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The Design and Construction of Standard Signal Generators†

By C. J. FRANKS and MALCOLM FERRIS

THE first section of this paper will discuss in some detail the general requirements of any standard signal generator which is to be suitable for the laboratory testing of modern highly sensitive and selective radio receivers. Following this will be descriptions of three particular generator models, each of which was designed to fulfill the general requirements and some special requirements. This section will also consider briefly some of the problems encountered in the performance testing of a signal generator after its construction has been completed.

In the past few years the radio art has developed certain so-called standard tests to be used in rating radio receiving apparatus. These standard tests, in contrast to the old, uncertain method of determining performance by listening tests, provide a simple, fairly accurate, and readily reproducible method of evaluating any receiver in terms of certain quantities such as sensitivity, selectivity, fidelity, overload, etc. These quantities when properly determined define quite accurately the performance of any receiver and so permit the comparative worths of various receivers to be stated. It is the purpose of this paper to describe in detail the apparatus whch is necessary for, and the development of which has made possible the making of, these standard tests.

It must be noted in passing that these standard tests, important and significant though they may be, can never wholly replace listening tests. There are still certain features of receiver performance that cannot be fully determined by the standard tests, and which can best be determined under actual operating conditions. Another important function of the listening tests is to confirm the conclusions reached in the laboratory measurements; this function must always be utilized if the laboratory data are to serve their greatest usefulness.

The apparatus to be described was designed to make possible the rapid and accurate performance of tests on such receivers as come to the engineer for rating, as well as to provide for the laboratory tests which accompany the design of all new receiver models. It is evident that one of the important uses of such a device is the rapid and continuous testing of a receiver model which is in process of design. A simple method of measurement makes possible the evaluation of each small change or improvement in the receiver design as soon as it is made, so that the worth and economy of each change and its effect on the final performance of the receiver may quickly be determined and its inclusion or exclusion in the final design decided.

The principal requirements of the apparatus for making possible the various tests mentioned above have already been stated in an article by P. O. Farnham and A. W. Barber which appeared in the I.R.E. Proceedings for August 1930.

Reduced to essentials, the apparatus for making tests on a radio receiver consists first of a generator for producing a signal to be introduced into the receiver, and second, some sort of output meter for measuring the audio frequency output of the receiver. Other auxiliary apparatus is of course desirable and necessary for the investigation of certain secondary properties of the receiver, but the standard signal generator and output meter are the chief tcols with which the engineer has to deal and, in fact, are the only items necessary for the making of the most important tests, sensitivity, selectivity, fidelity, and overload. Suitable output

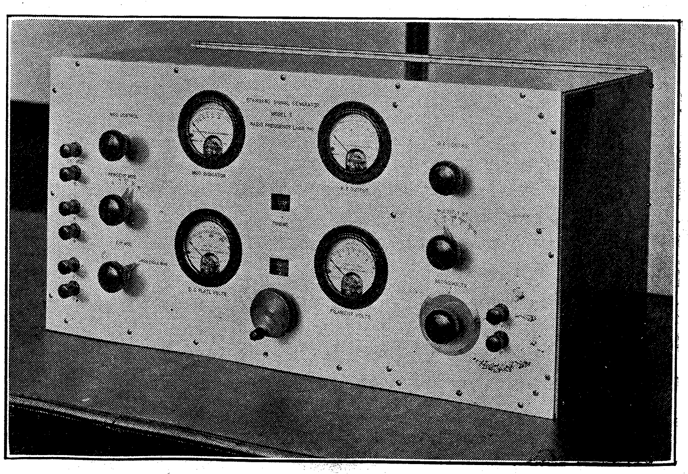

Fig. 1. Signal generator for 150 to 7500 kc. range.

† *Delivered before the Club March* 11, 1931.

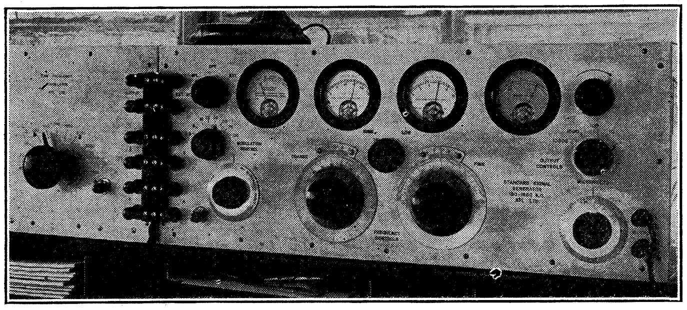

Fig. 2. Signal generator for 150 to 1500 kc. range.

meters have been described and are available on the market, and need no further exposition here. This brings us to the discussion of the standard signal generator proper, or microvolter, as it is more commonly called.

The Properties and Requirements of a Standard Signal Generator

Simply stated, a standard signal generator is a source of modulated radio frequency voltage whose carrier frequency, modulation frequency, depth of modulation and absolute value of output voltage are all accurately controllable and known. These fundamental properties of the microvolter will bear considerable detailed discussion, but before entering into this discussion it may be well to digress long enough to state several other considerations to be taken into account in the design of a practical instrument. They are chiefly concerned with convenience of operation and range of usefulness of the apparatus. While the features to be mentioned are very desirable, they are not to be taken as absolutely necessary to the fulfillment of the fundamental requirements just stated.

1. The complete apparatus should be of such size and weight as to be completely portable, and the power supply requirements should be such as to permit operation from ordinary battery sources. This will permit motorization if desired for field strength investigations.

2. The shielding of the generator should be sufficiently complete to permit its operation in the same room with, and even very close to any receiver apparatus under test.

3. It should be possible to cover the complete range of the generator as regards frequency, output voltage and modulation without the necessity of making any laborious adjustments or changes which might require disassembly of the apparatus.

