the GENERAL®RADIO Experimenter

INDEX

TO

GENERAL RADIO
EXPERIMENTER

VOLUMES XVIII AND XIX

June, 1943 to May, 1945

GENERAL RADIO COMPANY
CAMBRIDGE MASSACHUSETTS
U. S. A.

INDEX
TO GENERAL RADIO EXPERIMENTER
Volumes XVIII and XIX, June 1943 through May 1945

INDEX BY TITLE

INDEX BY TYPE NUMBER

INDEX BY AUTHOR

INDEX

TO

GENERAL RADIO EXPERIMENTER

VOLUMES XX AND XXI

June, 1945 to May, 1947

GENERAL RADIO COMPANY
CAMBRIDGE MASSACHUSETTS
U. S. A.

I N D E X
TO GENERAL RADIO EXPERIMENTER
Volumes XX and XXI, June 1945 through May 1947

INDEX BY TITLE

Strobolux, Measuring Lateral Motions in a Rotating System with the (Kipling Adams: April, 1946)

Strobotac, Balancing to 0.000070 Inch with the September, 1945)

Tag before Returning Equipment for Repair, Ask for This (May, 1947)

Test Oscillator, A Wide-Range U-H-F (R. A. Soderman: November, 1946)

Test Set, Vacuum-Tube (April, 1947)

Testing with GR Instruments, Airline (July-August, 1946)

Testing with Impedance Bridges, Production (September, 1945)

The Constant Waveform Frequency Meter (H. H. Scott: February, 1946)

The New Broadcast Monitoring Equipment (November, 1946)

The Series and Parallel Components of Impedance (W. N. Tuttle: January, 1946)

Those Iron-Cored Coils Again (P. K. McElroy: December, 1946; January, 1947)

Trout Fishing, An Engineering Approach to (January, 1946)

Tuning Fork with Vacuum-Tube Drive, A Precision (Horatio W. Lamson: September, 1945)

Type 650 Impedance Bridge?, Have You a (Horatio W. Lamson: April, 1946)

Type 707-A Cathode-Ray Null Detector (September, 1946)

Type 1260-A Variac Rectifier (E. E. Gross: March, 1946)

Type 1261-A Power Supply (E. E. Gross: March, 1946)

U-H-F Ranges, A Peak-Reading Voltmeter for the (Arnold Peterson: October, 1946)

U-H-F Test Oscillator, A Wide-Range (R. A. Soderman: November, 1946)

V-5 Series Variacs--New Improved Models Replace 200-C Series (Gilbert Smiley: May, 1946)

V-10 Series Variacs--New, Standard Models, Intermediate Between 200-C and 100 Series (Gilbert Smiley: July-August, 1946)

Vacuum-Tube Drive, A Precision Tuning Fork with (Horatio W. Lamson: September, 1945)

Vacuum-Tube Test Set (April, 1947)

Vacuum-Tube Voltmeter, A New (C. A. Woodward, Jr: September, 1946)

Variac, Meter Calibration with the (May, 1947)

Variac Overload Protection (Gilbert Smiley: May, 1947)

Variac Rectifier, Type 1260-A (E. E. Gross: March, 1946)

Variacs--New, Improved Models Replace 200-C Series, V-5 Series (Gilbert Smiley: May, 1946)

Variacs--New, Standard Models, Intermediate Between 200-C and 100 Series, V-10 Series (Gilbert Smiley: July-August, 1946)

Versatile Monitor for Use from 1.6 to 150 Megacycles, A (C. A. Cady: February, 1947)

Vibration Measurements, An Analyzer for (W. R. Saylor: November-December, 1945)

Voltage Divider Now Available, Decade (December, 1946)

Voltmeter, A New Vacuum-Tube (C. A. Woodward, Jr: September, 1946)

Voltmeter for the U-H-F Ranges, A Peak-Reading (Arnold Peterson: October, 1946)

Wavemeter for 240 to 1200 Megacycles, A (Eduard Karplus: October, 1945)

Wavemeter, Improvements in the Precision (March, 1947)

Wide-Frequency-Range Capacitance Bridge, A (R. F. Field and I. G. Easton: April, 1947)

Wide-Range U-H-F Test Oscillator, A (R. A. Soderman: November, 1946)

INDEX BY TYPE NUMBER

INDEX BY AUTHOR

THE General Radio EXPERIMENTER

VOLUME XIX Nos. 8 & 9 JANUARY - FEBRUARY 1945

ELECTRICAL MEASUREMENTS AND THEIR INDUSTRIAL APPLICATIONS

FIFTH ARMY-NAVY "E" AWARD TO GENERAL RADIO COMPANY

Also

IN THIS ISSUE

Page

● **A FOURTH STAR** for our "E" banner, marking the fifth Army-Navy Production Award, was granted to the General Radio Company on December 23, 1944. We are proud of this recognition of our efforts, and it gives us pleasure to be one of the few in the electronic industry that have received the award for the fifth time.

The production of precision electronic test equipment is a highly specialized business. Test equipment is produced in a wide variety of designs for its many uses, but only in relatively small quantities of each.

War requirements have increased the demand for our test equipment many-fold. We were faced with the problem not of conversion to war materials production, but of increasing peacetime volume sufficiently to meet the demands of war. However, even the requirements

for war are usually not sufficient to permit mass-production methods. Therefore, other means of expansion had to be found.

The maintenance of quality and precision regardless of quantity is a primary consideration. These can only be effectively maintained by close supervision of the final manufacturing operations, including final assembly, calibration, and test. To assure this at General Radio we have kept these operations under our own roof, where both the best facilities and the most experienced personnel are available.

A large part of the other manufacturing operations have been subcontracted. For instance, several excellent machine shops have been located, where many of the machining operations are being done. Although these shops were not previously familiar with the type of work which we require, a group of our highly skilled representatives circulate among them to assist them in following our specifications and requirements. Across the street from our main factory is located the plant of one of the largest candy manufacturers in New England. Owing to wartime restrictions, this thoroughly modern plant found it necessary to curtail operations. Taking advantage of the opportunity thus afforded, we arranged to start them in as a major subcontractor, and an entire floor of the candy factory was converted to the production of electronic components. Personnel skilled in candy making were taught, and quickly learned, the techniques of electronic component production. This one subcontracting arrangement alone provided a most efficient source of supply of vital components which would otherwise have been a serious bottleneck.

Many other processes that were originally performed here were also sent out to other plants which had available the facilities and skills to perform them. This extensive use of subcontracting freed a sizable portion of our main factory for concentration on the final production operations which are so critical in the maintenance of quality.

The necessary expansion of the Calibration and Test Laboratory entailed most serious difficulties, because the procedures are necessarily complicated and can only be undertaken by very well-trained and able personnel. To meet this need, training classes were started for groups of female employees. The fundamentals of electricity and radio were taught, and the theory and practice of electronic measurements were gone into as far as time permitted.

Occasionally the demand for a particular instrument has exceeded the capacity of our expanded facilities. In these cases we have turned over to other firms complete designs, drawings, and models for their exclusive use. No royalties or license fees were charged.

In common with every other electronic producer, we were and are faced with the problem of the continual substitution of materials and components. Some of the substitutions of materials, for instance, were carried on to the fifth degree. In components also, new sources of supply are continually being investigated to insure a smooth flow of these vital elements.

The Army-Navy "E" award is a recognition of production achievement. Another achievement of which we are proud is the substantial contribution that our Engineering Department has been able to make to the prosecution of the war by development work on secret war projects that the General Radio Company has undertaken. Still another is the large amount of consulting engineering service that has been given the Armed Services on problems where our experience could be helpful. Many thousands of hours of highly skilled engineering service have been devoted to the solution of the specialized problems of this technical war. Our hope is that we have contributed our best toward an early victory.

GET YOUR ORDER IN NOW FOR POSTWAR DELIVERY

● **YOU ARE UNDOUBTEDLY GIVING** consideration to the replacement of some of the old test equipment in your postwar plant with new and modern designs as soon as they become available for civilian use. A monitor for the broadcast station, a standard-signal generator for the receiver laboratory, and a new vacuum-tube voltmeter for general test purposes may be among the possibilities.

A plan for accepting orders without priority rating now for delivery later when war conditions permit has been in operation for some time. A brief mention of this "reservation-order" plan was made in last month's issue of the General Radio *Experimenter*. Under the plan we shall be glad to receive your reservation-order for new equipment of the latest design for delivery to you as soon as conditions permit.

Our reservation-order plan is very simple. Send us your order on your regular order form marked "Reservation-order — for delivery later." We will fill these orders chronologically by the date that we receive them. We guarantee that these reservation-orders will receive first attention as soon as the priority restrictions are lifted, that the latest design of equipment will be used to fill them, and that no other orders will be filled until all of the reservation-orders are taken care of. No deposit or guarantee is required.

