tone which may include a component at any integral multiple of the a-c power supply frequency. It may be due to the loudspeaker itself, to the a-f stages or to the r-f stages.

When the field winding of a speaker is used for filtering, hum may appear in the voice coil even although some neutralizing is accomplished by connecting a hum-bucking coil in series with the voice coil. The I.R.E. recommendation is that this type of hum "should be measured in terms of the hum current through the loudspeaker voice coil itself, rather than in terms of the voltage across the loudspeaker, and the total hum calculated using this current and the loudspeaker voice coil impedance. The loudspeaker is connected in the normal manner to the radio receiver when the observations are made. The current measuring equipment should introduce into the voice coil an impedance which is negligible as compared with the voice coil impedance. In the case of a loudspeaker having a field coil carrying hum current, this procedure evaluates the combined effect of hum originating in the radio receiver itself and hum induced in the voice coil from the field coil, with due regard to their phase relations."

"Hum from the a-f stage of the receiver should be measured

- (a) with the volume control at minimum,
- (b) with the volume control left at that setting which would produce normal test output with mean-signal input, but with the intermediate-frequency-amplifier circuits inactivated, as by-passing the last i-f plate to ground,
- (c) with the volume control at full volume and the i-f system inactivated.

"In the case of phonograph combinations, a-f hum should also be measured with the phonograph pick-up connected to the a-f amplifier under the following conditions :

- (a) with the phonograph motor de-energized, the pick-up on the rest, and the volume control at minimum
- (b) same as (a) but with the volume control at maximum
- (c) with the volume control adjusted, while reproducing the outside 1000 cycle band on R.M.A. Frequency Test Record No. 1 to give normal test output, the needle then lifted not more than $\frac{1}{4}$ inch above the record, with the motor still running."

"Hum modulation is produced by hum sources which modulate a carrier being received, and its intensity generally increases with increasing carrier voltage.

The hum-modulation test is intended to evaluate the hum components introduced in a radio receiver by hum disturbances modulating the received carrier. In order to measure hum modulation, as distinguished from a-f hum, the former is accentuated by the adjustments of the receiver. The receiver is tuned in the normal manner to each of the four standard input voltages at 1000 kilocycles. If the receiver has a tone control, it should be set in the "high" position. The volume control is first adjusted to give the normal test output with the given signal voltage modulated 30% at 400 cycles and the modulation is then reduced to zero. The hum is measured with the load and output-measuring equipment connected as in the electric-fidelity test, and is expressed in terms of reduction in decibels below standard test output."

Hum distortion can also occur. It is identified as sidebands of frequencies differing from the audio frequency of modulation by an amount equal to the frequency of the hum disturbance causing the distortion.

A typical design likely to introduce hum distortion is one in which the plate of the output valve is fed directly from the rectifier output (assuming a condenser-input filter). No specific test procedure for measuring this effect is given by the I.R.E. or R.M.A. but owing to its unpleasant effects it should be eliminated if this is possible.

Acoustical measurement of hum output is desirable but difficult by available methods. The results of the electric measurement must be interpreted with reference to electric- and acoustical-fidelity curves and the characteristics of audition.

(I) Frequency shift (I.R.E.)

"This test is intended to show the variation in the frequency of the oscillator of a superheterodyne receiver. The tests are normally performed with the receiver tuned to a frequency in the middle of each tuning range of the receiver. If observations under the worst conditions are desired, the receiver should be tuned to the highest frequency of each range.

"The variation of frequency is observed with the aid of a beat note obtained between the oscillator under test and another oscillator of constant frequency. For example, the frequency of the beat note may be observed by comparison with a calibrated a-f oscillator.

"(a) The frequency varies with time during the warming-up period of the receiver The time is measured from switching on the receiver but observations are ordinarily started one minute later.

"(b) The frequency varies with power-supply voltage in a manner that depends on the rate of variation of this voltage. The major change occurs almost instantly following a change of the power voltage. Therefore the test is performed as quickly as possible to minimize other effects. In the case of operation from a 115-volt power line, the line voltage is varied at least between 105 and 130 volts and the resultant frequency shift is observed. The amount of frequency shift is expressed in cycles per 1 per cent change of power voltage, as an average value over the specified range of power-line voltage.

"(c) If the receiver has automatic gain control, the variation of signal-input voltage affects the oscillator frequency indirectly by way of the control circuit. The frequency shift with variation of signal-input voltage is observed after the receiver has been in operation a sufficient length of time to reach temperature stability."

(J) Spurious response (I.R.E.)

"With the radio receiver tuned to each of the test frequencies, the signal generator should be continuously varied over a wide frequency range to discover if the receiver is simultaneously resonant at frequencies other than the test frequency. These other resonant frequencies are called spurious-response frequencies and are most often found in superheterodyne receivers. Each spurious-response frequency is noted and the spurious-response sensitivity-test input is measured as in the sensitivity test, provided it is smaller than 1 volt. Its ratio to the desired-signal sensitivity-test input may be computed, and is called the spurious-response ratio."

"Care should be taken that the harmonic output of the signal generator is attenuated sufficiently not to affect the observation of the spurious response of the receiver."

Image response. "A superheterodyne receiver is generally responsive to two frequencies whose difference from the local-oscillator frequency is equal to the intermediate frequency. One of these (usually the lower) is the desired-signal frequency, and the other is called the image frequency. This is a special case of spurious-response frequency, and is tested as such. Its observed characteristics are referred to as 'image-sensitivity test input' and 'image ratio.'"

Intermediate-frequency response. "Another special case of a spurious-response frequency in a superheterodyne receiver is that due to the sensitivity to an intermediate-frequency signal input. The test procedure is the same as for other spurious responses, and the observed characteristics are referred to as the intermediate-frequency-response sensitivity and the intermediate-frequency-response ratio."

(K) Noise audibility (I.R.E.)

"The actual audibility of random noise, hum, and miscellaneous noise is best determined by a listening test. Such observations are not capable of precision, but are fundamentally sound, as distinguished from less direct electrical observations. The completely assembled and operating radio receiver is placed in a quiet room, and an experienced observer with normal hearing notes the greatest distance at which the noise is audible under stated conditions. The distance is used to express the audibility of the noise. The room is preferably large, or treated to minimize rever-

beration. This method takes into account noise produced both by loudspeaker radiation and by mechanical vibration of parts. A brief description of the sound heard is useful, in addition to the audibility observation. Obviously, this method is suited only for observing a small amount of noise, audible for only a short distance.

The noise-audibility test is intended to evaluate collectively random noise and hum under operating conditions. The radio receiver is tuned in the normal manner to each of the four standard input voltages at 1000 kilocycles. If the receiver has a tone control, it is set in the 'high' position. The volume control is adjusted to give normal test output with the signal modulated 30% at 400 cycles, and then the modulation is reduced to zero. The audibility of the remaining noise is then observed. The residual noise audibility is likewise observed, with no signal and with the volume control set at minimum."

