SPECIAL COMMUNICATION RECEIVERS AND MEASUREMENT OF RECEIVER CHARACTERISTICS

36 RC

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STUDY SCHEDULE No. 36

For each study step, read the assigned pages first at your usual speed, then reread slowly one or more times. Finish with one quick reading to fix the important facts firmly in your mind. Study each other step in this same way.

☐ 1. The Double Superheterodyne and Diversity Receivers . . . . Pages 1-4

You study the triple detection principle, the superhet converter, diversity receivers, selective fading, and polarization diversity. Answer Lesson Questions 1, 2, and 3.

☐ 2. Single Side-Band Receivers . . . . Pages 5-7

This section tells about the advantages of a narrow spectrum, the methods of accomplishment, and exalted carrier reception. Answer Lesson Questions 4 and 5.

☐ 3. Frequency Modulation and Frequency Shift Keying . . . . Page 8

The advantages of frequency modulation and frequency shift keying are discussed.

☐ 4. Panoramic Receiver and Adapters . . . . Pages 9-13

You study the panoramic receiver, the observation and interpretation of signals. Answer Lesson Question 6.

☐ 5. The Crystal Detector . . . . Pages 13-15

Here the butterfly mixer, the coaxial line input mixer, and the wave guide are discussed.

☐ 6. Receiver Characteristics and How They are Measured . . . . Pages 16-36

In this section we take up sensitivity, selectivity, and fidelity measurements. Answer Lesson Questions 7, 8, 9, and 10.

☐ 7. Start Studying the Next Lesson.

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SPECIAL COMMUNICATION RECEIVERS AND MEASUREMENT OF RECEIVER CHARACTERISTICS

The Double Superheterodyne and Diversity Receivers

WE have already noted that the requirements of adjacent-channel selectivity and image rejection are in opposition, and a practical receiver working at frequencies below 30 mc. must employ an i.f. which compromises between these characteristics. At higher frequencies, there is no good compromise value, and either adjacent-channel selectivity must be made very poor to get good image rejection, or if this rejection is good, the adjacent-channel selectivity is very poor. An attempt to compromise makes them both poor. One way out of this difficulty is the double superheterodyne or triple detection principle, the block diagram of which is shown in Fig. 1. The first conversion employs a high i.f. to get good image rejection, and the second conversion employs a sufficiently low i.f. to get the desired adjacent-channel selectivity. A typical example is a receiver for 100 mc. which employs a 30-mc. first i.f. and a 465-kc. second i.f. Such a receiver may have a 60-db or better image rejection ratio and any desired adjacent-channel selectivity from about 0.2 to 20 kc.

The double superhet with its two local oscillators is capable of producing many more spurious responses than a receiver with only one oscillator. Beats can be formed between the harmonics of the oscillators as well as between either of them and any off-resonance signals. Care must be exercised in the design of such a receiver to shield, filter, and decouple each oscillator.

THE SUPERHET CONVERTER

An existing medium or high-frequency super can be used to receive signals of higher frequencies than it normally covers by inserting a device called a superhet converter between its antenna and its antenna terminals. The superhet converter consists of a ganged local oscillator and mixer, and

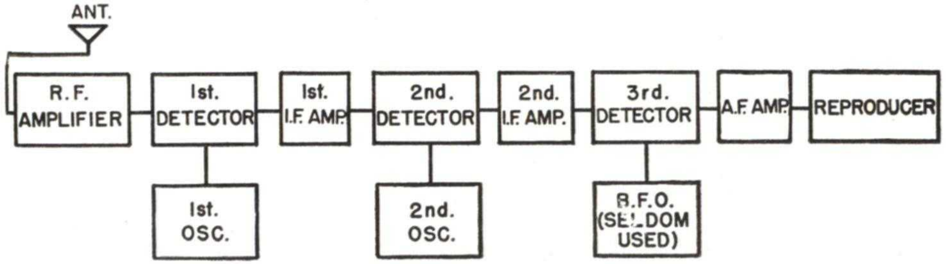

FIG. 1. Block diagram of double superheterodyne or triple detection receiver used for v.h.f.

sometimes one or two r.f. stages at signal frequency. The converter i.f. output is some frequency to which the medium or high-frequency receiver will tune. The receiver is then tuned to the converter i.f. output frequency, and its tuning is left alone. Signals are tuned in on the converter dial and the i.f. produced come into resonance with the fixed receiver. This combination converter-receiver constitutes a double superhet and has its advantages at high frequencies as long as the original receiver i.f. is not too sharp for the signal stability.

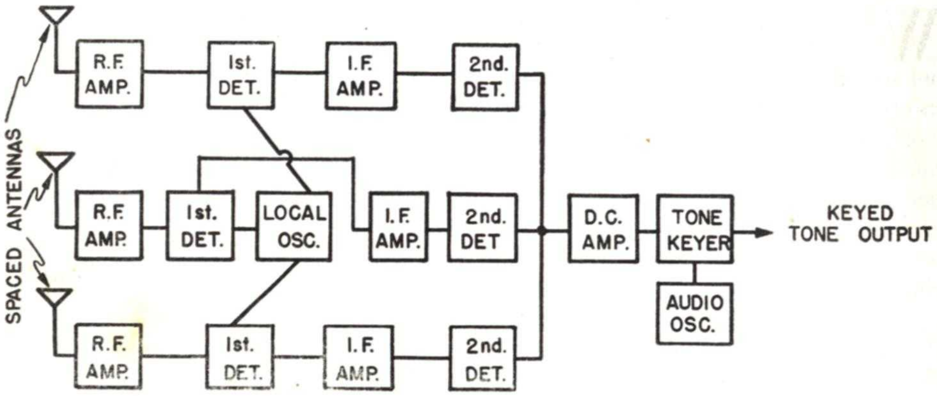

FIG. 2. Diversity radiotelegraph receiver block diagram.

DIVERSITY RECEIVERS

The phenomenon of fading, where the signal strength gradually varies with time, is observed to some extent at most communication frequencies over greater than line-of-sight distances. Fading is produced by slight shifts in the ionosphere density or height which change the effective path lengths taken by the signal to the receiving antenna. The received signal is the resultant of the signals arriving over several paths from the ionosphere, and these signals may all be in phase, or shift so that cancellation takes place. It has been found that cancellation does not take place at the same instant in receiving antennas placed several wavelengths apart physically. A system in which several widely spaced antennas are used simultaneously on the same signal combination, is called a diversity system. Usually there is a separate r.f. mixer, i.f., and second detector on each antenna with a common local oscillator and audio amplifier. Three such "front-end" receivers appear to be as many as are needed for optimum readability of the signal. For code reception, the system outlined in the block diagram of Fig. 2 is used. Three antennas spaced several wavelengths apart are brought in to three separate r.f. amplifiers, each of which feeds a separate mixer or first detector. All r.f. and mixer stages are tuned to the same signal. One local oscillator feeds all three mixers, so there will not be any spurious beats which might be produced with three separate local oscillators if they were not exactly on the same frequency. A separate i.f. amplifier follows each mixer, and a separate diode second detector follows each i.f. amplifier. The outputs of the three second detectors are paralleled so that whichever one is receiving the best signal will produce the highest d.c. voltage, and this will bias the other detectors to cut-off so that they will not add noise to the output. The resulting d.c. output is amplified by a single d.c. amplifier with a filter to cut out the higher frequency noise components (usually having a cut-off frequency of about 50 c.p.s. for hand-keyed speeds). The d.c. amplifier output feeds the grid of a tone keyer, which is an amplifier biased to cut-off with no signal present, but the presence of a signal biases this keyer more positively so it amplifies. The keyer is fed with a steady tone signal from a local audio oscillator, but output of this tone appears only when a signal is present, so a keyed tone of constant output, which follows the keying of the incoming signal, appears. Fading and slight shifts of signal or local-oscillator frequency do not affect the output tone frequency or amplitude. The signal-to-noise ratio is vastly improved over that of a conventional receiver. Because the identity of the original signal is lost, and all signals are converted to the same tone frequency, selectivity ahead of the tone keyer must be very good. Crystal filters in the i.f. may be required to accomplish this, and often the local oscillator is crystal-controlled to hold the drift within the i.f. filter band width. This type of receiver is expensive and complex, and requires much space for its associated antennas, so it is used only for long point-to-point circuits at specially selected shore sites. The tone output is often fed into a telephone line and sent several miles to a control point in a near-by city.

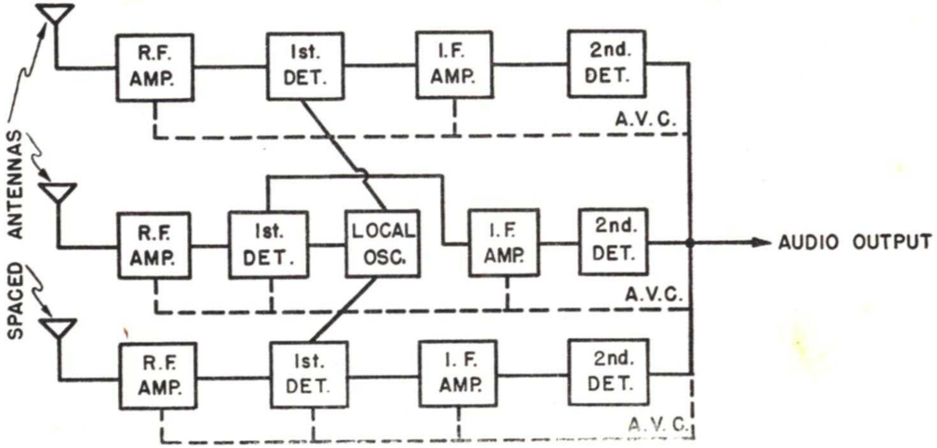

FIG. 3. Diversity radiotelephone receiver block diagram.

The block diagram of a diversity radiotelephone receiver is shown in Fig. 3. The arrangement is similar to that of the code receiver, except that the audio output is fed to a common audio amplifier from the common output of the three second detectors. A.V.C. is taken from the common second detector output, so the a.v.c. voltage is obtained from whichever channel is getting the strongest signal. The common a.v.c. is applied to all the r.f. and i.f. amplifiers and to all the mixers. The gain of the channels receiving poor signals is reduced more than that of the one getting the best signal, so that signal-to-noise ratio is improved, and as the signal fades out of one channel and into another, the shift to the best detector takes place automatically. In most present commercial diversity radiotelephone circuits, a cross-connected amplifier arrangement is used so that as the output of one channel increases, that of another decreases. This may be accomplished after detection in each channel. It requires considerably more apparatus and complexity than the simple system shown, but gives much improved signal-to-noise ratios.

SELECTIVE FADING

It has been found that over long signal paths, some side-band frequencies are at full strength. At a later instant, the carrier may fade out, leaving all the side bands, and still later the first side-band frequency will be present, and another one will have dropped out. This phenomenon is called selective fading. It causes distortion on voice, and results in errors in copy where telegraph or tone keying on a single carrier or side-band frequency is used. Selective fading is combatted by the use of tone modulation on a c.w. keyed carrier so that if the carrier fades out, two side bands are left to convey the intelligence, or when tone keying of a carrier is used, the same keying may be used with two different tones simultaneously, so that if one fades out instantaneously, the other is still present, and vice versa. This is known as frequency diversity, and is often combined with space diversity which has been previously discussed. Phase modulation of the carrier is sometimes used to accomplish this same reduction in selective fading.

POLARIZATION DIVERSITY

When the signal has faded out of a horizontal antenna, it may be strong in a vertical antenna at the same location. Advantage can be taken of this by connecting differently polarized antennas to a diversity receiver. This can be combined with the other types of diversity reception.

Single Side-Band Receivers

You may have wondered why a receiver must have a band width wide enough to accommodate the carrier and both side bands, or why both side bands are transmitted, when one set of them merely duplicates the intelligence contained in those on the other side of the carrier. The normal detection process requires that both side bands be present to prevent excessive distortion. A special and more complex receiver can be used for the reception of a signal consisting of a suppressed carrier (much weaker than would usually be used for that side-band power), and only one set of side bands. Since most of the transmitted power is ordinarily in the carrier, the reduction of its power and that of one side band permits the use of less transmitter power, or provides a more reliable signal if the same total power is used. ~~Only half the former~~ band width is required, so the receiver can be more selective, reducing noise, and thus improving ~~still further~~ the signal-to-noise ratio.

The block diagram of such a receiver in simplified form is shown in Fig. 4. A double super circuit is employed to reduce image response and to get the second i.f. down to a low enough frequency to separate the desired side bands from the carrier by means of special quartz crystal filters. The carrier is filtered from the second i.f. amplifier output and is separately amplified to bring it up to the proper strength with respect to the side bands. The third detector is of the so-called "balanced demodulator" type in which only one set of side bands is required with a carrier of the proper strength to give undistorted output. The detector is operated push-pull with the side-band voltages applied across the two grids through a center-tapped transformer, and the carrier is applied between the center tap and the grounded cathodes. Audio output is taken from a transformer connected to the push-pull plates.

