

THE

General Radio EXPERIMENTER



VOLUME XII NOS. 3 and 4

AUGUST-SEPT., 1937

ELECTRICAL MEASUREMENTS AND THEIR INDUSTRIAL APPLICATIONS

Also IN THIS ISSUE

	<i>Page</i>
STANDARDIZING THE STANDARD-SIGNAL GENERATOR	8
STANDARD FREQUENCIES FOR THE MUSICIAN	10

A NEW INSTRUMENT AND A NEW CIRCUIT FOR COIL OR CONDENSER CHECKING

● THE REACTANCE AND RESISTANCE of coils and condensers used in modern radio receivers are frequently held to extremely close tolerances. Acceptance tests and equipment for checking these factors are important to both parts manufacturers and receiver manufacturers. Laboratory instruments of high accuracy are available for making these measurements, but their relatively high cost usually prohibits their use on the production line. The same resultant accuracy, however, can be obtained by measuring and adjust-

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FIGURE 1. Two TYPE 721-A Coil Comparators arranged for testing coils at two frequencies.



A NEW CIRCUIT—
ITS ADVANTAGES

ing a standard coil in the laboratory and comparing others with the standard by means of simple, inexpensive instruments. Primarily for this latter purpose the General Radio TYPE 721-A Coil Comparator has been designed.

What method of measurement should be chosen if it is desired to compare, at a radio frequency, a number of production coils with a standard sample? There are available the familiar bridge methods, resonance methods, detuning methods, etc. Direct substitution can be used equally well with all of these, and any not too elaborate circuit which permits the comparison to be made readily with the desired degree of precision should be satisfactory. Bridge measurements rely on a null indication and can be made, consequently, with almost any required precision. They are difficult to set up, however, and require considerable equipment. Resonance methods, although capable of giving satisfactory results when the losses in the coil are low, frequently do not permit settings to be made sufficiently closely in other cases. Detuning methods, such as the zero-beat substitution method, likewise require, for stable and satisfactory operation, a considerable amount of equipment, and are difficult to adapt to the checking of coil losses.

A new measuring circuit has been adopted for the TYPE 721-A Coil Comparator in order to keep the simplicity of a resonance method, but with considerably increased precision of setting. This circuit, which is a bridged-T network, is shown in Figure 2. Like a bridge, it is capable of being balanced for a perfect null indication, but unlike a bridge, one side of the generator, of the detector, and of the coil under test are connected to a common grounded point. This simplifies considerably the whole arrangement, and the stray capacitance from the generator to ground, or from the detector to ground, does not have to be balanced out or otherwise compensated for. Readings are completely independent of both generator and detector impedances. The effective low impedance of the circuit, moreover, makes other effects, such as capacitance between input and output and capacitance to the operator's body, almost unnoticeable.

The conditions for balance, if the two condenser sections are approximately equal and if the coil has a reasonably high Q , are as follows:

$$L\omega = \frac{1}{(C_1 + C_2)\omega} \quad (1)$$

$$R = \frac{R_S}{4} \quad (2)$$

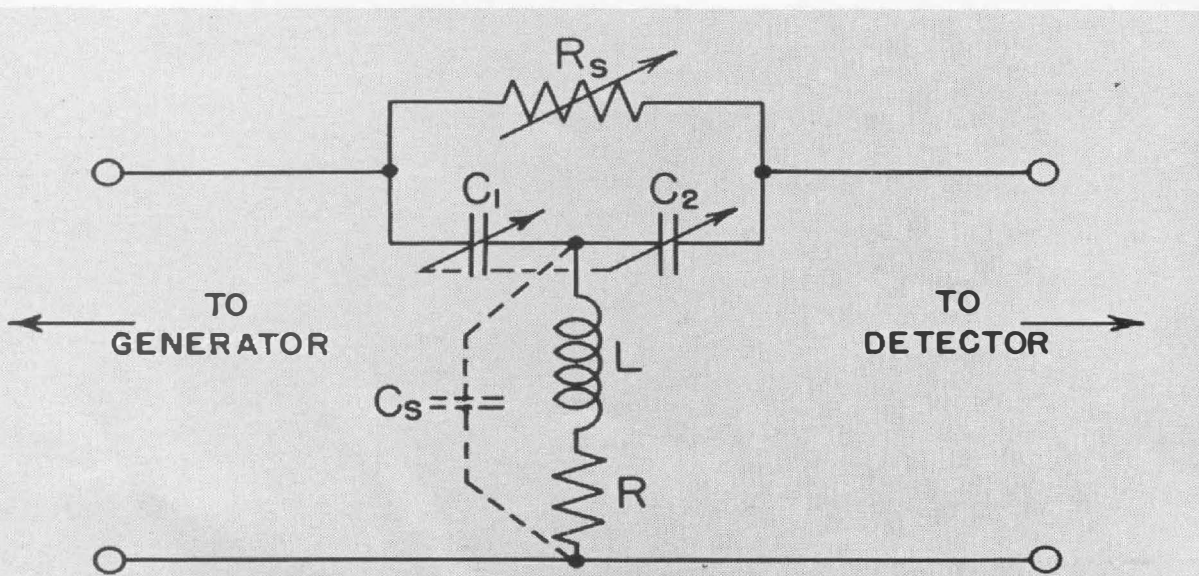


FIGURE 2. Circuit of the TYPE 721-A Coil Comparator. C_1 and C_2 are ganged and operated by a single control. L and R are the inductance and resistance of the coil under test, and C_s is the stray capacitance of the measuring circuit

In other words, the sum of the capacitance of the two sections of the tuning condenser must be sufficient to tune the coil to resonance, and the bridging resistance must be equal to four times the coil resistance. If the coil were perfect and had no losses, the bridging resistance would have to be zero and the circuit would become that of Figure 3, which shows a simple series-resonant circuit shunting the line, the coil being tuned by the two condenser sections in parallel. The circuit of Figure 2 is seen to be a series-resonant wave-trap in which losses in the coil are compensated for by splitting the condenser and inserting a bridging resistance. In this way perfect suppression of the applied voltage can be obtained regardless of coil losses.