Because you may change your mind before shipment can be made, or because we may find that for some reason we will not be in a position to supply the particular material called for, these reservation-orders may be cancelled by either of us up to sixty days before shipment would be made. We will, of course, advise you in time of the estimated shipping date and will then supply you with complete specifications and price.

Although no public announcement of this reservation-order plan has been made until recently, it is already very popular, and a substantial number of orders have been received.

Our Engineering Department has been fully occupied with research and development for war purposes. Out of these developments are emerging plans and designs for greatly improved postwar products. We expect to have new designs available to supersede a number of the instruments listed in our last general catalog of 1939. These new products will embody the important developments and advances that have been made during the war years. For the purpose of reservation, however, your order may make reference to the now current type numbers or names.

The requirements for the Armed Services come first. When the war job is done, we will convert to the production of the most modern designs of precision test equipment for the civilian market. Reservation-orders will come first.

CORRECTIONS FOR RESIDUAL IMPEDANCES IN THE TWIN-T

● **WHEN MEASUREMENTS ARE MADE** near the upper frequency limit of the Type 821-A Twin-T Impedance Measuring Network, it becomes necessary to correct the observed results for the effects of certain undesired impedances that exist within the measuring circuit. The only internal impedances that give rise to significant errors are the residual inductance and resistance of the precision condenser across which the substitution measurement is made. All other impedances in wiring or circuit components have been reduced to negligible values or else do not affect the measurement, because of the substitution method employed.

In the approximate equivalent circuit (Figure 1) of the precision condenser are shown the relative locations of the important residual impedances. Average values are as follows:

$L_C = 6.1 \times 10^{-9}\ h$

$R_C = 0.026\ \Omega$ at 30 Mc

$L'' = 3.15 \times 10^{-9}\ h$

$L' = 6.8 \times 10^{-9}\ h$

These values are all essentially independent of the setting of the condenser and, with the exception of the resistance R_C, are independent of frequency. The latter varies directly as the square root of the frequency, inasmuch as skin-effect is complete at frequencies where R_C can have any significant effect on measurements.

The errors introduced are, in general, proportional to the square of the frequency, to the magnitude of the susceptive component of the admittance being measured, and to the initial setting of the precision condenser. Because of this latter fact, the initial setting should always be as low as possible.

Nature of Errors

The four residual impedances listed above introduce several correction factors which must be applied to the observed readings to determine the true value of the unknown admittance $Y_X = G_X + jB_X$. The complete approximate expressions that include all terms significant at any frequency within the operating range of the instrument are

$$B_X = \frac{\omega(C_{e_1} - C_{e_2})}{1 + \omega L' B'_X} \qquad (1)$$

$$G_X = \frac{G''(1 - \omega^2 L'' C_{e_1})^2 + R_c \omega B'_X (C_{e_1} + C_{e_2})}{(1 + \omega L' B'_X)^2} \qquad (2)$$

In these equations the symbols that appear are identified in Figure 1 and as below.

C_{e_1} and C_{e_2} are the effective capacitances between the point b' (Figure 1) and ground, for the two settings of the precision condenser. They differ from the direct-reading static values of ca-

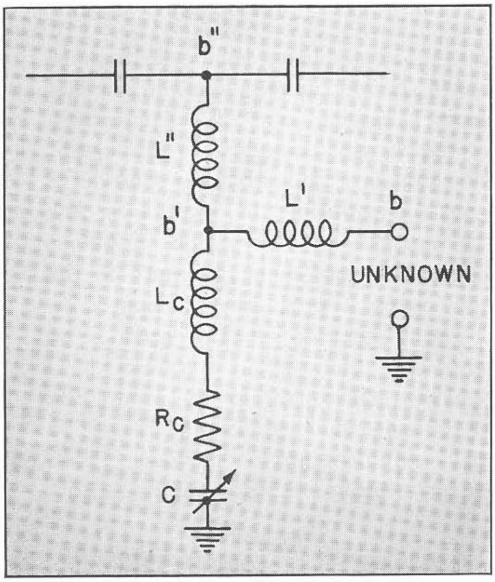

Figure 1. Equivalent circuit of the precision condenser used in Type 821-A Twin-T, showing the location of residual impedances.

pacitance because of the inductance L_C, in accordance with the expression

$$C_e = \frac{C}{1 - \omega^2 L_c C} = \frac{C}{\alpha} \qquad (3)$$

where α is defined as $1 - \omega^2 L_c C$ and C is the reading of the precision condenser.

The quantity B'_X is the effective susceptance difference between the two settings and is equal to

$$B'_X = \omega(C_{e_1} - C_{e_2}) \qquad (4)$$

The quantity G'' is the apparent conductance as determined directly from the dial readings.[1]

Correction for Errors

Although the above expressions are formidable, the calculations involved can be reduced considerably by the use of charts, together with a systematic tabular form of calculation. In the following, the expressions for G_X and B_X are rewritten in forms that lend themselves readily to comparatively rapid evaluation, using the charts presented.

Designating the admittances at the points b' and b'' by a corresponding system of primed notation, and identifying the various correction factors by suitable symbols, we may write

$$B_X = \frac{B'_X}{\gamma} \qquad (5)$$

$$G_X = \frac{G'_X}{\gamma^2} \qquad (6)$$

The quantity $\gamma = 1 + \omega L' B'_X$ is the correction factor introduced by the inductance L', which is effectively in series with the unknown admittance.[2]

In turn, the quantities B'_X and G'_X are related to the observed quantities by

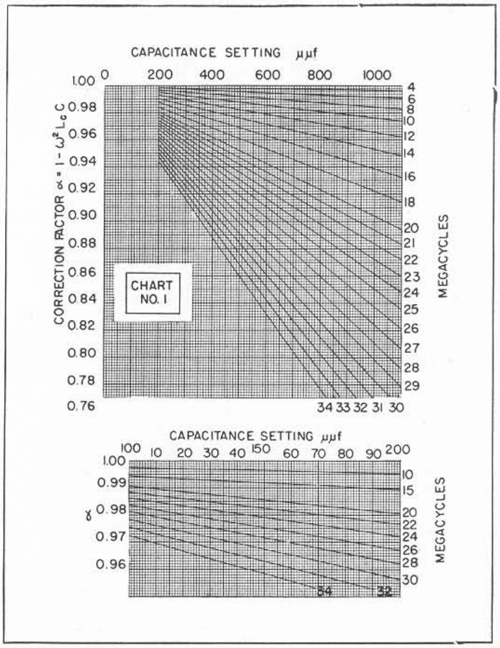

FIGURE 2. Chart No. 1 for determining the quantity ∝. To facilitate reading the chart at low values of capacitance, the portion below 200 $\mu\mu f$ is expanded and plotted below the main chart.

$$B'_X = \omega(C_{e_1} - C_{e_2}) \qquad (7)$$

$$G'_X = G''\beta + \Delta_G \qquad (8)$$

G'', C_{e_1}, and C_{e_2} have been previously identified. The factor $\beta = (1 - \omega^2 L'' C_{e_1})^2$ is the correction introduced by L''. The quantity Δ_G is the correction introduced

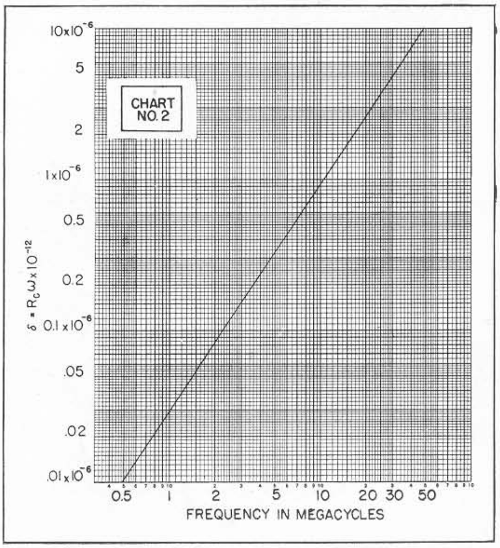

FIGURE 3. Chart No. 2 for determining the quantity δ which is used to calculate the correction term ΔG.

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[1] The conductance dial reads directly in μmho at 1, 3, 10, and 30 megacycles. At all other frequencies the reading must be multiplied by the square of the ratio of the operating frequency to the nominal frequency for the particular switch setting used.

[2] L' is also in series with the inductance of any external lead that may be used to connect the unknown to the instrument. It is shown later that, because of this fact, the chart for the L' correction may also be used to correct for lead inductance.

