THE General Radio EXPERIMENTER

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ELECTRICAL MEASUREMENTS AND THEIR INDUSTRIAL APPLICATIONS

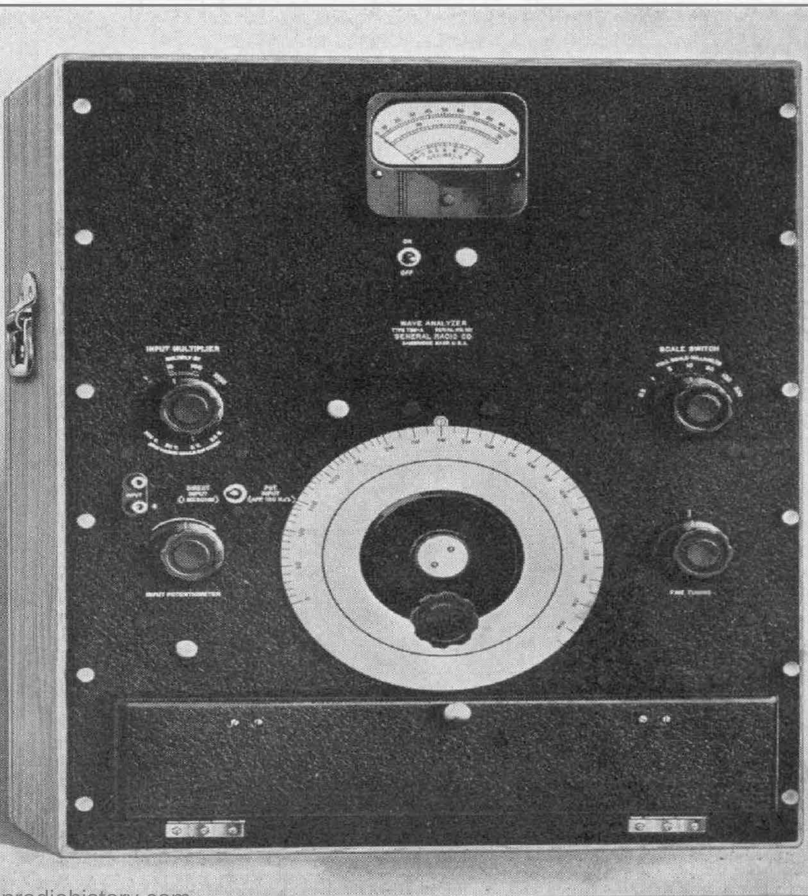
Also

IN THIS ISSUE

RADIO-FREQUENCY DISTORTION MEASUREMENTS WITH AN AUDIO-FREQUENCY ANALYZER

● **AN IMPORTANT STEP** in the design of the modulator stage of a standard-signal generator is the selection of the proper tubes and operating voltages for maximum output and freedom from distortion. Measurements of power output and distortion are necessary to determine the proper operating conditions.

