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Overall Measurements on Broadcast Receivers

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A Paper Delivered before the Radio Club of America on June 13, 1928

ALTHOUGH I appreciate the psychological handicap which I may encounter by beginning with an excuse, I will state that the title of this paper is incomplete, though perhaps not misleading. The general subject of overall measurements on any kind of a radio set is one about which engineers do a great deal of talking but not much writing. Thus the literature of the subject is in a rather unsatisfactory state, although the technique of providing small measured radio-frequency voltages at definitely localized points is quite generally understood, and is now being extensively employed for the standardization of broadcast receivers, even in laboratories which do not profess to be centers of research. It is not my intention to attempt supplying you with a general compendium of information, as my title seems to imply. I merely wish to review certain experimental methods and point out the assumptions and implications involved. I shall limit myself at the outset to antenna-operated receivers. If we are willing to accept some approximations which are fast becoming conventional, and admit the necessity for a wholesome amount of experience in interpreting the results in terms of what the ear thinks it hears, adequate ratings may be derived for broadcast receivers with the aid of rather simple and inexpensive measuring equipment.

Most laboratory measurements on a radio receiver are based upon the assumption that the action of a wave field upon an exposed aerial, in building up a high-frequency voltage across a receiver input impedance at the base, may be simulated so far as the receiver is concerned by a locally generated signal which is fed into the receiver through a local impedance having reactive constants equivalent to those of the aerial. I suppose there is nothing in the assumption itself to arouse the apprehensions of the most critical; the complications are brought in when one attempts to define the equivalent constants. Of course we can resolve any difficulty by shrewd definitions. For example the effective height of an antenna is any length in meters which makes a conventional formula give the right numerical result. But on many occasions in this cruel competitive age the design engineer is forced into the embarrassing responsibility of deciding whether receiver A will give more service per dollar than receiver B, without having the leisure or the facilities for operating both A and B in a hundred different localities on a hundred different antennas. The problem of making a laboratory measurement from which valid generalizations can be derived is then of vital importance which cannot be resolved by definition.

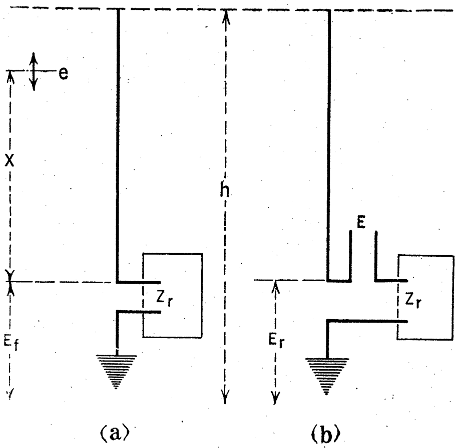


FIG. 1

It may appear self-evident that a radio receiver which behaves well with a locally generated signal impressed across the input terminals will behave equally well when the signal is derived from a coil in the base of an antenna. That the point is not wholly academic, however, is indicated by the recurrence of such questions as this: receivers A and B contain equal amplifiers; A has an untuned input circuit and B has a loose-coupled tuned input circuit. On local-signal test B is five times as sensitive as A. On a certain aerial, station XYZ produces simultaneously 15 volts output from B but it produces 10 volts output from A. Should we not therefore conclude that the local-signal test is misleading because although the antenna voltage is increased by five in the tuned input circuit of B, there was less there to start with because the antenna current reacted on the field to a greater extent with B than with A? I think the reasoning here is wrong. But it emphasizes the danger of carelessness in generalizing from laboratory data.

Before impressing signals from a local generator upon a radio receiver let us summarize the arguments for this procedure and point out its limitations.

Imagine an antenna consisting of a conductor exposed to a wave field, having an arbitrary impedance Z, at its base across which a receiver may be connected. The function of the antenna is to develop voltage across Z, by collecting energy from the wave field. Suppose that at each point of the antenna, defined by the distance X from its base, there is a certain component e of the electric field parallel to the antenna. Make e any arbitrary function of X, i. e. allow it to vary with X in any desired way and we thereby avoid specific questions as to the shape or inclination of both field and antenna, which are not important in this particular argument. Each element of the antenna will have a certain inductance L, resistance R and capacity C, which are also functions of X only, i.e. constants of the antenna. If we then write out the usual equations for the antenna as a line having these distributed constants, this line being excited by a string of elementary voltages e, a result is obtained which may be simplified to the following form *regardless oj how* L R and C or the elementary voltages induced from the field are assumed to vary with X:

$$E_f = \frac{E^1 Z_r}{Z_r + Z_a (L, R, C, \omega, h)}$$

I will not bother you with the computation; I merely wish to point out the result. In this equation E_f is the net voltage due to the field, developed at the base of the antenna and Z_a is a term (which may be quite complicated) expressing the effective impedance of the antenna. But Z_a is a function only of the frequency and the constants of the antenna, entirely independent of the field voltages, e. Furthermore the term E^1 appearing in the numerator, is a function (which may also be quite complicated) of the elementary field voltages, their distribution, and also of the antenna constants. The antenna constants obviously should enter into E^1 because it is a term expressing the effective voltage at the base arising from this series of elementary voltages induced all along the line by the field. But once the antenna is fixed, nothing can change E^1 but a change in the nature and strength of the field.

Now, the conclusion and moral of this is, that if a receiving antenna acts like a line having distributed constants, into each section of which the wave field induces a voltage which depends only upon the field strength at that section, the whole system may be regarded as a driving voltage E^1 in series with a lumped impedance Z_r and an equivalent antenna impedance Z_a. The terms Z_r and Z_a may be easily computed for simple cases such as a wire of uniform constants in a uniform field.