(L) Radiation from local oscillator (I.R.E.)

"A local oscillator, such as is employed in a superheterodyne receiver, may radiate sufficient power to cause interference in other radio receivers operating in the same neighbourhood. Such radiation may be caused by coupling to the antenna, power line, or other external leads, or by incomplete shielding of the oscillator and the circuits coupled thereto.

The receiver is connected to its proper antenna, and the electric- and magnetic-field intensity in the neighbourhood is observed by any of the known methods. There is no simple form for expressing the results. (The recommendation for local oscillator radiation in F-M receivers is that results are to be expressed in field intensity as a function of distance from the receiver under test. Observations are made at least at the middle frequency of each tuning band, and preferably at the extreme frequencies of each band."

(M) Microphony

Microphony troubles are of two main types, audio frequency only and those involving radio frequencies. A convenient test to apply for the first type—which might be due to feedback between the speaker and a pick-up mounted in the same cabinet for instance—is to feed the receiver into a dummy load with an output meter across it, and excite the speaker, mounted in its normal position by means of a variable a-f oscillator.

The pick-up is allowed to stand on a stationary record and a tendency to microphony is indicated by appreciable output across the dummy load at any particular frequency. When the voltage across the dummy load equals the voltage across the speaker, microphony would occur (assuming equal speaker and dummy load impedance at the frequency concerned). Another speaker can be used instead of a dummy load if desired, so long as no sound from this speaker reaches the receiver.

This test has the advantage of indicating the margin available in a particular model before sustained microphony will be experienced. It can also be used for types of microphony involving radio frequencies, but owing to the increased number of possible variables it loses some of its advantages. Tests outlined in (O) 1 below may be used for r-f microphony.

(N) Phonograph combinations (I.R.E.)

"In addition to the above tests on radio receivers, there are several special tests which reveal useful information on the operation of the phonograph portion of combination receivers . . . In addition to hum, the following characteristics should be measured :

- (1) Electric fidelity
- (2) Rumble
- (3) Maximum output
- (4) "Wow" or flutter.

Definitions of these characteristics, with methods of measurements, are given below.

(1) **Fidelity.** The fidelity of a phonograph reproducer corresponds to the a-f fidelity described in Sect. 1(vi)C of this chapter except that RMA Frequency Test Record No. 1 is used instead of a modulated carrier. This RMA Frequency Test Record No. 1 contains, on side A, a gliding frequency from 10 000 to 30 cycles for

usual nominal level testing. Side B contains five 1000-cycle bands, recorded at 0, 2, 4, 6 and 8 decibels above the 1000-cycle reference on side A, and a gliding frequency 6 to 8 decibels above side A in the range between 3000 and 30 cycles for checking pickup tracking at various levels.

In making the fidelity test, side A is used, and the output is first set at standard output using the outside 1000-cycle band. Readings of output are then made at all announced frequencies, including the 1000-cycle bands at start and finish.

Suitable correction usually must be made for noise resulting from needle scratch to provide accurate data above 1000 cycles.

(2) **Rumble.** Rumble is a low-frequency tone or series of random pulses generated at the phonograph pickup as a result of vibrations of the record player. It is generally a maximum when the needle is near the outside of a 12-inch record.

Rumble is measured with the load and output-measuring equipment connected as in the electric-fidelity test, except that a low-pass filter is used with a sharp cutoff at 300 cycles. The measuring equipment should have low wave-form error.

Side A of the test record is also used in this test. The volume control is adjusted to give normal test output while reproducing the outside 1000-cycle band and with the low-pass filter disconnected. The filter is then reconnected and measurements made of rumble components while the needle is in the region between the 1000-cycle tone and the 10 000-cycle tone.

In some cases, a particular rumble frequency may predominate, resulting from motor vibration or pickup-arm resonance. Measurements of such a frequency may be accomplished by means of a tuned filter or harmonic analyzer.

(3) **Maximum output.** The maximum audio output on phonograph may be less than that obtained on radio, because of the absence of automatic-gain-control voltage which normally causes a rise in plate and screen voltages in the audio amplifier.

The test is made by reproducing the 1000-cycle tone on side A of the test record and adjusting the volume control to produce maximum output. The measuring equipment used must give an accurate indication of root-sum-square independent of wave form.

(4) **'Wow' or flutter.** 'Wow' or flutter is caused by minute imperfections in the motor and/or transmission means used to drive the phonograph turntable; and, if present to an appreciable extent, may noticeably impair the quality of reproduction. It is usually evident when a steady note is being reproduced, such as the 1000-cycle band, and evidences itself as a cyclic variation in pitch; hence the name 'wow.' While there is no great distinction between 'wow' and flutter, the former is usually applied to very low cyclic variation, the latter to the more rapid type.

'Wow' or flutter is measured as a percentage of root-mean-square deviation in frequency of a tone to the average frequency. Special equipment is required to make such a measurement, this equipment being capable of responding uniformly to all flutter rates up to 200 cycles, and of measuring to a precision of 0.02% flutter.

Care should be exercised to insure that the method of measurement permits normal conditions to exist as when playing a commercial pressing."

(O) Miscellaneous

(1) Tuning tests

Some receivers which perform well when tuned to a station exhibit undesirable characteristics while being tuned. A test which shows up most of these effects is to tune in unmodulated signals of varying strengths up to the maximum liable to be encountered in service, moving the tuning control slowly and also as rapidly as possible. The volume control should be at its maximum setting, and the test should be repeated at the high and low frequency end of each wave range, and also with modulated signals.

Faults which are liable to be discovered are squeaks as the receiver is tuned rapidly through the sidebands of a signal, flutter on short-waves (and sometimes medium-waves) with slow tuning, microphony, or a rapid variation in the tuning rate near the carrier frequency on short waves due to varying electrode potentials or capacitances affecting the oscillator frequency. This should not be taken as a complete list of possible faults and any unusual effect should be investigated.

Other tests should be made with different aerial lengths (including very short aeriels, and none) and signals tuned in all sections of the tuning range. Regeneration at the low frequency end of the broadcast band, particularly when a short aerial is placed as closely as possible to the second detector, and oscillation on the short-wave band with no aerial are possibilities in this case.

(2) Dry battery receiver tests

A set of batteries which has been discharged by normal use to a required low voltage should be used to test battery receivers at least for sensitivity, power output, stability and oscillator grid current (using a valve on the low limit of oscillator mutual conductance).

The requirement that the batteries should be discharged by normal use is necessary since rapid discharge gives a lower value of internal resistance. To simulate a discharged battery by means of added resistance, fresh heavy duty batteries can be tapped and the following table (Ref. 21) used.

Resistance Required to Simulate Discharged Radio "B" Batteries.