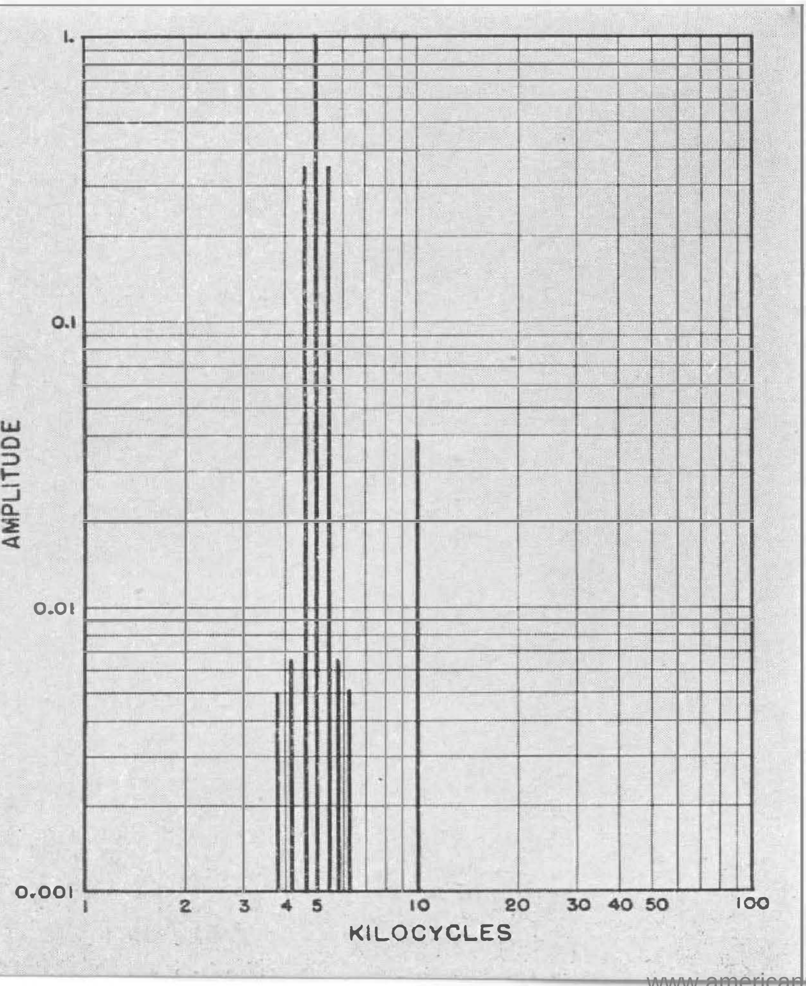
FIGURE 1. TYPE 736-A Wave Analyzer used in the measurements described in this article.



In the design of broadcast transmitters, the measurements are made by rectifying the carrier with a linear detector and then measuring the distortion in the audio-frequency output. This method is often inapplicable to standard-signal generator measurements because the output voltage may be but a fraction of a volt, and it is practically impossible to make a detector linear at so low a signal level.

A more laborious method is to measure the radio-frequency output as a function of the bias on the electrode to which the modulating voltage will be applied. If the characteristic is essentially linear, it is usually assumed that the audio-frequency envelope will be nearly free of distortion. However, it is necessary to measure the output and the bias with a precision of the same order as the minimum percentage distortion and, when the accuracy of ordinary voltage and current meters is not sufficiently good to give the desired accuracy in the result, this method cannot be used. This situation is analogous to that encountered in predicting distortion in amplifiers from measurements of the grid voltage — plate current characteristic.

FIGURE 2. Frequency spectrum for 70% modulation obtained with a low-frequency model of the TYPE 605-B Standard-Signal Generator. The unimportant components $2p \pm q$, $3p \pm q$, etc., have been omitted. While measurable they were not of practical importance. If the signal had been 100% modulated the side-bands $p \pm q$ would have had half the carrier amplitude.



The most direct way of obtaining the results would be to measure the amplitudes of all the products of modulation with a radio-frequency wave analyzer. Unfortunately, wave analyzers for radio frequencies are not available, but the use of an audio-frequency model of the radio-frequency circuit makes it possible to follow the same procedure with an audio-frequency analyzer. In the audio-frequency model, impedances are made the same as they would be at radio frequencies by multiplying the original values of all condensers and inductors by the ratio of the radio frequency to the audio frequency.

An outstanding advantage of this method is that the connection of measuring instruments to the circuit does not appreciably alter the circuit impedances and, therefore, does not affect the operation of the circuit.

If a distorted audio-frequency wave is used to modulate a high frequency in an ideally linear modulator, the resultant signal will be of the form

$$i = [1 + mf(qt)] \sin pt$$

where:

m is the percentage modulation, $f(qt)$ is the audio modulating signal and is assumed to have a peak amplitude of 1, and p and q are the angular velocities of the carrier and audio frequencies respectively.

If this expression is expanded it is found that the spectrum consists of a carrier, first order side-bands $(p + q)$ and $(p - q)$, and higher order side-bands $(p + nq)$ and $(p - nq)$. Each envelope distortion component is proportional to the ratio of the amplitude of $(p \pm nq)$ and $(p \pm q)$.

If carrier distortion is present (corresponding to non-linearity over the high-frequency cycle) there are additional terms containing np. If the high-frequency distortion varies over the audio-frequency cycle, there are still more complex products, such as $(2p \pm q)$, etc.