But we are not yet through with the argument. Let us take the same antenna out of the field and excite it with a known voltage E impressed in series with the load at the base, instead of with the distributed voltages previously considered. This is shown in Fig. 1 (b). Working through the line equations again we arrive at the same result as before, namely:

$$E_r = \frac{EZ_r}{Z_r + Z_a}$$

where E replaces the effective field voltage E^1 and the term Z_r representing the net or effective antenna impedance is exactly the same as before. The conclusion from this is that if we impress a voltage at the base of our antenna and measure the impedance of the antenna, as looked at from the base, that is precisely the same impedance which determines the current developed at the base when the antenna is excited by a wave field, regarding the antenna as this impedance in series with an effective voltage which is derived directly from the field strength. Thus the practice of measuring a receiving set by assuming an "equivalent" local or dummy antenna and impressing a voltage in series with it would seem to be justified by theory. This theoretical argument as outlined is not new. It was recently summarized by Colebrook (*Experimental Wireless and the Wireless Engineer*, p. 657, Nov. 1927). A flaw in the argument rests in the initial assumption that when the antenna is excited by a wave field the elementary voltages strung along the antenna depend only upon the field and the position coördinates X, and is not influenced by the resulting current. In other words the conclusion that the receiving antenna may be replaced by a constant-voltage generator and equivalent impedance merely follows from the assumption that each element of the antenna length is an elementary impedance supplied from an elementary constant-voltage generator which is the potential gradient in the field at that point. I am not prepared to answer this objection completely. It is opposed by the provision that by the "equivalent impedance" of the antenna we mean the impedance as measured at the base, with the antenna in a radiating condition when the measurement is made. Also the objection is answered more completely by two kinds of experimental evidence as follows:

EXPERIMENTAL EVIDENCE

FIRST, if an antenna is series-tuned to some frequency lower than its fundamental, excited by a wave field, and various resistances are inserted at the base, enough to vary the current at the base over a wide range, a linear relation will be obtained between current and resistance, indicating that the voltage due to the wave field acts like a constant voltage in series with some impedance, which is substantially independent of the current, at least over certain ranges. *Second,* if a tuned receiver-input circuit is compared with a pure resistance on an antenna excited by a wave at frequencies below the fundamental, and then compared at the same frequency excited by a local generator through an impedance equal to the antenna impedance as measured at the base, the relative factors of merit will be the same for each form of measurement.

Thus it may be concluded that the use of a local signal in measuring antenna-operated receivers is partially justified by the theory I have outlined and is better justified by experience.

A primary necessity for such measurements is a local signal generator of such a form that a known minute radio-frequency voltage may be produced between two particular terminals and *nowhere else.* With this available we can forsake the pernicious practice of measuring the individual amplifier stages, detectors and what not, independently, and multiplying the results together to arrive at the performance of the set. I do not question the value of the piecemeal measurements; they constitute essential steps in the design. But what we are now concerned with is an appraisal of the final result.

There are two schools of thought with regard to the design of refined local sources. One advocates the inductive-coupler method, in which a measured current is passed through an exposed coil and the small test voltage is picked up on a second coil having a small, calculated mutual inductance with the first. This method probably originated as the most direct mode of approach in the case of a loop-operated receiver. A typical design has been described by Rodwin and Smith. (*Proc.* I.R.E. Feb. 1928, p. 155). It is open to certain objections as to both convenience and accuracy. The current in the generator coil must be varied over a wide range, necessitating either a series of thermal meters or a radio current transformer, and the mutual inductance between the coils may be modified by different amounts at different frequencies by adjacent shields or other conductors. On the other hand the method has the advantage of impressing a field directly upon the loop designed for use with a receiver under test, instead of impressing a voltage in series with the loop, from which the equivalent field must be calculated.

In accordance with the second method, the test voltage is developed across a small known resistance which terminates a resistance attenuation network fed by a measured radio current. This method presents the general advantage of allowing all current-carrying impedances to be buried in shields, exposing only a single terminal which is above the shield by the amount of the test voltage. It allows a rating which is directly expressible in field strengths for normal signal in the case of an antenna-operated receiver.

One application of a resistance attenuator for producing small voltages has been in use for some time by the engineers of Bell Laboratories. (See "Portable Receiving Sets for Measuring Field Strengths at Broadcasting Frequencies" by A. G. Jensen, *Proc.* I.R.E., June 1926, page 133. Also *Physical Review,* July 1925, page 118, same author). The system described by Jensen is adapted for use with small input currents, measured on a high-resistance thermo-couple which avoids the necessity of inconveniently heavy shielding. I have used a system similar to this in receiver testing in an elaborate laboratory outfit with good success. One characteristic of this scheme is that the radio current is varied to provide the requisite continuous variation in voltage between the attenuator steps. Since with a single d.c. instrument it is difficult to cover accurately a range of more than 2 to 1 on one thermo-couple, this is a source of inconvenience. An outfit which I think is more interesting, in that it is moderately portable and yields results comparable in accuracy with the more bulky equipment, is the one which I am about to describe.

A STANDARD SIGNAL GENERATOR

THIS outfit was developed to fulfill four conditions:

(1) A portable source equipped for use with external, unshielded batteries.

(2) A range of output voltages from one microvolt up, with sufficient shielding to prevent the induction by stray fields of voltages in any adjacent tuned circuit comparable with the output voltage.

(3) An accuracy well within the consistency of measurements with highly stable receivers.