Volts per 22½ volt section	Resistance per 22½ volt section	
	Farm type batteries	Portable type batteries
22½	0 ohms	45 ohms
20	10 ohms	60 ohms
17	50 ohms	110 ohms
15	110 ohms	175 ohms
12	250 ohms	330 ohms

The following points are important. First, only fresh heavy-duty batteries should be used, their resistance being negligible. Second, if intermediate voltage taps are used the added resistance must be distributed between the taps in proportion to their respective voltages. Third, voltage readings should be taken only under load and across the battery cable terminals to include the voltage drop of the load current through the added resistances.

Battery end-of-life tests can be carried out in accordance with R.M.A. (U.S.A.) specifications M4-431 and M4-432 at 1.1 volts per cell for the A battery and 17, 15 and 12 volts per 22½ volt section for the B battery.

The lowest filament voltages used for testing battery valves by valve manufacturers are 1.1 volts for 1.4 volt valves and 1.7 volts for 2 volt valves. Below these voltages, performance may not be consistent.

(3) Interference tests

A suitable test for vibrator operation is to wrap a short lead around the battery cable and battery, connect one end of the lead to the aerial terminal of the receiver and check for interference throughout the tuning range of the receiver at maximum sensitivity. In a well designed receiver no interference will be heard.

Car-radio interference tests can be arranged using appropriate parts from the ignition system of a car, but such tests give no guarantee of interference-free reception from the receiver installed in a car.

The R.M.A. Standard REC-11 reads as follows :—
Chassis Pickup of Vehicular Receivers.

Vehicular receivers shall be considered as complying with the principles of good engineering practice if, when installed according to the manufacturers' instructions and using materials supplied by the manufacturer, there is no perceptible chassis pick-up with any setting of the user controls.

"Chassis pick-up" is defined as the interference arriving in the vehicular receiver other than through the antenna.

"Perceptible" is defined as the difference in the noise output of the receiver with the engine running and with it stopped.

Testing for chassis pickup shall be done by replacing the antenna of the installed receiver by an antenna equivalent, adequately shielded and grounded; the antenna trimmer of the receiver shall be tuned for resonance at the normal aligning frequencies; and observation made of any perceptible noise output.

(4) Distortion

Causes of distortion may be present in a receiver and remain undetected in spite of reasonably thorough testing with instruments. One such type of distortion occurs with insufficient capacitance by-passing a.v.c. lines, which results in low frequency intermodulation or perhaps hum modulation in a back-biased receiver. Another may be due to simultaneous high modulation levels and high signal strengths, and another may be the hum distortion mentioned in (H) above which is easily missed. Because of this, testing is not completed until critical listening to broadcasting stations over a period of time has shown that such faults are not present.

(P) Acoustical tests

Refs. 1, 2 and 5 should be consulted.

SECTION 2 : F-M RECEIVERS

(i) *Definitions* (ii) *Testing apparatus* (iii) *Test procedures and operating conditions* (iv) *Receiver adjustments* (v) *Performance tests.*

(i) Definitions

The information presented in this section, except where otherwise stated, is taken from the "Methods of Testing Frequency-Modulation Broadcast Receivers, 1947," Standard on Radio Receivers (Ref. 12), published by the Institute of Radio Engineers. Additional F-M information is available from the "Standards of Good Engineering Practice Concerning FM Broadcast Stations" published by the Federal Communications Commission in 1945.

(A) The three **standard test frequencies** are 88, 98 and 108 Mc/s. When only one frequency is used for testing it should be 98 Mc/s.

(B) The five **standard input values** may be expressed in terms of available power or of input voltage. The available power is that delivered by a generator to a matched load and is equal to $E^2/4R$ where E is the equivalent open-circuit voltage of the generator and R is the internal resistance of the generator (including the dummy-antenna resistance).

Five standard input values are specified, the voltage and power figures being equivalent when the receiver has an input impedance of 300 ohms and R is 300 ohms.

(a) Standard Input Powers

- (1) 130 decibels below 1 watt
- (2) 110 decibels below 1 watt
- (3) 90 decibels below 1 watt
- (4) 50 decibels below 1 watt
- (5) 30 decibels below 1 watt

(b) Standard Input Voltages

- (1) 11 microvolts
- (2) 110 microvolts
- (3) 1100 microvolts
- (4) 110 000 microvolts
- (5) 1.1 volts.

(c) The standard mean-signal input is either 90 decibels below 1 watt, or 1100 microvolts.

(C) The **standard test modulation** is a deviation at 400 c/s of $22\frac{1}{2}$ Kc/s (30% of maximum deviation).

(D) The **standard test output** is as set out from the I.R.E. Standards for A-M Receivers in Sect. 1(ii)C of this chapter.

(E) The **maximum undistorted output** is as set out from the I.R.E. Standards for A-M Receivers in Sect. 1(ii)D of this chapter.

(F) The **standard 300-ohm antenna** comprises a pair of resistors, one connected in series with each terminal of the signal generator, of such value that the total impedance between terminals, including the signal generator, is 300 ohms (Fig. 37.2).

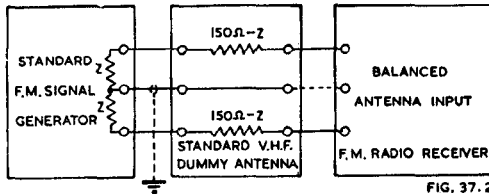


Fig. 37.2. *Standard v-h-f dummy antenna and method of connection (from Ref. 12).*

FIG. 37.2

(G) The **standard pre-emphasis characteristic** has a rising response with modulating frequency, equivalent to that provided by a single circuit in the modulating source having a time constant of 75 microseconds. The characteristic may be obtained by taking the voltage across an inductor and a resistor connected in series and fed with constant current. The inductance in henries is 0.000 075 times the resistance in ohms.

(H) The **standard de-emphasis characteristic** has a falling response with modulation frequency, the inverse of the standard pre-emphasis characteristic, equivalent to that provided by a simple circuit having a time constant of 75 microseconds. The characteristic may be obtained by taking the voltage across a capacitor and a resistor connected in parallel and fed with constant current. The capacitance in farads is equal to 13 333 divided by the resistance in ohms. The standard de-emphasis characteristic is usually incorporated in the audio circuits of the receiver.

(ii) Testing apparatus

(A) "A **frequency-modulated signal generator** is required for testing frequency-modulation radio receivers.

The signal generator should cover at least the carrier-frequency range from 88 to 108 megacycles. It preferably also covers the intermediate-frequency range and frequency ranges required for spurious-response tests.

The generator output should be controlled by a calibrated attenuator, and the output should be adjustable over a range of at least 1 microvolt to 100 000 microvolts, and preferably from 0.1 microvolt to 1.1 volts. Balanced output terminals should be provided for the radio-frequency ranges, and single-sided output terminals for the intermediate-frequency range. It may be desirable to provide single-sided output terminals for the radio-frequency range also. All of these terminals should be provided at the end of a flexible cable.