4. The instrument should be entirely direct reading, so that measurements can be made directly without the use of any calibrations, calculations, or corrections.

5. The instrument must be entirely self-contained, no external meters, attenuators, or other apparatus being permitted.

Fundamental Requirements of Standard Signal Generator

The carrier frequency must be adjustable and known to an accuracy of about one-half per cent over the range of radio frequencies likely to be encountered in present-day receiver design. With the advent of the superheterodyne this range has been considerly extended, until now it includes frequencies from 1,850 kilocycles down to 150 kilocycles or even lower in some cases. In addition to the main frequency adjustment, a fine adjustment for varying the frequency in small steps to at least 30 kilocycles each side of any test frequency must be provided for the making of selectivity measurements. It should be possible to adjust the frequency in increments of about one kilocycle at the highest carrier frequency in the range. The means provided for making this adjustment will ordinarily permit even smaller increments to be read at any lower frequency, due to the characteristics of any practical means for accomplishing this end.

Any consideration of carrier frequency requirements must also include the matter of frequency modulation. This last has of late become of such great importance, due to the increasing amounts of selectivity being built into modern receivers, as to merit discussion in some detail.

The ideal way of obtaining the modulated radio-frequency wave in a microvolter is, without doubt, the modulation of a separately excited amplifier system. With proper design such a system results in an absolute stability of carrier frequency (zero frequency modulation). However, any attempt to design a standard signal generator along these lines very quickly leads to a result which in size and power requirements bears more resemblance to a broadcast transmitter than to a piece of laboratory apparatus. It is not necessary to go into detail on the difficulties encountered in shielding so large a project successfully. For these reasons it is usual to obtain the modulated wave directly from a self-excited oscillator, whose power is purposely kept as small as possible in order to minimize power supply and shielding difficulties. Modulation is readily accomplished by inserting into the plate circuit of this oscillator a voltage containing both direct and alternating components, the ratio between these components being adjusted to give the desired modulation ratio.

In a triode oscillator of the usual type a variation of plate voltage changes the frequency of oscillation. When the plate voltage is varied at an audio-frequency rate the result is an output wave whose amplitude and frequency both are varying over a certain range. When a wave of this type is applied to a receiver tuned exactly to the generator mean frequency, as is the case when measuring most of the receiver characteristics, no bad effects from the frequency modulation are evident. If, however, the resonant frequency of the receiver differs from the frequency of the impressed signal, as is the case when measuring selectivity, the variation of carrier frequency, in effect, slides the point of coincidence between the wave and the response curve up and down on the curve. This causes

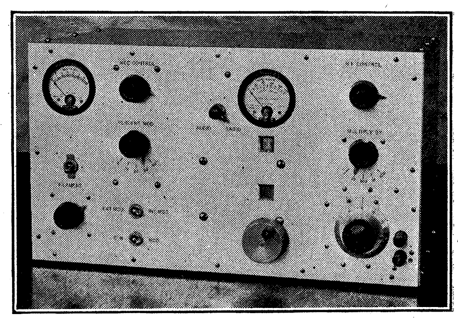

Fig. 3. Miniature portable signal generator.

a variation of amplitude of the wave reaching the demodulator of the receiver, or in other words the frequency modulation is translated to amplitude modulation.

When operating on one side of the resonance point the amplitude modulation due to frequency modulation adds to the normal amplitude modulation, while on the other side of resonance it subtracts. It is chiefly this effect which causes the large asymmetries noted on a great many of the selectivity curves which have appeared in various radio publications as representing performance data of sample receivers. The amount of amplitude modulation produced from a given amount of frequency modulation is proportional to the slope of the resonance curve at the point of operation. In the modern highly selective receiver it is easily possible, with the amount of frequency modulation usually encountered in a small signal generator, to produce enough amplitude modulation to cancel completely the normal amplitude modulation. The resulting wave has practically zero modulation, except for the fortuitous presence of sundry harmonics, and under these conditions the demodulator may reach radio-frequency overload long before standard output power is obtained from the audio system of the receiver.

The ultimate effect is a selectivity curve which is slightly bulged out on one side of resonance and considerably sucked in on the other; this is usually interpreted as a fault of the receiver under test instead of being charged to the signal generator used.

Frequency modulation in the microvolter can always be detected by taking a selectivity curve of a receiver, using constant carrier (or intermediate frequency) voltage at the demodulator as standard signal, rather than audio output. If under these conditions a normal symmetrical curve which does not agree with previous measurements is obtained, and if, during the run in which the demodulator carrier voltage is held constant the audio-frequency output varies through wide limits, the presence of frequency modulation is clearly indicated.

Experience has shown that, in order not to give trouble when used with the highly selective modern receivers, frequency modulation in the microvolter must be held below about 200 cycles for a plate voltage change corresponding to 30 per cent modulation.

The modulation frequency of the standard signal must be readily variable over the entire audio-frequency range comprising the frequencies used in voice and music transmission. Since radio receivers seldom transmit frequencies outside of the range 40 to 7,000 cycles, these frequencies are used as the limits between which the microvolter must be easily modulated. The change of depth of modulation with change of modulation frequency (fidelity of the microvolter) should not vary more than about two per cent over the audio range, if the use of troublesome correction data is to be avoided.

The final fundamental requirement of the microvolter is that the absolute value of carrier voltage appearing at the output terminals shall be accurately adjustable and known. It is safe to say that this one requirement will cause the designer more trouble than all of the others combined, particularly if he tries to live up very strictly to an initial high standard of performance. The reasons for this are many, among them being the complete absence of any absolute method of measurement for radio-frequency potentials of the order of a few microvolts, the unreliability of all practical checking methods, and the relatively tremendous errors caused by stray voltages introduced by invisible couplings and leakages. Thus the requirement stated concerns not only the measurement and attenuation of small voltages but the whole physical structure of the complete apparatus, since the elaborate shielding required to prevent the radiation of stray fields becomes one of the major mechanical problems.