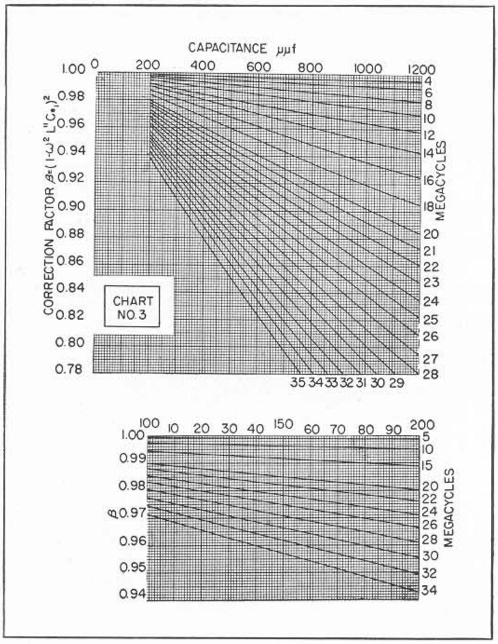
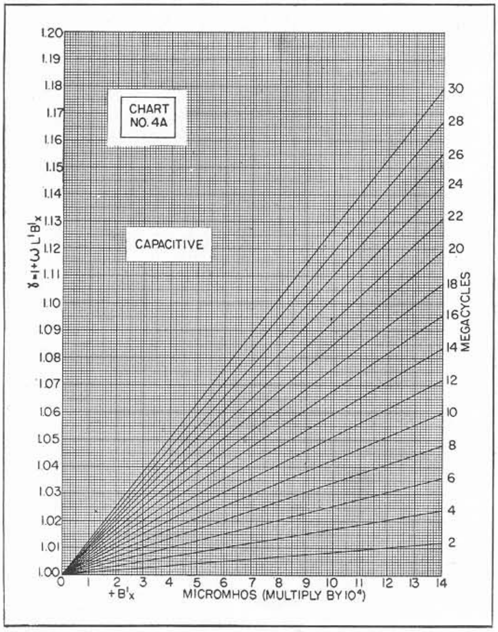


FIGURE 4. The correction factor β is determined from Chart No. 3, shown here. Full-size reproductions of these charts are available to users of the Twin-T upon request to the General Radio Company.

by the resistance R_C and is given by

$$\Delta_G = R_C \omega B'_X (C_{e_1} + C_{e_2}) \qquad (9)$$

$$= \delta B'_X (C_{e_1} + C_{e_2})$$



The charts give the quantities α, β, γ and δ, using the average values of the residual impedances as previously given.

In terms of the quantities α, β, γ, and δ, expressions 1 and 2 become

$$B_X = \frac{\omega\left(\frac{C_1}{\alpha_1} - \frac{C_2}{\alpha_2}\right)}{\gamma} = \frac{B'_X}{\gamma} \qquad 1(\text{a})$$

and

$$G_X = \frac{G''\beta + \delta B'_X\left(\frac{C_1}{\alpha_1} + \frac{C_2}{\alpha_2}\right)}{\gamma^2} \qquad 2(\text{a})$$

The charts are plotted in units corresponding to the dial calibrations (megacycles, micromhos, and micromicrofarads) so that no conversion factors need be used.

The data sheet of Figure 8 tabulates the various quantities involved, in the sequence they are used in arriving at the final answer. The use of a data sheet of this kind, in connection with the charts, reduces the amount of calculation required, greatly minimizes the chances of error, and provides a permanent and orderly record.

Numerical Examples

Several actual calculations are shown in the table, for different unknown admittances and at several frequencies. The observed data for these examples were as follows:

	f	C_1	C_2	G''
No. 1	30 Mc	100.0	388.1	300
No. 2	30 Mc	250.0	151.5	55
No. 3	25 Mc	100.0	139.8	62.5
No. 4	30 Mc	100.0	110.0	1000
No. 5	10 Mc	1000.0	442.4	80

Corrections for External Lead

The result obtained by the method described gives the conductance and

FIGURE 5. Chart No. 4, for determining γ, is given in 3 parts. Chart No. 4A, shown here, is used for positive susceptances, corresponding to capacitive unknowns.

susceptance of the admittance *at the terminals* of the Twin-T. In many cases, of course, the admittance to be measured cannot be brought directly to these terminals and an external lead must be used. Such a lead will in itself introduce correction factors which may under certain circumstances easily exceed those produced by the internal impedances, even if care is taken to make the lead as short as possible.

The capacitance to ground of the external lead introduces no error if the initial balance is established with the leads in place but disconnected at the unknown.[3] The inductance of the lead (L_l) causes the observed admittance to differ from the true admittance. Since the lead inductance is in series with the internal inductance L', it is apparent that the correction introduced by L_l is identical in form with that introduced by L'. The correction for the series inductance depends, for a given B'_X, on the *reactance* of the series inductance. Accordingly, the corrections introduced by the sum of L' and L_l will be equal to the corrections that would be produced by L' alone at some higher frequency, f'.

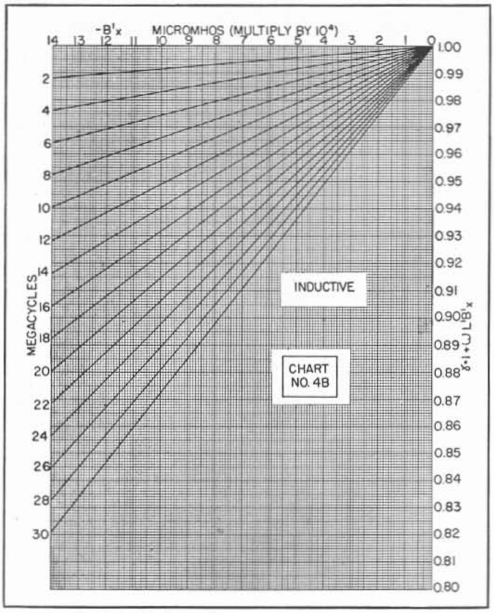


Figure 6. For negative susceptances (inductive) Chart No. 4B, above, is used.

That is,

$$f' = f\left(1 + \frac{L_l}{L'}\right) \qquad (10)$$

where f' is the frequency at which the correction factor given by Chart No. 4 (for L' alone) equals the total correction for $L' + L_l$ at the actual frequency of measurement (f). Thus the correction

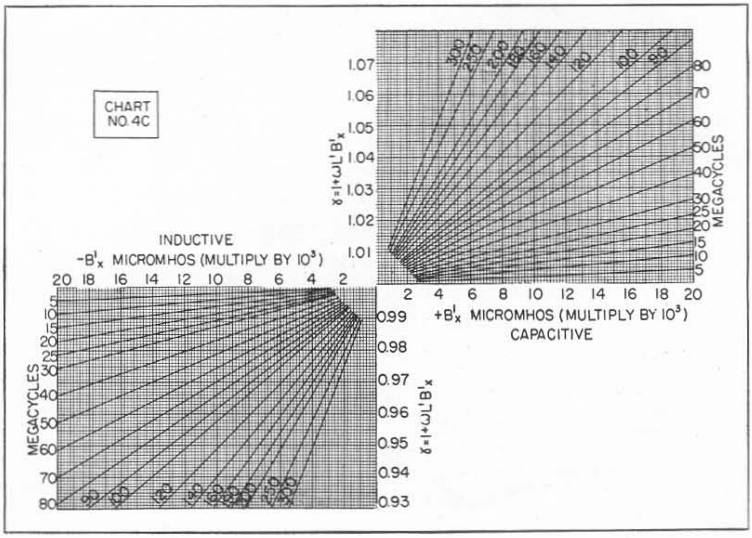


Figure 7. Chart No. 4C shows expanded the crowded portions of Charts 4A and 4B. For use in determining lead corrections (see text) a much wider range of frequency is shown.

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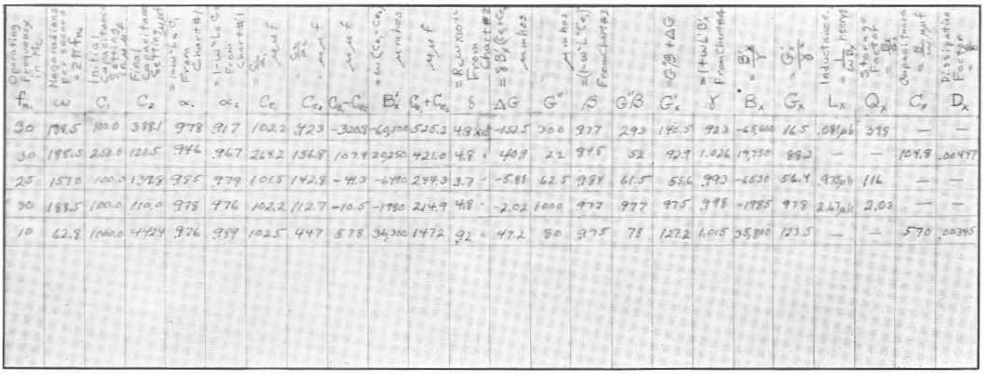
[3] This point is discussed on page 13 of the instruction book for the Type 821-A Twin-T Impedance-Measuring Circuit.