(4) The whole outfit to be reproducible by ordinary skilled shop labor.

A diagram of the circuits employed is shown on Fig. 2. A single audio oscillator tube is provided within the apparatus for modulation at a fixed frequency of about 400 cycles. This is the frequency normally used for the most common measurements, sensitivity and selectivity. This oscillator comprises the tube shown at the left of the drawing and the iron-core transformer tuned by a fixed condenser. This transformer feeds a modulation transformer through a resistance voltage-divider marked "Modulation control." The audio voltage is impressed by the modulation transformer through a one-to-one ratio upon the plate circuit of the radio oscillator tube, and is measured by a thermal voltmeter comprising a resistance, a thirty-ohm thermo-couple, and a panel-mounting d.c. galvanometer shown at the lower part of the figure. The outfit is not entirely self-contained if fidelity measurements are to be made, requiring the use of a series of different audio frequencies. In this case an external audio oscillator is necessary, for which provision is made with a third winding on the modulation transformer. This third winding is connected through a low-pass filter to exposed "External Modulation" terminals on the main panel. This filter permits the use of an unshielded external audio oscillator which may be positioned anywhere with respect to the signal generator and the receiver under test, and which may be connected to the signal generator through unshielded leads. The radio oscillator tube has a "parallel feed" plate circuit comprising the secondary of the modulation transformer and a radio-frequency choke coil in series with the positive B battery terminal and the plate. The tuned circuit of the radio oscillator consists of a "vario-coupler" inductance which is connected by a metal belt to the variable tuning condenser, both being operated by a tuning dial on the front panel. A small variable condenser is provided in shunt with the main condenser for fine tuning adjustments. The tuned circuit is closed through an attenuator, which is bypassed to ground by a non-inductive variable resistance marked "Radio Control." This resistance thus furnishes a means for adjusting the modulated radio-frequency current flowing into the attenuator. The current which passes into the attenua-

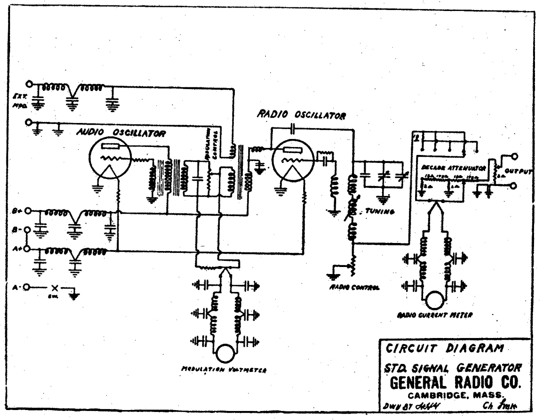


FIG. 2

tor is measured on a four-ohm thermo-couple connected through a twin two-section filter into a panel-type d.c. galvanometer which is exposed on the front panel of the outfit. The output end of the attenuator terminates in a two-ohm non-inductive slidewire which is connected to the output terminals on the front panel. This slidewire consists of a short piece of No. 38 manganin wire stretched over a copper return path with an insulation strip between them .01-inch thick.

It will be noted, first, that all battery lines, the external modulation lines, and the lines to the two d.c. meters pass through filters. These particular filters were evolved from a number of different laboratory outfits and finally reduced to the minimum amount of inductance and capacity which could be used and still maintain the insulated terminals at negligible radio-frequency potentials above the external shield. Filters of some sort are, of course, absolutely necessary if external batteries and modulation sources are to be allowed. Also the advantage of being able to expose the current measuring instruments without covering their dials with metallic screens is obvious. The coils in all the filter sections consist of bobbins wound with No. 20 wire to an inductance of about 400 microhenries, and each mounted in an individual copper shielding cell. All the capacities in the battery and instrument lines are 0.5 microfarad. The end capacities on the modulation filter are 0.25 microfarad, making this line an impedance of about 30 ohms throughout the audio-frequency band, as looked at from the external modulation terminals. The modulation transformer winding which is fed through this line is a correspondingly low-voltage winding.

The resistance attenuator is built of small non-inductive units in which no wire larger than No. 38 manganin is employed. It will be noted that no single resistance unit is larger than 178 ohms. This permits the use of the reversed-loop form of winding which experience has shown to be more reliable as a radio-frequency voltage-drop resistance at 1500 kilocycles than the so-called bifilar or parallel-strand winding. Capacity effects in the reversed-loop winding would be important, even with wire as small as No. 38, if high resistances were employed. Many different considerations entered into the selection of an attenuator of this form, combined with a slidewire output unit. For instance, it is necessary in an outfit of this type providing no space for a radio power amplifier, to employ a low-resistance thermo-couple for measuring the radio current. At the same time a panel-mounting galvanometer is required, and the maximum sensitivity of such instruments is of the order of 0.5 milliampere full scale. This requires at the outset that the radio current be relatively large, of the order of 50 to 100 milliamperes, in order to be easily measurable. The output resistance should be about one ohm—certainly not more than two ohms. In any case we must use fine wire for all resistance units to avoid frequency errors in resistance and a two-ohm unit of fine wire is about the smallest that can be accurately adjusted. Thus the maximum current (or voltage) attenuation must be of the order of 10,000 to 1. A step-by-step attenuator with a fixed output resistance could be used, relying upon current variations for continuous adjustments between the steps. But this would require either a multiplicity of current instruments or an excessive number of attenuator steps. The latter would lead to the use of single units of high resistance and the former is impractical in a small outfit, as well as being inconvenient. Suitable methods of using radio-frequency slidewire in radio gain-measuring outfits have already been developed and an adaptation of the older technique is employed, whereby not only the ratios on the wire but the absolute value of the total resistance of the wire are substantially freed from frequency errors. Voltage ratios of over 10 to 1 may easily be obtained on a wire not over one inch long. Thus by the use of the slidewire to provide the necessary continuous variation, steps of 10 to 1 may be employed on the attenuator and a single value of current may be employed for all values of test voltage from the highest to the lowest, which is a great advantage from the standpoint of convenience. The only disadvantage attending the use of the slidewire lies in the fact that the resistance introduced by the signal generator into any external circuit varies during the course of a measurement. Experience shows that in the majority of receiver measurements this is unimportant provided the slidewire resistance is not greater than two ohms. In the few cases where it may be important, as for instance when the test voltage is introduced into a low resistance loop an external compensating resistance may be used, or at worst, a compromise may be effected between variations in radio current over a limited range and variations in the slidewire setting.