Experience has shown that satisfactory limits of performance as to output are about as follows:

1. The output voltage should be adjustable between one and 200,000 microvolts.

2. Voltages should be indicated with as much accuracy as their known absolute accuracy justifies.

3. The output voltage should be continuously adjustable between the limits stated.

4. The output impedance of the generator should not exceed two ohms.

5. The attenuation system used must give consistent operation over the range of carrier frequencies to be used.

6. Adjustment of the magnitude of the output voltage must have absolutely no effect upon the carrier frequency.

7. The voltage supplied to the attenuation system should be fairly constant with carrier frequency.

8. The voltage appearing at the output terminals when the attenuator is set for zero output should not exceed about one-tenth of a microvolt.

9. The shielding of the complete generator and the wiring of the attenuator must be so carefully worked out that stray radio-frequency potentials greater than about one microvolt cannot be detected anywhere about the apparatus.

It is evident that some of the above points concern not only the attenuator system and structure, but the entire electrical system and mechanical layout of the complete generator.

The Shielding Problem

Some idea of the magnitude of the shielding problem may be obtained from a consideration of the voltage levels to be found in the various parts of a complete standard signal generator system. In a practical system, the one which will be described in detail, the oscillating circuit develops about one hundred volts, while the input to the attenuator proper is one-half volt. Thus if we desire to use outputs of the order of one microvolt, the attenuator must have a useful range of 500,000 to one, while in order to keep strays well below the magnitude of the voltages being used, the shielding system of the microvolter is called upon to effect an attenuation in excess of 100,000,000 to one, or a matter of some 160 decibels.

This concludes the detailed consideration of the things which we shall want to find in the signal generator which we are going to build for use in the laboratory. Let us now take up the discussion of the way in which all of these widely varying factors affect the practical design of such a piece of apparatus. One encounters many difficulties in the attempt to consolidate so many requirements into a single physical unity, and many compromises must be made between the various factors. It is safe to say that it is electrically impossible to fulfill in the strictest sense all of the requirements just stated. We must sacrifice some of them almost entirely and fulfill others only as completely as may be done without jeopardizing still others of greater importance than the first. Here is an example of the way it works out:

The shielding problem may of course be considerably simplified if some of the requiremnts stated in the beginning as being desirable but not absolutely necessary are made less severe. That is, if the generator be operated in a screened room different from the one in which the receiver under test is being operated, the shielding of the gen-

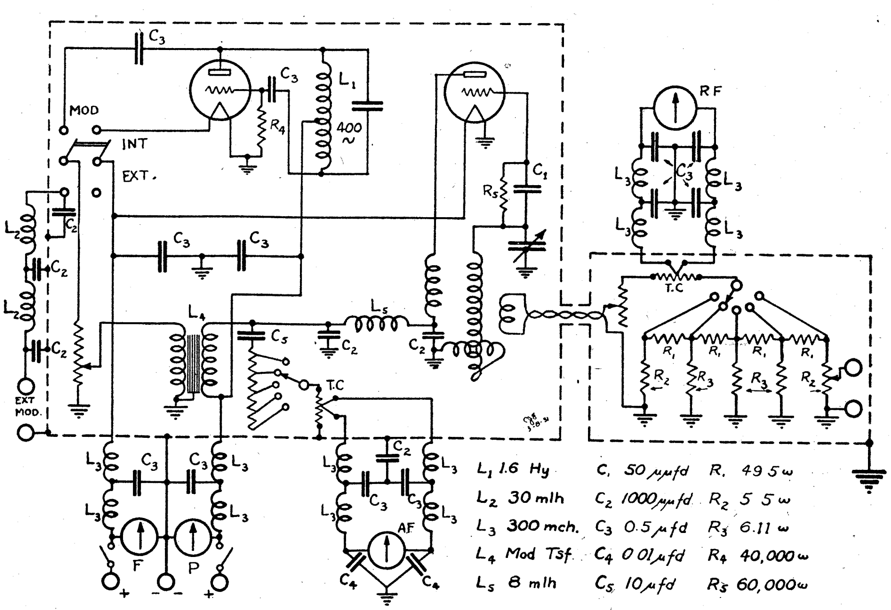

Fig. 4. Generalized circuit of laboratory type generator.

erator itself need not be nearly as complete as when the two are to be operated in direct proximity. The simplification is, however, only apparent. It is obvious that the total attenuation between generator oscillator and receiver input must remain exactly as great as ever, so that the total shielding required is not diminished in the slightest. If some shielding is removed from the generator proper it must be put back in another guise, as for example the separate screened room. It is felt that the net result is an economy when the generator is properly and completely shielded in itself, for the slight additional difficulty of complete shielding is more than compensated for by the elimination of the extra screened room and the extra operator. Most important, however, is the greatly increased facility and convenience of operation and the lessened opportunities for errors of misunderstanding when all of the apparatus involved can be placed within the reach and under the direct control of the engineer making the tests. In all of the generators described in this paper sufficient shielding has been included to make possible operation of the generator very close to the receiver under test.

Practical Examples of Standard Signal Generator Design

Three types of signal generator are shown in the illustrations. The first two, shown in Figs. 1 and 2, are similar in design and construction, both being intended for general laboratory use where performance and convenience of operation are of greater importance than size and portability. The third generator, shown in Fig. 3, is of a much smaller size. It is completely self-contained including batteries, and of course has had certain performance features sacrificed to some extent in order to permit the reduction in size.

The two larger generators differ only in the carrier frequency range covered, and in the means provided for covering the range. The circuit details are so nearly identical that but one diagram will be sufficient to explain the operation of both. This circuit diagram is shown as Fig. 4.