The output meter of the signal generator should indicate the open-circuit voltage at the terminals, and the internal impedance should be stated.

The generator should be capable of being frequency-modulated at rates from 30 to at least 15 000 cycles per second, and at deviations from zero to at least rated system deviation and preferably to twice that value. It should be provided with a deviation indicator reading from not more than 5 kilocycles up to the maximum deviation.

The modulation circuit of the generator should be provided with a standard pre-emphasis network. A switch should be provided for cutting this pre-emphasis network in or out of the generator circuit at will.

The generator should provide a frequency-modulated signal at 400 cycles up to maximum rated system deviation with less than 2%, and preferably less than 1% (root-sum-square) distortion. Amplitude modulation resulting from the frequency modulation should be kept to a minimum.

The frequency and amplitude modulation of the output voltage due to power-supply ripple should be negligible, in comparison with the effects under observation. The proper connection of a balanced-output signal generator for testing a balanced receiver is shown in Fig. 37.2."

(B) **Audio-output and distortion-measuring devices** are the same as those required for the testing of amplitude modulation receivers. See Sect. 1(iii) of this chapter.

(C) **Two-signal tests** are carried out using two signal generators and dummy antennas of twice the standard 300 ohms value with each generator as shown in Fig. 37.3. The output terminals of the two dummy antennas are then connected in parallel and to the input terminals of the receiver. With this connection the impedance connected across the receiver input terminals is the normal value and the open-circuit signal voltages are half the values indicated by each generator.

(D) **A standard-signal generator for amplitude-suppression testing** should be capable of simultaneous 400 c/s amplitude modulation and 1000 c/s frequency modulation with preferably less than 1% of incidental frequency modulation in the amplitude modulation process. Alternatively two signal generators may be used, connected as described above, but precautions must be taken that the beat note between the two carriers does not influence the undesired output and that the amplitude modulated generator is free of incidental frequency modulation.

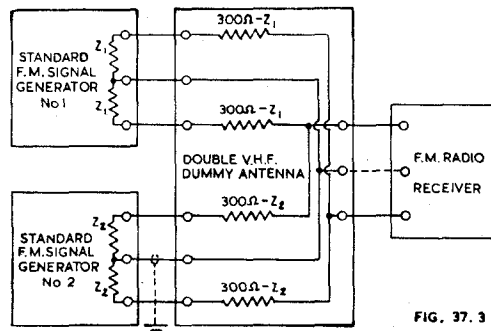


FIG. 37.3

Fig. 37.3. Standard v-h-f dummy antenna for two-signal test and method of connection (from Ref. 12).

(iii) Test procedures and operating conditions

(A) **Input measurements** are made through a standard 300-ohm dummy antenna on receivers designed for a balanced antenna. If only a single-sided signal-generator output is available, one terminal of the input circuit of the receiver is connected to the grounded terminal of the generator output circuit, and the correct value of dummy antenna resistance must be used.

There are two simple tests for unbalance, the balanced receiver input coil can be reversed, or the power-line connection for either the receiver or the signal generator is moved to a different outlet. Any change in the sensitivity observed on alternating these connections indicates an error due to unbalance.

(B) **Output measurements** are made as described in Sect. 1(iv)A of this chapter.

(C) **Operating conditions** are similar to those in Sect. 1(iv)B of this chapter.

(iv) Receiver adjustments

The **tuning control** is adjusted until the desired a-f output is obtained either with the least possible r-f input power or with the lowest possible setting of the volume control. This is an **approximate** adjustment.

A receiver for frequency-modulated waves is tuned **accurately** to a desired signal by first tuning it approximately and then adjusting the tuning controls until either the undesired noise is a minimum or the harmonic distortion of the demodulated desired signal is a minimum. In many receivers these two tuning positions coincide.

When they do not coincide it should be stated whether the tuning is for minimum noise or for minimum distortion.

A simple method of tuning for minimum distortion in many receivers is by observing the audio wave form on a cathode ray oscilloscope while increasing the deviation somewhat beyond 100%.

The **tone control** is adjusted to give maximum modulation-frequency output unless otherwise specified.

(v) Performance tests

(A) Sensitivity

There are three sensitivity values of general interest in relation to frequency-modulation receivers. Each gives information as to the usefulness of the receiver, and in expressing results the type of sensitivity should be specified.

The **maximum sensitivity** is measured with the signal generator connected to the receiver through the dummy antenna. The receiver controls are adjusted for greatest sensitivity, and the output of the generator, which is modulated 30% (22½ Kc/s) at 400 c/s, is adjusted to obtain standard test output from the receiver.

When the tuning for minimum noise does not coincide with that for minimum distortion, the above test and the following test should be repeated with the receiver tuned for minimum noise.

The **maximum-deviation sensitivity** is measured by applying to the receiver a strong signal-input modulated 100% (75 Kc/s) at 400 c/s, tuning the receiver for minimum distortion and adjusting the receiver volume control to give standard output. The output distortion should be observed and the signal input reduced, keeping the indicated receiver output constant by readjusting the volume control if necessary, until the output distortion increases to 10%, or until the input is below that required for standard output. The signal input at which the distortion reaches 10% is the maximum-deviation sensitivity input and is expressed in decibels below 1 watt or in microvolts.

The **deviation sensitivity** is measured with the receiver volume control at maximum and with the standard mean-signal input (1100 μ V) applied. The generator is modulated at 400 c/s and the deviation adjusted to the value which gives standard test output. The value of deviation required is the deviation sensitivity, and it is expressed in Kc/s or as a percentage of rated system deviation.

The **quieting-signal sensitivity** is measured by applying a signal of mean value, 30% modulated at 400 c/s, to the receiver with the volume control adjusted to give a convenient output below audio overload. The modulation should then be switched off and the signal intensity reduced to the least value which will produce a 30 db rise in indicated output with standard test modulation as compared with the indicated output with the unmodulated carrier. The results are expressed in decibels below 1 watt, or in microvolts.

(B) Co-channel interference

This test is intended to show the effect of an interfering signal of the same frequency as the desired signal, and includes the inherent effect of the detector, the limiter and the automatic volume control.

Two signal generators are required, only one of which need be capable of frequency modulation. The outputs of both are applied simultaneously to the receiver under test at the mean carrier frequency of 98 Mc/s.

With the desired signal frequency having standard test modulation and an intensity equal to one of the standard input values, the a-f output of the receiver is adjusted by means of the volume control to the standard test output.

The modulation of the desired signal is then removed, keeping the intensity of its carrier unchanged, the interfering signal, frequency-modulated 30% at 400 c/s, is turned on and the output of the receiver read as the level of the interfering signal is increased from zero to 1 volt or more.

The result of the test includes the effects of both the cross-talk and the beat-note components of the interference. If the results are desired for the cross-talk only, a 400 c/s filter is used in the output.