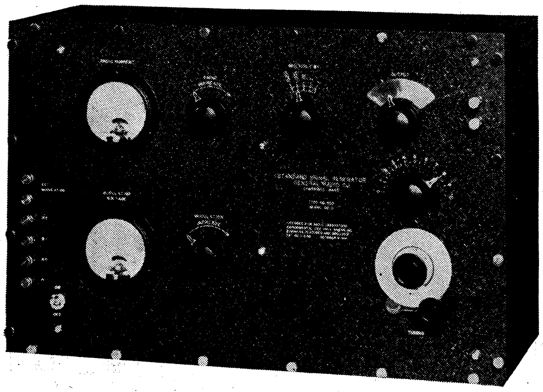


FIG. 3

By using the slidewire, then, we are enabled to employ a decade attenuator having only five steps. Using the values of resistance shown the attenuation ratios at the various points on the attenuator from left to right are respectively as follows: 10,000 to 1, 1000 to 1, 100 to 1, 10 to 1, and 1 to 1. The slidewire is normally provided with a calibrated scale of 20 divisions. Thus with the current through the Radio Current Meter adjusted to a fixed value of 50 milliamperes and the attenuator at the last point on the left a radio voltage of one microvolt is impressed between the output terminals with the slidewire on its first scale division, and 10 microvolts with the slidewire at maximum. The slidewire scale is correspondingly multiplied in microvolts output at other points on the attenuator. The current may also be operated at twice the foregoing value without forcing the meter off scale, which provides a maximum output voltage of 200,000 microvolts.

The sliding-contact switch shown above the decade attenuator in the diagram is simply a device for throwing a fixed resistance of approximately 16 ohms in series with the attenuator on alternate points in order to keep the total resistance in the radio-frequency circuit constant and prevent current variations as the attenuator is shifted. This compensating resistance is controlled by a separate switch mounted on the same shaft with the attenuator switch because it and its associated leads must be carefully shielded from the right-hand or low-voltage portion of the attenuator. The shielding of this attenuator is a delicate and rather complicated matter, brought about by the fact that for convenience we elected to start with large radio-frequency currents. It may appear strange to the casual observer that we simply wind up a set of individually measured resistances, connect them together in an attenuation network, and assume that the attenuated voltage is equal to a value computed from the diagram. I can state in all sincerity that the features of the physical apparatus which justify this process are not shown on this diagram. I shall not go into the details of this internal shielding. Its nature may be suggested by the fact that at the point of maximum attenuation, a current of 100 milliamperes may be in the attenuator switch arm, whereas a current of 10 microamperes and no more must flow into the slidewire. This means that the net capacity between all conductors connected to the switch arm and all conductors connected to the last attenuator point (including the slidewire) must be less than 0.5 micro-microfarad in order to reduce the capacity error to 2 per cent. at 200 meters. The switch points are shielded from each other, the units of the attenuator itself are distributed through three copper boxes one inside the other, the compensator resistance and switch is in a separate shield, and finally, the radio control rheostat and all leads carrying the main current from the oscillator are separately shielded from the slidewire and the leads connected to the output terminals. In localizing a measured microvolt between two terminals, as is done here, it is also found that the question of ground currents from the attenuator points and elsewhere is very important. The proper locations for the various ground connections shown in the diagram were worked out only after some thought and a great deal of discouraging experience. One consoling feature in a development of this sort is the fact that everything is consistent, if the experimenter takes the trouble to interpret all the signs. The phenomenon called "skin effect" becomes more than an academic fiction when attempts are made to constrain radio shield currents.

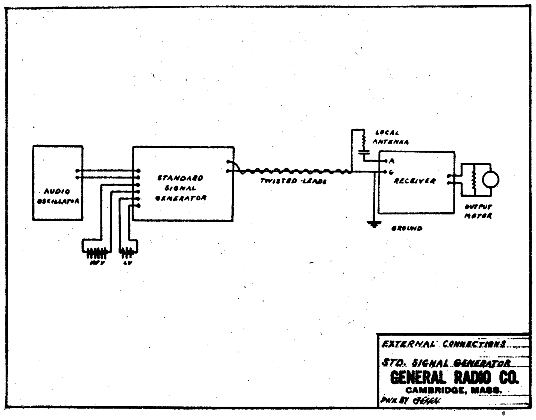


FIG. 4

GENERAL SHIELDING

REGARDING the general shielding of the outfit little has been said because it is more or less conventional. The radio and audio oscillator circuits are mounted in a heavy copper box with a removable lid. The fittings are rather massive because the lid could not be soldered on and forgotten, as is readily done with laboratory equipment. This main internal shield is fitted to a metal sub-panel, which is attached by metal studs to the outside panel, also of metal. The outside panel is screwed tightly to a copper-lined cabinet and forms with it the outside shield. In some outfits of this sort it is better to insulate the internal assembly in its shield, from the outer shield; this is determined in general by the location of the attenuator and associated equipment with respect to the radio oscillator circuit, which determines the ground current paths. The various filters are each distributed, part inside the internal shield and part between the internal and external shield. All controls are brought through both shields to the front panel on *insulated* shafts Metal shafts are undesirable because they frequently make rubbing contacts with one or both shields and produce unexpected and disturbing phenomena.