The two condensers C_1 and C_2 are equal and are operated by a single control which determines the reactance setting. A small condenser, also in two sections, is in parallel with the main condenser and is used to show small differences in reactance in comparison measurements. The new circuit makes it possible to provide an almost ideal arrangement: a single control, with an incremental adjustment, for reactance, and an independent control for resistance.

CORRECTIONS

The simple relations which have been given for the balance condition hold,

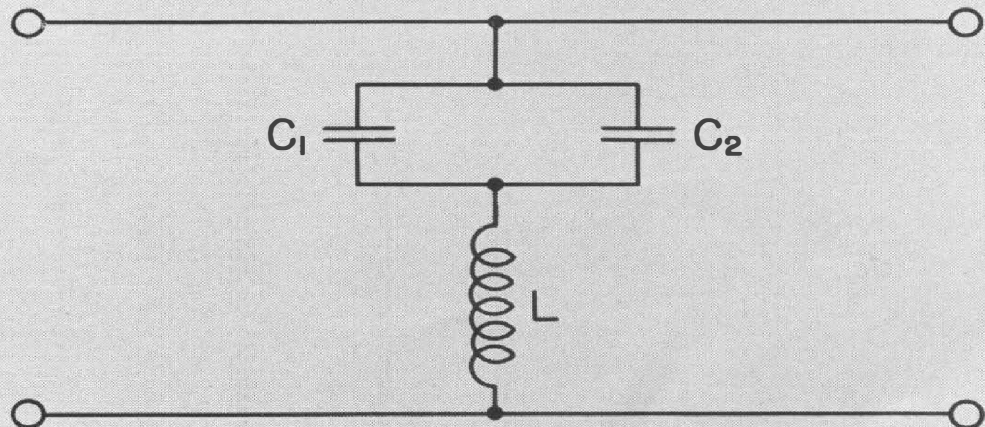
however, only when the coil has reasonably high Q . Moreover, between the junction of the two condenser sections and ground, there is usually an appreciable amount of stray capacitance which is directly in parallel with the coil and cannot be separated out in the measurement. The coil is measured, therefore, when partly tuned by this additional capacitance. The condition for the resistance balance is changed because the partly-tuned coil has a higher apparent resistance. The reactance condition is not affected, except that the stray capacitance decreases by just so much the tuning capacitance required in the two condenser sections and raises the value of the minimum tuning capacitance that can be obtained. The complete balance equations, taking account of both the coil Q and the stray capacitance, are as follows:

$$L\omega = \left(\frac{1}{1 + \frac{1}{Q^2}} \right) \frac{1}{(C_1 + C_2 + C_S)\omega} \quad (3)$$

$$R = \left(\frac{1}{1 + \frac{1}{Q^2}} \right) \frac{R_S}{4} \left(\frac{C_1 + C_2}{(C_1 + C_2 + C_S)} \right)^2 \quad (4)$$

The correction for Q is seen to be generally very small. If Q is 100, the correction is only one part in 10,000. Q may be

FIGURE 3. If the coil under test had no losses, the coil comparator circuit would be as shown here. This is a series tuned circuit directly across the line



as low as 10 without the correction exceeding 1%. The correction for Q will be recognized as the familiar expression for the ratio between the equivalent series reactance and the equivalent parallel reactance of a coil. The complete reactance condition (3) merely states, therefore, that the total capacitance ($C_1 + C_2 + C_s$) must tune the coil to parallel resonance.

It is interesting that the bridging resistance has no effect whatever on the total tuning capacitance required. The total capacitance is the same as would be used under operating conditions when the coil is tuned by a parallel condenser. Since the two condenser sections C_1 and C_2 are operated together as a unit, and since the stray capacitance C_s depends only on the condenser setting, it follows that the instrument can be calibrated directly in terms of the total capacitance ($C_1 + C_2 + C_s$) as if it were a simple condenser. Referring to the diagram, it will be seen that this can be accomplished by shorting the oscillator and detector terminals and measuring the total capacitance across the points at which the coil is to be connected.

The correction in expression (4) for the effect of the stray capacitance on the resistance measurement depends on the condenser setting alone and is independent of frequency. The bridging resistance for balance is in all cases proportional to the coil resistance, but the factor of proportionality is changed if the stray capacitance is appreciable compared with the total tuning capacitance.

PRODUCTION CHECKING OF REACTANCE

The instrument is particularly convenient for this application, since the direct measurement of L and R is less impor-

tant than the ability to compare accurately a production coil with a standard sample.