This type of receiver requires refinements such as carrier and side band a.v.c., a.f.c., and special filters for noise reduction and tone separation when tone keying is used. It is so complex and expensive in its usual commercial form where all possible forms of diversity reception are added in, that it is used only on long commercial circuits which must handle considerable traffic with best possible reliability. By using special filters and separate channels, double side-band transmission may be used where the two side bands are completely unrelated, such as two separate

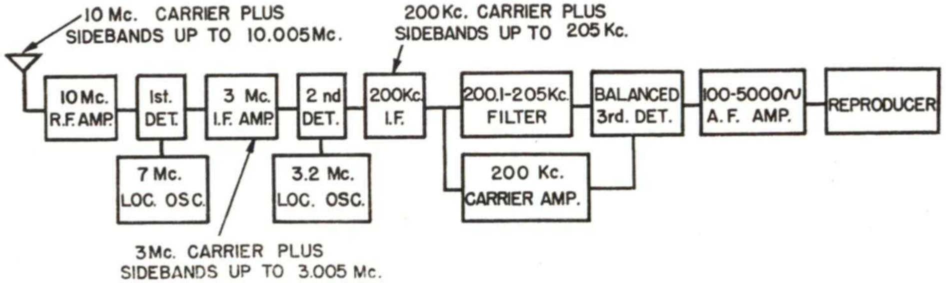

FIG. 4. Simplified block diagram of single side-band suppressed carrier receiver tuned to a 10-mc. signal. Voice modulation covering a 100 to 5000 c.p.s. range is assumed.

voice conversations, or several tone-keyed channels on each side. The tone channels are often used for radio teletype purposes.

EXALTED-CARRIER RECEPTION

In the single-side-band method of reception, the primary purpose of raising the carrier at the receiver is that of bringing the carrier back up to its proper strength from the reduced value radiated by the transmitter. In the exalted-carrier method of reception, conventional double-side-band amplitude modulation with normal carrier radiation is used. In the first case, the object is to save room in the radio spectrum and to effect a power gain by concentrating the power capabilities of the transmitter in the side band. The exalted-carrier method, on the other hand, is used for reliability of reception, to minimize harmonic distortion produced by fading of the carrier with respect to the side bands. The block diagram in Fig. 5 shows the essential elements of an exalted-carrier (raised level) receiver. Units 1 to 7 inclusive comprise an ordinary double-superhetrodyne receiver. The i.f. output of this receiver divides into two branches; one feeding recombining detector 12 directly, and the other feeding carrier filter 9 which separates the carrier from the side bands. The filtered carrier is fed from 9 to limiter 10 which holds the carrier amplitude at a constant level. The filtered and limited carrier is then recombined with the side bands at a phase determined by the R-C network in phase adjuster 11. The resulting signal is then detected at 12 and fed to a.f. amplifier 13 for use.

The most important part of the carrier-exalting receiver is the carrier filter and automatic-frequency-control (a.f.c.) discriminator contained in 9. A very valuable feature of the carrier-filter system is the provision for an automatic-frequency-control discriminator which uses the same crystal for both the carrier filter and frequency discriminator. Fig. 6 shows the carrier filter and a.f.c. discriminator circuit. A crystal filter of the type used in communication receivers acts as the carrier filter. The output of this filter is combined with the unfiltered energy in proper phase to form a sharp frequency discriminator similar to the phase shift type found in f.m. receivers. The crystal X is fed by center-tapped primary P which also furnishes opposite-phase voltage to crystal-holder neutralizing condenser C_n. The output of the carrier filter appears across tuned circuit Z and is the source of pure carrier for the carrier limiter. The filtered output also combines with the voltages E_{S1} and E_{S2}. Diagram A in Fig. 6 shows vectorially how the crystal output combines with these secondary voltages. Primary voltage E_P is not shifted in phase by the crystal filter. Hence the phase of E_X is the same as E_P. The secondary voltages E_{S1} and E_{S2} are shifted 90° by the transformer action. For the in-tune condition shown, the resultant voltages E_{R1} and E_{R2} are of equal amplitude and produce equal and opposite voltages across diode resistors R_1 and R_2. As a result, the a.f.c. voltage is zero.

When the carrier frequency shifts, vector diagram B is produced. Since E_{R1} and E_{R2} are no longer equal, a difference voltage appears across the diode resistors. The resulting voltage is positive or negative, depending upon the direction of the frequency shift. This voltage is used to control a reactance tube, which in turn governs the frequency of the second oscillator. Thus a shift in the frequency of the incoming signal will not change the frequency of the second i.f. because the second oscillator will automatically shift to the proper frequency to keep the i.f. constant. If the frequency of the second i.f. were to change, the crystal would reject the carrier, and no exaltation would occur. Exalted-carrier receivers are admirably suited for diversity work. This is the most effective system for reliable reception.

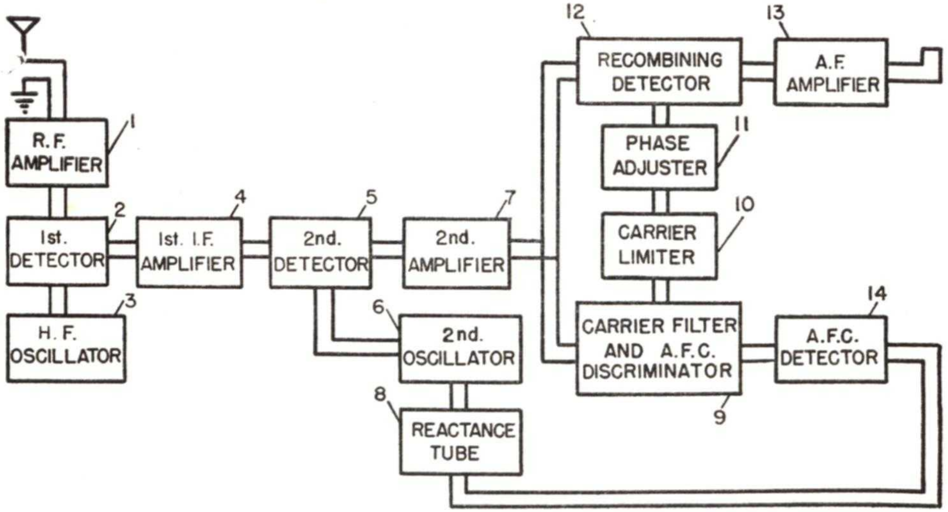

FIG. 5. Block diagram of an exalted-carrier receiving system.

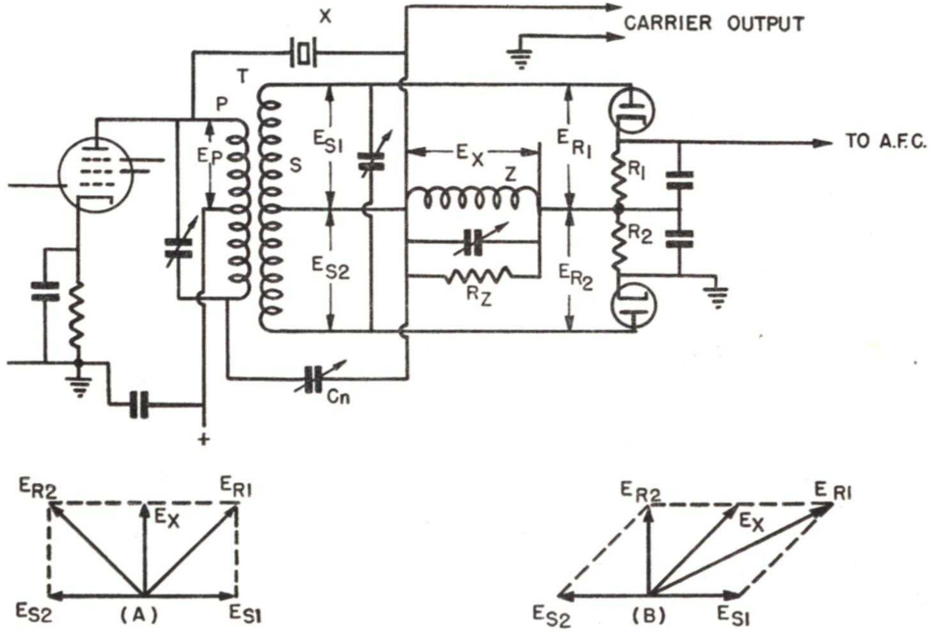

FIG. 6. Carrier filter and automatic-frequency-control discriminator circuit.

Frequency Modulation and Frequency Shift Keying

In frequency modulation, the carrier amplitude is held at a constant value, and the carrier frequency is varied in accordance with the desired modulation. The frequency of the modulating signal governs the rate of carrier shift, and the amplitude of the modulating signal determines the amount of carrier shift. A superheterodyne receiver is used. It operates like a standard a.m. set up to the second detector input. Of course, the i.f. amplifier has a much wider band width to accommodate the frequency variations. The second detector, or discriminator as it is called, converts the frequency variations into amplitude variations which are then sent through a conventional audio amplifier. Any noise pulses which are picked up result in amplitude variations. In one system, all amplitude variations (noises) are wiped out by passing the signal through a limiter before detection. The limiter, since it is operated in a saturated condition, will not respond to variations in amplitude. The discriminator operates on the same principle as the automatic-frequency-control discriminator shown in Fig. 6. Of course, the crystal shown in Fig. 6 is not used in f.m. receivers. The limiter is required because this type of discriminator responds to amplitude as well as frequency variations. However, a new type of discriminator known as the ratio detector has recently been developed. This detector will not respond to amplitude variations, making the use of a limiter unnecessary. This detector will be discussed in the Lesson devoted to f.m. receivers.

FREQUENCY SHIFT KEYING

The advantages of f.m. are realized to a considerable extent for code or teletype signals by having the carrier on one frequency for "key down" conditions, and on another frequency about 800 c.p.s. away for "key up" conditions. As the carrier is always on one or the other frequency, a.v.c. may be used, and noise does not cause the same trouble as when it appears during carrier off periods of the usual on-off keying. All forms of diversity may be combined with frequency shift keying. A receiver for frequency shift keying (f.s.k.) may use a conventional super with a special output audio filter for the "mark" and "space" (key down and up) tones produced. The outputs of the two filters may operate a polar keying relay or a vacuum-tube keyer. A newer system has a discriminator in the i.f. system similar to that used in an f.m. receiver. The d.c. output feeds a locking circuit which flops from mark to space every time the signal shifts. This system is very tolerant of receiver or transmitter drift. The demonstrated improvement in performance of f.s.k. has caused it to supersede most of the on-off keying circuits formerly used. It will handle teletype speeds up to 400 words per minute, which is beyond the ability of a single teletype machine to copy. The recorded messages can be played back slowly into teletype machines at their normal speeds, and several can copy in parallel the different parts of the message which is later reassembled.

Panoramic Receivers and Adapters

A good receiver should cover only one channel at a time to avoid interference from near-by channels. Frequently it is desirable to know what activity is going on in near-by channels, or if interference is obtained, it is desirable to know in a minimum of time where near-by clear channels are located. The panoramic receiver enables an operator to "see" a predetermined slice of the radio spectrum with all the signals present in it on the screen of a cathode-ray tube. He usually sets it up so that the signal to which he is listening appears in the center of the screen as a vertical deflection from a horizontal base line, and signals below this frequency appear as similar deflections to the left, while signals above this frequency appear to the right of the center. A panoramic adapter can be added to an existing communication receiver without affecting its normal operation. The block diagram for such a device is shown in Fig. 7. Output is taken from the receiver mixer

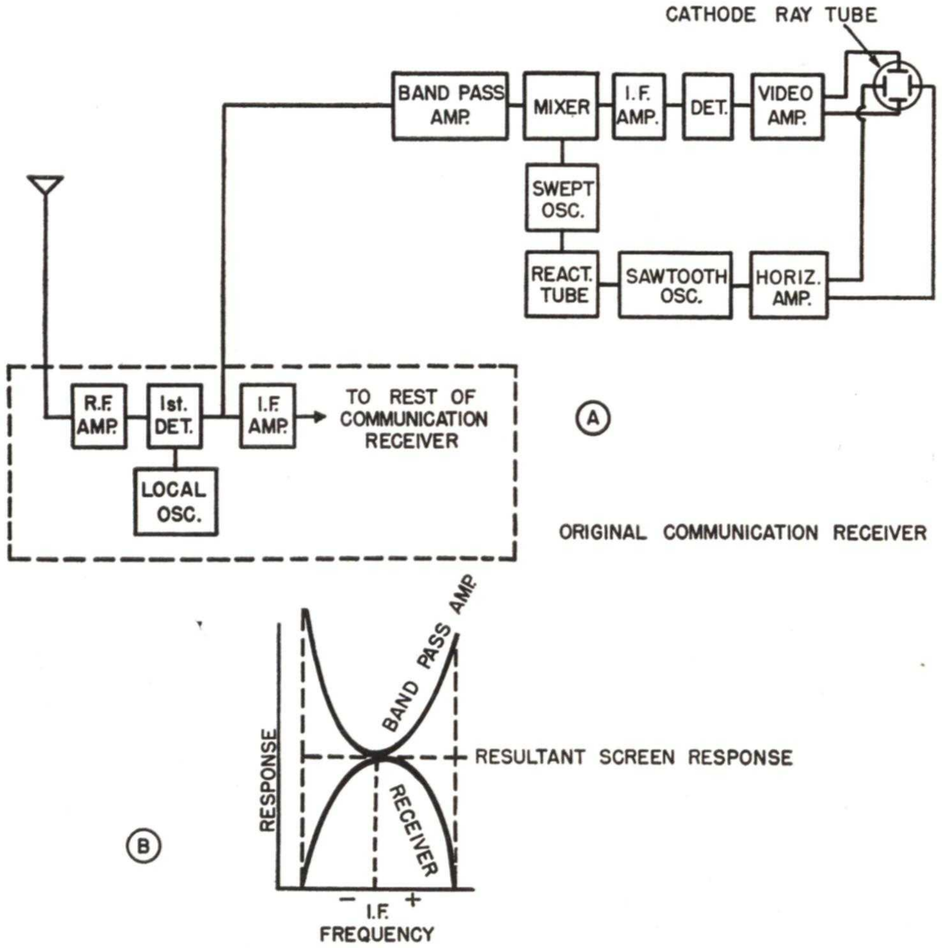

FIG. 7. Block diagram of panoramic adaptor showing how compensation for receiver selectivity is obtained.