Fig. 3, is an external view of the outfit. The various instruments and controls will be recognized from the description previously given. The output terminals are at the upper right-hand corner. Unfortunately no measuring-rod was included in this photograph. The external dimensions of the cabinet are 17 x 15 x 12 inches. At the bottom of the main or front panel is the main oscillator shield with cover screwed on. On top of this box are the separate shields of the attenuator and the compensating resistance and switch flanked by the two instrument filters. The radio thermo-couple is here located. The audio voltage thermo-couple is inside the oscillator box and the leads from it are brought out into the voltmeter filter at the left, through copper braid. The slidewire is mounted between the inner and outer panels. A rectangular metal box is screwed in place over the attenuator, thermo-couple and rheostat assembly

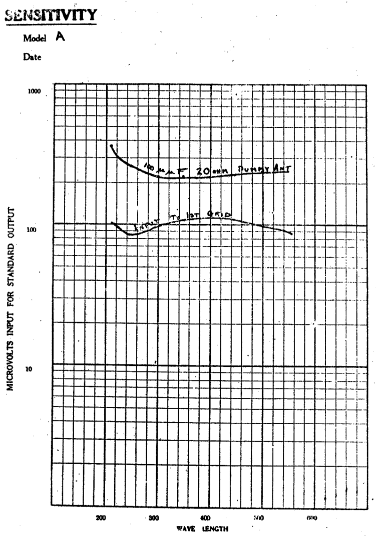


FIG. 5

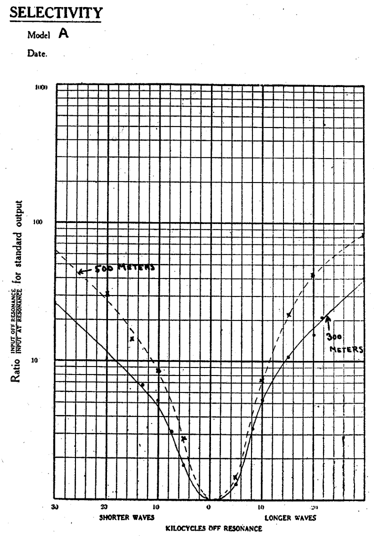


FIG. 6

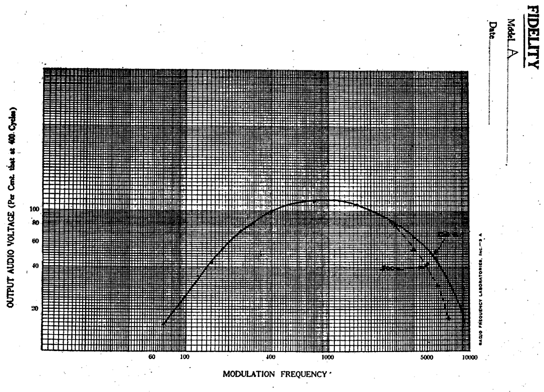


FIG. 7

in the middle. This serves to stop electrostatic leakage from the exposed current-carrying leads over the top of the sub-panel around to the slidewire terminals.

Fig. 4, shows a conventional method of connecting the Signal Generator through a local or dummy antenna to a receiver under test. For the sake of completeness an external audio oscillator is shown. The receiver may be positioned at any convenient point near the source, and twisted leads a foot or so in length do not introduce an appreciable error since the impedance at the generator end is never more than two ohms. A word should be said as to the accuracy of the voltages supplied from the generator. Certain methods are available for checking the voltage ratios by comparison with an external voltage divider, and by comparison with known current ratios, also for checking the absolute values of voltage against other sources of a different nature. Thorough cross checks and intercomparisons on this particular system indicate the following points: (1) The error in any ratio on the slidewire or decade attenuator is not greater than 3 per cent. at any frequency above 1500 kc.; (2) The error in the absolute value of the voltage between the generator terminals is not greater than 4 per cent. at any frequency and is probably much less for voltages above 10 microvolts.

The accepted practice in measuring and rating receivers is to impress the known voltage from the generator in series with the local antenna circuit and the input terminals of the receiver. The output of the receiver is equipped with a resistance load appropriate to the power tube or tubes which terminate the audio amplifier. A "normal signal" is specified for all receivers, usually 50 milliwatts. All measurements are referred to the radio-frequency voltage, with a specified percentage modulation and a specified antenna, which will produce normal signal in the output load of the receiver. With an output load of 2000 ohms, for example, normal signal corresponds to about 14 volts which is a reasonable loud speaker voltage. A simple "output meter" is required for all such measurements. It may be a vacuum-tube voltmeter or a thermal meter. Furthermore, sensitivity measurements are usually made with a modulation frequency of 400 cycles and 30 per cent. modulation. Suppose a receiver with specified antenna constants gives