In many cases a reactance check alone is all that is required. In such cases the procedure is extremely simple and straightforward. The small condenser, marked LIMITS, is set at the center-scale zero, and balance obtained for the standard coil by varying the resistance control and the control of the main condenser, marked STANDARD SETTING. The reactance setting is locked by a clamp provided, the standard coil is replaced by the production coil, and balance restored by varying the auxiliary LIMITS condenser and the resistance control. If the production coil is similar in construction to the standard, the test can almost invariably be made with sufficient precision by adjusting only the LIMITS condenser, leaving the resistance setting unaltered. In this way, an extremely rapid check can be obtained. If a meter, in place of an audible tone, is employed to indicate balance, its scale can be marked to correspond to the required limits. This arrangement may be preferable for certain applications.

Condensers can be checked as readily as coils, but it is necessary to use an external coil to obtain balance. The LIMITS dial reads directly in micro-microfarads, $1 \mu\mu\text{f}$ per division, and the scale extends from $-13 \mu\mu\text{f}$ to $+13 \mu\mu\text{f}$. Differences can be estimated to $0.1 \mu\mu\text{f}$.

Although it is anticipated that the single frequency test described above will be generally adopted for production checking, the circuit of the comparator lends itself particularly well to more detailed tests. For example, a convenient arrangement for checking coils at two frequencies to obtain a measure of the distributed capacitance can be made by employing two TYPE 721-A Coil Com-

parators side by side, each with its separately-tuned detector. If the oscillator fundamental and second harmonic are used for the test frequencies, the two inputs can be connected together. It is then only necessary to shift the high-potential coil lead to test at the two frequencies and to insure that the reactance value in each case falls within the specified limits.

PRODUCTION CHECKING OF RESISTANCE

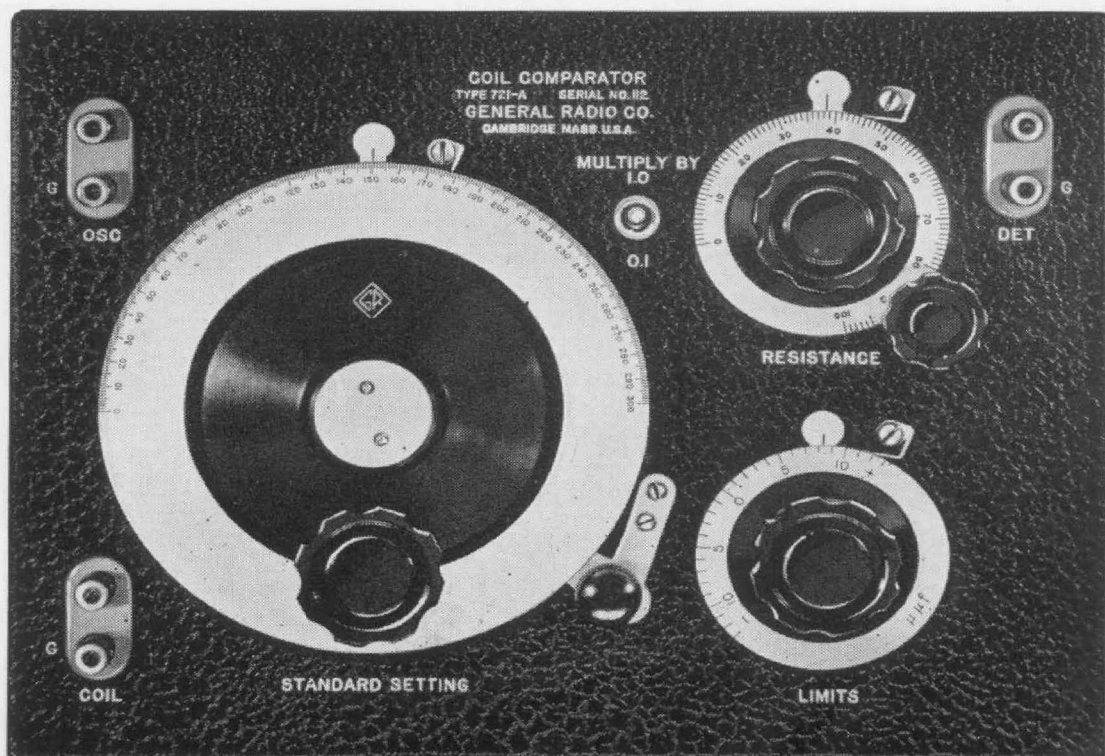
Production coils can also be checked for resistance or for Q in comparison with a standard coil. It has been shown above that for coils of the same reactance the setting of the resistance control is always directly proportional to the coil resistance. The percentage deviation in R or Q is equal in magnitude to the percentage deviation of the resistance control setting. The correction factor for the stray capacitance need be considered only for an absolute determination of R or Q . Two ranges of the resistance control are provided, reading directly 0-10 and 0-100 ohms "nominal," i.e., uncorrected, coil resistance.

DIRECT MEASUREMENTS OF R AND L

Although the TYPE 721-A Coil Comparator has been developed principally for production checking, it is believed that it frequently will be found valuable in the laboratory for direct measurements of reactance and resistance where precise results are not required.

The circuit makes it possible, essentially, to compare a coil with a condenser and resistor without any complications due either to the impedance of the voltage source or of the indicator employed, and it permits the comparison to be made as closely as desired. Assuming an accurate condenser calibration, the accuracy of measurement under such circumstances depends principally on how much the constants of the circuit elements vary with frequency. At high frequencies the capacitance of a condenser may differ widely from its low-frequency value, and its Q may become comparable to that of the coil. The difficulties in making a variable resistance operate satisfactorily at high frequencies are well

FIGURE 4. Panel view of the coil comparator. For production testing, the main dial is locked at the standard setting and deviations are read on the LIMITS dial



known. Although the TYPE 721-A Coil Comparator is not primarily intended for direct measurements, both the condenser and resistor have been designed so that high-frequency effects are reduced as much as is practicable, and the scales provided permit readings to be made with sufficient precision.