Courtesy Hallicrafters Co.

Front view of Skyrider Panoramic Model SP-44.

plate which delivers i.f. to the adapter. This i.f. is much broader than that obtained after passing through all the receiver tuned i.f. circuits. A typical receiver selectivity curve over the desired band at the first detector output is shown as the lower curve in B of Fig. 7. The response falls off as the frequency deviates from resonance. The band-pass amplifier of the panoramic adapter has a response curve similar to that at the upper curve in B of Fig. 7, where the response increases as the signal goes farther off resonance. This is accomplished by using overcoupled double-tuned circuits and staying inside the "humps," by stagger tuning, or by a frequency-selective a.v.c. system. The resultant of the two curves gives a uniform response on the screen for any signal within the selected band width. The output of the band-pass amplifier is fed to a mixer where it is combined with a local oscillator to produce a low-frequency i.f. giving a high degree of selectivity for the desired band width. A second detector and the video amplifier apply the signal to the vertical plates of a cathode-ray tube. The local oscillator of the adapter is swept through the desired frequency range 30 times per second by a reactance tube driven in turn by a saw-tooth oscillator operating at a 30-c.p.s. frequency. The same saw-tooth oscillator also drives an amplifier, which drives the horizontal plates of the cathode-ray tube, sweeping the spot horizontally 30 times per second. The base line thus produced can then be calibrated in kilocycles off the frequency to which the receiver is tuned.

As the receiver is tuned from a low to a high frequency, the signal deflections will move across the screen from left (plus) to right (minus). The reverse is true when tuning from a high to a low frequency. Those signals appearing on the plus side of the zero mark are higher in frequency than the station heard through the receiver by the amount indicated by the screen calibrations, each calibration mark being equal to 20 kilocycles. (Note:—The signals appearing on the minus side of zero are true only when the local oscillator in the receiver tracks above the incoming signal. The reverse is true when the frequencies of the incoming signals are higher than the local oscillator frequency. Fig. 8 shows the determination of a single frequency at maximum scanning width.)

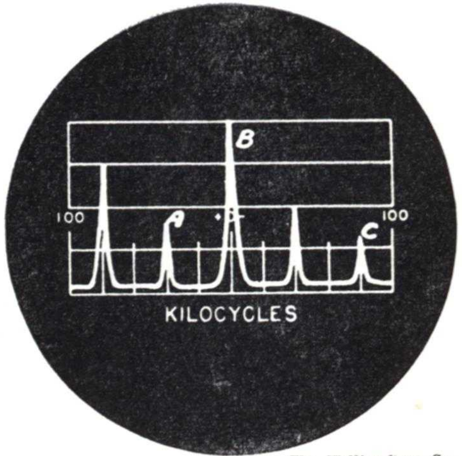

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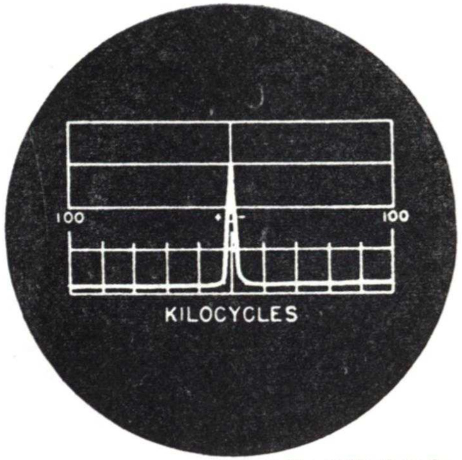
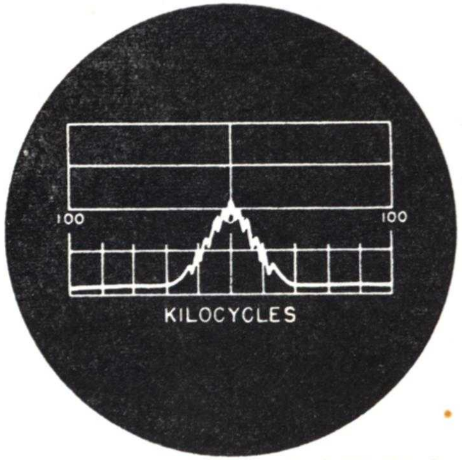
FIG. 8. Illustration showing determination of a single frequency at maximum scanning width.



Courtesy The Hallicrafters Co.

An unmodulated carrier.



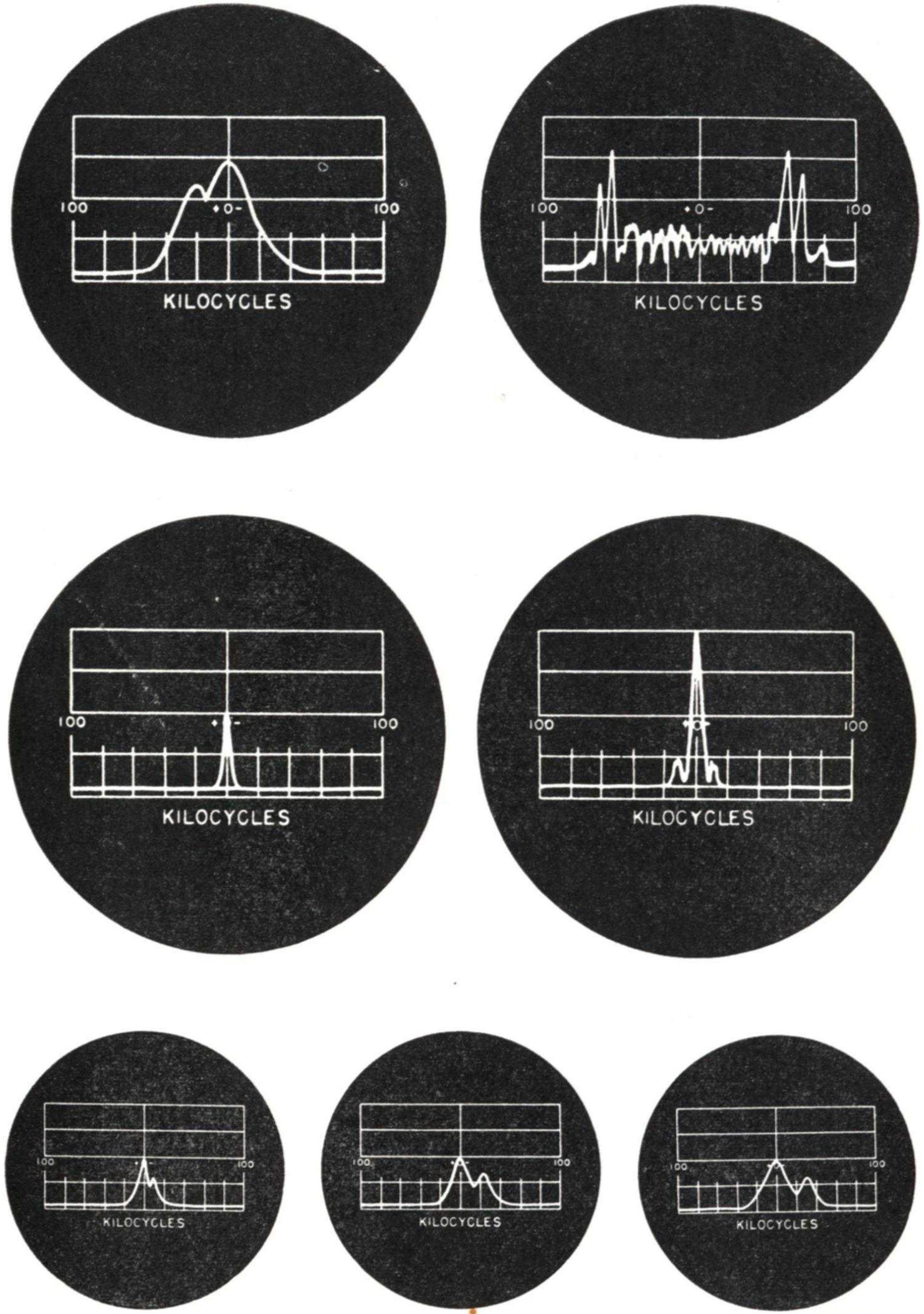
Courtesy The Hallicrafters Co.

Amplitude modulated carrier at reduced sweep-width.

INTERPRETATION OF SIGNALS

With a little experience it is possible to recognize visually the character of various types of signals without listening to them. However, the panoramic can show only what the radio receiver is able to receive and no more. A poorly adjusted receiver cannot be expected to give good results even with a perfectly adjusted adapter. The illustrations here and on the next page show patterns of various signals received on the panoramic screen.

Transient Disturbances. Those disturbances received as noises in the receiver, are of two types, periodic and aperiodic transients. Periodic transients, such as produced by automobile ignition, motors, vibrators, buzzers, etc., appear as signals moving along the frequency sweep base line in one direction or another. Thus, an automobile which is accelerating will produce a set of deflections which may move first in one direction, slow down, stop, and move in the opposite direction. This is caused by the fact that the



All above courtesy The Hallicrafters Co.

Upper left, a single side-band signal; upper right, frequency-modulated signal at reduced sweepwidth; center left, c.w. signal; center right, m.c.w. signal at reduced sweepwidth; bottom, appearance of two interfering signals as scanning is reduced.

panoramic is sweeping at a fixed rate (25 or 30 times per second), whereas the transient occurs at a variable rate. The images stand still on the screen when there is synchronism between the two. If the transient disturbance is synchronized with the 50- or 60-cycle line, the "noise" appears as a fixed signal which, however, varies only in height. Such deflections may appear like amplitude-modulated signals or like steady carriers. Aperiodic transients, such as static, appear as irregular deflections and flashes along the whole frequency sweep axis.

Tube Noises. These are due to too great an amplification of the receiver, the panoramic, or both, appearing as varying irregularities along the frequency sweep axis. Proper adjustment of the sensitivity controls should reduce or eliminate this disturbance.

Panoramic devices are being used for direction finder applications, but their main use seems to lie in the field of amateur radio.

The Crystal Detector

Certain mineral crystals such as galena, iron pyrites, silicon, zincite, and carborundum, will pass current much more readily in one direction from a point contact conductor than in the other direction. These crystals can be used in a circuit the same as a diode. Some of them are more sensitive than the diode, require no power such as a filament supply to operate them, and have far less shunt capacity than the best diodes. In the days before vacuum tubes, such detectors were very popular. They are now being used extensively as mixers in superheterodynes at frequencies higher than those at which vacuum tube detectors can be made to operate satisfactorily, because of the low capacity obtainable. They are mounted in holders which plug into a clip or socket similar to that for an automobile fuse. As shown in Fig. 9, the conductor, B, is in contact with the crystal at a sensitive spot, A. It is held in place with some type of cement inside an outer ceramic case. Very

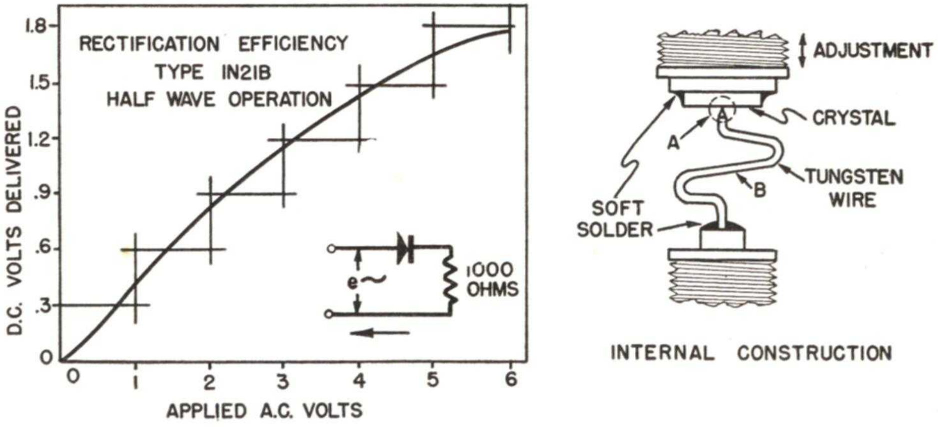


FIG. 9. Internal construction and characteristic of IN21B crystal.