Operating Frequency in Mc f_m	Megaradians per second $= 2\pi f_m$ ω	Initial Capacitance Setting in μμf C_1	Final Capacitance Setting μμf C_2	$= \frac{1}{1-\omega^2 L_0 C_1}$ From Chart #1 α_1	$= \frac{1}{1-\omega^2 L_0 C_2}$ From Chart #1 α_2	$= \frac{C_1}{\alpha_1}$ μμf C_{e_1}	$= \frac{C_2}{\alpha_2}$ μμf C_{e_2}	μμf $C_{e_1}-C_{e_2}$	$= \omega(C_{e_1}-C_{e_2})$ μmhos B'_x	μμf $C_{e_1}+C_{e_2}$	$= R_0\omega \times 10^{-12}$ From Chart #2 δ	$= \delta B'_x(C_{e_1}+C_{e_2})$ μmhos ΔG	μmhos G''	$= (1-\omega^2 L C_{e_1})$ From Chart #3 β	$G''\beta$	$= G''\beta + \Delta G$ G'_x	$= (1+\omega L' B'_x)$ From Chart #4 γ	$= \frac{B'_x}{\gamma}$ B_x	$= \frac{G'_x}{\gamma}$ G_x	Inductance $= \frac{1}{\omega B_x}$ henrys L_x	Storage Factor $= \frac{B_x}{G_x}$ Q_x	Capacitance $= \frac{B_x}{\omega}$ μμf C_x	Dissipation Factor $= \frac{G_x}{B_x}$ D_x
30	188.5	100.0	388.1	.978	.917	102.2	423	-320.8	-60,500	525.2	4.8×10^{-6}	-152.5	300	.977	293	140.5	.923	-65,600	165	.081μh	395	—	—
30	188.5	250.0	122.5	.946	.967	264.2	156.8	107.4	20,250	421.0	4.8 "	40.9	22	.945	52	92.9	1.026	19,750	88.2	—	—	104.8	.00447
25	157.0	100.0	137.8	.985	.979	101.5	142.8	-41.3	-6490	244.3	3.7 "	-5.88	62.5	.984	61.5	55.6	.993	-6530	56.4	.975μh	116	—	—
30	188.5	100.0	110.0	.978	.976	102.2	112.7	-10.5	-1980	214.9	4.8 "	-2.02	1000	.977	977	975	.998	-1985	978	2.67μh	2.03	—	—
10	62.8	1000.0	442.4	.976	.959	1025	447	578	36,300	1472	.92 "	49.2	80	.975	78	127.2	1.015	35,800	125.3	—	—	570	.00345

FIGURE 8. Typical data sheet for tabulating the correction factors and facilitating calculations.

for L' and L_l can be made simultaneously by entering Figure 4 with the frequency f' as determined by Equation (10). Alternatively, the combined correction can be determined from Chart No. 4, using the operating frequency but using a value of B determined by multiplying the actual B'_X by $1 + L_l/L'$.

The value of L_l can be estimated fairly well by calculation or can be measured by a method described in the instruction book (page 13).

Although the magnitudes of the residual parameters used in preparing the charts are average values, the charts can also be used with values as measured on any particular instrument by using methods similar to that described above for lead inductance. Ordinarily, however, the use of the average corrections rather than those measured on any particular instrument will produce no significant error in the result.

The charts and data sheets reproduced here are available in limited quantities without charge to users of the TYPE 821-A Twin-T Impedance Measuring Network. A set of charts and a quantity of data sheets will be sent promptly upon receipt of the serial number of the instrument with which they are to be used.

—IVAN G. EASTON

ACKNOWLEDGMENT The use of charts for determining corrections on the Twin-T was originally suggested by Mr. Dwight Blanchard, of the Standards Laboratory, Sperry Gyroscope Company, who prepared a set of charts for his own use.

The charts shown here differ slightly from those used by Mr. Blanchard, but are an outgrowth of his work.

THE GENERAL RADIO PULSE GENERATOR

● **MODERN ELECTRONIC MEASUREMENTS** often involve the use of square waves or pulses. For tests involving rise and decay time, band width or transient characteristics, a steep wavefront is necessary.

Square waves and pulses are essentially the same thing. However, in common usage the terms are generally used to differentiate between rectangular waveforms having respectively symmetrical and nonsymmetrical positive and negative portions.

In many types of work with square waves, it is necessary that the waveform be symmetrical. That is, that the positive and negative portions of the cycle be equal in time duration. This is particularly desirable in testing audio-frequency amplifiers or other similar devices in which continued application of a nonsymmetrical waveform will cause a shift in automatic bias circuits. On the other hand, for testing circuits such as those used in various types of timing and ranging equipment, extremely short pulses are preferable so that the square waveform may actually have the negative portions of the cycle 1000 times as long as the positive portions, or vice versa.

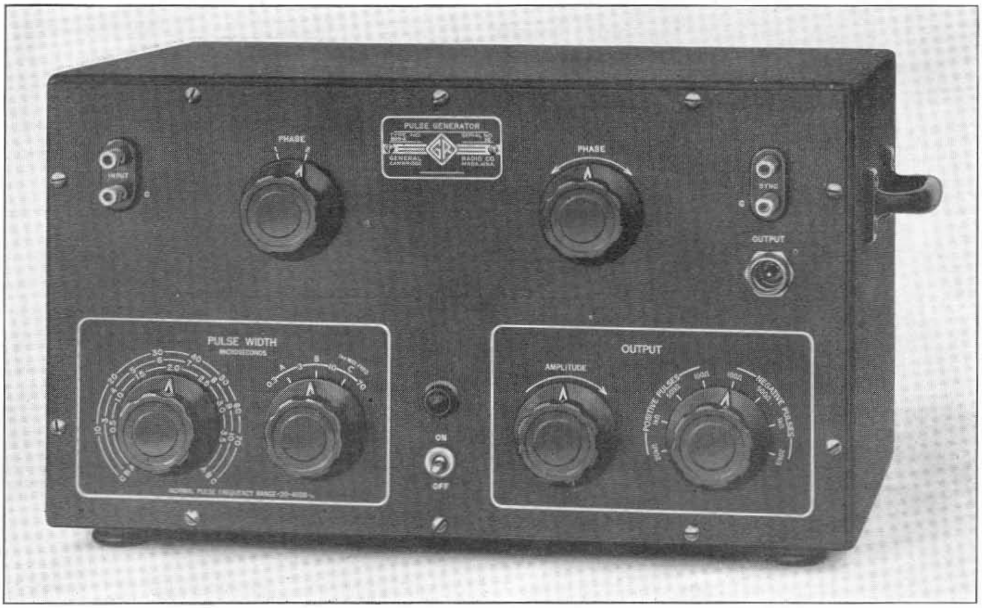
With a symmetrical square wave the average voltage is midway between the positive and negative peaks. With a pulse wave, on the other hand, the average voltage approaches that of the longer of the two peaks, so that the wave becomes in effect a series of pulses, positive or negative as the case may be. This is shown in Figure 2. It is particularly desirable in many tests to modulate a standard-signal generator with this type of waveform, thus providing an output which consists of a series of relatively short pulses of radio frequency timed accurately and with practically complete cutoff of the radio-frequency signal between pulses.

The General Radio Type 869-A Pulse Generator has been developed particularly for these applications. While this instrument has in the past been manufactured only for a few special applications, it is now available in sufficient quantities to be added to the regular General Radio line of laboratory equipment.

The pulse circuit itself is of standard design, comprising two thyratrons, one of which turns the pulse on, while the other turns it off. Pulse length is adjustable from 0.3 to 70 microseconds by means of an adjustable time delay circuit which controls the second thyratron. An approximate calibration is provided on the panel so that the instrument is direct-reading in pulse length for most practical applications.

The pulse rate may be varied between 20 and 4000 per second and is controlled by synchronization from an external source, which may be a part

Figure 1. View of the Type 869-A Pulse Generator, showing panel and controls.