It has been shown that the stray capacitance correction for resistance depends only on the condenser setting. The condenser can be calibrated directly, therefore, once for all, not only in terms of total effective tuning capacitance, but also in terms of resistance correction factor, obtainable from the ratio of easily measured direct capacitances in accordance with equation (4). This correction curve does not vary appreciably from one instrument to another, and the average curve given in the operating instructions is sufficiently close to permit very satisfactory direct measurements of resistance. It is merely necessary to multiply the reading of the resistance control by the correction factor corresponding to the condenser setting to obtain the true series resistance of the coil.

It must be emphasized, however, that the TYPE 721-A Coil Comparator is offered principally for comparison measurements and no guarantee can be made, either with regard to frequency range or accuracy when it is used as a direct-reading instrument. It is hoped that further experience with the new circuit will make it possible to evaluate the errors which occur at high frequencies so that the advantages resulting from its inherent simplicity may be fully realized in direct measurements.

CONSTRUCTION

The condenser has the rotor and both stators insulated from the frame. Con-

nection to the rotor is made at the center between the two sections to reduce the size of the inductive loop and improve the high-frequency performance.

The variable resistance has low residual inductance, and is capable of smooth and continuous variation. The unit employed is similar to the type used as an output potentiometer in General Radio standard-signal generators. It is wire-wound on a form of small cross-section, and the winding is of the Ayrton-Perry construction.

Two separate variable resistors are employed, controlled by the same dial, a toggle switch selecting the range desired. The dial has 100 divisions giving directly, without calibration, the "nominal" coil resistance referred to above.

AUXILIARY EQUIPMENT

The TYPE 721-A Coil Comparator is supplied without oscillator or detector, in order to permit the greatest possible flexibility and economy in the construction of test benches. A single master oscillator can be used to furnish power for several coil comparators. If a modulated oscillator is employed, a small broadcast receiver can be used for the detector and is very much less expensive than a specialized piece of test equipment. An unmodulated oscillator can be used, if preferred, with a heterodyne detector, or with a straight radio-frequency detector such as a radio receiver with an electron-ray tube tuning indicator. The oscillator should be sufficiently shielded magnetically to avoid coupling to the coil under test and should furnish, preferably, about 10 volts output, although even a standard-signal generator can frequently be used satisfactorily. A new General Radio modulated oscillator, suitable as a source of power, will be announced in the near future. — W. N. TUTTLE

SPECIFICATIONS

Tuning Capacitance: The effective tuning capacitance is adjustable between 75 $\mu\mu\text{f}$ and 1200 $\mu\mu\text{f}$ when the auxiliary condenser is set at zero (mid-scale). This includes a stray capacitance of 25 to 32 $\mu\mu\text{f}$, depending on the setting of the main condenser.

Resistance: The resistance control reads directly within 5% the "nominal" coil resistance from 0.5 Ω to 95 Ω , in two ranges. The correction for stray capacitance, however, lowers the maximum measurable coil resistance to 46 Ω when the tuning capacitance is 100 $\mu\mu\text{f}$, and to 85 Ω at 1000 $\mu\mu\text{f}$.

Inductance Range: Any coil can be tested which can be tuned to resonance at the test frequency by a capacitance between the limits given above, and which has a series resistance lying within the range specified above.

Calibration: An approximate capac-

itance calibration is supplied for the main dial; this is actually the average of a number of instruments and is within $\pm 5\%$. The auxiliary condenser dial is direct reading in micromicrofarads and the resistance dial in ohms. A correction curve for the effects of stray capacitance is supplied.

Mounting: The instrument can be supplied in a walnut cabinet for table use, or with a metal dust cover for building into test equipment.

Accessories Required: Radio-frequency oscillator, preferably modulated for use as a power source, and a radio receiver for use as a detector.

Dimensions: Panel, 12 x 9 inches; depth behind panel, TYPE 721-AM, 9 $\frac{1}{8}$ inches; TYPE 721-AR, 8 $\frac{3}{4}$ inches.

Net Weight: TYPE 721-AM, 12 $\frac{7}{8}$ pounds; TYPE 721-AR, 8 $\frac{3}{4}$ pounds.

Type		Code Word	Price
721-AM	With cabinet	BIBLE	\$85.00
721-AR	With metal dust cover	BIGOT	80.00

In the laboratories of public utility companies where 60-cycle testing and standardization are carried on, the *VARIAC* is widely used as an easily-

adjusted source of test voltage. The photograph below shows the *VARIAC* being used for this purpose in the laboratory of the Edison Company of Boston.



STANDARDIZING THE STANDARD-SIGNAL GENERATOR

● IN A RECENT ISSUE of the *Experimenter* a high-frequency standard of voltage was described.* One of the chief uses of this device has been the standardization of signal generator output levels at high frequencies. The following article is written to give the large number of signal generator users a brief idea of how these measurements are made. The equipment described is purely experimental; it has not been put in commercial form and is not available for sale.