The above discussion shows that, in aperiodic or broadly tuned circuits, the envelope distortion can be measured by a simple wave analysis of the direct, non-rectified signal. In sharply tuned circuits, other factors may enter the problem, in particular side-band clipping and asymmetrical phase shift in the side-bands, which will introduce envelope distortion, even though no other modulation products are present. Since this article is intended to indicate the method rather than to give a complete treatment of the subject, only the aperiodic case is considered.

Figures 2 and 3 show the results of measurements on an audio-frequency model arranged for studying the modulator of the Type 605-B Standard-Signal Generator. A pure 5-kilocycle signal is used in place of a high-frequency carrier, and this is modulated by a 400-cycle signal. A spectrum for 70% modulation is shown in Figure 2. Figure 3 shows the distortion for various percentages of modulation.

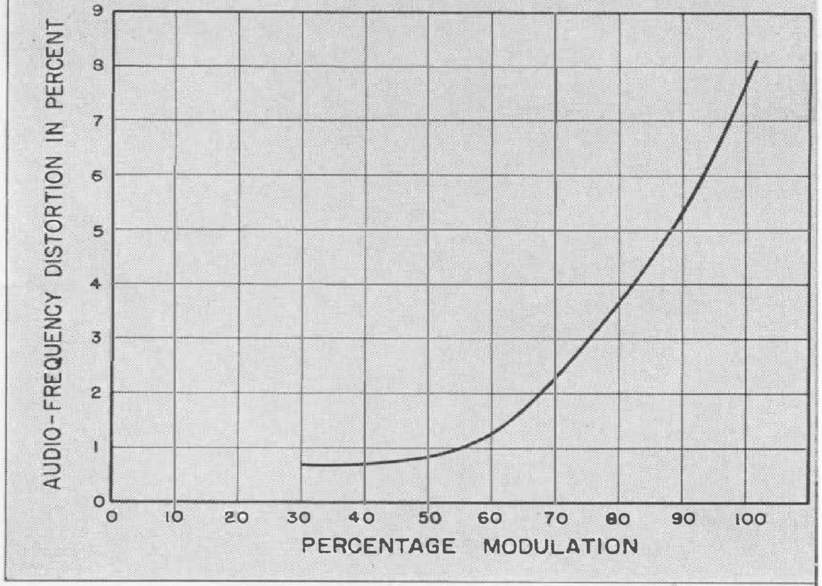


Figure 3. Total distortion as a function of modulation percentage.

Neither the use of a low-frequency model nor the direct analysis of a modulated wave to determine envelope distortion is at all new, but the method has been found so convenient and dependable in designing signal generators that it should find increased usefulness in other non-linear radio-frequency circuits.

— L. B. Arguimbau

EXTENDING THE FIELD OF APPLICATION OF THE VARIAC

● **FREQUENTLY** in attempting to make use of the Variac for voltage control it is found that a particular application involves exceeding in some respect the ratings of the Variac. The voltage may be too high, the frequency of the supply circuit too low, or the current to be handled too great. In some of these instances the method to be suggested may enable one to make use of a standard Variac where it apparently would not be applicable.

The method here proposed is indicated by the diagram of connections shown in Figure 1, and the normal connection that it replaces is shown in Figure 3. It is essential to this method of use that the Variac be used for making adjustments over only a limited range of voltage. The circuit may be used in either direction; that is, to obtain an output voltage variable over a small range with a constant input voltage or to obtain a constant output voltage from an input voltage which varies throughout a small range (or, of course, any reasonable combination of the two). A second requirement is that the transformer primary winding must have three leads instead of the two usually encountered.