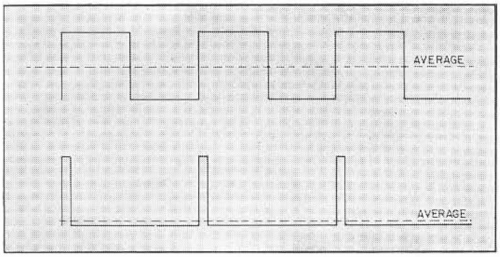


FIGURE 2. (*above*) Square Wave and (*below*) Pulse Wave.

of the equipment under test or a standard audio-frequency oscillator. The only restriction in this frequency range is that pulse lengths above 10 microseconds cannot be used at rates above 1000 cycles because of the deionization time in the thyratrons themselves.

The pulses are essentially flat-topped with an effective rise time of 0.1 microsecond for pulse lengths below 10 microseconds. For longer pulses the rise time is always less than 10% of the pulse width.

While the pulsing circuit itself is fairly conventional, certain circuit refinements have been added to improve the life of the thyratrons and to provide completely independent controls for pulse amplitude, length, and rate. The pulse length is independent of the load connected to the generator. A synchronizing amplifier of the limiting-differentiating type is included to provide highly accurate timing of the pulses, even when they are controlled from a low-amplitude sine wave. The output of this amplifier is also available for triggering a cathode-ray oscilloscope, thus providing a high degree of synchronization in the pattern on the screen. This is a particularly important feature for most pulsing tests, since any error in the timing of the pulses must be small compared to the rise time, or an unsteady pattern will be produced upon the oscilloscope screen, thus completely obscuring those very details which it is most desirable to observe. Phasing controls are provided to adjust the position of the pattern on the screen. An oscilloscope for use with this pulse generator should of course be of the triggered-sweep variety.

The pulse generator was originally designed for modulating various General Radio signal generators which were in use in the field and which had been modified to allow pulse modulation. It is, of course, also suitable for pulsing various radio-frequency oscillators that have been designed for the purpose.

The instrument includes a phase-inverting output amplifier providing either positive or negative pulses at various impedance levels, as shown in Table I. For best pulse shape, the lowest possible output impedance should be used. The instrument is completely shielded and provided with a shielded

TABLE I
PEAK OUTPUT VOLTS—OPEN CIRCUIT

Output Setting	*Pulse Polarity*								*Operating Frequency**
	Positive				*Negative*				
	20 KΩ	1000 Ω	500 Ω	100 Ω	100 Ω	500 Ω	1000 Ω	20 KΩ	
Range A	90	80	70	20	18	80	150	300	500 ∽
Range B	100	90	80	20	18	90	170	300	500 ∽
Range C	100	80	80	20	18	90	180	300	500 ∽

*For other operating frequencies, the voltages will be approximately within 20% of the values given above. In general, the open circuit output voltage will tend to decrease as the pulse width and operating frequency increase.

cable for connection to a signal generator, thus permitting operation of the signal generator at low carrier output levels without interference from the pulse generator. The pulse generator is adapted for making a wide variety of laboratory tests where steep wavefronts are required.

— H. H. Scott
C. A. Cady

SPECIFICATIONS

Repetition Rate: 20 to 4000 cycles. Pulses longer than 10 microseconds are limited to a maximum frequency of 1000 cycles.

Input Voltage: Between 5–10 volts are required for normal control. For improved stability at the lowest frequencies, this may be increased to a maximum of 30 volts.

Input Voltage Waveform: This is not critical, and may vary from a sine wave to a triangular wave. Care must be taken, however, to keep this signal reasonably free from power supply hum voltage.

Synchronizing Output: A clipped sine wave appears across the synchronizing output terminals of approximately —160 and +50 peak volts. This may be used to control the high-speed sweep circuit of an oscillograph, that has been provided with suitable triggering amplifiers.

Phasing Controls: Panel controls are provided to permit adjustable phasing of the output pulse, with respect to the voltage obtained at the synchronizing output terminals, over a limited range.

Pulse Width: The output pulse is continuously adjustable over three ranges. These are 0.3–3.0, 3–10, and 10–70 microseconds, respectively. The calibration of these controls is approximately correct over the entire frequency range.

Pulse Amplitude Control: A panel control permits the pulse amplitude to be adjusted from zero to maximum, with a negligible effect upon the pulse waveform.

Pulse Waveform: The pulse is essentially flat-topped, and has an effective rise time of 0.1 microsecond for pulse widths less than 10 microseconds. For longer pulses, the rise time is less than 10% of the pulse width.

Output Selector: A panel switch permits any one of four impedances to be inserted in the output amplifier, and also provides either positive or negative pulses.

Output Amplitude: See Table I.

Effective Output Impedances:

Positive

Impedance Setting	20 KΩ	1000 Ω	500 Ω	100 Ω
Output Impedance	350 Ω	350 Ω	350 Ω	100 Ω

Negative

Impedance Setting	100 Ω	500 Ω	1000 Ω	20 KΩ
Output Impedance	120 Ω	550 Ω	950 Ω	11,000 Ω

These values are approximate, and will change with the load applied, due to the limiting action of the output amplifier.

Power Supply: Either 115 or 230 volts, 50–60 cycles may be used. A variation of ±10% in the supply voltage will cause a minor variation in the output pulse amplitude, and will generally tend to change the pulse width. For optimum performance, operation at the 115- or 230-volt value is recommended. Power input is 60 watts.

Accessories Required: To drive the generator an a-c source is needed. The General Radio Type 913-B Beat-Frequency Oscillator is recommended.

Accessories Supplied: A seven-foot line connector cord, two Type 274-M Plugs, one Type 774-R2 Patch Cord, spare fuses, and pilot lamps are supplied.

Tubes Supplied with Instrument:

2 — Type 6H6
1 — Type 6AC7
1 — Type 6X5
1 — Type VR-150-30
2 — Type 884
1 — Type 6SC7
1 — Type 6ZY5G
1 — Type VR-105-30

Mounting: Metal cabinet.

Dimensions: (Length) 19 x (height) 9¾ x (depth) 12⅛ inches, overall.

Net Weight: 38¼ pounds.

Type		*Code Word*	*Price*
869-A	Pulse Generator	OLIVE	$260.00

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THE General Radio EXPERIMENTER

VOLUME XIX No. 10 MARCH 1945

ELECTRICAL MEASUREMENTS AND THEIR INDUSTRIAL APPLICATIONS

HIGH-FREQUENCY COMPENSATION FOR AMPLIFIERS

Also

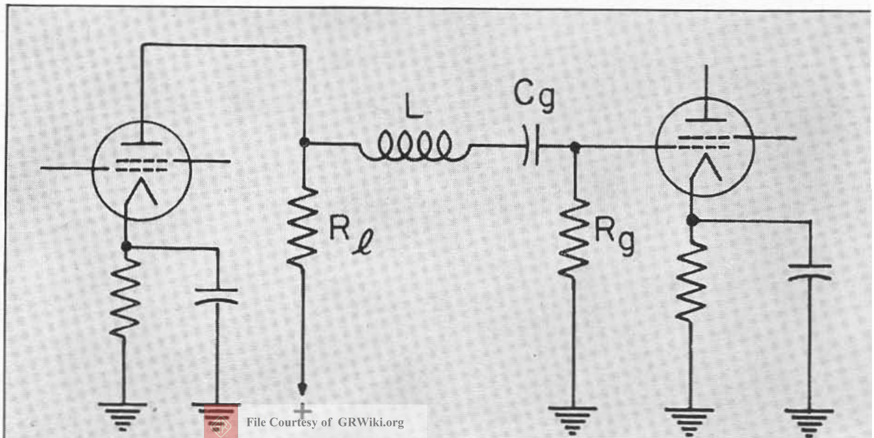
IN THIS ISSUE

Page

● **ONE OF THE MOST USEFUL TYPES** of high-frequency compensation for a broadband amplifier is a series coupling inductor as shown in a typical interstage connection in Figure 1. The simplified representation of Figure 2 illustrates that this inductor, *L*, forms with the output capacitance of one stage, C_1, a low-pass filter. Wheeler[1] has shown that for a termination of such a filter by the image impedance of a constant-k section, best results will be obtained with a capacitance at the terminated end of one-half that at the unterminated end.

In actual practice, the termination is usually a resistor, which does not satisfy Wheeler's condition; and, while the ratio of the capacitances can be varied by locating the grid resistor and blocking condenser at one or the other end of the series coil, it is not always possible to obtain a capacitance ratio of ½ unless a capacitor is added to one end. Since

Figure 1. Interstage coupling circuit with series peaking inductor.



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[1] Harold A. Wheeler, "Wide-Band Amplifiers for Television," *Proc. I.R.E.*, Vol. 27, No. 7, July, 1939, pp. 429–438.