A standard-signal generator usually consists of an oscillator coupled through an attenuator to output terminals. The constants of a resistive attenuator are determined at dc or at audio frequencies, those of inductive or capacitive units by computation from the physical dimensions or from audio-frequency measurements. It is possible to intercompare different types of attenuators, and a very carefully constructed unit may be used

*L. B. Arguimbau, "A High-Frequency Voltage Standard," *General Radio Experimenter*, Vol. XII, No. 1 (June, 1937).

as a standard in checking cruder attenuators. It is much better, however, to use an entirely independent method.

As is well known, a detector tube with an input consisting of two frequencies superposed will give an output signal of the beat or difference frequency. If one of the signals is fairly large (e.g., 1 volt), while the other is much smaller (e.g., 1 millivolt), the amplitude of the beat frequency will be very closely proportional to the amplitude of the small input signal. This proportionality holds over a very wide range of amplitudes such as 60-80 db, so that the amplitude of the difference frequency will serve as a measure of the small input signal even when this signal is varied from $0.1 \mu\text{v}$ to $1000 \mu\text{v}$ or even $50,000 \mu\text{v}$. This is a very useful relationship because it permits comparison to be made of the amplitudes of high-frequency signals by measuring amplitudes of low-frequency beat signals.

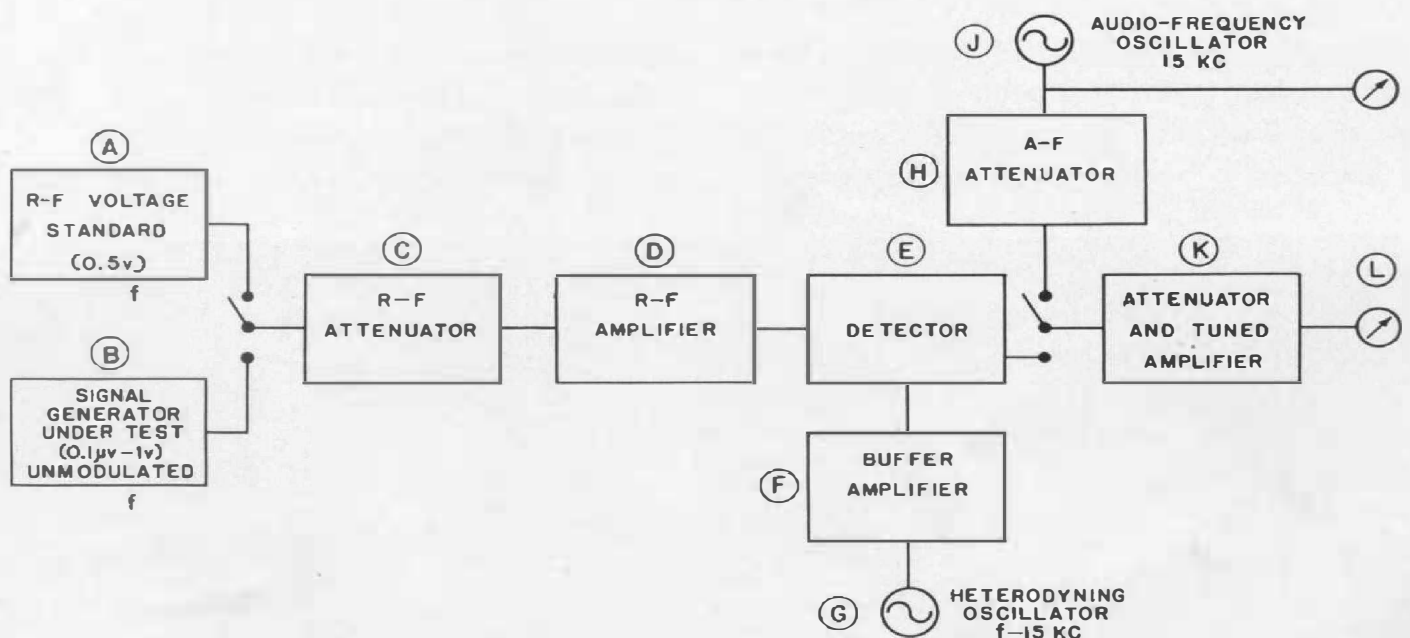


FIGURE 1. A functional diagram showing the equipment and method of measurement used to standardize signal generators

Of course precautions must be taken to make certain that the conditions outlined above are really obtained. For example, it is important that the small signal to be measured should not react on the local heterodyning oscillator. Furthermore, the detection should all occur in the detector rather than in the audio measuring circuits. It is also important that the measuring circuits should measure the beat frequency rather than 60 cycles or vacuum-tube noise of one sort or another, a requirement which makes highly selective audio-measuring circuits necessary. When these precautions have been taken, however, one has a method of comparing any voltage level with the output of the high-frequency standard previously described.