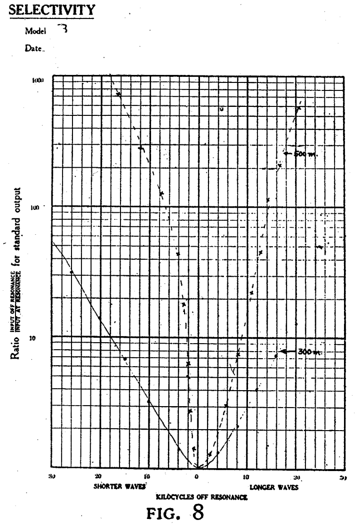


FIG. 8

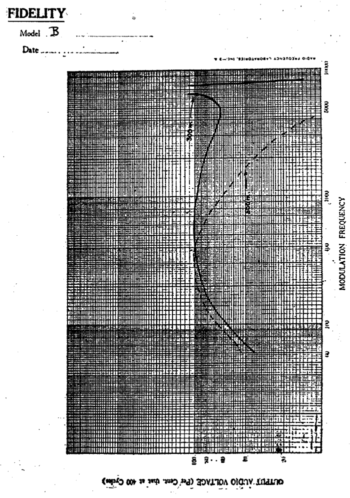


FIG. 9

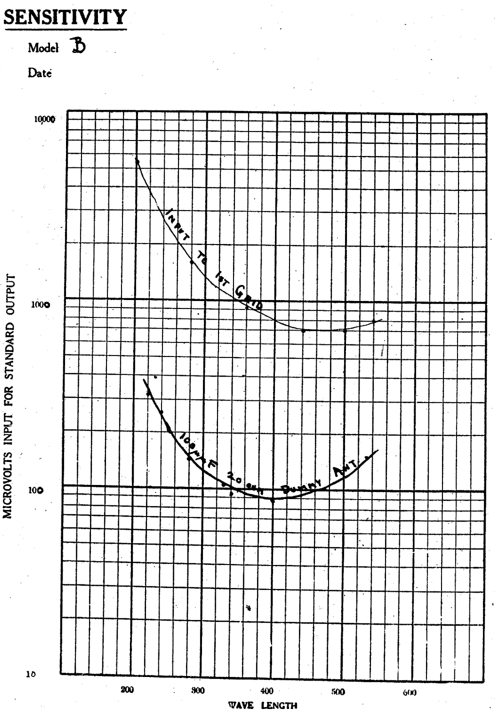


FIG. 10

normal signal at 100 microvolts. This figure of 100 microvolts is a rational sensitivity rating for the receiver because it means physically that if the receiver is fed from a 2-meter antenna having substantially the same effective inductance and capacity as that used in the measurement, a field strength of 50 microvolts per meter is required to provide entertainment—provided of course that the modulation is of an entertaining character.

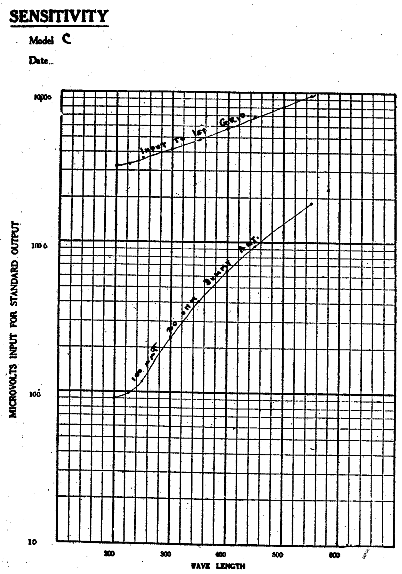


FIG. 11

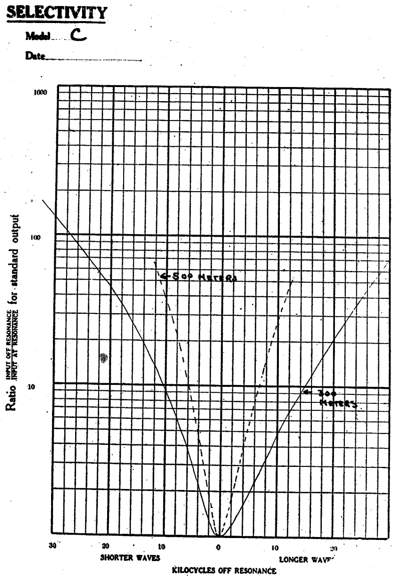


FIG. 12

ACTUAL RECEIVER PERFORMANCE

THE next few figures show some receiver performance curves made with an outfit of the character described above. These were merely picked at random as illustrative of the general types of information yielded by these measurements, and are by no means intended as a complete study of any one receiver. All these curves were taken with a local antenna of 20 ohms resistance and 100 microfarads capacity. This does not affect the selectivity and fidelity appreciably but for a study of sensitivity, various antenna combinations should be employed.

Fig. 5 shows the sensitivity of Receiver A in microvolts for normal signal. This receiver has two tuned radio-frequency stages, stabilized by grid suppressors with a third radio-frequency tube at the input fed by an untuned antenna circuit—six tubes in all, with three tuned circuits. With a small antenna, its sensitivity ranges from 350 to 250 microvolts; it is not very sensitive with a small antenna, owing to the voltage loss in the untuned input circuit. This is shown by the lower curve which was taken for comparison with the antenna circuit cut out. Fig. 6 shows selectivity