The unit around which the entire apparatus is built is of course the radio-frequency generator. This employs one 112-A tube in the well-known tuned grid circuit, and of course requires external sources to supply the filament and plate power. The first model of generator, shown in Fig. 1, has for its distinguishing feature an extremely wide range of carrier frequency. It has proven entirely satisfactory over the range 150 to 7500 kilocycles, and has in fact been operated at frequencies up to 13,500 kilocycles. However, at these extremely high frequencies the difficulties involved in accurate checking have prevented the making of a sufficient number of tests to be certain that operation in this region is entirely satisfactory.

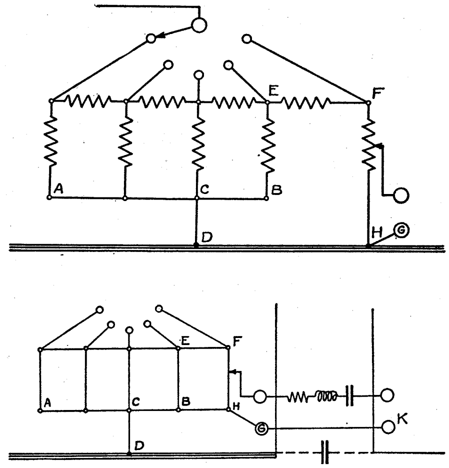

Fig. 5A
Fig. 5B
Sources of error in an attenuator system.

Plug-in coils make possible the covering of this wide frequency range. Eight coils cover the range 150 to 7500 kilocycles with quite generous overlaps. A special feature of the design is that coils can be changed very quickly. Both the inner and outer shields are provided with hinged lids. Since no screws or other fastenings need be removed the entire coil changing operation can be accomplished in ten to fifteen seconds.

The tuning condenser is operated by a worm drive similar to that used on precision wavemeters. This in effect provides a dial having 2500 divisions and makes possible a very accurate setting of the oscillator frequency. The frequency spread is sufficient to permit adjustment in the small steps used in selectivity measurements, thus eliminating the need for any form of separate vernier or fine frequency control.

The attenuator structure in this model required very careful design and construction to permit operation at the very highest frequencies in the range. Checks with other sources and methods have indicated that this has resulted in an absolute accuracy of output of quite a high order even at frequencies as high as 6000 kc.

The second signal generator, shown in Fig. 2, was intended for use only in the frequency range 150 to 1500 kc. This permitted the elimination of plug-in coils, since the entire range could be covered by the use of only two oscillating coil systems. These are both contained within the body of the instrument, each being enclosed in its own magnetic shield, and either is selectable by means of a control knob appearing on the front panel. The coil is connected to the tube, tuning condenser, and output circuits by means of a switch of the familiar cam-and-leaf-spring type, whose low losses and low electrostatic capacity make it suitable for this use.

The tuning condenser in this model does not have the worm drive for fine adjustment. Instead, each coil system is provided with a small rotor coil connected in series with the tuned coil, and rotatable from the front panel by means of another dial. The normal position for the coil is at right angles to the grid coil. Rotating the coil in one direction decreases the total inductance of the tuned circuit and raises the carrier frequency while rotation in the other direction lowers the frequency. A variation of about five per cent plus and minus is obtained by proper proportioning of the numbers of turns on the coils.

Grid excitation for the oscillator is obtained through the usual condenser-and-leak series impedance, although the values of these are rather unusual ones for this use, as will be seen from the constants given on the circuit diagram. These values, as well as the various other constants of the circuit, were arrived at by an experimental process of design in which such features as frequency stability, constancy of output with frequency, low current consumption, and satisfactory modulation characteristics were the desiderata. Many of those named were found to be incompatible with others, the design thus becoming somewhat of a compromise between the various factors. The values finally arrived at give a degree of performance which is entirely satisfactory when used with the most advanced receivers being built at the present time.

Modulation System

The radio-frequency oscillator is modulated by inserting into its plate circuit, in series with the d-c. supply, an alternating voltage. This is accomplished by supplying the d-c. through the secondary winding of a modulation transformer, the d-c. resistance being kept low to reduce voltage drop at this point. The source of modulating voltage is connected to the primary of the transformer, and the resulting voltage at the plate of the radio oscillator tube is one which has both a-c. and d-c. components. The ratio of a-c. to d-c. volts is considered as being equal to the per cent modulation, this assumption being based on the fact that the modulation or input-output characteristic of the radio oscillator is very nearly linear. The d-c. component is read on the 150 v. d-c. panel voltmeter. This voltmeter indicates the battery voltage applied at the terminals of the generator, while the voltage actually appearing at the oscillator plate is smaller by the amount of the drop through the filter system and modulation transformer. However, by careful design this difference has been kept so small as not to affect the accuracy of the result greatly.

The alternating component of plate voltage is measured by means of a high resistance thermocouple voltmeter connected from the plate supply lead to ground through a condenser which keeps the d-c. out of the voltmeter but is large enough not to affect the a-c. reading even at frequencies as low as 40 cycles. This a-c. voltmeter is calibrated in peak volts rather than r.m.s. volts. It is provided with a series multiplier whose total resistance is such that the scale indicated on the voltmeter becomes correct when the switch is set to the tap marked "100 per cent modulation." Thus, if the reading of the voltmeter is brought equal to the reading of the d-c. voltmeter, the peak of the a-c. wave will be equal to the d-c. voltage and the plate voltage of the oscillator will be 100 per cent modulated. For any other percentage of modulation the voltmeter multiplier switch is set to the desired tap, the resistance in circuit at this tap bearing the same relation to the total resistance as the desired percentage bears to 100. If then the input be readjusted to bring the readings of the two voltmeters again to equality, the modulation ratio will be the value indicated on the tap used.