The co-channel interference characteristic may be expressed as the interfering-signal input, in decibels below the desired-signal input, which produces an output 30 decibels below the standard test output

(C) Masking interference

The masking effect of an unmodulated interfering signal is obtained by a test similar to that for the co-channel interference but with the desired signal 30% modulated at 400 c/s and with the interfering signal unmodulated. The output signal is noted as the level of the interfering signal is increased from zero.

(D) Selectivity

Test conditions are similar to those described for the co-channel interference test [(B) above] except that the interfering signal generator is separated in frequency from the desired signal by one standard channel separation.

The desired signal, unmodulated, is applied at the lowest value of standard input and the output of the receiver is recorded as the level of the interfering signal, frequency modulated 30% at 400 c/s, is varied from zero to a value capable of producing standard test output. This procedure is repeated for all values of standard test input. The measurements are then repeated with the interfering signal generator separated from the desired signal by twice the standard channel separation.

The adjacent-channel and second-channel interference may be expressed as the interfering signal input which produces an output 30 decibels below the standard test output.

(E) Amplitude-modulation suppression

This test measures the suppression of amplitude modulation which may be present in a frequency modulated signal. It is carried out at the standard mean carrier frequency. The frequency modulation is at a 1000 c/s rate with a deviation of 30% of maximum system deviation. The standard mean input-signal value having this modulation is applied to the receiver in the usual manner. The volume control is adjusted to produce standard output. The input signal is then amplitude-modulated at 400 c/s and 30% modulation. The intensity of the undesired output of the receiver is measured by filtering out the 1000 c/s frequency.

The amplitude suppression is the ratio of the undesired output to standard test output expressed in decibels. In order to determine the variation of amplitude-modulation suppression with input, the test is repeated with the other standard input-signal values.

(F) Electric fidelity (frequency response)

Methods similar to those for A-M receivers [Sect. 1(vi)C of this chapter] are used at the standard mean carrier frequency and with a standard mean signal input. The standard pre-emphasis characteristic is employed in the standard-signal generator and the modulating voltage is to be maintained constant at that value which provides a modulation of 30% of maximum rated system deviation when the modulation frequency is 400 c/s.

(G) Harmonic distortion

The tests are similar to those used for A-M receivers [Sect. 1(vi)D of this chapter] but variation of input signal testing is recommended with 30% and 100% of maximum rated system deviation. In addition there is a deviation distortion test.

The **maximum-deviation distortion** test is the measurement of the distortion due to inadequate bandwidth and/or inadequate amplitude-modulation rejection. It is measured at 98 Mc/s with the signal generator connected to the receiver through the 300-ohm dummy antenna. Distortion at standard test output is measured at full system deviation over the range from maximum sensitivity levels to 30 decibels below 1 watt.

(H) Maximum undistorted output

As for A-M receivers—Sect. 1(vi)E of this chapter.

(I) Automatic-volume-control characteristic

This test is similar, except for carrier frequency, to the I.R.E. test for A-M receivers—Sect. 1(vi)F of this chapter.

(J) Spurious responses

The testing of F-M receivers for spurious responses is carried out in a similar manner to that specified for the tuning of A-M receivers—Sect. 1(vi)J of this chapter. However spurious response sensitivity test inputs up to 1.1 volts are recorded and an additional intermediate frequency response test is specified.

The procedure is to inject the intermediate-frequency test input signal, amplitude modulated 30%, between the two antenna terminals of the receiver, connected in parallel, and ground, through a standard 300-ohm dummy antenna. The frequency of the test signal is adjusted for maximum receiver output.

(K) Hum

Hum in F-M receivers has similar characteristics to hum in A-M receivers, and is measured in the same way—Sec Sect. 1(vi)H of this chapter.

(L) Noise audibility

The noise audibility test for F-M receivers is the same as that for A-M receivers—Sect. 1(vi)K of this chapter.

(M) Tuning characteristic test

The tuning characteristic shows the variation in audio output of the receiver as it is tuned through a signal. This characteristic is of importance in frequency-modulation receivers since they may have spurious output responses adjacent to the correct tuning point. The effect is usually more easily measured by variation of the signal-generator frequency than by variation of receiver tuning, since the signal generator usually has better frequency control and calibration than the receiver.

The receiver is tuned to the mean carrier frequency for each standard input signal value with standard test modulation and the volume control adjusted to standard output. The output is then measured as the signal is detuned to each side of the carrier frequency. A tuning curve is plotted for each signal input value (Fig. 37.4)

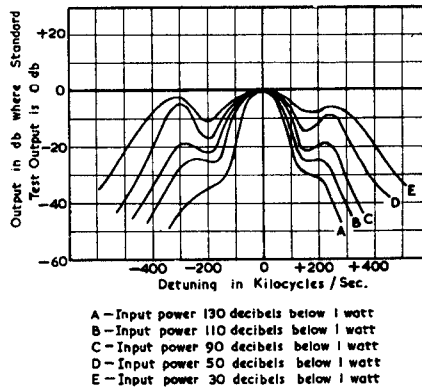


FIG. 37.4

Fig. 37.4. Tuning characteristics (from Ref. 12).

(N) Frequency drift

This test is carried out in the same way as that for frequency shift in A-M receivers—Sect. 1(vi)I of this chapter—except that it is to be performed at the standard signal carrier frequency.

(O) Low-frequency instability

This test is intended to evaluate the limiting conditions for unstable operation of the receiver as affected by low frequency feed-back which may be electrical or acoustical in nature, and which may involve both carrier frequency and audio frequency and the audio-frequency circuits. At any given frequency, the variables employed to induce instability are the signal-input power, the tuning control, the manual volume

control and tone control, the modulation frequency and degree of modulation, and, in battery receivers, the age and condition of the batteries. All parts of the receiver, including the loudspeaker, are mounted in their normal relations.

The test is performed at the standard test frequencies. The receiver is tuned to a modulated test signal, after which the modulation is switched off. The conditions most conducive to the detection of any tendency to instability are found by trial. It is suggested that the frequency of the signal be varied manually over a range of about 100 Kc/s above and below the normal test frequency as the test input power is varied from zero to a maximum of 0.01 watt. An observation is made of the maximum signal-input power at which any unstable operation appears. The maximum of such input power is also recorded if less than 0.01 watt.

(P) Radiation from local oscillator

Tests are made in a manner similar to that for the A-M receiver tests—Sect. 1(vi)L of this chapter. Observations are made with the receiver tuned to each of the standard test frequencies. Results are expressed in field intensity as a function of distance from the receiver under test.