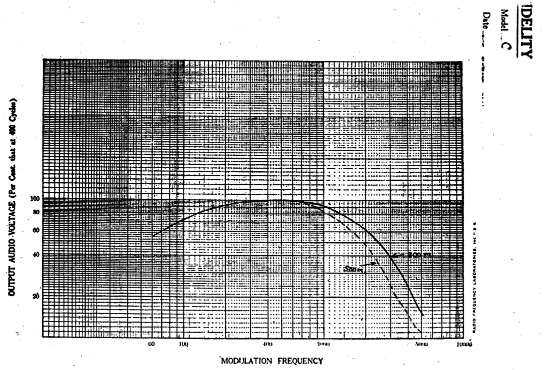


FIG. 13

curves for this receiver at 300 and 500 meters. The abscissae are kilocycles off resonance and the ordinates are in the form of a ratio off resonance to a ratio at resonance. At 500 meters the receiver is much more selective owing both to regeneration and to the improved repeater selectivity of the amplifier. The curves are not carried out far enough to show clearly the effects of regeneration. Fig. 7 shows a fidelity curve for this receiver obtained by varying the modulation frequency, at constant percentage modulation, from 60 to 9000 cycles. The set has a fairly good audio amplifier, although the response at 1000 cycles is higher than at 400 cycles. The effect upon the audio quality of the greater selectivity of the radio amplifier at 500 meters is clearly shown.

Fig. 8 is a selectivity curve for a similar receiver which happened to be strongly regenerative at 500 meters, producing a sharp, unsymmetrical curve. The effect of this upon the audio quality of this receiver is shown in Fig. 9 which is a fidelity curve for the same set. The sensitivity curve on this receiver is shown in Fig. 10. This particular set has an audio amplifier which shows a bad resonance peak at 7000 cycles. This is indicated on the overall curve for 300 meters, when the radio amplifier is quite flat. But at 500 meters when there is strong side-band cutting in the radio amplifier, the overall measurement does not show this peak at all. Here one design error tends to compensate the other.

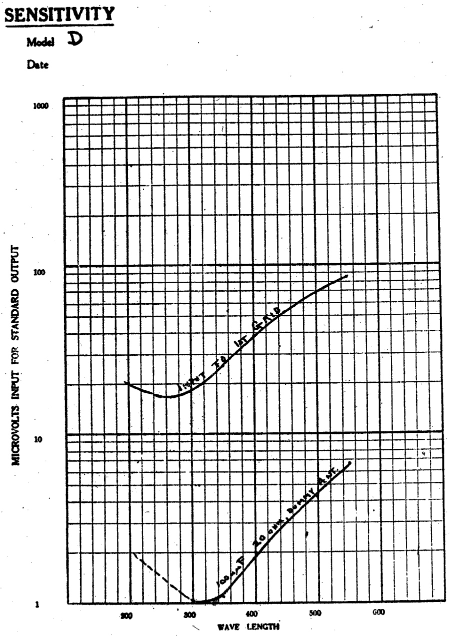


FIG. 14

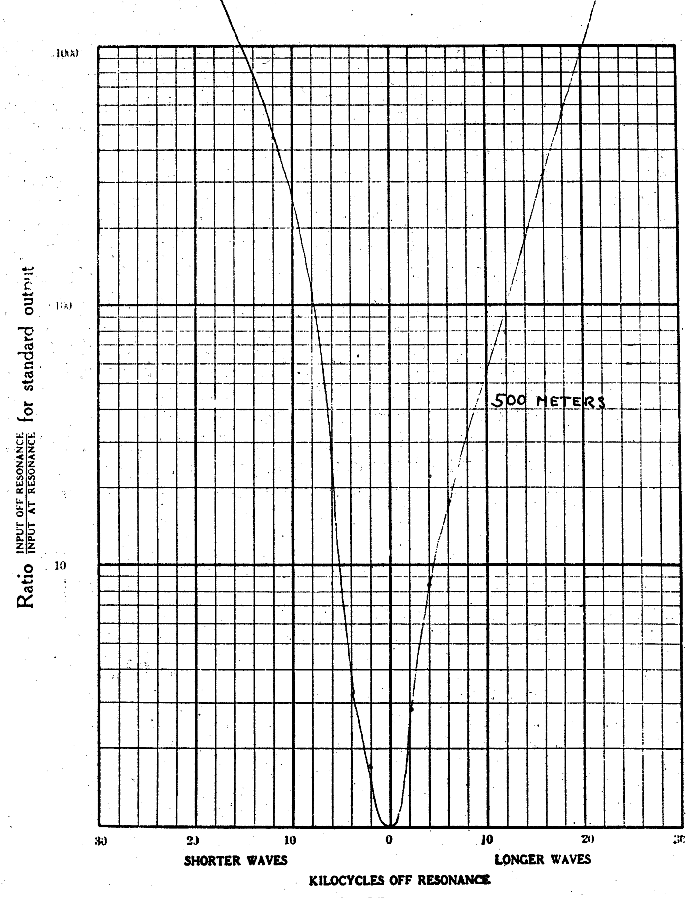
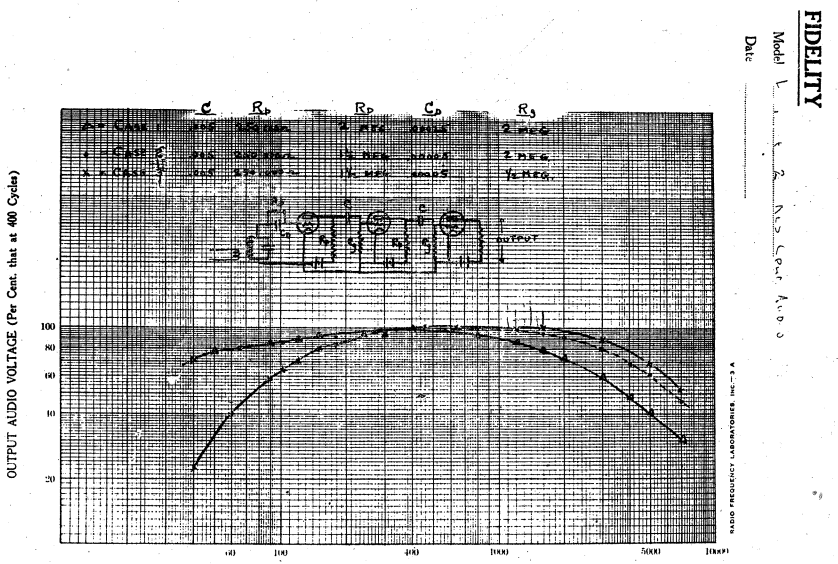