The advantages of this system are that no calculations or interpolations are ordinarily necessary, sufficient taps being provided to cover almost all requirements. The percentage of modulation can be checked as often as desired, a mere glance at the panel serving to show whether or not the readings of the two meters are in equality. Further, the meter indication is always kept at the same part of the scale, so that small modulation percentages may be read as easily and accurately as large ones. Should it ever become necessary to use a modulation ratio not provided for by the switch a simple calculation and resetting of the a-c. voltmeter will make this possible.

Modulation Ratios

The accuracy of the various percentages relative to each other depends only upon the accuracy with which the voltmeter multiplier resistances are adjusted. However, the absolute depth of modulation of the emitted wave is dependent upon the slope and linearity of the oscillator input-output or modulation characteristic. Since a certain amount of irregularity has unavoidably been permitted to exist here, the absolute modulation ratios may be in error by from five to eight per cent. These errors affect the output of the receiver in direct ratio and may therefore contribute errors of this magnitude to the final result. However, for ordinary purposes this error is entirely negligible. In a series of comparative tests it of course cancels from the results, while even for careful quantitative tests the error, while by no means small, is usually exceeded by other errors inherent in the apparatus or the method.

The oscillator characteristics vary with the oscillator circuit constants, and therefore the modulation depth errors vary with the output frequency. The lowest frequency in each range will usually be found to be the least accurate as to modulation. For example, the modulation depth being set to a nominal 30 per cent by means of the panel meters, the actual modulation depth of the output wave was found to be almost exactly 30 at 1400 kilocycles, rising to almost 33 per cent at 600 kilocycles. There is also a slight variation in this factor between tubes and in a given tube during its life; it appears to be least for tubes of high conductance.

The modulating source may be either an external oscillator or the self contained oscillator. Throwing the modulation control switch to "Ext" connects the adjusting potentiometer, through a suitable filter to prevent radio frequency currents from leaking out at this point, to the panel binding posts marked "Ext. Mod." In the center position the input potentiometer is left unconnected so that an unmodulated carrier is emitted, while when the switch is thrown to "Int" the potentiometer is connected to the output of the internal oscillator and the filament circuit of this tube is closed so as to set it in operation. Only one frequency, 400 cycles approximately, is available from this internal oscillator, and its output, having purposely been kept small to minimize battery drain, is only sufficient for a maximum of 30 per cent modulation. This, however, is sufficient for about 90 per cent of the measurements which will be made with the generator.

Output and Attenuator System

The takeoff coils which are coupled to the main oscillating circuits of the generator have their turns and coupling so arranged that they provide a current of 100 milliamperes through a load of 15 ohms. Of this, five ohms are in the attenuator, five in the thermocouple, and the remaining five are supplied by the adjusting rheostat. This amount is provided to serve as a margin of safety to take care of variations of oscillator output due to battery aging and to changes of circuit conditions as the carrier frequency is varied over its range.

The current indicating device is a Weston Type 425 thermo-galvanometer. In order to prevent radio-frequency potentials from appearing at the meter face the thermo junction is removed from the instrument case and mounted inside of the attenuator shield, filters being inserted in the d-c. leads to the indicating portion of the meter. The meter scale is then recalibrated, the deflection corresponding to a current of 100 milliamperes being indicated on the scale.

The attenuator proper is a five step constant impedance ladder type, the input to the net being connected to any desired step by means of the multiplier switch, which thus permits attenuation ratios of 1, 10, 100, 1,000, and 10,000 to be used. The last shunt branch of the system is a continuously variable slidewire potentiometer which permits intermediate values of output to be obtained. The scales of the two controls are marked in inverse attenuations so that the value of output voltage is obtained directly in microvolts by a simple mental multiplication of the two readings. The attenuator impedance being five ohms, a maximum of 0.5 volt is obtainable at the output terminals. The output impedance of the system, looking into the output terminals from the load, is variable, depending on the setting of the slidewire, and is equal to the slidewire reading divided by ten, in ohms.

It will be seen that we have exceeded the limit of two ohms which at the beginning we placed on the generator output impedance. This was necessary in order to obtain the additional output voltage over the .2 volt originally specified. However, since at this .2 volt output the generator impedance is actually only two ohms, the requirements have been met, in the spirit if

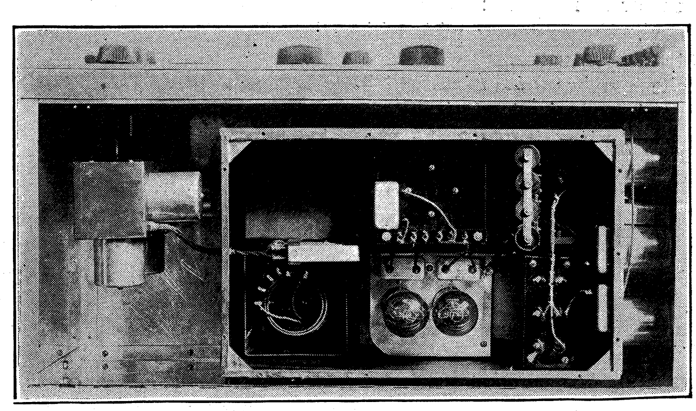

Fig. 6. Interior of 150 to 1500 kc. generator.

not in the letter. It is possible so to use the generator that the impedance never rises above the two ohm limit, simply by staying below the "20" point on the output slidewire. Even the five ohm impedance, however, will not cause any appreciable error if care is taken that the load connected to the generator terminals is of sufficiently high impedance not to load the source. The artificial antenna commonly used, containing a 200-mmfd. series condenser, presents an impedance high enough to fulfill this requirement.