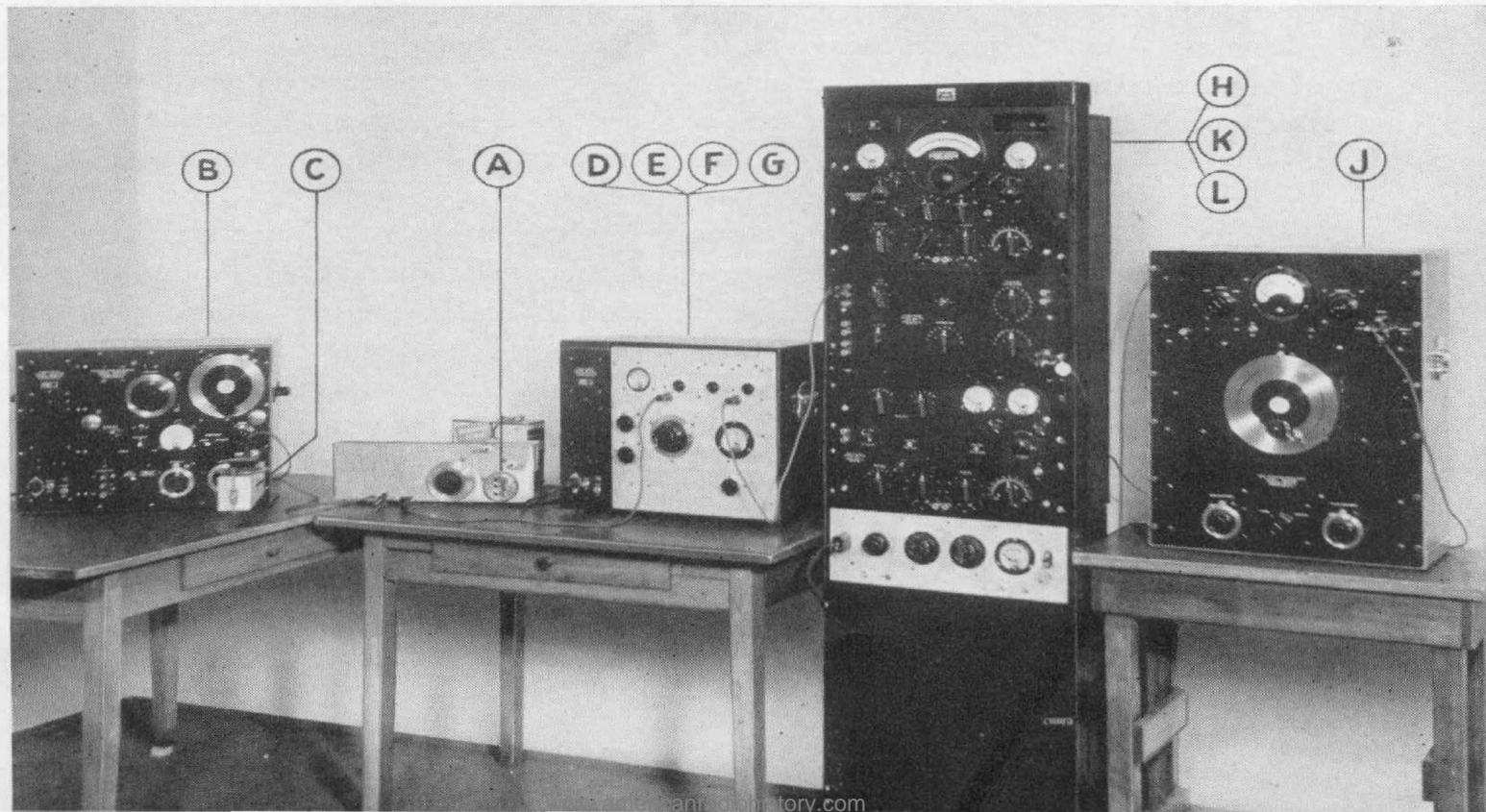
The system is shown in the functional diagram of Figure 1. Either the fixed voltage standard or the signal generator under test is connected through an attenuator to a high-frequency amplifier. The attenuator is a capacitive one of very low input capacitance and of com-

paratively high resonant frequency. (The construction is similar to that which was used in the TYPE 604-B Signal Generator.)* This attenuator is included chiefly to provide a high input impedance for the test circuit, although it is also used for adjusting the circuit operating level. It is removed when comparisons are made between different low levels of the same generator. As indicated in the figure, the amplified high frequency is heterodyned with another high frequency, and the low-frequency output is passed through a low-pass filter to audio-frequency measuring equipment. The audio equipment consists of a tuned circuit analyzer† built in a particularly flexible manner with gain controls in various positions; the circuit being ar-

*E. Karplus, "Receiver Testing in the Ultra High-Frequency Bands," *General Radio Experimenter*, Vol. VII, No. 9 (February, 1933).

†A. G. Landeen, "Analyzer for Complex Electric Waves," *Bell System Technical Journal*, Vol. VI, pp. 230-247 (April, 1927).

FIGURE 2. Photograph of the apparatus used at General Radio. The encircled letters correspond to those in the diagram of FIGURE 1



ranged to give a minimum of vacuum-tube noise. The comparison audio-frequency signal was provided with an attenuator of 120-db range in 0.2 db steps. Interpolation made it possible to estimate to about 0.01 db under favorable conditions.

The procedure in making the measurement is evident from the functional diagram of Figure 1. The standard voltage is applied and a reading obtained on the audio-frequency voltmeter. The unknown voltage from the generator under test is then substituted for the standard and the audio-frequency attenuator is adjusted to produce the same deflection. The difference in the attenuator settings for the two conditions then gives the difference in level between the standard and unknown voltages.

At standard broadcast frequencies, the accuracy of measurement is in the vicinity of 0.1%. At high frequencies (30 to 100 Mc), although the error in the voltage standard itself is small, differences between the internal impedance of the standard and that of the generator under measurement may lead to unpredictable errors at some frequencies because of resonant effects. In general, however, the error at high frequencies is not greater than 2% or 3%.