(Q) Mistuning

The degree of mistuning is represented by the total signal output distortion resulting when the receiver is adjusted to a frequency other than the desired signal frequency. The measurement is made by setting the signal generator to standard input voltages successively, modulating the signal generator to 75 kc deviation at standard test output. The signal generator is then adjusted off tune by successive increments, the volume control is adjusted for standard test output, and the total distortion in per cent (or db) is measured. For each value of input signal a curve is plotted, having as abscissa the frequency difference of detuning, and as ordinate the distortion expressed in per cent, or db. Distortion components will comprise all frequencies present except the fundamental frequency of the modulating tone. In these tests the signal generator is adjusted off tune on each side of the signal frequency.

The standard measurement will comprise setting the signal generator on each side of the signal frequency and noting the amount of mistuning that will produce 10% distortion, expressing the degree of mistuning as the average of the measured plus and minus frequency excursions. The signal input for this test shall be the standard mean signal input (1100 microvolts).

This mistuning test should be correlated with the frequency drift test—Sect. 2(v)N.

(R) Downward modulation

This test will define the ability of the receiver to withstand the effects of downward amplitude modulation. In this test it is assumed that the principal forms of distortion are caused by the downward component of modulation.

The test is made at the standard mean-carrier frequency (98 megacycles). Frequency modulation is impressed at a 400-cycle modulation rate at 30% of maximum rated system deviation and the volume control is adjusted for standard output. The input signal is then simultaneously amplitude modulated at a 100-cycle rate. By means of a band cut-off filter, the 100-cycle modulation is eliminated in the receiver output. The amplitude modulation is then increased until the total distortion reaches 10%. The percentage modulation at this point is the downward modulation capability of the receiver. The test is made at all values of standard input signal voltages.

(S) Open field method of measurement of spurious radiation from frequency modulation and television broadcast receivers

See I.R.E. Standard (Ref. 41).

SECTION 3 : AUDIO FREQUENCY AMPLIFIERS

(i) *Equipment and measurements* (ii) *Tests.*

(i) **Equipment and measurements**

The equipment already specified for testing the a-f end of a radio receiver is sufficient for the testing of a-f amplifiers. There are however additional tests commonly used in the design of a-f amplifiers and these tests need more instruments.

Intermodulation testing requires at least another a-f signal generator, and equipment is available (Refs. 19, 22 and 27) which is specifically designed for the purpose. The technique of square-wave testing (Refs. 16 and 20) also needs an appropriate generator as do similar techniques using other wave shapes (Ref. 18).

Measurements of voltage, current, dissipation and heating differ if at all only in the higher values found in high-power a-f amplifiers and the appropriate parts of Section 1 of this chapter are applicable.

(ii) **Tests**

The American R.M.A. Standard SE-101-A on Amplifiers for Sound Equipment gives details of tests for noise level, amplifier gain, amplifier frequency response, distortion and power output. The following conditions of measurement apply to each of the tests mentioned.

“The amplifier shall be operated at its rated power supply voltage and frequency. When a range of line voltage values is indicated for specified power input terminals, the arithmetic mean of the voltages specified for this range shall be applied except when R.M.A. standard M3-217* applies. The frequency of the power supply shall be within $\pm 2\%$ of the lowest frequency specified. The rms harmonic voltage of the power supply voltage shall not exceed 10%.

Manufacturers of amplifiers designed to work from crystal microphones or other capacitive devices and photocells, may provide additional ratings based on the stated source impedance applicable to condition of use.

“The input and output shall be terminated† in pure resistance equivalent to the rating impedance within $\pm 5\%$. Grounding of the circuits and chassis shall be as normally used.

“The gain control shall be adjusted to give a maximum gain” (except when measuring noise and frequency response when it is set to give maximum noise and to reduce the gain 6 db below maximum respectively) “and any other controls shall be adjusted to give the most nearly uniform frequency response.

“The measurements shall be made after the amplifier has been operated for not less than one hour at an output 6 db less than the rated output at 400 cps, and at a room temperature of not less than 20°C.”

The vacuum tubes used shall be selected to have the rated values of those characteristics which particularly affect the amplifier characteristic under test.

(A) **Amplifier distortion**

Definition (R.M.A. standard SE-101-A) :—“Amplifier distortion is the difference between the harmonic content of the voltage at the output terminals and that of the input voltage expressed as a percentage of the total rms output voltage”

Additional test conditions are :—

“Three distortion measurements shall be made with signals having frequencies of 100, 400 and 5000 cps applied to the input terminals. The harmonic content of these signals shall inappreciably affect the distortion of the amplifier.

“A distortion factor meter shall be used that is capable of filtering out or suppressing the fundamental frequency with respect to its harmonics by at least 60 db, without affecting the phase or amplitude of the generated distortion.”

*R.M.A. Standard M3-217 states “When no means for adapting an electric radio receiver to the line voltage is provided, it shall be standard to adjust the secondary voltages so that the filaments and heaters of tubes are supplied with rated voltage when a line voltage of 117 volts is applied to the receivers.”

†The input is effectively a low-impedance generator in series with a resistance equal to the rating source impedance. See Fig. 19.3.

If the amplitude of individual harmonics is measured and the distortion is small, the percentage of total harmonic distortion is given approximately by

$$D \approx \sqrt{(H_2\%)^2 + (H_3\%)^2 + \dots}$$

where H_2 = second harmonic percentage, etc.

with an error not exceeding 1% if D does not exceed 10%—see Chapter 14 Sect. 2(iv).

A knowledge of the manner in which distortion decreases as output is reduced is desirable. Amplifiers with a large amount of feedback usually have very little distortion until the output is almost a maximum, but a class B amplifier may even give increased distortion with decreased output.

A simple test which can be used as an indication of freedom from distortion at low levels is the plotting of a linearity curve, i.e. a graph of input voltage against output voltage. Over the range of output for which the curve is a straight line the amplifier can be assumed to have a low distortion level. However in many cases the graph is curved almost from the zero point.

Intermodulation measurements are made with two signals applied to an amplifier through a suitable mixing network (e.g. bridge), either from separate a-f oscillators or from a combined unit designed for intermodulation testing. The usual procedure is for one frequency to be low (40, 60, 100, 150 or 400 c/s are used) and for the other to be high (1000, 2000, 4000, 7000 or 12 000 c/s). One test is carried out with the low frequency approximately at the low frequency limit of the amplifier and another at 100 or 150 c/s. The low frequency signal is usually made four times larger than the high frequency signal, although a 1 : 1 ratio is also used. The low frequency test will show distortion due to transformer saturation and the latter will be more representative of normal operation.

Distortion is mainly dependent on the peak voltage output so that an amplifier delivering at the same time two output voltages of 4 units and 1 unit (total output voltage = 5 units) would have distortion equivalent to a power output of 5^2 whereas the true output would be only $4^2 + 1^2$. Because of this, the indicated output power is multiplied by 25/17 when intermodulation tests are carried out under the conditions above.