FIG. 15

Fig. 11 shows the sensitivity of a high-grade five-tube set containing two well-balanced radio stages and a good audio amplifier. It is shown to bring out the effect of using a high turn ratio in the radio transformers in order to obtain selectivity in a non-regenerative set having only three tuned circuits. Fig. 12 shows the excellent low-frequency fidelity resulting from the use of heavy audio transformers. The high-frequency part of the curve indicates that the designer might profitably have decreased the losses in the audio transformers in view of the amount of side-band cutting present in the radio amplifier.

Fig. 13 gives the selectivity of the receiver.

Fig. 14 is an example of extreme and mostly undesirable sensitivity. This receiver has four tuned, balanced radio stages with five tuned circuits. At 300 meters, one microvolt in an antenna of 100 micro-microfarads capacity produces normal signal. The decrease in sensitivity below 300 meters is due to the fact that the gang condenser was not properly aligned. The next curve, Fig. 15, of selectivity shows the razorlike effect of five tuned circuits and also the effects of some accidental regeneration.



MODULATION FREQUENCY

FIG. 16

Fig. 16 comprises curves showing the utility of a standard radio source as an aid to audio design. Here a single broadly tuned circuit was fed from the signal generator. It was connected to a detector and resistance-coupled audio amplifier and measurements were made in the usual way to determine the best values for leak resistances in the detector as well as the amplifier. In all cases the coupling condensers and plate resistances are the same. Case 1 is for 2 megohms in all grid leaks and .00025 mfd. as the detector grid condenser. The low frequency transmission is excellent at 40 cycles but the system is weak at the high frequencies. Decreasing the detector grid leak and condenser in case 2 improves the high frequencies without appreciably changing the low frequencies. Passing on from this point and reducing the amplifier grid leaks to 0.5 megohm improves the high frequencies slightly further, but the good reproduction at 40 cycles is lost.

I am indebted to Mr. Malcolm Ferris of Radio Frequency Laboratories for selecting these curves for me from his files.

The study of overall performance curves is fascinating because it offers endless opportunity for interpretation. I have by no means discussed all the measurements which can profitably be made on broadcast receivers even after their design is completed. But I do not wish to minimize the importance of constant listening to receivers and manipulation of them on actual reception of broadcast signals. I believe that an experimenter can best employ his facilities by making constant comparisons and correlations between the overall performance curves of any receiver and his reasoned impressions of its behavior in actual signal reception. By such a procedure a mature and valuable experience in the interpretation of overall characteristics can be obtained, without which they are apt to be nothing but scraps of paper.

RADIOTRONS
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A. C. OPERATION

POWER AMPLIFIER RADIOTRON UX-171

Filament—5 Volts—.5 Amperes

Plate Voltage	90	135	180	Volts
Negative Grid Bias	16½	27	40½	Volts
Plate Current	10	16	20	Milliamperes
Plate Resistance (A. C.)	2500	2200	2000	Ohms
Mutual Conductance	1200	1360	1500	Micromhos
Voltage Amplification Factor	3.0	3.0	3.0	
Max. Undistorted Output	130	330	700	Milliwatts

R. F. & A. F. AMPLIFIER RADIOTRON UX-226

Filament (A.C.) 1.5 Volts—1.05 Amperes

Plate Voltage	90	135	135	180	Volts
Negative Grid Bias	6	12	9	13½	Volts
Plate Current	3.7	3	6	7.5	Milliamperes
Plate Resistance (A. C.)	9400	10,000	7400	7000	Ohms
Mutual Conductance	875	820	1100	1170	Micromhos
Voltage Amplification Factor	8.2	8.2	8.2	8.2	
Max. Undistorted Output	20	60	70	120	Milliwatts

DETECTOR RADIOTRON UY-227

Heater (A. C.) 2.5 Volts—1.75 Amperes

Plate Voltage	45	90	Volts
Grid Leak	2-9	¼-1	Megohms
Plate Current	2	7	Milliamperes
Plate Resistance (A. C.)	10,000	8000	Ohms
Mutual Conductance	800	1000	Micromhos
Voltage Amplification Factor	8	8	

FULL WAVE RECTIFIER RADIOTRON UX-280

A.C. Filament Voltage	5.0	Volts
A. C. Filament Current	2.0	Amperes
A. C. Plate Voltage (Max. per plate)	300	Volts
D. C. Output Current (Maximum)	125	Milliamperes
Effective D. C. Output Voltage of typical Rectifier Circuit at full output current as applied to Filter	260	Volts

HALF WAVE RECTIFIER RADIOTRON UX-281

A. C. Filament Voltage	7.5	Volts
A. C. Filament Current	1.25	Amperes
A. C. Plate Voltage (Max. per plate)	750	Volts
D. C. Output Current (Maximum)	110	Milliamperes
Effective D. C. Output Voltage of typical Rectifier Circuit at full output current as applied to Filter	620	Volts

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