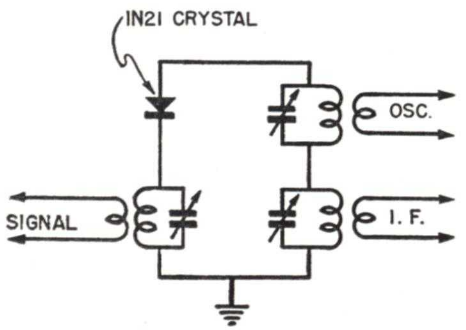


FIG. 10. Series injection with crystal detector.

strong signals may burn out the crystal, which must then be replaced.

Although the crystal detector is now used more as a mixer than a second detector, it can be used as a second detector by omitting the oscillator and substituting audio output for i.f. output.

The equivalent electrical connections of a crystal mixer are shown in Fig. 10. It is difficult to show a schematic diagram for the usual microwave crystal detector, as the inductance and capacities used are often distributed, or exist because of placement of parts, and are not readily recognizable as are their lower frequency counterparts. An attempt to show such circuits is made in Fig. 11. The important inductances are shown as coils, although they may actually be large pipes, rods, castings, or even sections of the chassis. The important capacities are shown in conventional form, but actually they may be rods running through holes, bits of metal near the walls of cavities, and the like. Minor circuit refinements used for equalizing oscillator voltage over the range, decoupling, and loading, are omitted for the sake of simplicity.

BUTTERFLY MIXER

A "butterfly" crystal mixer circuit is shown in Fig. 11A. This name is derived from the shape of the rotor element of the split-inductance tuning unit sketched at the top. The two halves of the tuning unit are designated L_1 and L_2, and the rotor, which is similar to a condenser rotor having plates meshing with those of L_1 and L_2, is designated C_1. This combination tunes to the signal frequency. The crystal is tapped down on the tuned circuit, as it is a low impedance. This gives a better match for the crystal and avoids excessive loading of the tuned circuit. Condenser C_2 applies signal to the other side of the crystal with negligible loss, and also passes the oscillator frequency readily, but is high impedance to the much lower i.f. Condenser C_3 which tunes the i.f. transformer primary L_4, by-passes both signal and oscillator frequencies readily. Oscillator voltage is induced in L_2 from a similar oscillator inductance L_3 placed adjacent to it. This circuit can be used to obtain the modulation on the signal directly by omitting the oscillator and substituting an r.f. by-passed audio or video load for the i.f. transformer. Such a circuit is used at frequencies up to about 3000 mc.

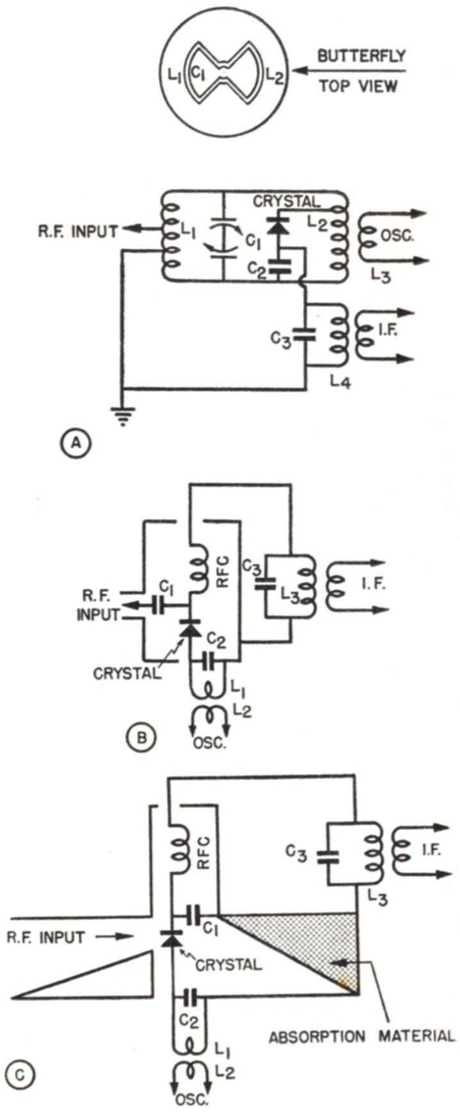


FIG. 11. Typical crystal detector circuits. A, Butterfly mixer; B, coaxial line input mixer; C, waveguide mixer.

COAXIAL LINE INPUT MIXER

A crystal mixer circuit for coaxial line input is shown in Fig. 11B. There is no tuning at signal frequency, all tuning being done with the oscillator. This, of course, gives double spot tuning on all signals. Condenser C_1 couples the signal to the crystal. Condenser C_2 by-passes r.f. to ground, and does not resonate with L_1 in the band to be covered. Oscillator voltage from L_2 is coupled to L_1, and is not excessively by-passed by C_2. The r.f. choke, RFC, prevents the signal from passing into the i.f. circuit, and being shorted out by C_3, but it permits passage of i.f. The i.f. output is attenuated very little in RFC or L_1, and appears across tuned circuit L_3-C_3. An audio load could be used instead of L_3-C_3 if audio output was desired. The input of this mixer could be tuned with a resonant cavity or coaxial line to provide preselection. This circuit is used up to frequencies as high as coaxial lines are employed.

WAVE GUIDE CRYSTAL MIXER

A wave guide crystal mixer circuit is shown in Fig. 11C. The manner in which microwave signals travel in the hollow wave guide will be covered in a later Lesson. A voltage at signal frequency is induced in the crystal, and is by-passed from the other circuits by C_1 and C_2. The remainder of the circuit functions similarly to that of Fig. 11B. The absorption material at the end of the wave guide prevents reflections which would be objectionable and would reduce the signal strength. This circuit is used at frequencies as high as radio waves are generated.

Receiver Characteristics and How They Are Measured

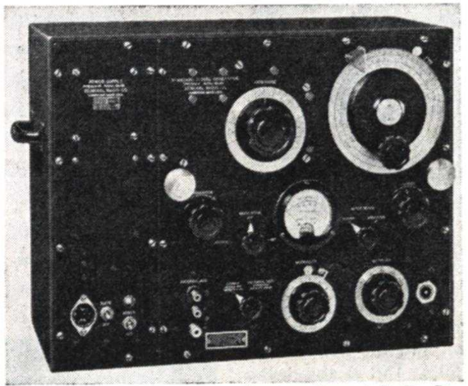
THE IMPORTANCE OF RADIO MEASUREMENTS

Measurements of receiver characteristics were at one time limited entirely to laboratories. The expensive equipment and the exact, time-consuming, scientific methods needed caused radio maintenance technicians to "steer clear." Today, however, the more widespread use of vacuum tube voltmeters, the cathode-ray oscilloscope, signal tracers, etc., has placed the necessary equipment in the larger maintenance shops. Further, set manufacturers have begun to release measurement data made with such service equipment, so the problem of getting a useful measure of sensitivity, selectivity, fidelity, etc., has been greatly simplified. As a result, many technicians are using these measurements as a means of determining radio characteristics more exactly.

Ordinarily, the only guides to the performance a particular radio receiver should exhibit are the statements of the operator and data which may be a part of the service information on the set. Of course, it is possible to judge the performance of some particular model after having worked on several identical receivers. However, this experience may not be too helpful when you meet a different model, for different types of communication receivers vary considerably in their characteristics.

Courtesy Supreme Inst. Corp.

A standard signal generator such as used by servicemen. Frequency ranges are selected by push-buttons at the upper right. When the carrier level control is adjusted to give an indication at the point marked on the meter, the output in microvolts will be indicated by the output control setting. The r.f. attenuator reading is multiplied by the r.f. multiplier push-button being used. There is a built-in variable frequency audio oscillator, and the percentage of modulation is indicated on the meter.



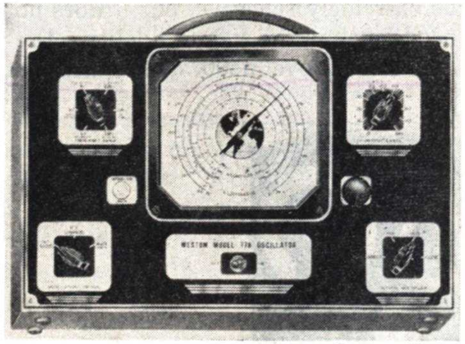
Courtesy General Radio Co.

A standard laboratory type signal generator. The output is calibrated in microvolts, and the percentage of modulation is variable and indicated on the meter.

Contrary to popular opinion, the number of tubes in a receiver shows little about its performance. It is quite possible, for example, for a 6- or 7-tube receiver to have far greater sensitivity than a receiver with 12 or 15 tubes. Even receivers with the same number of tubes may be of different design and therefore have far different performances. Thus, a 5-tube a.c.-operated receiver with a power transformer may have a far greater output than a 5-tube a.c.-d.c. or a 5-tube battery-operated set, and these receivers may have better selectivity or better sensitivity characteristics than the a.c. receiver.

Today, it is possible for the radio engineer to build into the receiver any desired amount of selectivity, sensitivity, and fidelity, within the limits of cost and the necessary compromises between these factors. The engineer, in designing a set, takes into consideration the use to which the receiver is to be put and the sales features desired. A communications set, for instance, must have a high sensitivity and must be extremely selective, but it does not need much in the way of fidelity. (Frequencies above 3500 cycles are not needed for voice or code transmission, and cutting them off gives less noise and better selectivity.) On the other hand, a high-fidelity receiver is usually made relatively insensitive, with rather poor selectivity, but with very good fidelity or tone quality. The average broadcast set is a compromise between these two extremes.

The fact that such wide variations exist in the designed performances of radios makes it desirable to use fairly accurate measurements if you are going to revitalize receivers which have lost their pep. You must have some clear way of comparing the actual performance of a set with the performance it was designed to have—otherwise, you may waste a great deal of time attempting to give to a receiver characteristics that were never built into it and that it cannot have without extensive modifications. Only actual measurements of performance will let you make such a comparison.



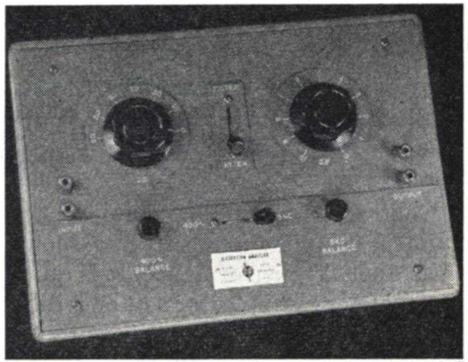
Courtesy Weston

Another service-type signal generator. The output controls are calibrated in microvolts, and the output level is held constant by a built-in automatic level control circuit. The audio modulation is a 400-cycle signal, and the percentage of modulation is fixed at 50%. This is above the 30% value used in standard sensitivity measurements. Radios would have an apparent sensitivity better than they actually have if this signal generator is used. Otherwise, this is an excellent general purpose signal generator.

Comparison of actual performance with the rated value by means of measurements will be of particular help when the operator believes there is a lack of selectivity, fidelity, or sensitivity in his radio. Measurements will show if the complaint is really justified and if the condition can be corrected at reasonable expense. And, finally, measurements are extremely useful as checks on your work, since they will show definitely how successful you have been in your attempts to bring the set back to "good as new" condition.

Naturally, when servicing a set you are not going to have the equipment or the time to make laboratory measurements. In recognition of this fact, the modern practice is for the set manufacturer to take laboratory measurements in a standardized manner so as to compare receiver characteristics, then to give service data measurements taken with service instruments. However, even though you may never make laboratory measurements yourself, it is desirable for you to know how they are made, what they mean, and how close service measurements are to them in results. Then you will be able to interpret more clearly the results you get from measurements made with service instruments.

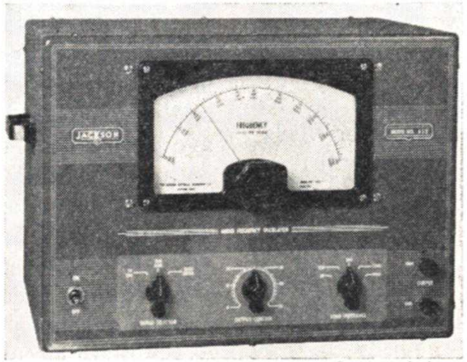
In this Lesson we shall give a brief description of the manner in which the set manufacturers make their measurements, so you can understand the exact meaning of the ratings you may find in radio service data. Then, we shall show how simplified measurements can be made with service equipment, which will permit an approximation of these results and give you some means of comparison.