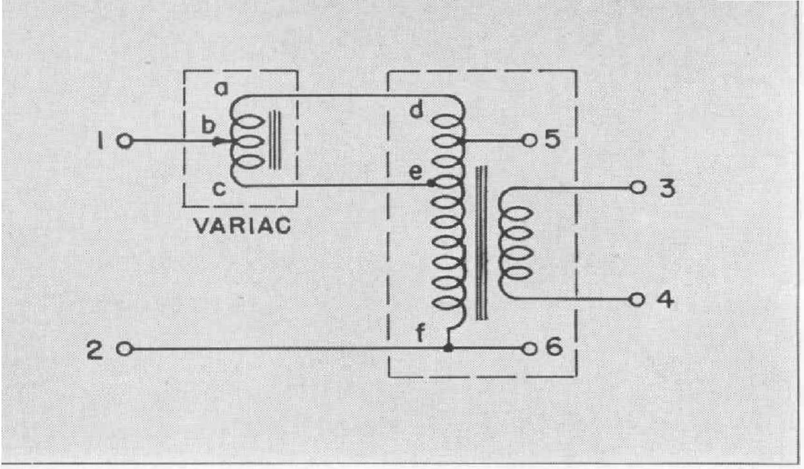


FIGURE 1. Generalized circuit of the type described in this article.

Figure 1 is almost self-explanatory if it be realized that energy fed to terminals 1 and 2 as input energy can be derived, either autotransformerwise at terminals 5 and 6, or by inductive coupling at terminals 3 and 4. Variations in the voltage of the source may be manually compensated by use of the Variac. Analogous parts of Figures 2 and 3 are designated by the same letters or numbers used in Figure 1.

FIRST APPLICATION

In a typical example, that which first occasioned the use of this method by us, it was desired to use the Variac to compensate for variations likely to be encountered on commercial power lines. The transformer fed from the Variac was to furnish plate and filament power for electronic equipment. For a nominal 115-volt line it was felt that provision for line voltages between 90 and 130 volts would be adequate. Accordingly, the transformer primary, in addition to the common terminal, had leads brought out from turns corresponding to 90 and 130 volts. The extremes of the Variac were connected to the latter two terminals (see Figure 2) and energy fed into the system through the Variac brush and the common terminal of the transformer primary. A number of inductively-coupled secondary loads were to be used, lumped together in the figure as winding 3–4. It will be noted that the voltage drops linearly (with turns or rotation angle) between points *a* and *c* on the Variac and between points *d* and *e* on the transformer primary. In effect then, the Variac provides a vicarious means of moving an input connection up and down on the turns of the transformer primary until a point is found such that the resultant flux density produces the correct voltages in the inductively-coupled windings.

ADVANTAGES

The advantages gained are as follows:

(a) Finer adjustment of voltage because of lower voltage-per-turn of the Variac.

(b) Variac may be used on circuit of higher voltage than would be the case if the connections were made as in Figure 3, that is, with the Variac extremities connected across the full line voltage and with the Variac arm and common point feeding a transformer primary designed for the lowest voltage to which the line might be expected to drop (90 volts in the example given).

(c) As in (b), the Variac could be used on a circuit of lower supply frequency than when using the connections of Figure 3.

(d) In almost all cases, the power-handling ability of the Variac is increased.

(e) A single set of circuit connections in an instrument assembly can be used

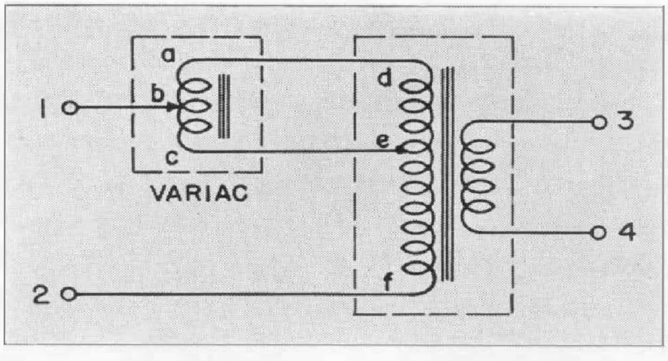


FIGURE 2. Specific circuit used by the author.

for practically all combinations of supply voltage and frequency likely to be encountered. In the example given, the total voltage across the Variac is only 40 volts whereas ordinarily it would be allowed to go as high as 135 volts, at 50 cycles.[1] This ratio of approximately 3.5 to 1 is available as the approximate maximum for the product of the ratios of supply circuit voltages and frequencies which can be accommodated simultaneously. Actually, if a Variac rated at 135 volts, 50 cycles, be used according to Figure 2, on a supply circuit of 115 volts, 50 cycles, the flux density would be 1/3.5 of the maximum allowable. Using the same Variac at 230 volts, 25 cycles, would result in a flux density four times as great, or only slightly more than the rated value. In practice, the combination of 230 volts and 25 cycles is rarely encountered, but the slightly increased flux density could probably be tolerated because of the lower supply frequency without resulting in excessive no-load losses.