Two models of this equipment have been built and development has been started on a third. The first unit was built in 1930 for use in the standard broadcast band; the second, built two years later, could be used at frequencies up to 30 megacycles and it is hoped that the new unit will operate up to 100 megacycles.

— L. B. ARGUIMBAU

STANDARD FREQUENCIES FOR THE MUSICIAN

● ON JUNE 1, 1937, the National Bureau of Standards began a new and unique standard-frequency service. Intended for musicians, the new transmission consists of a 5-megacycle carrier modulated at 440 cycles per second, the American standard of musical pitch for A above middle C.

Experimental transmissions were given in August and September, 1936, and the interest displayed by musicians, musical organizations, and manufacturers of musical instruments was sufficient to justify their continuance as a regular standard-frequency broadcast.

Both the 440-cycle modulating frequency and the 1000-cycle frequency used on other standard-frequency transmissions are derived from a standard-

frequency oscillator by means of multivibrators supplied by the General Radio Company.

Figure 1 shows how these frequencies are obtained from the standard frequency of 200 kc. A frequency of one kilocycle is produced by dividing 200 kc in three steps of 4, 5, and 10, respectively. The output of the 1-kilocycle multivibrator is filtered to obtain a pure 1000-cycle voltage which is then used to modulate a standard frequency transmitter. To produce a 440-cycle frequency, the 11th harmonic of the 1-kilocycle multivibrator is selected by means of a filter and used to control an 11-kilocycle multivibrator. Two successive reductions by factors of 5, using multivibrators of 2.2 kc and 0.44 kc, are then

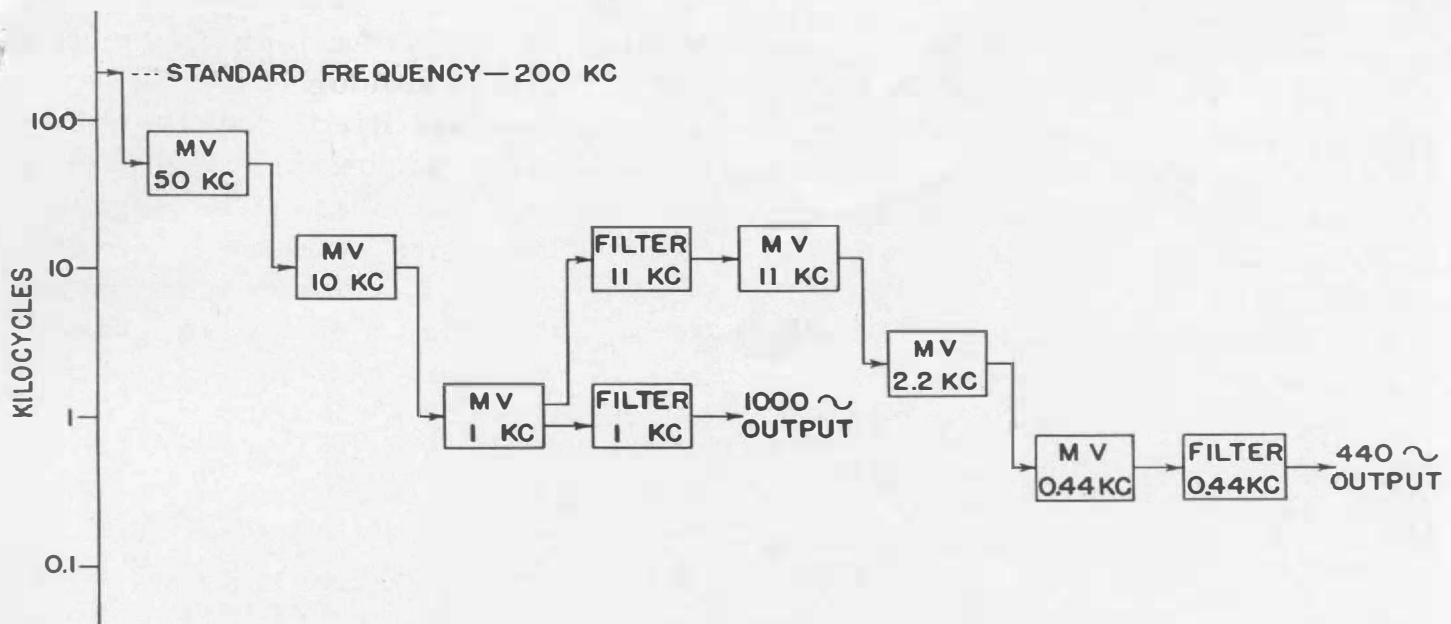


FIGURE 1. Block diagram showing how frequencies of 1000 cycles and 440 cycles are derived from a 200-kilocycle standard frequency

necessary to produce the desired 440 cycles per second. A filter is used to eliminate harmonics from the 440-cycle voltage.

The National Bureau of Standards is interested in receiving reports of methods of use or special applications of the standard frequencies.