Courtesy Hewlett-Packard Co.

This distortion analyzer checks distortion at two frequencies, 400 cycles and 5000 cycles. It contains a tuned filter and an attenuator, so arranged that either one may be switched into use. A c.r.o. is used as an output indicator. The operating steps are: first, the tuned filter eliminates the fundamental frequency voltage, which leaves only the amplitude of the harmonic voltages indicated on the c.r.o. screen. Then the filter is switched out and the attenuator is used to reduce the c.r.o. indication to the same value as that obtained with the filter. The attenuator calibration then gives the harmonic distortion in db below the fundamental level. It is necessary that the audio source produce fundamentals of 400 cycles and 5000 cycles without any distortion.

Of course, these measurements will not be needed so very often in your work, as by far the greatest number of troubles will be straightforward cases, easily and directly solvable. Furthermore, as your experience grows, you will develop the knack of judging receiver response, so you will need to make measurements only in those comparatively rare cases where ordinary methods fall down.



Courtesy Jackson

A typical audio-signal generator designed for servicemen.

Among the measurable response characteristics of a receiver are: sensitivity; selectivity; fidelity; hum level; noise level; frequency shifts; image rejection; dead spots; and receiver power consumption. Let's see just how the measurements of these characteristics can be made.

SENSITIVITY MEASUREMENTS

The receiver sensitivity is a measure of its ability to pick up and properly reproduce weak signals from low-powered or distant stations. A loss of sensitivity first shows up as an inability to pick up weak distant stations, and then progresses gradually to weak reception even from strong near-by stations.

We could measure the sensitivity of a receiver by determining the weakest possible signal which would give even the slightest output from the receiver, if we wished to do so. However, a more useful value is found by measuring the input signal which will give some definite rated output. This latter measurement is far more valuable because it gives some idea of how weak a signal can be and still be amplified enough by the set to give reasonable reception.

Laboratory Sensitivity Measurements. Let us first consider receivers designed to operate from regular antennas (not loop aerials). To measure the sensitivity of the receiver, we must be able to measure both the signal voltage fed into it and the output voltage of the receiver.

It is not practical to radiate a signal and depend on an antenna for pickup, as there is a possibility of the set picking up the signal directly. Just feeding from the signal generator directly into the antenna-ground terminals will upset the input circuit of the receiver, because of the signal generator loading effects. The usual way of solving this problem is to feed a measured signal voltage into the radio receiver through what is called a dummy antenna. This dummy antenna is a combination of parts which simulates the inductance, capacity, and resistance of an ordinary receiving antenna.

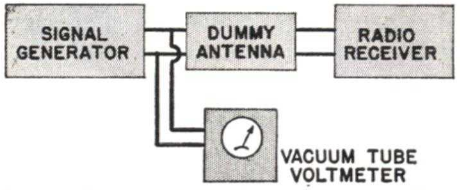


FIG. 12. The connections for making a sensitivity check.

When the measured signal is fed through this device, the receiver "feels" an antenna at its input and will react as if it were connected to an average antenna.

The input signal must be measured with accuracy if the sensitivity measurement is to mean anything. One method of making this measurement is to use a sensitive vacuum tube voltmeter, as shown in Fig. 12. However, modern standard* signal generators having a controlled output are used in most laboratories. In these, a built-in vacuum-tube voltmeter is used to adjust the signal level fed into an attenuating network. The controls of the attenuator are marked directly in microvolts output. (A microvolt is one-millionth of a volt.) Usually, there will be two controls, one reading from zero to 10, the other being a switch type of control varying the output in steps of ten. (It reads 1, 10, 100, 1000, and 10,000; the output is found by multiplying the two dial readings.) This permits the output to be varied from a fraction of 1 microvolt up to 100,000 microvolts on most standard signal generators.

Fig. 13 shows the connections for a standard signal generator, and also shows the components of a standard dummy antenna. As we said, this particular arrangement of parts has been chosen to simulate the effects of an antenna on the receiver input, so the measurement will be in terms of signal strength fed into an average antenna.

The Dummy Load. To measure the output, the loudspeaker voice coil is disconnected, and a resistor is used in its place, as shown in Fig. 13. The resistor R is called a dummy load, and is chosen to have the same ohmic value as the voice coil impedance. The voltage across this resistor is measured with an accurate a.c. voltmeter. Once we know the voltage and the resistance, we can determine the power output ($P = E^2 \div R$).

An equally acceptable way to measure the output is to place a resistance in the plate circuit of the output tube or tubes, as shown in Fig. 14. Leaving the secondary winding of the output transformer open makes the primary impedance practically infinite, so the dummy load resistor R is chosen to give the proper load impedance for the tube used. The advantage of using the circuit shown in Fig. 14 lies in the fact that the voltmeter need not have an extremely low range. The resistance value of R in Fig. 14 is much higher than that of R in Fig. 13, and a higher voltage is developed across it for the same power output.

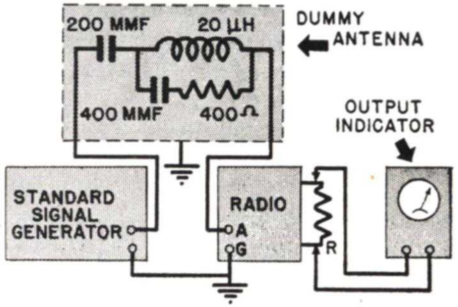


FIG. 13. Standard signal generators have built-in level indicators, so they do not need an external v.t.v.m. for measuring the receiver input. The parts values for a dummy antenna are given here.

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*Signal generators of the "standard" type are so named because they are made to laboratory specifications and have extremely accurate and reliable output signals.

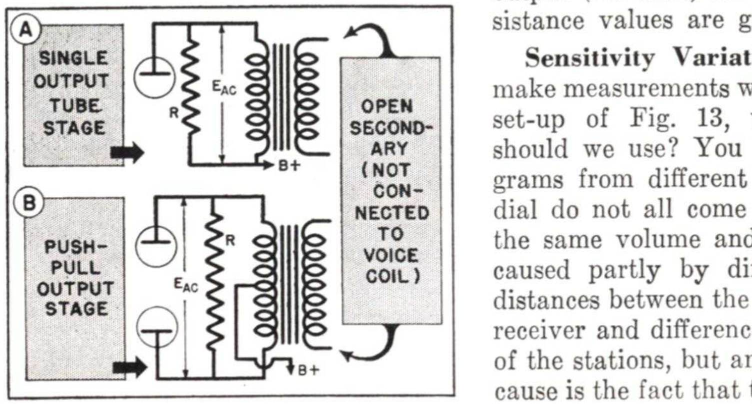


FIG. 14. These connections are used when the dummy load resistor is connected in the plate circuit of single-ended (A) and push-pull (B) output stages.

The Standard Output. The standard output power used for sensitivity measurements is .05 watt (50 milliwatts) for a set which has an undistorted output power of 1 watt or less, and is .5 watt for a receiver with an undistorted output power of 1 watt or more.

Thus, on a low-powered set, we adjust the input signal until the output indicator used with the set shows .05 watt output; similarly, with a high-powered set, we adjust the input until an output of .5 watt is indicated. We can then tell from the amount of input necessary to produce this standard output just how sensitive the set is.

Assuming we are using the 50 milliwatt output level, which is the one most often used, you can see that the voltage across a low resistance will be small. (This voltage is found from the formula, $E = \sqrt{P \times R}$.) Thus, if the resistance has a value of 5 ohms, and the power is .05 watt, the voltage is only .5 volt. If the resistance is higher, the voltage will be higher, so the method illustrated in Fig. 14 is somewhat more desirable.

Voltages equivalent to standard output (.05 watt) for various load resistance values are given in Fig. 15.

Sensitivity Variations. When we make measurements with the standard set-up of Fig. 13, what frequency should we use? You know that programs from different stations on the dial do not all come in with exactly the same volume and power. This is caused partly by differences in the distances between the stations and the receiver and differences in the powers of the stations, but another important cause is the fact that the sensitivity of a receiver is not the same at all frequencies. Therefore, as we take measurements over a band of frequencies, we will find that different amounts of input will produce the standard output.

For this reason, we cannot say that a receiver has a certain sensitivity

VOLTAGES FOR STANDARD OUTPUT OF .05 WATT

Dummy Load	Volts	Dummy Load	Volts
1	.22	1000	7.1
2	.32	1500	8.7
3	.39	2000	10.0
4	.45	2500	11.2
5	.50	3000	12.3
6	.55	3500	13.2
7	.59	4000	14.1
8	.63	4500	15.0
9	.67	5000	15.8
10	.70	5500	16.6
11	.74	6000	17.3
12	.78	6500	18.0
13	.81	7000	18.7
14	.84	7500	19.4
15	.87	8000	20.0

FIG. 15. This table gives the voltages that indicate a .05-watt output across various load resistance values.

without specifying the frequency at which the sensitivity was measured. A typical curve showing the variation in sensitivity over the broadcast band is given in Fig. 16.

Thus, to make a really complete study of the sensitivity of a receiver, it is necessary to start at one end of the band, tune the receiver and the generator to the same frequency, and note the microvolts input necessary to produce the standard output. The measurement must then be repeated at other points throughout the frequency range of the set.

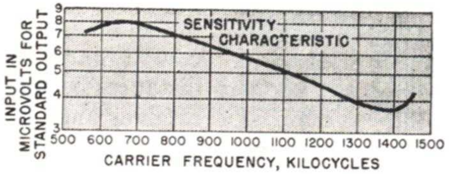


FIG. 16. The sensitivity varies over the tuning range, as shown here. The maximum sensitivity is indicated by the least input which will give the standard output, so this particular set is most sensitive near 1400 kc. Sometimes the readings near the center of the tuning range are given as the average over-all sensitivity value.

Of course, for comparison purposes, we do not need to measure the sensitivity over the entire band as long as we know what the sensitivity should be at some particular frequency and make our measurements at that same frequency.

Signal Generator Modulation. As the output voltage is an audio voltage, the signal generator must be modulated a certain exact amount at a certain frequency for the output measurements to be reliable. Standard measurements are made with the signal generator modulated 30% by a 400-cycle audio signal. The modulation percentage must be accurately adjusted. Most laboratory-type standard signal generators have a means of varying modulation percentage and use a meter to indicate the exact percentage used.

Loop Aerials. When the receiver has a loop aerial, it is not possible to substitute a dummy antenna for the loop. When measurements are made on such a receiver, one method is to use a carefully designed radiating loop antenna, connected to the signal generator and then arranged a certain distance from the receiver loop, as shown in Fig. 17A. From the dimensions of the two loop antennas and their distance apart, it is possible to calculate the energy fed into the receiver loop and, from this, the input to the receiver.

Another way of accomplishing the same result is shown in Fig. 17B. A small resistor is inserted in series with the receiver loop aerial, and the signal generator output is applied across it. The current flow through the resistor is measured by the meter M. From this, the voltage drop across the resistor—that is, the signal voltage introduced into the loop circuit—is calculated.

Sensitivity Tests With Service Equipment. The technician with a great amount of practical experience rarely needs to make sensitivity measurements. He may put a set on the test bench and simply try tuning in a number of stations on the band. From experience, he knows what other sets of various types will do in his particular location on the same antenna, and he judges the performance of the radio on which he is working by the way it acts. If he knows that certain distant stations can be tuned in only by a receiver having good sensitivity, and finds he can pick up these stations on the set being checked, he knows that the sensitivity of the radio he is testing is pretty good.

He may also judge the sensitivity by the action obtained when he tunes off resonance. Normally, he would expect the noise level to increase greatly as the set is tuned away from a station signal and the a.v.c. action increases the set sensitivity to maximum. If he finds that he doesn't get much of a "roar" as he tunes off resonance, he knows the set does not have very much sensitivity. If the receiver is a type which should be reasonably sensitive, he would then go to work to discover the reasons for the lack of sensitivity.

A technician with less experience is unable to judge radio receivers this way, and even an expert can be fooled occasionally, so a more exact procedure is desirable.

Better and better equipment is being made available, so today many have standard signal generators which they use for alignment purposes. If you have such a standard signal generator (with an output *accurately* calibrated in microvolts), you can measure receiver sensitivity by the same method used by the set manufacturer.