Accordingly, the same Variac could be used in a given instrument for all types of power supply, and the only changes necessary would be those that would have to be made anyway, that is, substitution of a power transformer with the correct windings for the higher voltage and/or lower frequency.

DISADVANTAGES

The disadvantages, less important, are as follows:

(a) The one inherent in the system, namely, that voltage cannot be varied down to zero, but only over a restricted range.

(b) The transformer primary requires three terminals instead of two. To the instrument manufacturer, however, this disadvantage is more apparent than real. If the Variac were used according to Figure 3 for the same purpose of accommodating varying line voltages, the transformer would have to have a special primary suitable for the lowest voltage to be encountered. It is not much more serious to provide a special three-terminal primary when the two-terminal primary would have to be special anyhow.

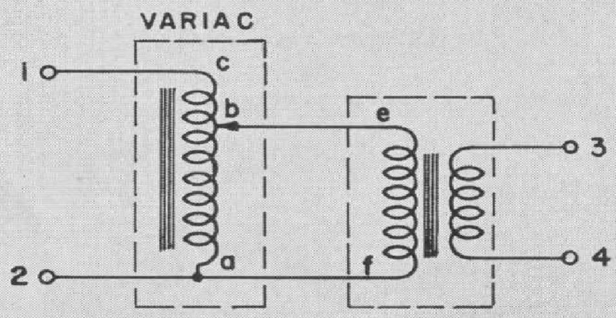


FIGURE 3. Normal method of connection for the Variac.

HOW TO CHOOSE AND APPLY THE CORRECT VARIAC

Selecting the correct size of Variac for use in the circuit of Figure 2 is very little different from the same problem for the circuit of Figure 3. It must be made certain that under the conditions of use the rated and maximum currents of the Variac are not exceeded. The only difference comes about from the fact that the brush carries not the load current but the primary current. With the Figure 3 connection, one usually wishes to derive a certain current on the secondary side, that is, through the brush. The current-rating curves given in the Variac bulletin and in instruction sheets indicate safe conditions of use for this connection. The way they are interpreted must be modified for the Figure 2 type of connection. In this instance, with a given output,

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[1] Note that the TYPE 200-B Variac is rated at 135 volts for 60 cycles line frequency only. At 50 cycles and supplying all the energy allowable, temperature rise would exceed 50° C. on continuous duty. Conditions of use would have to be adjusted if this rise is to be avoided.

the input current through the brush varies inversely with the input voltage, that is, with the position of the brush. The normal brush current should be determined by dividing 115 volts into the secondary volt-amperes (not watts; the Variac rating is in amperes), allowance having been made for the losses in the Variac and the power transformer. This will be the brush current when the line is at normal, 115 volts. If we now refer back to the example given at the beginning of this article, where line voltage may vary between 90 and 130 volts, the brush current will vary respectively from 1.28 times down to 0.88 times the normal brush current. With the normal line voltage about in the middle of the span of the Variac, the normal brush current should not exceed the so-called *rated* current of the Variac. With the line voltage low and the Variac brush rotated to the low-voltage end of the Variac, the brush current is larger and should not exceed the so-called *maximum* current of the Variac. This distinction between *rated* and *maximum* currents is made because, for instance, in the case of the TYPE 100 Variacs, the rated and maximum currents have the same value, and hence the Variac rating using a Figure 2 connection will be determined by the *maximum* current rating of the Variac. In most other instances, however, the determining factor will be the *rated* current of the Variac.

In wiring up a Variac in this way it must be remembered that the end connections should be reversed from those normally employed. For example, in Figure 3, to produce increasing output voltage with clockwise rotation the clockwise terminal *c* of the Variac should be the *high* one. With this method of Figure 2, however, the clockwise terminal *c* must be the *low* one in order to yield increasing output voltage with clockwise rotation.