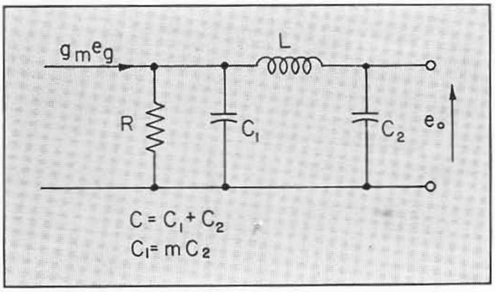

Figure 2. Simplified equivalent circuit of interstage coupling with low-frequency effects neglected.

the unavoidable circuit capacitances are the initial factors limiting the gain for a given band width, adding capacitance seems at first an undesirable procedure.

Since there seem to be no published data giving additional details for design, an analysis has been made of the simple four-element circuit of Figure 2, in order to determine if this ratio is necessary for uniform gain over the desired band. The present analysis has been carried through only for the amplitude characteristic. In many cases the phase characteristic is sufficiently important to require a design based on considerations of both amplitude and phase.

The circuit of Figure 2 shows C_1 as the total shunt capacitance at the terminated end of the filter, C_2 as the total shunt capacitance at the unterminated end, and R as the parallel combination of the plate load resistor, R_l, and the dynamic plate resistance of the amplifier tube. The grid resistor, R_g, is neglected as being very large compared to that parallel combination. If R_g is on the same side of the inductor as R_l, it too can be put into the parallel combination. In addition, C_1 is expressed as a fraction of C_2 in order to simplify reference to this important ratio, m.

A straightforward calculation of the circuit of Figure 2 shows that the magnitude of the ratio of grid-to-grid voltages, normalized to give unity at low frequencies, is

$$\left|\frac{g_m R e_g}{e_0}\right|^2 = \left[1 - \frac{1}{1+m}\left(\frac{L}{CR^2}\right)(\omega CR)^2\right]^2 + \left[\omega CR - \frac{m}{(1+m)^2}\left(\frac{L}{CR^2}\right)(\omega CR)^3\right]^2$$

Here one can select various values of m and observe the effect on the gain characteristic (the square root of the reciprocal of the above expression) of various values of inductance. Some representative results are shown in Figure 3. The typical curve, representing the gain

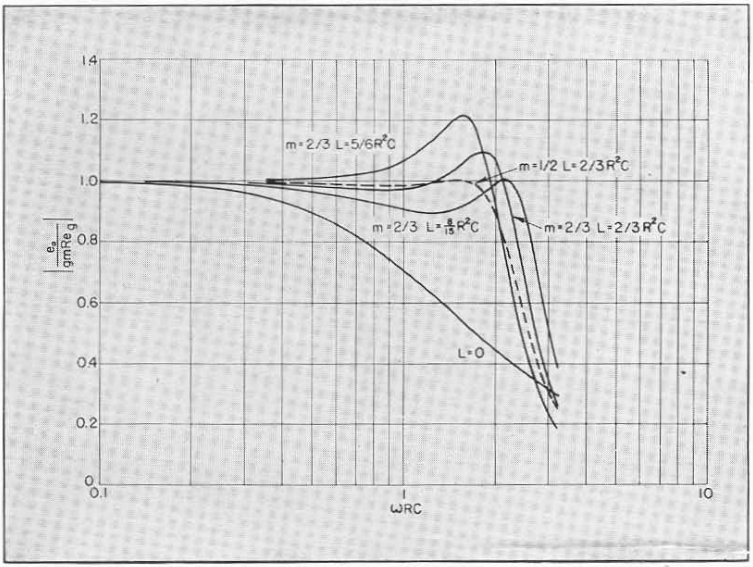

Figure 3. Gain characteristic of a single stage for various values of the capacitance ratio and peaking inductance.

as a function of frequency, as the frequency is raised, shows first a sag and then a rise just before the curve drops off at cutoff.

The four solid-line curves of Figure 3 apply to the ratio of $\frac{2}{3}$, and show the effect on the gain characteristic of increasing values of inductance. In determining which value of inductance to use, one can plot a series of this type and select one that gives the best compromise between band width and flatness. Another procedure is to set up certain requirements for the gain characteristic and on that basis determine the value of inductance. Thus if

$$L = \frac{4m(1-m)}{(1+m)} R^2C,$$

the gain rises as a maximum, after the sag, to the same gain as at low frequencies. This value of inductance corresponds to the usual one given for the ratio of $\frac{1}{2}$, viz., $L = \frac{2}{3}R^2C$, and the gain characteristic for this value is shown as a dashed curve in Figure 3. The corresponding curve for $m = \frac{2}{3}$ is one with $L = \frac{8}{15}R^2C$ shown in Figure 3. However, this value of inductance is not a desirable one except for ratios in the vicinity of $m = \frac{1}{2}$. For values less than $\frac{1}{3}$ or greater than 1, the original requirements cannot be fulfilled, so that some other basis must be used for those extremes.

One interesting condition that can be set up is based on a consideration of the derivatives of the gain with respect to frequency at zero frequency. All the gain characteristics for the present circuit have an initial horizontal slope (first derivative equal to zero at zero frequency), with a resulting flatness at low frequencies (without consideration of the effect of the C_g–R_g combination). As the frequency increases, the slope of the gain characteristic changes from horizontal, and the gain deviates from the low-frequency value. By making this change in slope as slow as possible one can obtain an improved flatness. Analytically this condition can be expressed as setting the next higher order derivatives equal to zero. Thus if

$$L = \frac{(1+m)}{2} R^2C,$$

the first three derivatives are zero at zero frequency. Furthermore, at the $\frac{1}{3}$ point, what has been called maximal

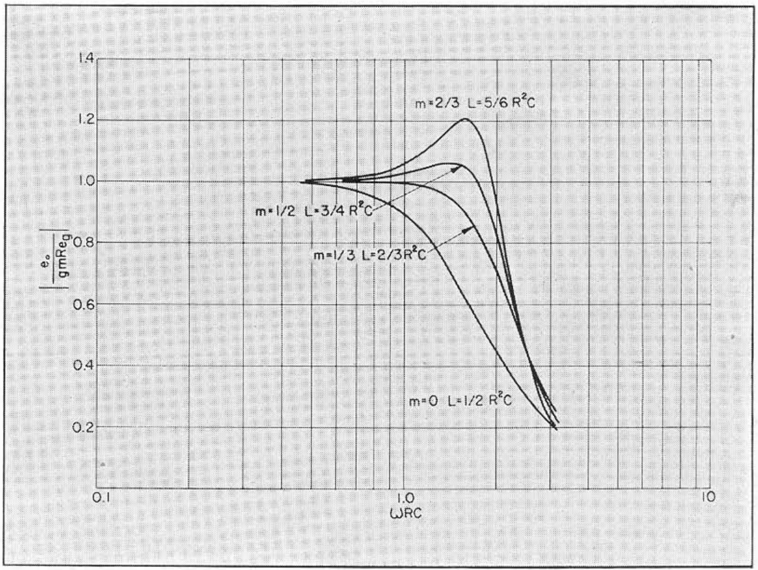

FIGURE 4. Gain characteristic of a single stage with $L = \frac{(1+m)}{2} R^2C$, the value required to make the first three derivatives of the gain with respect to frequency zero at zero frequency.

flatness[2] is obtained, with the first five derivatives equal to zero. This value is a transition one, and the nature of the transition can be seen in Figure 4, where curves for various values of m and inductance values corresponding to the flatness condition are shown. For values of m less than ⅓, the gain decreases continually with increasing frequency, while for values greater than ⅓ the gain increases before it finally drops off at cutoff.

When it is desired to maintain the gain uniform over the band with a certain tolerance in departure, both above and below the low-frequency value, the value of required inductance is not readily expressed in terms of m. However, the possibilities can be analyzed on the basis of curves calculated by cut and try to give the maximum band width within the tolerance. If the total capacitance, C, is held constant and the ratio, m, varied, the following results are obtained when the inductance, L, is adjusted in each case for that maximum band.

From the condition of zero capacitance at the terminated end ($m = 0$), the usable band width for a given tolerance increases with increasing values of m until a value of m of ⅓ is reached. Up to this ratio no sag occurs in the frequency characteristic.

Beyond this value of ⅓ a sag in the curve will in general occur, and the usable band width continues to increase if the tolerance requirements on gain are chosen sufficiently large. Thus, as shown in Figure 5, for ±0.1 db tolerance in a single stage, a ratio of ½ gives a band width about 1⅓ times that for $m = ⅓$. For ±0.5 db tolerance a ratio of ⅔ gives about 1½ times, and a ratio of ½ gives about 1¼ times the band width[3] obtained for a ratio of ⅓. For ±0.1 db, however, a ratio of ⅔ has a band width only about 0.8 that for a ratio of ⅓.