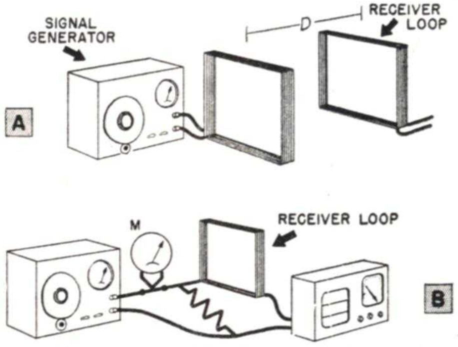
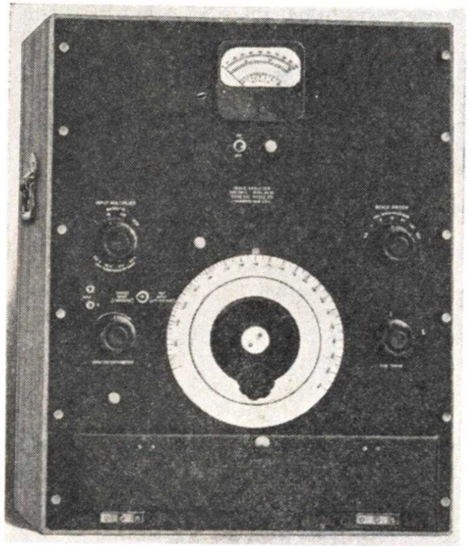


FIG. 17. Two ways of feeding a signal into a loop antenna. The practical serviceman would use the first method, winding a loop of 5 or 10 turns to connect to his signal generator. He won't know what the induced voltage is, so cannot determine the Q of the loop, but using a signal tracer will permit measurements from the loop onward.

Checking the set sensitivity in the manner just described will give the actual over-all sensitivity of the receiver. Comparing this with the manufacturer's ratings gives valuable information about the over-all gain of the receiver. If there is any wide difference between the measured sensitivity of the receiver and its proper value, trouble in the radio is indicated. Unfortunately this indication does not tell which *stage* the trouble is in, so the entire receiver must be carefully checked.

The development of signal tracing equipment has, to a great extent, permitted quick localization of the defective stage. A signal tracer cannot be depended on to indicate accurately the *number* of microvolts of signal at any point in the radio. However, it *can* be used to measure the *ratio* of the output to the input of any desired stage. The ratio of the output to the input is a measure of the gain or amplification of the stage and is accurately determined by the signal tracer, for any errors caused by the tracer will be in both measurements and will cancel each other. Since the receiver sensitivity depends on the amplification obtained in each stage, this measurement of stage gain is an indirect measure of sensitivity. Even more important, if you know the gain which should exist in each stage, *you can localize the defective stage (or stages) by making stage-by-stage measurements with the signal tracer.*



Courtesy General Radio Co.

A wave analyzer. A beat frequency is formed between the complex input wave and a built-in oscillator. This changes each audio frequency to a different i.f., as each frequency will form a different beat with the fixed oscillator. Thus the complex wave is spread over an r.f. band, and tuning circuits can be used to select each frequency component. An r.f. type v.t.v.m. then indicates the output at each frequency contained in the audio wave. Hence, the number and strength of each harmonic can be found.

Since a check of the over-all gain indicates only that a defect exists, but does not localize the trouble, you can see that the signal tracer, with its ability to localize the defective stage, is more valuable in service work.

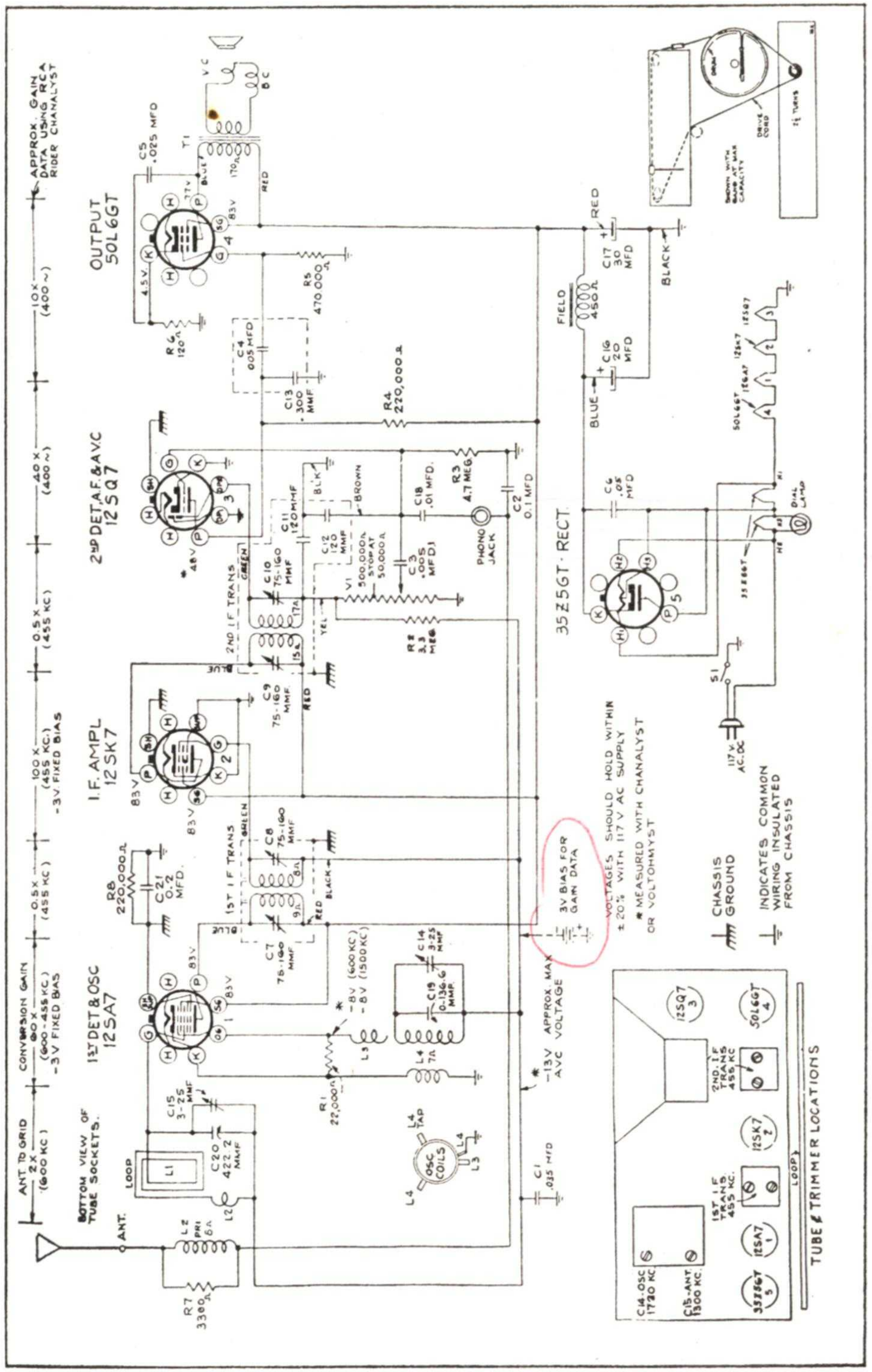
Manufacturers' Gain Values. Before stage gain readings can mean much, we must know what to expect from each particular stage. In recent years, receiver manufacturers have cooperated in furnishing this data. Some give the gain data directly on the diagram; others show it in a table apart from the diagram.

Fig. 18 is an example of the diagram system. This simple a.c.-d.c. broadcast super has been used rather than a complicated communications set since in both cases the same procedures are employed. Notice the gain values given above the schematic. As you can see, the input gain is figured at 600 kc. At that frequency, the gain from the antenna to the first tube grid is 2. If we have, for example, a 30-microvolt 600 kilocycle signal between the antenna and ground (chassis ground), the circuit should give us two times this signal level (a 60-microvolt signal) between the first tube grid and chassis ground, if everything is normal.

With the 600-kilocycle signal still tuned in, there is a conversion gain of 60 in the first detector-oscillator tube. This means that if we measure the 600-kilocycle signal fed to the grid of the 12SA7 tube, then measure the 455 kc. i.f. signal developed between this tube plate and the chassis ground, we should have an increase of about 60. With a 60-microvolt signal applied to the 12SA7 tube, we should have 3600 microvolts (60 × 60) of i.f. signal between the plate of this tube and ground.

Notice, however, that the gain of this tube will vary with the grid bias, which is controlled by the a.v.c. cir-

FIG. 18. On the opposite page, a simple a.c.-d.c. broadcast super. We have shown this rather than a complicated communications set, since the same tests are used in both instances.



cuit. If we allow the normal a.v.c. action to occur, strong signals will increase the bias and hence reduce the gain. For the gain measurement to mean anything, we must block the a.v.c. action.

Therefore, when any measurements are made in the r.f. and i.f. sections of a receiver, it is necessary to disconnect the a.v.c. circuit from the source of a.v.c. voltage and substitute in its place a certain value of fixed bias. The fixed-bias value must be that recommended by the set manufacturer—usually 3 volts. To make measurements on the receiver shown in Fig. 18, you should disconnect resistor R_2 (either end) and place a 3-volt bias from a battery between the grid return lead and chassis as shown by the dotted lines in Fig. 18. Of course, you must observe the proper polarity in connecting this battery. In a communication set, simply throw the a.v.c. switch to the off position and set the r.f. sensitivity control full on. No bias battery need be inserted in a communication receiver which has an r.f. sensitivity control.

Continuing with our example, the next gain measurement is taken from the plate of the 12SA7 tube to the grid of the 12SK7 tube. This measures the gain of the i.f. transformer, which is given as .5 (the same as ½). This means that the signal in the secondary of the transformer is only half as strong as that in the primary; in other words, we actually get a loss in this transformer. Thus, if we have 3600 microvolts between the plate of the 12SA7 and the chassis, we can get only one-half this, or 1800 microvolts, at the grid of the 12SK7 tube.

In the next stage, there is a gain of 100 between the grid and the plate of the i.f. amplifier, then a loss of one-half in the second i.f. transformer.

There is a loss (not shown on the diagram) in the second detector too. The audio output of the detector depends on the percentage of modulation of the input signal.

Following the audio signal further, we find a gain of 40 in the triode section of the 12SQ7 tube. (Notice that in making the measurement on the audio tube stage we are comparing the signal levels found at its grid and plate terminals, and are measuring the 400-cycle audio modulation signal from the signal generator.) Finally, there is an audio gain of 10 between the grid and plate of the 50L6 output tube.

Using Signal Tracers. In making gain measurements with a signal tracer, you do not worry about the actual *amount* of microvolts. Instead, you are interested in the *ratio* between the two points where you make your measurement. You can make your measurements either with a signal tracer which gives a meter reading or with one which uses a magic-eye indicator.

If you use the second type of tracer, you will determine the gain ratio from the control settings. First, connect the signal tracer probe to the input side of the stage, feed in a signal, and adjust the controls until the eye closes. Make a note of the control settings which close the eye. Then, move the probe to the output side of the stage and adjust the controls until the eye is again closed. Dividing the second gain control reading by the first will give the relative increase in gain.

If your signal tracer indicates the signal input level on a meter, measure the level at both the input and the output of the stage, keeping the tracer gain control at the same point. Dividing the second meter reading by the first will give the gain of the stage.

A vacuum tube voltmeter could be used in the same manner, but there is considerable chance of the vacuum tube voltmeter reading stray voltages instead of the signal. For this reason, a tuned signal tracer, which can be made to select the proper signal, is the more desirable instrument.

With either type of signal tracer, a signal generator is used as the signal source. It does not have to have a calibrated output voltage control, as you depend on the signal tracer for the signal ratios. A dummy antenna should be used, however, when checking the gain of the preselector. If the set uses a loop antenna, just wind a four- or five-turn loop of wire and connect it to the output of the signal generator. Bring this loop near the set loop. You can't measure the preselector gain, but all other gain values can be obtained.

Gain Variations. The readings given by the manufacturer in his service information are average readings for the particular set type. These readings will not necessarily apply to any other receiver put out by the same manufacturer. When the gain data is given on the diagram, you can expect variations of as much as 20% in either direction. Variation in parts values can easily cause this much change.

If readings vary by more than 20%, then there is probably some defect in the set. If all readings are below normal, the set may be completely out of alignment, or the over-all sensitivity may be low.

More generally, a defect in a single circuit will be the cause of below-normal gain. In this case, you can expect most of the readings to be normal except in the one affected stage, where the reading will be very low.

Don't be surprised at readings somewhat above normal, for better-than-average tubes, or coils with exceptionally high Q factors, will give increased gain. On the other hand, if the gain is very high and the receiver has a tendency to go into oscillation, look for circuit faults causing regeneration.

Average Gain Values. When gain data on the receiver on which you are working is not available, you must use tables of average gain values. The gain to be expected from any stage depends on the type of receiver and on the number of stages.

The table in Fig. 19 gives maximum and minimum values found by analyzing the information furnished by a number of manufacturers. It is quite possible that some receivers may have gain values above or below these averages, but in general you can expect most receivers to fall within these limits.

The possible variations here are quite wide. For example, the gain in the r.f. section from the antenna to the first grid in auto sets may be anywhere from 10 to 50. If you get a reading near the minimum value, you won't know whether this is natural for the receiver or whether the gain for this particular section should be near the maximum and is actually far below normal. You will have to be guided in cases like this by the results you obtain in the rest of your gain measurements and by the performance of the receiver.

If the receiver has less sensitivity than you would expect, yet all the readings are within the average limits, probably the loss of sensitivity is an over-all condition and the stage gains throughout are below normal. On the other hand, if the gain of some one stage is low, but the other stages all give gain near the maximum, it would be logical to suspect the stage where the readings are low.