The intermodulation products from the two signals can be measured separately or collectively. If they are measured separately and the lower frequency is f_1 and the higher f_2 , then the intermodulation products to be investigated—considering f_2 as the carrier—are $(f_2 - f_1)$, $(f_2 + f_1)$, $(f_2 - 2f_1)$, $(f_2 + 2f_1)$, $(f_2 - 3f_1)$, $(f_2 + 3f_1)$, . . . The intermodulation distortion percentage referred to f_2 , based on the r.m.s. sum, is

$$\frac{\sqrt{(E_{f_2 - f_1} + E_{f_2 + f_1})^2 + (E_{f_2 - 2f_1} + E_{f_2 + 2f_1})^2 + (E_{f_2 - 3f_1} + E_{f_2 + 3f_1})^2 \dots}}{E_{f_2}}$$

If the r.m.s. sum of the intermodulation products is measured collectively a high-pass filter can be used to separate the low and high frequencies and their respective intermodulation products. The modulated high frequency is then rectified and passed through a low pass filter, the remainder being low frequency components previously modulating the high frequency signal. Descriptions and circuits of equipment of this type will be found in Refs. 19, 22, 23 and 27.

The **peak sum modulation method** is described in Chapter 14 Sect. 3(v).

Le Bel's Oscillographic method is described in Chapter 14 Sect. 3(vi).

Another method of measurement is to keep a **constant difference frequency** (say 400 c/s) between the outputs of two a-f generators and determine the magnitude of the difference frequency as the generators are tuned through the a-f range of the amplifier (Ref. 28)—see Chapter 14 Sect. 3(iii).

For an indication of the distortion tolerable under different conditions, reference should be made to Chapter 14 Sect. 2(iii). Intermodulation distortion is covered in Chapter 14 Sect. 3 and References (B).

Hum distortion may be overlooked if the individual distortion components are measured separately. It is due to intermodulation between signal and hum frequencies and with a 50 c/s power supply (100 c/s hum) and a 1000 c/s signal, hum distortion products will be found at 900 and 1100 c/s and also as sidebands to the harmonics

of the signal. Hum modulation is most likely to be experienced at full output in an amplifier in which the filtering of the plate supply to the output valves is inadequate.

(B) Amplifier Power Output

Definition (R.M.A. standard SE-101-A) :—“ Amplifier power output is the maximum rms power output (including distortion) at rated distortion which the amplifier will deliver into its rated load under normal operating conditions.”

An additional requirement is that “ The power output shall be measured using an indicator which measures rms values, such as thermally actuated meters, simultaneously with the distortion ”

During design it is helpful to measure power output over a range of frequencies as it may decrease at both low and high frequencies. When bass and treble boosts are available to the user it is particularly important for the power output to be maintained over the range of frequencies to which the boosting applies. At high frequencies the response may be falling and the degree of overloading may not be apparent because the amplitude of the harmonics may be appreciably decreased, for instance by a capacitor across the primary of the output transformer. It is in such a case that the value of intermodulation measurements becomes apparent.

When measuring amplifier power output and other characteristics it is advisable to connect an oscilloscope across the output terminals so that the presence of parasitic oscillations can be detected.

(C) Amplifier Gain

Definition (R.M.A. standard SE-101-A) :—“ Amplifier gain is the ratio expressed in db of the power delivered to the load, to the power which would be delivered to the same load if the amplifier were replaced by an ideal transformer which matches both the load and source impedances.”

Additional test requirements are

“ The gain shall be measured at a frequency of 400 cycles per second and at an output 3 db less than the rated power output. The harmonic content of the input signal shall inappreciably affect the gain of the amplifier.

“ The gain shall be measured using input and output meters and associated measuring equipment that does not affect the frequency response or gain of the amplifier.”

(D) Amplifier Frequency Response

Definition (R.M.A. standard SE-101-A) :—The amplifier frequency response is the variation of gain as a function of frequency over the range specified, expressed in db relative to the gain at 400 cycles per second.”

Additional test requirements are

“ Any automatic limiting or dynamic range control in the amplifier shall be disconnected during this test.

“ The frequencies for testing shall be obtained from a source whose rms harmonic voltage does not exceed 5% of the fundamental voltage at any point in the frequency range of measurement.

“ Measurements shall be made with the input voltage adjusted at each frequency to produce output levels of 3 db and 10 db respectively below rated power output.*

“ The input and output meters and associated measuring equipment shall not discriminate as to frequency over the frequency range of measurement.”

The frequency response of an amplifier is usually measured in terms of the output voltage across a resistive load. If feedback from the output stage is used it is advisable also to check the response with the normal loudspeaker load and with the minimum and maximum loads liable to be used.

In all cases the signal input must be small enough for the input-output characteristic to be linear over the frequency range being investigated. The frequency response may vary with output level at the low frequency end of the range and more than one curve may be necessary for this reason.

The effect of any controls which alter the frequency response should be shown by suitable curves.

*Frequency response is also sometimes measured at levels of 30 and 60 db below rated power output.

Square wave testing is used to obtain a rapid indication of frequency response (or phase shift) during design and in production. Two test frequencies can be used, one low enough for some low frequency attenuation or phase shift to be present at the fundamental frequency and the other high enough for some of the harmonics in the square wave to be attenuated. In production testing, limits for the wave shape can be indicated on a blank in front of the screen of the oscilloscope. Peaks in response are indicated (the approximate frequency of the peak being readily determined) as well as the degree of damping of the transient response and parasitic oscillation (Refs.16 and 20).

Details are given in Ref. 18 of a technique in which stepped sine waves are used in a similar manner.

(E) Noise Level

Definition (R.M.A. standard SE-101-A). (This is proposed as an interim standard for the measurement of steady state noise, and of pulse noise waves having a peak factor (ratio of peak to rms) approximating the maximum obtainable in speech):—
“Noise level is the level of any noise signals appearing at the output terminals with no signal applied to the input.

“The weighted noise level is the noise level weighted in accordance with the 70 decibel equal loudness contour of the human ear and expressed in dbm, i.e. decibels referred to a level of 1 milliwatt.”

An additional testing requirement is “The measuring amplifier shall be one whose audio frequency response is weighted with the 70 db equal-loudness contour of the human ear in accordance with Curve B of the ASA Specification Z24.3-1944 (Sound level Meters for Measurement of Noise and Other Sounds) with a standard VU meter as defined by ASA Specification C16.5-1942 (American Recommended Practice for Volume Measurements of Electrical Speech and Program Waves) as an indicator.

“Illustrative: A properly weighted amplifier may be obtained by applying an RC network with a 1 millisecond time constant to an amplifier having frequency response of ± 1 db from 50 to 15 000 cycles. This will give an attenuation of 1 db at 300 cycles, 5.7 db at 100 cycles and 9 db at 60 cycles.”

(F) Microphony

High gain, high output a-f amplifiers may be subject to microphony under some conditions of use. A test similar to the one described in Sect. 1(vi)M of this chapter enables variations between microphonic tendencies between different amplifiers to be checked reliably.