Since, in multiple-stage amplifiers, the irregularities are multiplied by the number of stages, the tolerances must be reasonably small for a single stage. Thus a ratio greater than ½ may be undesirable unless additional means are used for compensating for the irregularities.

—Arnold Peterson

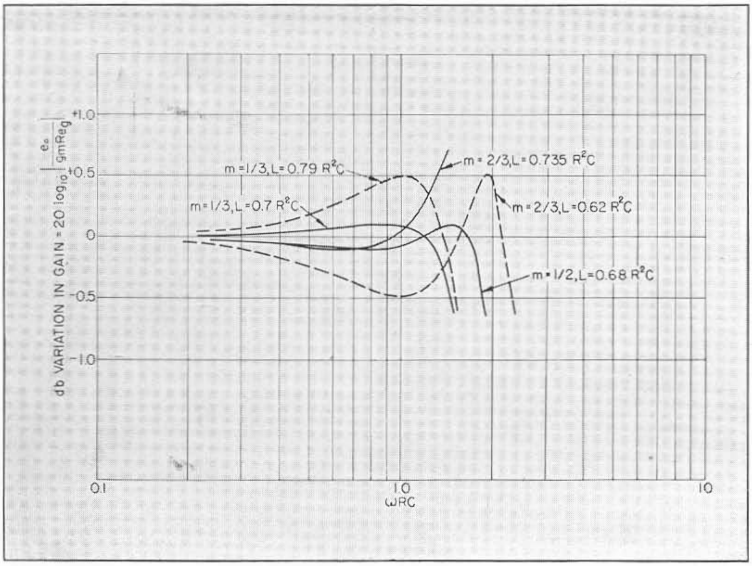

FIGURE 5. Gain characteristic of a single stage with L adjusted to give the maximum band within a flatness tolerance of ±0.1 db (solid-line curves) and ±0.5 db (dashed-line curves).

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[2] V. D. Landon, "Cascade Amplifiers with Maximal Flatness," *RCA Review*, Vol. 5, No. 3, January, 1941, pp. 347–362, and Vol. 5, No. 4, April, 1941, pp. 481–498.

[3] No significant increase in band width for $m = ½$ is obtained for the ±0.5 db tolerance by altering the inductance from the 0.68 R^2C value shown in Figure 5.

DYNAMIC BALANCING IN THE FIELD WITH THE AID OF A STROBOSCOPE

● **THE PROBLEM WAS** to balance a 2500 kw, 3600 rmp steam turbine. The usual field method of shifting balance weights and taking vibrometer readings on each setting was ineffective as the coasting and acceleration time of the machine was quite long. Furthermore, there was a kink in the shaft that threw in a couple that was hard to neutralize.

The erector on the job did not know where the high spot on the shaft was or which way the unbalance force moved when the shaft went through the critical and the kink threw out. Some sort of stroboscope was needed to spot this motion.

Available was a General Radio Strobotac, built so the bulb could be fired from a variably tuned firing circuit calibrated in rpm, or from a set of external contacts. This was rigged up to fire on the external contacts by making a contact that was mounted on the bearing cap. As indicated in the drawing below, a ¼″ bolt with SAE threads, a piece of sheet metal bent into an angle, and a piece of Micarta form an insulating mount.

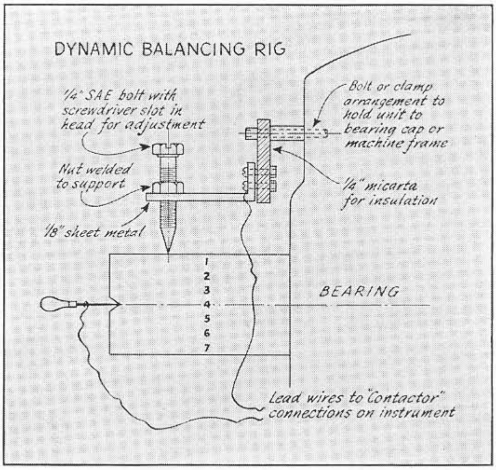
The bolt was ground to a needle point and set to run on a machined part of the shaft just outside the bearing. The other wire from the contactor was wrapped around an ice pick and held in the center of the shaft. Numbers were painted on the shaft and the machine brought up to the critical point. The adjustable contact screwed down until the bulb started firing. The machine was then run through the critical and the shift of the high spot observed. The minimum shaft shake in the bearings was .003″ and the contacts fired the strobotac satisfactorily on .002″ separation.

Later this rig was used to check dynamic balance on a high-speed armature from a 25 kw exciter by mounting two bearings on a frame of wood scantlings and driving the armature with a light belt from a 20″ diameter by 4″ face wood pulley, chucked up in an air drill for variable speed. Checking the deflection of the scantling mount with a dial gage and weights, and then calibrating the contact, made it possible to calculate the balance weight required with fewer balancing shots.

This trick is simply a mock-up of a dynamic balancing machine, built in the field around an instrument commonly available.

Reprinted from *Westinghouse Maintenance News* with the permission of the Westinghouse Electric and Manufacturing Company.

FIGURE 1. Diagram of arrangement and connections for dynamic balancing with the Strobotac.



THE USE OF VARIACS* AT VOLTAGES ABOVE 230

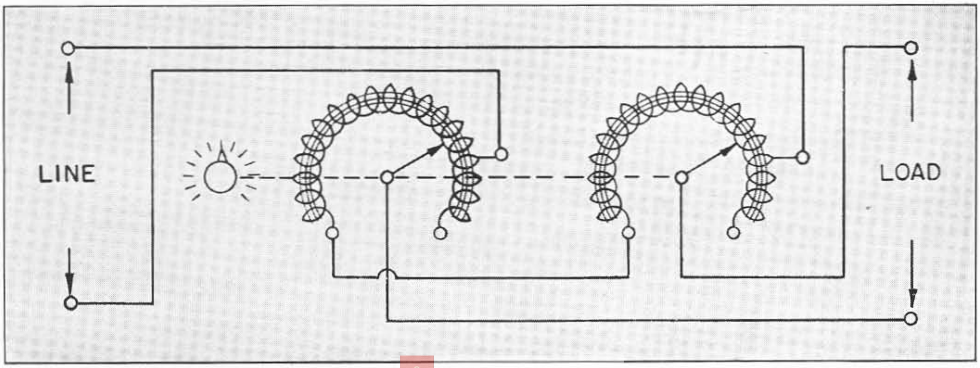
● **THE NORMAL OPERATING POTENTIAL** of Types 200-CUH, 200-CMH, 100-R, and 50-B Variacs is 0 to 270 volts when operated from a 230-volt, 50- or 60-cycle source, or 0 to 135 volts when operated from a 115-volt, 25-cycle source. However, it is sometimes desirable to operate equipment at a higher voltage, and, while such applications are too infrequent to justify production units, it is possible to extend the voltage range considerably by proper connections of existing units.

This extension of voltage range is made possible by the use of ganged units similar to, but differing slightly in connections from, the two ganged units normally supplied for open-delta, three-phase operation. Figure 1 illustrates this connection. When so connected the following ratings apply:

Variac Assembly		200-CUHG2	100-RG2	50-BG2
Input Volts	50–60 cycles	460	460	460
	25 cycles	230	230	230
Output Volts	50–60 cycles zero to	540	540	540
	25 cycles	270	270	270
Rated Current, amperes		2	9	20
Maximum Current, amperes		2.5	9	31
KVA at Input Volts	50–60 cycles	1.15	4.14	14.26
	25 cycles	.575	2.07	7.13
KVA at Max. Volts	50–60 cycles	1.08	4.86	10.8
	25 cycles	.54	3.43	5.4
Net Weight, pounds		17¼	59	175
Price		$44.50	$85.00	$225.00

*Trade mark registered in U. S. A. Variacs are manufactured and sold under U. S. Patent No. 2,009,013.

Figure 1. Diagram of connections for high-voltage operation of a 2-gang Variac.



MISCELLANY

● **MOST OF YOU WILL AGREE,** we think, that General Radio gives rapid service on repair work, particularly for war plants, to whom every minute of delay means a slowing down of production. Recently, however, a repair job went through our plant so fast that it left us gasping.

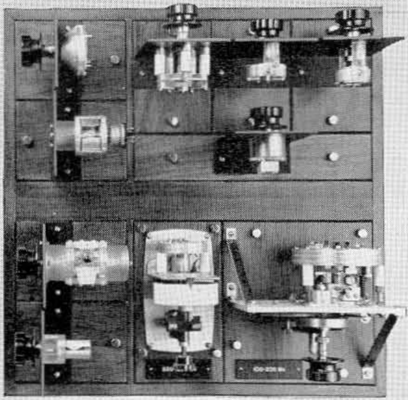
A Midwest radio manufacturer engaged in producing vital military radio equipment called us by telephone. His General Radio signal generator — a specially designed u-h-f model — had been in continuous use for over a year and was badly in need of repair and recalibration. Time was important — Army trucks were waiting outside his plant to take his products away as fast as they came off the production line. Could we do it? We could.