In general, allow a wider variation in the readings of the gain for the r.f. mixer and detector stages than for the other stages.

SELECTIVITY AND FIDELITY MEASUREMENTS

We will treat selectivity and fidelity together, since the selectivity of a receiver has a bearing on its over-all fidelity.

GAIN DATA, AVERAGE VALUES

R.F. SECTIONS	Gain Min.	Gain Max.
Ant. to 1st grid	2	10
Ant. to 1st grid, auto sets	10	50
R.F. Amp., supers, broadcast	10	40
R.F. Amp., t.r.f., broadcast	40	100
R.F. Amp., supers short wave	5	25
MIXER SECTION		
Converter grid to 1st i.f. grid (single i.f. stage)	30	60
Converter grid to 1st i.f. grid (2-stage i.f. amp.)	5	30
I.F. AMPLIFIER SECTION		
I.F. stage (single i.f.)	40	180
I.F. stage (2-stage i.f.) (per stage)	5	30
DETECTOR SECTION		
Biases det., 57, 6J7, 6C6, etc. (depends on % modulation)	5	40
Grid leak, det., square law	5	50
Diode detectors (a loss) (depends upon % modulation)	2	.5
AUDIO AMPLIFIERS		
Triodes (low gain)	5	14
Triodes (high gain)	22	50
Pentodes	50	150
POWER OUTPUT TUBES		
Triodes	2	3
Pentodes and beam	6	20

FIG. 19. Average amounts of gain found in radio receivers.

Selectivity is a measure of the ability of a radio to select the desired signal and to reject others on adjacent channels. If the set is not selective, interference is certain to exist between stations on adjacent channels if the stations are powerful enough. On the other hand, if the set is too sharply selective, the higher side-band frequencies of the desired channel will be cut out, and the fidelity of the receiver will be affected. In a communications receiver, fidelity is usually unimportant and what would be side-band cutting in a broadcast receiver is a desirable quality.

Laboratory Selectivity Measurements. It is possible to indicate selectivity by plotting resonance curves which show the amount of amplification or gain at the resonant frequency and the gain at frequencies off resonance. However, since the gain of different receivers is not the same, it is difficult to compare receivers by using curves of this sort. As we are interested in how much *better* the response is at resonance compared with the response off resonance, it is standard practice to draw curves showing this ratio. Direct comparisons between receivers can be made from such curves.

To find the data needed to plot the curve, laboratory engineers use the same set-up used for sensitivity measurements in Fig. 13. Of course, the manner of using the equipment is somewhat different. The receiver dial and the signal generator are tuned to some frequency (say 600 kc.), and the microvolts input needed to give the standard output is determined. Let us suppose this input is 10 microvolts.

Then, the receiver dial is left at the same setting, but the signal generator dial is rotated 10 kc. away from resonance. The signal generator output is turned up until the receiver output meter indicates the same output power as before. Since the receiver is not tuned to the same frequency as the generator, a greater input is necessary to force the signal through the radio.

Suppose it now takes 5000 microvolts input to give the standard output. Dividing the microvolts input for the off-resonance frequency by the microvolts input at the resonant frequency gives us a ratio number (called the "signal ratio") that is a measure of selectivity (in this case, 5000 ÷ 10 = 500). For comparison, engineers consider a set to have good selectivity if it takes 1000 times as much voltage to force a signal 10 kc. off-resonance through the radio as it does a signal to which the radio is tuned. Signal ratios of 100 to 1000 are considered fair, and a ratio of 10,000 represents excellent selectivity.

To complete his data, the engineer continues in 10-kc. steps on each side of resonance, carrying out the readings over a range of 30 to 50 kc. on each side of resonance, and computing the signal ratio for each frequency. The ratio at each frequency is then plotted to form what is called a selectivity curve.

Fig. 20 shows several typical selectivity curves. The curve marked A-A shows fair selectivity. The broad dotted curve B-B is an example of poor selectivity, as the signal ratio for signals 10 kc. off resonance is less than 10. The curve C-C represents excellent selectivity. However, the extreme sharpness of this curve near the resonant frequency-setting indicates that the fidelity of the receiver will be poor if used for reception of music.

The ideal curve for both good selectivity and good fidelity is shaped like the shaded area of Fig. 20. It has the selectivity of the curve C-C at the off-resonant frequencies, but has a broad flat "nose" around the resonant frequency, so that approximately equal amplification will be given the resonant frequency and its adjacent side-bands. Comparing this area with the other curves, you can see that the curve B-B indicates reasonably good fidelity, as the discrimination shown by this curve against frequencies 5 or 6 kilocycles away from resonance is not great. However, as you just learned, curve B-B also indicates very poor selectivity. Thus, selectivity and high fidelity are not likely to be found in the same receiver, unless the receiver uses some form of band-pass tuning to give a response like the relatively square-shaped ideal.

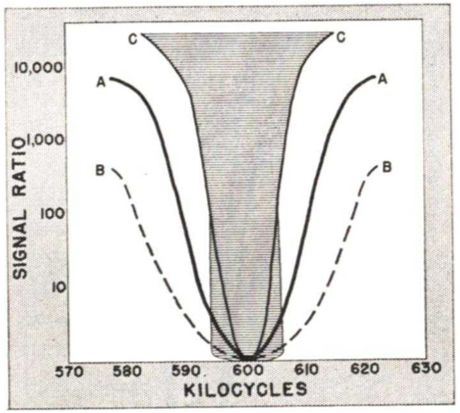


FIG. 20. Typical selectivity curves, showing excellent, fair, and poor selectivity. The shaded area shows the ideal, representing excellent selectivity without side-band cutting. The signal ratio is the ratio of the input off resonance to that at resonance, both giving the standard output.

Usually, selectivity curves are taken at several frequencies over the band. Like sensitivity, selectivity varies at different frequencies. A typical curve showing the selectivity at 600 kilocycles compared to that at 1400 kilocycles is shown in Fig. 21.

Service Tests Of Selectivity. As far as the technician is concerned, the only way in which selectivity measurements actually can be taken is by the laboratory method just described. Hence, only with standard signal generators is it possible to check selectivity accurately.

However, extremely accurate selectivity measurements are rarely necessary. Anything which affects the selectivity of a receiver greatly will also affect the sensitivity and other characteristics at the same time, and the trouble can be run down by investigating these other effects. If the receiver is badly out of alignment, the selectivity is reduced and the sensitivity will be very low. If the receiver is too sharply aligned, the fidelity will suffer and the sensitivity will be above normal. (The selectivity may also go up because of regeneration.) Of course, after you have quite a bit of practical experience, you will become adept at judging the selectivity. The practical technician tunes in some medium distant station, and then tunes away from the resonant point to determine how many dial degrees can be tuned through before the signal fades out. The "spread" on the dial is a rough indication of the selectivity of the set. If the station is tuned out by a small dial movement, the selectivity is usually good.

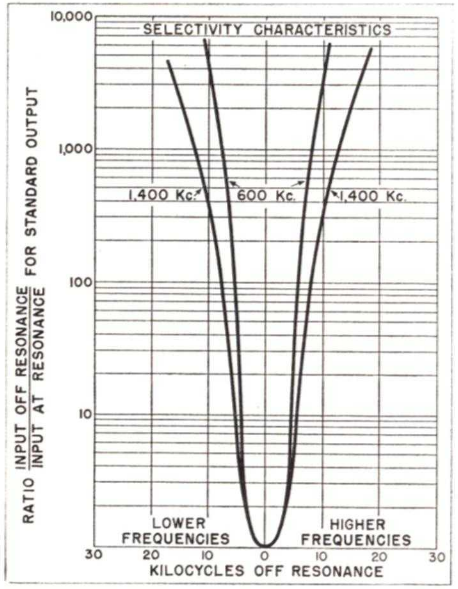


FIG. 21. How the selectivity varies at different points in the tuning band.

Laboratory Fidelity Measurements. The fidelity of a receiver is a measure of its ability to reproduce exactly the modulation transmitted by the broadcast station. The ideal receiver would amplify all desired frequencies equally and would not introduce wave-distorting harmonics.

The audio amplifier is primarily responsible for the receiver fidelity characteristics, although the tuned circuits in the r.f. and i.f. stages may affect the high-frequency response. Theoretically, we need equal amplification of all frequencies from 30 cycles to perhaps 15,000 cycles to reproduce music with high fidelity. The response range of the average communication receiver is far more limited than this—a reasonably flat response from 150 cycles to 3500 or 4000 cycles is about all we will usually find.

To measure the over-all fidelity response of the receiver, the same basic set-up as that shown in Fig. 13 is used. The only additional equipment needed is a variable audio oscillator, which is used to modulate the standard signal generator.

To get the response characteristic, the audio oscillator is first adjusted to produce a signal of 400 cycles, and the modulation percentage is adjusted to 30%. Then, with the receiver dial and the signal generator tuned to, say, 600 kilocycles, the signal generator output is adjusted to give some convenient output indicator reading. (This need not be the standard output value—just some convenient reading.)

This reading, obtained with a modulation frequency of 400 cycles, is our reference value. The audio signal generator is now varied to other audio frequencies, such as 30, 40, 50, 100, 1000, 3000, 5000, 7000, 10,000, 12,000, and 15,000 cycles. The exact frequencies at which the readings are taken do not greatly matter, as long as points over the complete range of the receiver are used.

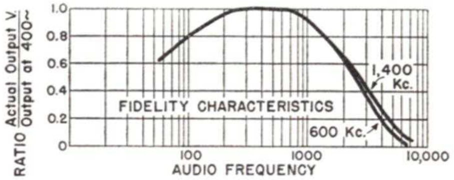


FIG. 22. Over-all fidelity curves.

At each of the new audio modulation frequencies, the percentage of modulation is adjusted to 30%, but the signal generator output controls are left alone, as the same r.f. frequency is being used. The new output meter reading is noted at each of these frequencies; then the ratio between the actual output voltage at this new frequency and the output at 400 cycles is computed. A curve similar to Fig. 22 then is made up by plotting frequencies against the ratio of output at each frequency to the output at 400 cycles.

As shown by Fig. 22, the high-frequency response depends on the selectivity. Another set of readings may be taken with the receiver and signal generator tuned to, say, 1400 kc. (Of course, the r.f. output must be adjusted to the same value as was used at 600 kc.)

The curves in Fig. 22 show the *over-all fidelity* of the receiver, excluding the loudspeaker and its response. Naturally, the loudspeaker and baffle assembly are going to affect the fidelity of the output to a great degree. However, we are now interested in getting the response of the receiver itself, and these curves give it.

Distortion Measurements. After plotting the frequency-response curves, measurements are made to determine the harmonic distortion. Any of several laboratory procedures may be used for this. For example, the set-up shown in Fig. 23 has a distortion meter or wave analyzer at the output instead of an output meter. With this equipment, it is possible to determine the percentage of harmonics introduced as a result of amplitude distortion in the amplifier.

The maximum undistorted power output can be determined by starting with a low input which is gradually increased until distortion is shown by the distortion meter or wave analyzer. An output meter is used with the distortion indicator, so that the power output level at which distortion first occurs can be measured.

Audio Amplifier Response. It is frequently desirable to check the characteristics of the audio amplifier alone. This is particularly true if you are working on a speech amplifier or an electric phono system, either of which normally contains nothing but an audio amplifier.

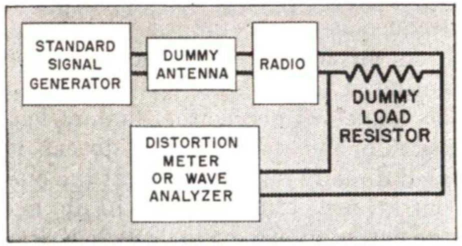


FIG. 23. Connections for determining distortion.

The set-up is shown in Fig. 24. A variable audio signal generator is connected to the input of the audio amplifier and an output indicator is used across the dummy load resistance.

Using a test frequency of either 400 or 1000 cycles, some reasonable output indication is obtained. Then, the audio signal generator is varied in steps over the range of audio frequencies, and output readings are made for each setting. The amplifier input must be adjusted (by the signal generator output controls) at each test frequency so that it is the same as it was at 400 cycles. Unless the audio signal generator has an output indicator, a vacuum-tube voltmeter is needed to check this.

We can again take the ratio between the output at other frequencies to that at the standard frequency, and plot another curve similar to that for the over-all response. The difference, of course, is that the response characteristic is that of the audio amplifier alone, and hence may vary widely from the over-all response, particularly at the higher frequencies.

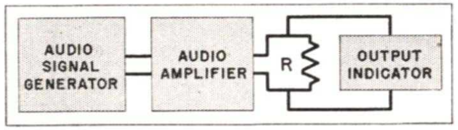


FIG. 24. How to get the response of an audio amplifier.