For some tests, notably those made upon detection systems, even the .5 volt maximum is not sufficient. A higher voltage than this can easily be obtained by utilizing a stage of radio-frequency amplication. One of the stages of the receiver under test can usually be made to serve very satisfactorily. If this is not convenient, a separate tuned circuit can be connected directly to the generator output, and the voltage developed across one of the reactances used as the high voltage source. Voltages up to 20 or 30 can be obtained in this way, but it is obvious that they must be measured by some external instrument such as a vacuum tube voltmeter, since the generator readings become meaningless under such load conditions.

The attenuator system has a usable range of output voltage of 500,000 to one microvolt. The absolute values of these voltages are set (or calibrated) by adjusting the current flowing through the attenuator to a value which will produce across the known resistance the desired value. In this case 100 milliamperes and five ohms are the values used. The accuracy with which the maximum voltage is known depends therefore upon:

A. The accuracy with which the current can be set to the standard value.

B. The accuracy with which the attenuator resistance is known. Since not strictly resistance, but rather impedance is the factor involved here, a knowledge of the frequency characteristics of the resistance structure used is implied.

When an output voltage less than the maximum is to be used another factor is involved:

C. The accuracy with which the attenuation ratios are known, including the number of ratios which must be used to obtain the desired voltage.

This last factor is by far the most serious limitation of the accuracy of the apparatus and will bear discussion in some detail. It is affected not only by the frequency characteristics of the resistance structures used in the attenuator but by all sorts of unsuspected stray couplings and leakages, the detection and elimination of which constitute a problem of considerable magnitude. It is not especially difficult to build resistance units which will be substantially free of inductive and capacitive effects, and it is very fortunate that in determining the resultant impedance of any element of the attenuator net, any reactive components must be combined vectorially and in quadrature with the resistive component. This means that, in series with a resistance of 5 ohms, an inductive reactance of 0.5 ohms, instead of causing a ten per cent error, will cause an increase of impedance less than one per cent. The table below shows the inductance in microhenrys which approximately corresponds to the 0.5 ohm value at various radio frequencies. It is essential that the inductance of each 5 ohm unit be kept below these values if proper operation is to be obtained at the frequency considered:

Frequency, kc....	100	500	1500	7500	15,000
Inductance, m.h..	.75	.15	.05	.01	.005

Practically, this means that inductances of leads which are normally not considered must not be neglected in the design of attenuators.

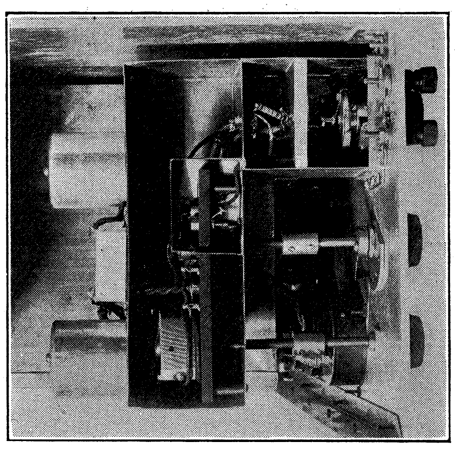

Fig. 7. Simplified attenuator structure in 150 to 1500 kc. generator.

The inductances considered were those whose magnitudes would cause appreciable errors when connected in series with a single element of the attenuator net. When inductances become common to two or more elements, however, very much smaller inductances than those listed will cause more serious errors. Fig. 5 has been drawn to illustrate how this can occur. The attenuator circuit considered is identical with that shown in Fig. 4, but the resistances are connected to ground in a different manner. The first four shunt branches are grounded to a metal subbase, AB, which is in turn connected to the main base or panel through an impedance CD. If we assume CD to have an impedance of as little as 0.01 ohm, due perhaps to a wire one half inch long, or to a slightly high resistance structural connection, it will, with the attenuator switch in the position shown, have across it a drop of 1000 microvolts. Thus the last attenuator section EFH, which should be actuated only by a 500 microvolt drop in EB, will really be actuated by this amount in series with the drop in CD, causing an error which may be larger than a ratio of two to one.

If an attempt is made to eliminate this error by connecting the lower end of the slidewire FH to B instead of to the main base a different type of error, which may be as great or greater than the first, will occur, as shown Fig. 5-B. The drop in FH is now of the proper value, but the voltage across CD acts through the distributed capacity between the microvolter case and the receiver case, producing a current which returns through the ground lead GK. The drop produced by this capacity current flowing through the impedance GK appears directly in series with the receiver input circuit, and thus may cause errors of many hundred per cent.

The proper solution, of course, involves making the impedance CD negligibly small—which, in the case of operation at 7500 kc. means smaller than 0.00005 m.h. inductive reactance. This is not easily done, even if the plate AB is placed directly in contact with the main base. A special arrangement of shielding to control the paths of the return currents has been found necessary to a practical solution of the problem.

The above examples are not in any way intended to be a complete summary of possible attenuator troubles. They are given merely to serve as examples of the difficulties encountered and of the magnitudes of the quantities which cause these effects. A great many of the faults of an attenuator structure will show up as stray or zero signal, an output voltage which appears at the receiver terminals when the microvolter output controls are set for nominally zero output. In the second case discussed, for example, the voltage drop in the ground lead GK will not be affected by the position of the output slidewire, and even with this control set at zero a very strong signal would still reach the receiver.

Of course, stray signals may also reach the receiver due to insufficient shielding of the generator or filtering of the supply leads. It is necessary to eliminate such strays before critical tests can be made on the attenuation system. The first step in testing a microvolter, therefore, is to make sure that the stray signal is negligible in comparison with the voltage being measured. If it cannot be made so, accurate results cannot be hoped for.