—P. K. McELROY

REVISION OF THE SEASHORE MUSICAL TALENT TESTS

● **SINCE** General Radio instruments are to be found in nearly all college laboratories, it is natural that they are being used continually in new and important development projects in many different fields. Psychological tests and studies always have been among the more interesting applications, and several times unique uses of apparatus in this branch of science have been mentioned in the *Experimenter.*

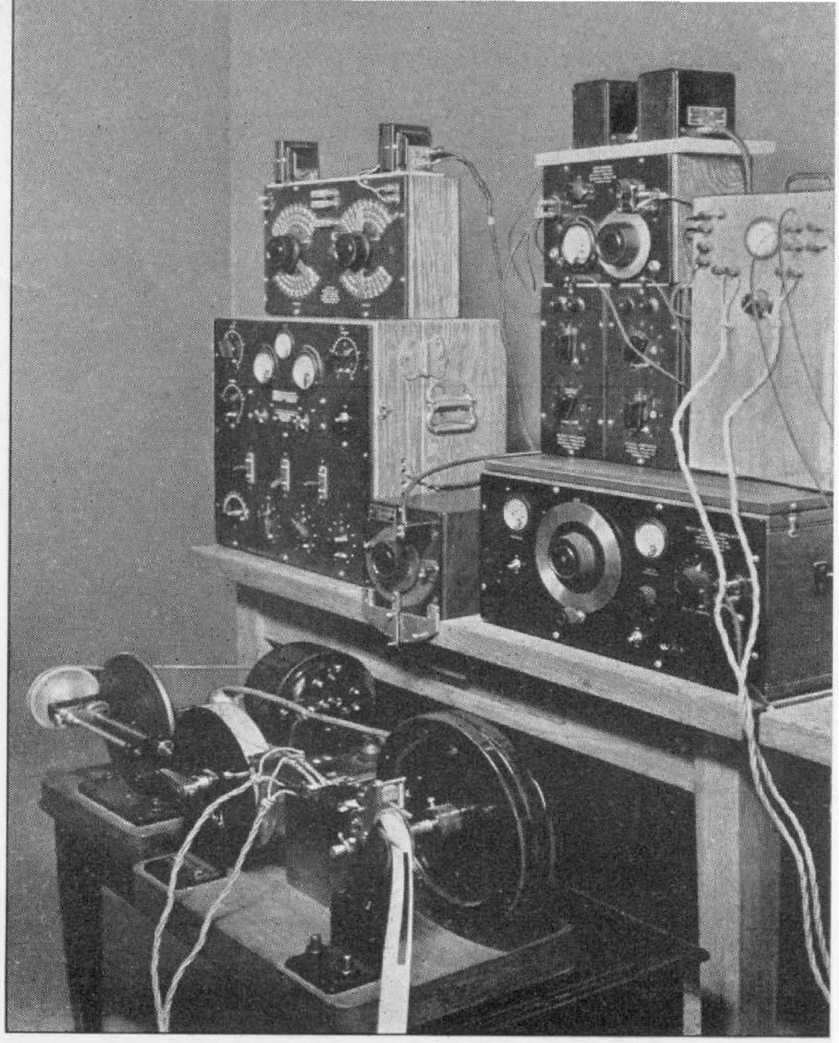
Recently at the State University of Iowa Psychological Laboratories, General Radio instruments were used in the revision of the Seashore Measures of Musical Talent which have been used internationally by schools, colleges, and universities for the past twenty years. Doctors Seashore, Lewis, and Saetveit revised the tests at the University as to both stimulus sources and values, and the final forms were then recorded on Victor records. Six tests were recorded: pitch, loudness, time, rhythm, tonal memory, and timbre.

The tone source of stimuli for the pitch, loudness, and time tests was a TYPE 613-B Beat-Frequency Oscillator, which was equipped with a TYPE 539-P Incremental-Pitch Condenser. Changes in pitch were made with the condenser, and to provide an accurate and rapid means for doing this a special indexing plate was mounted on the condenser. Pegs placed in appropriate holes served as stops for the rotating arm. To obtain the proper timing a special apparatus, carrying paper tape to make and break contacts, was used. The tape was cut to conform with a predetermined schedule of stimulus values, and, once it was inserted and the machine started, the output of the oscillator was started or stopped automatically. Since instantaneous making and breaking of the circuit caused a click, it was necessary to have the contacts control the grid bias on a one-stage amplifier which followed the oscillator and acted as a "transient eliminator." The oscillator output was not varied, but the signal was started and stopped by changing the bias on the amplifier. A condenser in the grid circuit could be adjusted to eliminate all the objectionable clicks.