MISCELLANY

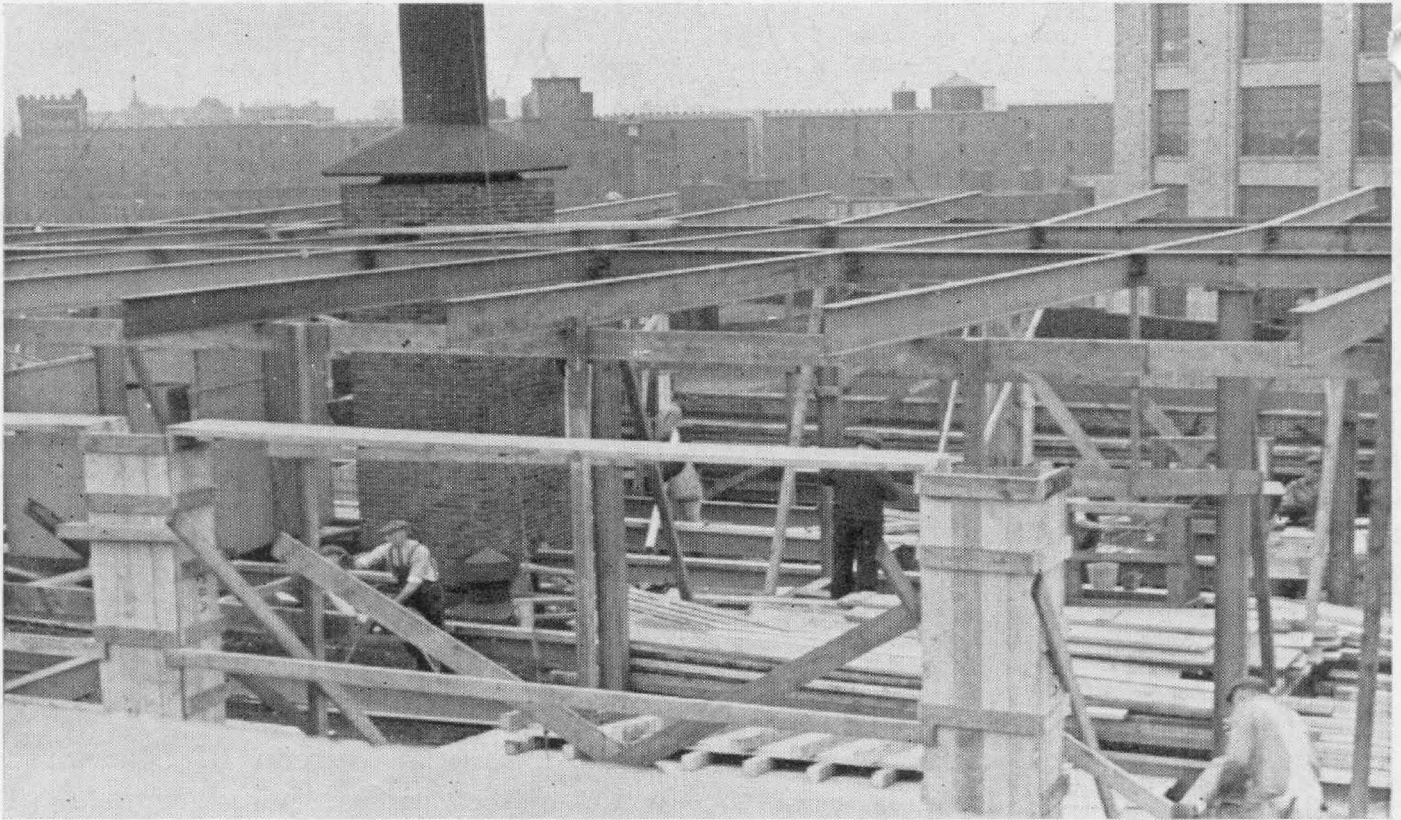
● **AT THE SUMMER CONVENTION** of the American Institute of Electrical Engineers held at Milwaukee in June, the Best Paper Prize for 1936 in the field of theory and research was awarded to Dr. Harold E. Edgerton of M.I.T. for his paper on "High-Speed Motion Pictures" presented at the Winter Convention of the Institute in New York in January, 1936. Dr. Edgerton is the originator of the Edgerton Stroboscope and of the high-speed camera manufactured by General Radio.

● **RECENT VISITORS** at General Radio: Messrs. I-Lun Liu and Chao-Chi Cheng, radio officers of the Chinese Navy; Mr. R. L. Palmer, Laboratory Supervisor, International Business Machines, Inc.; Mr. C. G. Motwane of East-

ern Electric and Engineering Company, Bombay, India.

● **MR. H. B. RICHMOND**, Treasurer of the General Radio Company, sailed with Mrs. Richmond and their two children on the *S. S. Saturnia*, on July 25, for Venice. He plans to spend several weeks in Europe and will visit a number of General Radio's foreign representatives.

● **AN APOLOGY** is due our readers for the photograph of Figure 5 in our May issue. Although diode characteristics are not linear for low values of voltage, this photo shows exactly linear meter scales. Upon investigation, we find that the meter shown was one of a lot rejected because the scales were incorrect.



● **THAT THE CURRENT** building boom has already reached General Radio is indicated in the accompanying photograph which shows a fourth floor being added to the only three-floor unit of our factory. This addition, now completed, brings our floor space to over 75,000

square feet, in three four-floor units. ● **TYPE 721-A COIL COMPARATOR** was designed by Dr. W. N. Tuttle, author of the article describing it which appears in this issue. These instruments are already in stock and immediate delivery can be made.

THE General Radio *EXPERIMENTER* is mailed without charge each month to engineers, scientists, technicians, and others interested in communication-frequency measurement and control problems. When sending requests for subscriptions and address-change notices, please supply the following information: name, company name, company address, type of business company is engaged in, and title or position of individual.

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