Checking Accuracy

The best method of checking the accuracy of a generator, after making sure that stray signals are negligible, is to check the ranges of the step attenuator against the slidewire. For instance, with the attenuator switch on X1 and the slidewire at full scale, a receiver connected to the generator is adjusted to obtain a given audio output. The attenuator switch is then placed on the X10 step, when the same audio output should be obtained with the slidewire set at one tenth full scale. Similar checks are made between the other attenuator steps and at various radio frequencies in the range of the generator. Any difficulties due to reactive errors in the attenuator will show a systematic increase with increase of frequency.

Similar checks can be made on the type of microvolter using a fixed output resistance and variable attenuator current, but not as accurately. The meter cannot be read over a ten to one range, and even a comparison over a smaller range will in general involve one reading quite low on the meter scale where accurate observations cannot be made. A further difficulty with this system is that in general the change of attenuator current reacts upon the oscillator supplying the current, changing its oscillation frequency somewhat.

Another method of check is to compare the attenuator with an external attenuator, increasing the ratio of one while decreasing that of the other and observing any change of receiver output. This method sounds easy but it actually offers numerous chances for error. For example, the use of a capacitive attenuator appears very attractive, but is in practice very troublesome. The two main sources of error are:

(1) Stray capacities in parallel with the low capacity unit.

(2) Small inductances in series with the high capacity unit.

Unless great care is exercised to guard against these errors, very misleading results may be obtained. A resistance attenuator of 45 and 5 ohms in series is probably the easiest type to construct accurately, and will give satisfactory results if properly made. Finally, the acid test of all such checking methods is to try at least two different combinations or methods. Then if the results obtained from them do not check each other, both methods should be viewed with suspicion until the source of error is found.

In any event, a properly designed attenuator system will usually be found to give quite accurate results, at least insofar as can be detected in ordinary usage. Indeed, the checks which are obtained in normal use, when proceeding from one range to the next, are usually so close to the accuracy with which the test can be performed and the readings taken that the operator is led to believe that he is justified in reading the output dial to one per cent. He is, as a matter of fact, justified in reading it to this accuracy only when making such measurements as selectivity, over load, and stage gain, which are relative and comparative rather than absolute determinations.

In this connection it may be well to point out the fallacy of attempting to obtain greater accuracy of measurement by operating the attenuator system at reduced values of current, commonly one-half normal. An analysis of the conditions, taking into account such factors as the greatly decreased accuracy and reliability of the current indicating meter, the load change which alters the oscillator characteristics, and the increased ratio between stray currents from the oscillator and the true attenuator current, will very quickly show that the net result is a serious loss of accuracy. The only benefit derived from the practice is an increased accuracy of reading of the output dials. This accuracy is already greater in most cases, however, than the known absolute accuracy of the instrument justifies.

Shielding

In order to prevent so far as possible the radiation of radio-frequency energy from any point other than the desired one, the output terminals, it is necessary to shield and confine the main oscillating circuits of the generator very carefully, and the attenuation circuits only slightly less carefully. The oscillating circuit coils, which are of course the source of the most powerful fields, are enclosed in a total of three separate shields, while the remainder of the oscillating circuit is shielded doubly and the attenuator in a partially separated double shield.

The oscillating coils are each enclosed in a small copper can shield which serves to confine the main magnetic field of the coil. These cans and the rest of the oscillating and modulating circuits which are at high r.f. potential are enclosed in a large box which is referred to as the main oscillator box. This is mounted on insulated pillars and all control shafts passing from it to the front panel have insulating couplings inserted in them. The object of the insulation is to prevent currents from circulating between the box and the panel and flowing through the face of the panel, setting up stray voltages and fields, and to insure that only one ground connection is provided for the main box. This single ground is obtained through the Belden braid which surrounds the output leads supplying the attenuator current. Thus all ground and return currents are forced to flow out along this braid, surrounding the output leads (which are continuously transposed by twisting them around each other) and eliminating large current loops which might produce stray fields.

The physical relation of the various parts of the generator is shown by Fig. 6 which shows an interior view of the second (150 to 1500 kc.) type of generator.

Attenuator

The attenuator is contained in a copper box which serves both as structural support and shield, and which is laid out physically in such a manner as to control the paths of the currents flowing in it and to force them to flow concentrically around the path of the current in the attenuator proper, thus avoiding couplings between the known and unknown currents. The structure for the first type of generator is somewhat complicated. It is composed of three separate shield boxes, one within the other, each carrying a portion of the attenuator network and the associated currents, in order to prevent couplings between the high and low potential parts of the attenuator net.

In the case of the second generator, however, the decreased frequency range permitted a considerable simplification of attenuator structure, all of the parts being contained in but one copper box provided with internal shields to separate the various sections of the net. A side view of this simpler attenuator, with the side cover removed to show the relations of the various parts, is shown

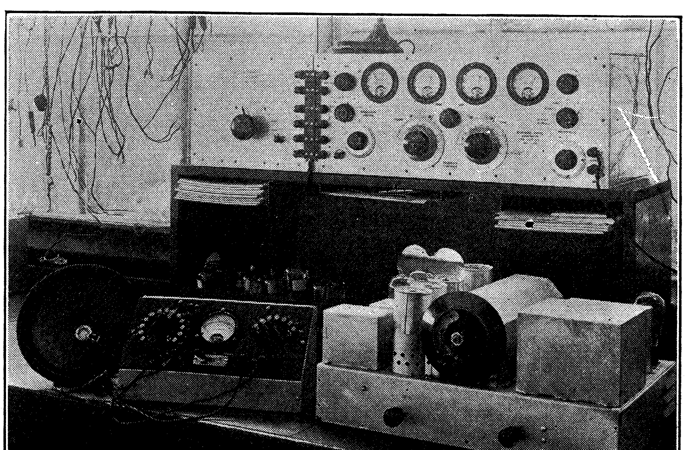

Fig. 8. Complete receiver testing setup in laboratory.

in Fig. 7. A feature of this construction is the easy access which it affords for adjustment or replacement of the slide wire. In the event of failure of the wire a new unit can be installed in two or three minute's time. This ease of replacement of the slide wire also obtains for the first type of generator although it is accomplished in a slightly different manner. The complicated shielding of the attenuator prevents access from the side, so the entire slide wire unit is made to be removable through a large hole in the panel, this hole being covered by the slide wire dial in normal use.