As an alternative method, a power output meter calibrated in decibels can be connected across the dummy load resistor, and the output in db can be read directly on the meter. If the output at, say, 1200 cycles is 10 db, and the output at 400 cycles is 8 db, we say the output at 1200 cycles is up 2 db. The curve prepared from such readings may be similar to that shown in Fig. 25A or 25B.

If we get a flat curve like that shown in Fig. 25A, the amplifier is definitely a high-fidelity type. This curve shows excellent response over the entire useful audio spectrum. However, it is quite likely that the amplifier response will be more like that shown in Fig. 25B, where the low frequencies drop off rapidly and there is some peak response around 3500 or 4000 cycles.

Theoretically, the ideal amplifier is one with an absolutely flat response. However, it may be necessary to "doctor" the response of the audio amplifier to compensate for deficiencies in the rest of the receiver. A rising response characteristic or even a peak in the response may be desirable at the high frequencies to compensate for the side-band cutting which occurs in the r.f. stages. Thus, by over-emphasizing the high frequencies, we can make up for some of the loss in the r.f. amplifier and can improve the *over-all* response.

Similarly, a rise in response at the low-frequency end of the band may be desired to compensate for a drop-off caused by the speaker or baffle characteristics.

The relatively smooth curve normally obtained when checking an amplifier response may be utterly different if speaker responses are included. A typical curve in which speaker response is included is shown in Fig. 25C. To make measurements for this kind of curve, a microphone and an amplifier are used, which have a combined response that is essentially flat. The microphone is mounted in front of the loudspeaker in a room with special acoustic properties.

The resonant characteristics of the loudspeaker cone spider voice coil assembly will cause numerous peaks and valleys in the characteristic curve. Hence, checking the over-all receiver response and the amplifier response merely gives us something with which we can make comparisons between similar amplifiers or receivers—it does not show the *actual output* of the radio. Only an acoustical output response curve like that in Fig. 25C will give the actual sound output characteristics. Such a curve can be obtained only in laboratories equipped with the proper acoustical rooms and proper measuring equipment.

Fidelity Measurements With Service Equipment. The measurements which can be made will depend greatly on the equipment available. With a standard signal generator and variable audio oscillator, over-all response curves can be made in the manner just described. Similarly, with a variable audio oscillator, it is possible to obtain the response curve of an audio amplifier.

As always, the technician is usually looking for some particular defect and will use short cuts. Rather than plot the audio amplifier response, it may be possible just to vary the audio signal generator over the band and watch for any sharp peaks or sudden dips that appear in the signal voltage measured across the dummy load resistor.

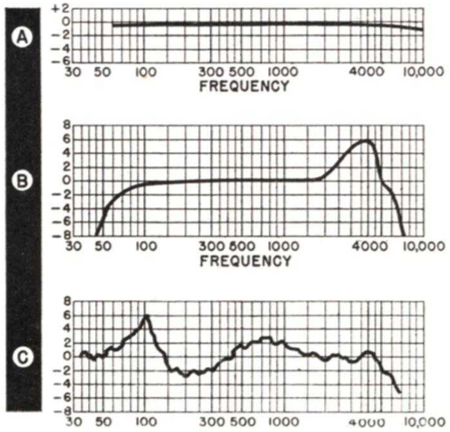


FIG. 25. Typical fidelity curves.

If the technician has a "musical ear," he can make a test by playing a record of known characteristics, and listening to the output of the audio amplifier. However, great care is necessary here: few people hear exactly alike, so the listeners may object to a response which sounds good to the technician.

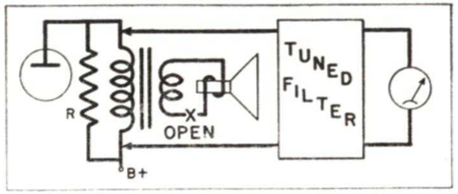


FIG. 26. A filter is necessary when measuring hum to eliminate noise components and to determine the amount of hum at each frequency. In practice, a serviceman would depend upon a listening test.

MISCELLANEOUS MEASUREMENTS

It is, of course, possible to measure any receiver characteristic one might imagine. There are a few of these which are of some interest, although technicians rarely measure them. Let's run through some of these.

Hum Measurements. In the laboratory, the residual hum level is measured by setting the radio volume control at maximum, and short-circuiting the r.f. input so that no signals are picked up. The output voltage across the dummy load resistor is the fundamental hum frequency, plus any harmonics of this frequency, plus any noise voltages which may be present. To eliminate noise, and also to make it possible to measure the frequency of the hum, a tuned filter may be used as shown in Fig. 26. This circuit is first tuned to 60 cycles and the amount of 60-cycle hum measured. Then the hum level is checked at 120, 180, and 240 cycles.

If the hum is modulation hum, an

unmodulated signal generator is connected to the input of the receiver, and the hum output resulting is measured in a similar manner. Usually a voltmeter with a very low range must be used, as the hum voltage may be quite small even though it produces an objectionable amount of hum *sound* output.

As a general rule, the technician just listens to the output of the receiver. If the hum is excessively loud, the technician is usually led right to the trouble by the frequency of the hum, which he can determine most easily by means of a c.r.o. or by having learned hum frequencies from listening to 60- and 120-cycle hum voltages. Modulation hum can be run down by moving the unmodulated signal generator back through the r.f.-i.f. amplifier noting the stage at which hum first becomes audible.

Power Consumption. The manufacturer usually checks the power consumed by a radio receiver, since he generally gives this figure on the receiver nameplate. He probably will use a wattmeter in the manner shown in Fig. 27A.

If the technician has a wattmeter, he should make similar connections. If not, it is possible to use a voltmeter and ammeter by making the connections shown in Fig. 27B. The voltmeter-ammeter method does not indicate true power—multiplying their product by .8 will give a close approximation for the average a.c. radio using a power transformer.

Before using either method, it is a good idea to make sure the receiver is not in such a defective condition that it will damage the wattmeter or ammeter.

Of course, any defects in the radio which cause a higher than normal current flow will be indicated by an increased power consumption. Thus, a leaky filter condenser or a short-circuited bypass condenser would result in an increased wattage consumption. However, the wattage test indicates only that trouble exists, without pointing out its location.

Frequency Shift Tests. Once in a while the oscillator frequency of a superheterodyne receiver will shift progressively as some component in the oscillator circuit is affected by the receiver heat. This will be indicated by the program becoming more and more distorted, with the distortion clearing up if the receiver is retuned. The oscillator drift causes the production of an incorrect i.f. frequency, so the wave is distorted because of side-band cutting. Usually the drift will be in a single direction, so that the receiver must be continually tuned to higher and higher frequencies, or to lower and lower frequencies, depending on the particular part causing the trouble and its temperature characteristics.

Of course, many receiver oscillators drift *slightly* during their warm-up period, but they settle down within a few minutes. This is the reason the receiver should be allowed to warm up for half an hour or so before it is aligned. For the same reason, the signal generator should be allowed to warm up if it is a.c.-operated.

The fact that retuning is necessary from time to time to obtain maximum response or to clear up distortion indicates clearly that there is an abnormal frequency shift. If you want to measure this, you can connect a signal generator to the input of the receiver, tune them to resonance with each other, and allow both to operate for a period of time. Then, retune the signal generator for a maximum output indication. The difference in frequency between the original setting and the new setting indicates the amount of drift in the receiver for that particular period of time, provided the signal generator is itself free from drift.

Dead Spots. The laboratory and service tests for dead spots are identical. The receiver dial and signal generator dial are rotated in step over the entire frequency range of the receiver. For example, if we wish to check the broadcast band, both the generator and the receiver dial should first be set to 550 kilocycles, then to 560 kilocycles, and so on at 10 or 20 kilocycle intervals up to 1500 kilocycles. At each setting we should listen to make sure the output is normal. A skillful operator can turn the genator dial with his left hand and the receiver dial with his right, keeping the two in step, and get a continuous check throughout the band.

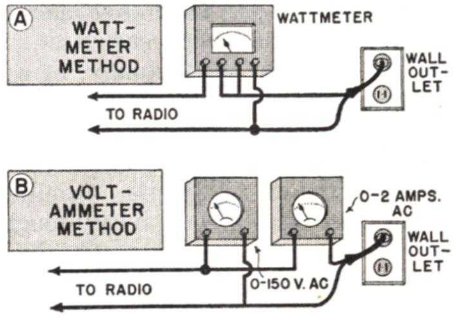


FIG. 27. Two methods of measuring the power consumed by a radio. The wattmeter is the more accurate.

Naturally, a dead spot would be indicated by a lack of reception or by a sharp drop in output over some portion of the tuning range of the receiver.

Image Rejection. Suppose a receiver dial is set to receive a 1500-kc. signal, and that the i.f. of the set is 460 kc. This means that the receiver oscillator will be working at a frequency of 1500 plus 460 or 1960 kc. Now, if a signal from a station at 2420 kilocycles is strong enough to get through the preselector, it also will produce the right i.f. value, since 2420 *minus* 1960 is 460 kc. Thus, it is possible for the proper i.f. value to be produced by signals either above or below the oscillator frequency. The interfering signal (from the station the receiver is not tuned to) is called an image, and is twice the i.f. value above the desired signal frequency.

The ability of the receiver to reject image interference is determined by the following procedure. First, the signal generator is set to the frequency to which the receiver is tuned, and the input necessary to give standard output is determined. Then, with the receiver dial left at this point, the signal generator is tuned to the image frequency. The output from the signal generator is adjusted again to produce standard output. Dividing the signal input at the image setting by the signal input at the receiver dial setting gives the image-rejection ratio. A ratio of 100 to 1 or greater is desired. A ratio below this value indicates poor receiver design or a receiver badly out of alignment. However, it is possible for image interference to exist even with a satisfactory image ratio if a very powerful station happens to be at the image frequency of a desired station. In this case, a change in the i.f. value of the receiver, or the use of a wave trap tuned to the interfering station would be an effective cure.

Testing For Noise. In the laboratory, the receiver is tested for noise output by a method similar to that used for the hum voltage check. The receiver is placed in a shielded room, and the power lines leading into the room are thoroughly filtered, so that whatever noise is heard must come from the radio itself.

To distinguish between noise and hum, tuned filters may be used between the receiver and the output indicator, tuned to *reject* the hum frequencies of 60, 120, and 240 cycles. Any remaining output from the receiver must then consist of noise components.

In the shop, a shielded cage to prevent direct noise pick-up by the receiver is seldom available. Usually, the technician depends on a power line filter to remove any noise that may be coming in this way, and then compares the noise level heard on a suspected radio with that normally heard in the shop on other similar receivers. It is well to be cautious about judging the noise when no signals are tuned in, however, as the more sensitive the receiver, the greater the amount of noise pick-up by the circuit wiring, and also the greater the tube noise level. In fact, you probably will have to explain many times why a large sensitive receiver is so much more noisy than some inexpensive set.

Actually, of course, the amount of noise heard between the stations is no criterion of the performance of the receiver when it is tuned to a station. It is quite possible that the reduction in sensitivity brought about by the normal action of the a.v.c. circuit may cut out all the background noise. The important factor is the amount of noise heard when tuned to a station giving normal reception in your locality.

Lesson Questions

Be sure to number your Answer Sheet 36RC.

Place your Student Number on *every* Answer Sheet.

Most students want to know their grade as soon as possible, so they mail their set of answers immediately. Others, knowing they will finish the next Lesson within a few days, send in two sets of answers at a time. Either practice is acceptable to us. However, don't hold your answers too long; you may lose them. Don't hold answers to send in more than two sets at a time or you may run out of Lessons before new ones can reach you.

1. On frequencies above 30 mc., which receiver characteristics are improved by the use of a double superheterodyne?
2. In a diversity receiver, why is the same local oscillator used for the individual mixers?
3. What complaints are caused by selective fading?
4. Why is it possible to get a better signal-to-noise ratio in a single sideband receiver?
5. Why is it necessary to employ an a.f.c. circuit to govern the frequency of the second oscillator in a carrier-exalted receiver?
6. To what point in a communications receiver may a panoramic adapter be connected?
7. What are the two standard output levels used for sensitivity measurements?
8. What advantage is found in using a signal tracer for sensitivity measurements rather than the standard input-output measurements?
9. Why must the a.v.c. be disconnected and a fixed bias used when making gain measurements?
10. Suppose you make a signal voltage measurement across the primary of a double-tuned i.f. transformer. Would you expect the secondary voltage to be: 1, *greater than;* 2, *the same as;* or 3, *less than* the primary voltage?

THE MAN WHO COUNTS

The man who counts is the man who is decent and who makes himself felt as a force for decency, for cleanliness, for civic righteousness. First, he must be honest. In the next place, he must have courage; the timid man counts but little in the rough business of trying to do well the world's work. In addition, he must have common sense. If he does not have it, no matter what other qualities he may have, he will find himself at the mercy of those who, without possessing his desire to do right, know only too well how to make the wrong effective.—Theodore Roosevelt

* * *

This statement of Theodore Roosevelt's has always appealed to me as being a very sound piece of practical advice. Read it carefully. It can be of real value to you.

J. E. SMITH