(G) Stability

In amplifiers without feedback the most probable type of instability is parasitic oscillation. This can best be observed on an oscilloscope while the signal input is varied from zero past the overload point at various frequencies (including very low and very high).

Varying load impedances and high mains voltages may also cause trouble and the test should be repeated at least for design purposes with the highest power supply voltage liable to be encountered in the field and with a range of load impedances varying from an open circuit through capacitive and inductive loads to a short circuit. The plate dissipation of the output valves in AB or B class amplifiers should be observed during tests with the load impedance smaller than specified as it may become excessive. On occasions, variation in input impedance can provoke trouble and all possible types of pickup and microphone inputs should be tried. Square wave, instead of sine wave, excitation may induce parasitic oscillation.

(H) Feedback

Probably the most important feedback test is that for stability and the tests under (G) should be adequate, although instability experienced may be due to causes other than parasitic oscillation. For example an amplifier with voltage feedback from the output stage may oscillate when operated with open-circuited output, due to excessive feedback.

The output impedance is liable to be variable with frequency in a feedback amplifier. It can be estimated by varying the output impedance and noting the change in voltage

across it (Ref. 26). However a variation in output impedance alters the amount of feedback and thus the impedance being measured. A more accurate determination can be made by connecting the correct load and driving source to the amplifier (it is only necessary to complete the input circuit if feedback is applied to the input stage, see Chapter 7 Sect. 2(vi)A) then connecting an a-f oscillator through a high impedance to the amplifier output and measuring the current flowing into the output circuit and the voltage across it. The impedance of the load in parallel with the output impedance of the amplifier is then obtainable and since the load is known the output impedance can be calculated. If output impedance is important it is desirable to make a measurement at least at the speaker resonant frequency as well as at mid-frequencies.

Another useful feedback test is a measurement of gain reduction vs. frequency. Such a curve is readily plotted and draws attention to any points at which the feedback may become positive. The shape of this curve is similar to an inverted output-impedance curve.

SECTION 4 : MEASUREMENTS ON COILS

(i) *Measurement of coefficient of coupling* (ii) *Measurement of primary resonant frequencies of aerial and r-f coils* (iii) *Measurement of distributed capacitance across coils.*

(i) Measurement of coefficient of coupling

The measurement of k , the coefficient of coupling, has been covered in Chapter 26 Sect. 4(ii)E and (iii)B.

(ii) Measurement of primary resonant frequencies of aerial and r-f coils

The usual methods of measuring primary resonant frequencies are either

- (a) connecting a valve voltmeter across the secondary circuit, which is tuned to a much higher frequency than that to be measured (or a much lower frequency in the case of low impedance primaries), and feeding in a signal from the signal generator. The primary resonant frequency shows up by a sharp increase in the voltage across the valve voltmeter as the generator is tuned through this frequency. The secondary detuning is readily effected by rotating the rotor of the gang condenser, say, half-way across the band, or
- (b) connecting the valve voltmeter straight across the primary winding, finding the resonant frequency, and then finding the true primary frequency by calculation after allowing for the input capacitance of the valve voltmeter, which can be measured on a Q meter or found by other means.

(iii) Measurement of distributed capacitance across coils

The distributed capacitance across a coil can be found with the use of a Q meter, following the methods given in most Q meter instruction books, as summarized below.

Approximate method ($\pm 2 \mu\mu F$)

This is suitable for large inductors only

1. Connect the inductor under test to the coil (L) terminals of the Q meter.
2. Set the tuning capacitor to about $200 \mu\mu F$ (C_1) and adjust the oscillator frequency for resonance.
3. Note the oscillator frequency f_1 .
4. Change the oscillator to a frequency exactly twice f_1 .
5. Set the tuning capacitor to a new value C_2 for resonance.

6. The distributed capacitance C_0 may then be calculated,

$$C_0 = (C_1 - 4C_2)/3 \mu\mu\text{F}. \quad (1)$$

If it is not convenient to use a frequency ratio of 2 : 1, the more general expressions for determining distributed capacitance are :

$$C_0 = \frac{(C_1 - C_2) - C_2(\alpha^2 - 1)}{\alpha^2 - 1} \mu\mu\text{F} \quad (2)$$

where $\alpha = (f_2/f_1)$.

The true inductance is given by

$$L = \frac{25\,330}{f_2^2(C_2 + C_0)} \mu\text{H}, \quad (3)$$

f being expressed in Mc/s

C_2 and C_0 in $\mu\mu\text{F}$.

$$\text{Natural resonant frequency of inductor} = f_n = f_2\sqrt{1 + (C_2/C_0)}. \quad (4)$$

Accurate method (accuracy about $\pm 4\%$)

This method involves measuring the natural resonant frequency of the inductor.

1. Connect the inductor to the coil (L) terminals of the Q meter, set the Q circuit tuning capacitor to about 400 $\mu\mu\text{F}$ and adjust the oscillator frequency for resonance. Call the frequency f_1 and the tuning capacitance C_1 .

2. Replace the inductor under test by a shielded coil having an inductance about 1/25 of that of the inductor under test.

3. Set the oscillator to a frequency about 10 times f_1 , and adjust the Q circuit tuning capacitor for resonance.

4. Connect the inductor under test to the coil (L) terminals of the Q meter, in parallel with the shielded coil, taking care to avoid coupling between the two coils. Then adjust the Q circuit tuning capacitance for resonance, observing whether the capacitance has to be increased or decreased from its previous setting. If the capacitance has to be increased, increase the oscillator frequency by an appreciable amount (10 to 20%). If the capacitance has to be decreased, decrease the oscillator frequency.

5. Disconnect the inductor under test and adjust the Q circuit tuning capacitance to resonance at the new frequency, repeating the procedure of (4) above, changing the oscillator frequency by smaller increments as it approaches the resonant frequency of the inductor under test, until the frequency reaches a value at which the Q tuning capacitance is unchanged when the inductor under test is connected or disconnected. The corresponding oscillator frequency is called f_0 .

6. The distributed capacitance, C_0 , of the inductor may then be calculated :

$$C_0 = \frac{C_1}{\frac{f_0^2}{f_1^2} - 1} \quad (5)$$

or by the close approximation

$$C_0 \approx \frac{f_1^2}{f_0^2} \cdot C_1. \quad (6)$$

The accuracy of this measurement depends on the inductance of the coil remaining constant over the two frequencies. This is reasonably accurate for commonly used coils, although it may not hold for coils having iron cores.

This method often requires a considerable amount of trial and error. As a starting point it is helpful to measure L (this is not the true inductance of course) and make a guess at the value of C_0 . The natural resonant frequency f_n can then be calculated to give a rough guide for starting more accurate measurements.

SECTION 5 : REFERENCES

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Additional references will be found in the Supplement commencing on page 1475.