Filters

Since practically every circuit element inside of the main oscillator box is at an appreciable radio-frequency potential to other elements and to ground, it follows that radio-frequency voltages appear on all of the leads entering and leaving this box for the purpose of supplying battery, modulating voltage, or the panel meters. These voltages must be removed before the leads can be exposed to the receiver circuits, to prevent the introduction of unknown voltages into the measuring circuits. Every lead is therefore provided with a suitable filter, excepting only the output current leads, which, in place of filtering, are provided with shielding.

The filters are of the familiar low-pass type in which inductance is inserted in series with the line being filtered and capacity is connected from line to ground. Most of these filters are very uncritical as to constants, it being necessary merely to use coils of convenient size and low d-c. resistance, and to provide capacities of a fairly large size. The filter constants used in the battery and output thermocouple leads were found experimentally to be adequate for these uses.

In the case of the modulation voltage input leads, however, another factor had to be taken into account, that of the efficiency and frequency characteristics of the filter, since it was desired to transmit all frequencies up to 7000 with little attenuation, and to work between impedances of the order of 5000 ohms. For this use a more careful determination of the constants of the circuit was necessary. Still another special case was that of the modulation voltmeter d-c. leads. The impedance of the battery lead filters is so low (25 ohms) that if used in the modulation circuit they would have presented an almost complete short circuit to the lower half of the high resistance thermo-couple used here, affecting the calibration seriously. For this reason a special type of filter was used, as shown on the circuit diagram. The capacity to ground was kept as low as was consistent with good filtering action, while the capacity across the two leads was made high in order that no radio voltages might appear across the meter terminals.

Miniature Portable Generator

The third type of microvolter is shown in Fig. 3. It was designed to be small in size, completely self-contained, and light in weight. The tubes used are the new 230 type, which can be economically operated from dry cells contained within the case of the instrument. The use of these smaller tubes will not permit obtaining as high an output as can be taken from the 112-A tubes. The maximum voltage is 100,000 microvolts, appearing across the same five ohm attenuator net. Since the oscillating circuit power appearing in the generator circuits is lower, the very complete shielding employed in the larger models can be partially eliminated. In this model the inner shield is not insulated from the outer case, permitting a much more rugged mechanical structure. Also, no battery circuit filters are required, although a filter for the external modulating voltage input circuit is provided to permit modulation from an external oscillator.

Only one meter is used to indicate both the modulating voltage and the radio-frequency current flowing to the attenuator. Two separate thermocouples are of course required, but the one indicating movement is used for both couples by means of a simple switching arrangement.

This model of generator was also desired to cover a large frequency range, and therefore the oscillating circuit coils were made plug-in. A worm-drive tuning condenser similar to that used in the larger generator is used here also.

Fig. 8, shows one of the larger generators as it is actually used in the laboratory. A small shelf or stand about fifteen inches high forms a very convenient mounting for the signal generator and its associated modulating oscillator. The generator is lifted up to a position where its dials are about on a level with the eyes of the operator, thus reducing reading errors and eye strain, while the bench top is left clear for the receiver under test, output meter, etc. A cable is provided to connect the generator to the battery box on the floor under the bench. Some installations have been made in which the plate voltage for the setup has been obtained from a generously designed "B substitute" power supply unit, and have given fair satisfaction. The poor voltage regulation of such devices is one of their chief disadvantages, especially where the external modulating oscillator is supplied from the same source.

Both of the larger generator models have been in almost constant use in the laboratory for somewhat over a year, and have proved to be very satisfactory under all operating conditions. No receiver has yet been encountered which could not be completely analysed by this type of generator.

THE BANQUET SMOKER

BROOKLYN, New York, was the scene on April 22, at the Elks Club, of the latest product of the Club's banquet committee: a banquet smoker and beefsteak dinner. L. C. F. Horle, acted as toastmaster, in which he was voluntarily assisted by J. V. L. Hogan. The banquet committee which nursed this event into reality was headed by Fred Muller of the Tropical Radio Telegraph Company. Muller, besides the extra work of looking after the banquet details, suffered an attack of influenza and, as if this were not enough, his radio personnel in Central America was being buffeted about by earthquakes and revolutions. To complicate matters, Mr. Horle, by accident or design (we know not which) was incapacitated with the same ailment, at the same time as was Mr. Muller. In spite of these handicaps, the banquet plans went ahead to a successful conclusion.

The beefsteak dinner was in the approved fashion, all guests wearing chef's caps and aprons. George H. Clark, the irrepressible one, graced the program with "A Psychoanalysis of the Radio Club," being a general exposure and indictment of everybody and everything. A sound movie, entitled "Parlez Vous," produced with portable equipment available through the courtesy of Louis Gerard Pacent, was highly entertaining. At the speakers dais were: L. C. F. Horle, toastmaster; Harry Sadenwater, Fred Muller, George H. Clark, George E. Burghard, J. V. L. Hogan, Thomas J. Styles, Zeh Bouck, Robt. H. Marriott, Donald McNicol. Among those present were: Donald Whiting with a group of Fox Film sound engineers; W. A. Winterbottom of R.C.A. Communications and a group of his staff members; W. R. G. Baker of RCA-Victor Company and several others from the Camden organization; Charles H. Stewart of the A.R.R.L. official staff; C. W. Horn of the National Broadcasting Company.