A 500-cycle band-pass filter followed the amplifier and preceded the TYPE 546-A Microvolter which was used to make changes in signal level. The output of the microvolter was fed through a transformer to a TYPE 329-J Attenuation Box, which was used in the loudness test to change the level by known amounts. From the attenuator the signal went to the recording apparatus.

In running the pitch tests the oscillator and attenuators were set at the beginning, and the only changes that were necessary were made by means of the incremental-pitch condenser. Once the timing tape was started through, it was only necessary for the operator to watch a copy of the test schedule and, acting much as the sound-effect man in a radio broadcast, move the arm and pegs on the condenser according to his cues. Thus the desired stimulus values were produced in the proper order of presentation with the durational factors controlled by the tape timer.

In the loudness tests the pitch was kept constant and the loudness was varied by means of the TYPE 329-J Attenuation Box. The technique for varying the stimulus values and determining the order of presentation was similar to that used in the preceding test — the operator listened to the tones and moved the attenuation dials in accordance with the schedule. Timing was again automatic. The time test required no manipu-



The photograph shows the apparatus used in producing the tones for the revised musical talent tests. On the table at the right are the TYPE 613-B Oscillator and the TYPE 539-P Incremental-Pitch Condenser equipped with the special indexing plate. The TYPE 377-B Oscillator is at the left. In the foreground is the tape timer which controlled the intervals and duration of the tones. The attenuator above the TYPE 377-B was used for varying the loudness. The transient eliminator, coupling transformers, and band-pass filter, together with a TYPE 546-A Microvolter used to vary the output, are atop the TYPE 613-B.

lation of either pitch or loudness controls, and consisted in precutting the tape as before to give the desired time intervals, and then running it through the timer. The same pitch and loudness level were used throughout.

Two oscillators were necessary for the rhythm test, and so a Type 377-B Oscillator was used in addition to the Type 613-B. One oscillator furnished the accented notes and the other the unaccented ones, there being a 4.5-decibel difference in intensity between the two levels. The tape-timing apparatus was arranged with two sets of contacts, and another "transient eliminator" was used with the second oscillator. The tape was punched with holes corresponding to predetermined rhythm patterns. The length of contact was 0.04 second with a tempo of 100 per minute.

For the tonal memory test a Hammond organ was used as the source. Five-hundred-cycle tones from the Type 613-B were used as timing signals for the organist. The oscillator impulses were in turn timed by the tape method. The tempo in the tonal memory test was increased with each succeeding increase of melodic span. In the sixth test, for timbre, a specially constructed electrostatic tone generator was used to produce the desired stimuli, which could not be obtained from an ordinary oscillator.

MISCELLANY

ERRATA

● **THE** following typographical errors occurred in the September *Experimenter:*

Page 4, column 1, should read:

$G_c = 100$ micromhos
$R_c = 0.05$ ohm
$L_c = 0.0055$ microhenry

Page 4, Equation (6) should read:

$$C_x = \hat{C}_{r_2} - \hat{C}_{r_1} \simeq \frac{C_{r_2} - C_{r_1}}{1 - \omega^2 L_c\,(C_{r_1} + C_{r_2})}$$

● **MR. L. B. ARGUIMBAU** has been granted a one-year leave of absence from the General Radio Engineering Department and has joined the staff of the Department of Electrical Engineering at the Massachusetts Institute of Technology, where he is engaged in research in high-frequency measurements.

● **DON'T FORGET** the Second Annual Instrumentation Contest sponsored by the Industrial Instrument Section of the Scientific Apparatus Makers of America. A total of 12 prizes, ranging from $200 to $10, is offered for the best papers on either of the two following themes:

(1) Instruments Save Money
(2) Instrumentation Makes Jobs

The contest closes November 15, 1939. For official entry form and copy of the contest rules, write to:

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