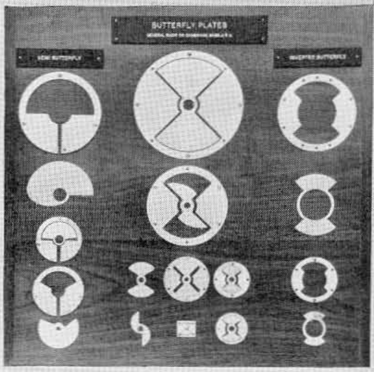
Tucking the generator under his arm, one of the manufacturer's engineers took a plane to Boston late that afternoon. At eight o'clock the next morning he was at our door. Our repair department and our standardizing laboratory went to work on the generator immediately and finished the job by late afternoon. Another plane ride and the generator was back in service the next day.

One of the things that keeps life interesting in our Service Department is the unexpected problem that turns up now and then. The latest of these concerns some output power meters rejected by the customer on the ground that some of the ranges were inoperative. The customer, we found, had drilled holes in the panel to attach his own name plates. Unfortunately he drilled right through the input transformers!

At a meeting of the Boston Section of the Institute of Radio Engineers, held January, 1945, Eduard Karplus of the General Radio Engineering Staff discussed Ultra-High Frequency Oscillators.

Mr. Karplus' paper covered the use in oscillators of the new butterfly circuits (*Experimenter*, October, 1944) as well as some newer types on which data have not yet been published. Display boards showing both butterfly plates and complete circuits were exhibited. These displays, which are shown in the accompanying photographs, were also on exhibition at the General Radio booth at the I.R.E. Winter Technical Meeting held in New York in January.





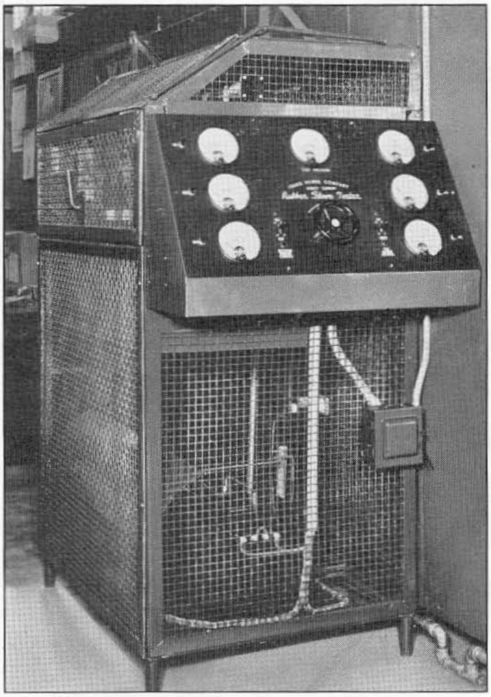


FIGURE 1. View of the rubber glove tester used by Idaho Power Company.

RUBBER GLOVE TESTER USES VARIAC

● **WHEREVER RECTIFIER POWER** supplies are used, the Variac provides a convenient method of adjusting voltage. The accompanying illustration shows a rubber glove tester designed by Mr. Leonard G. Walker of the Idaho Power Company. A Type 100-R Variac is used to vary the 240-volt a-c input to the plate supply transformer of the 15000-volt, d-c power supply. By means of the Variac, voltage is built up at the proper rate during the test cycle. Six gloves are tested simultaneously with this equipment. When a glove fails, voltage is reduced to the point where the overload relays do not trip, and the shorted unit is identified from the leakage current indicated by the corresponding milliammeter.

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THE General Radio EXPERIMENTER

VOLUME XIX No. 11 APRIL 1945

ELECTRICAL MEASUREMENTS AND THEIR INDUSTRIAL APPLICATIONS

MICROFLASH SHOWS FLIGHT DEFECTS IN PROJECTILES

Also IN THIS ISSUE

● **THE MICROFLASH**, a high-speed, high-intensity light source for photography, was originally described in the *Experimenter* in 1941,* with the statement that it was designed for use on urgent defense projects and was not available for general sale. Since that time, a considerable number of units have been built and have proved extremely valuable in research connected with the war effort.

The flash of light produced by the Microflash is of extremely short duration (about 2 to 3 microseconds), and its intensity is sufficient to produce well lighted photographs with the high-speed film emulsions now available. The high speed of the flash permits photographs of objects moving at extremely high speeds. An interesting example of the use of the Microflash is the work that has been carried on at Jefferson Proving Ground on the flight of projectiles

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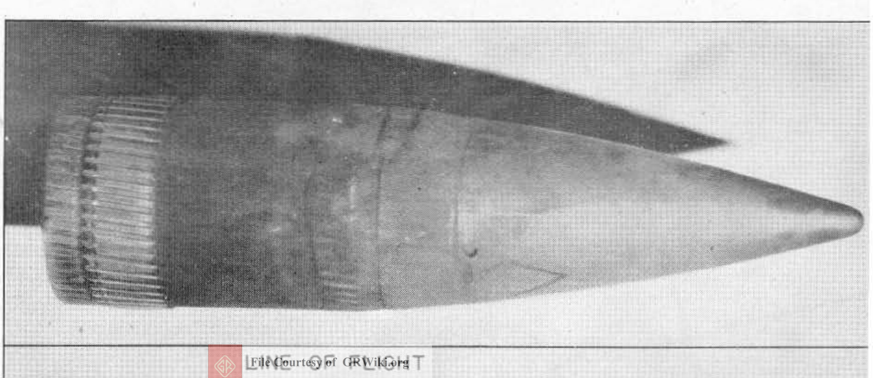
*"The Microflash — a Light Source for Ultra-High-Speed Photography," *Gene[illegible] Radio Experimenter*, XVI, 4 September 1941.

Figure 1. Microflash photograph of a 155-millimeter projectile 400 feet from the muzzle of the gun.



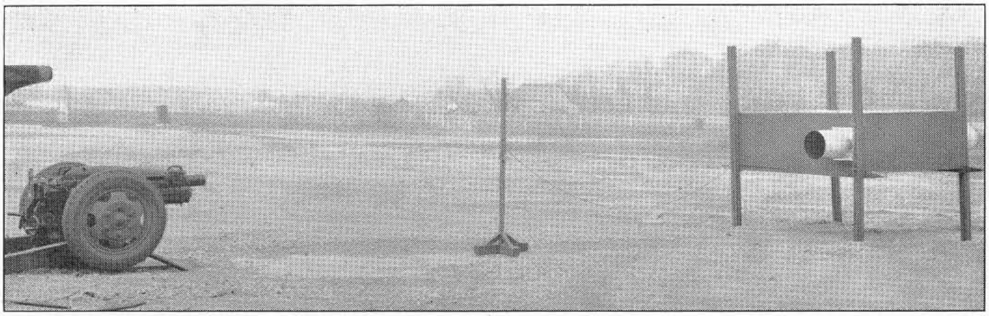


FIGURE 2. Arrangement of equipment for photographing projectiles 100 feet from the gun. At the left is the gun, at the right the box through which the projectile passes to be photographed. On the post between the two is the pressure switch which opens the shutter when the projectile passes.

as part of the proof acceptance testing of ammunition.

Two important factors affecting the flight of a certain type of projectile are the angle of yaw and the behavior of the windshield. It was known that some of the windshields were falling off the projectiles just after they left the muzzle of the gun, but no data were available on the behavior of those remaining on the projectiles.

Preliminary experiments indicated that photographs taken at night with the Microflash showed distinctly the condition of the windshield as the projectile passed in front of the camera. Following the advice of Dr. Harold E. Edgerton of M. I. T., an experimental pilot model, and later a more finished model, of a set-up for taking photographs in daylight were built.

Figure 2 shows the set-up used for these tests, consisting of a box containing the Microflash, and camera, and associated equipment: a diaphragm pressure switch mounted on a post and the gun. In Figure 3 is shown the interior of the box. Here the equipment consists of the camera and Microflash in permanent mountings, a microphone, and a card holder accessible through a sliding door in the side of the box.

Figure 2 shows the box set approximately 100 feet in front of the gun and the diaphragm pressure switch is about 15 feet from the box. The camera shutter is set at 1/100 second and cocked. As the projectile passes by the pressure switch, the pressure from the sound wave closes the switch, activating the synchronizing device, which in turn operates the magnetic tripper to open the shutter. During the 1/100 second interval while the shutter is open, the projectile passes through the box, the microphone picks up the sound wave from the projectile and trips the Microflash.

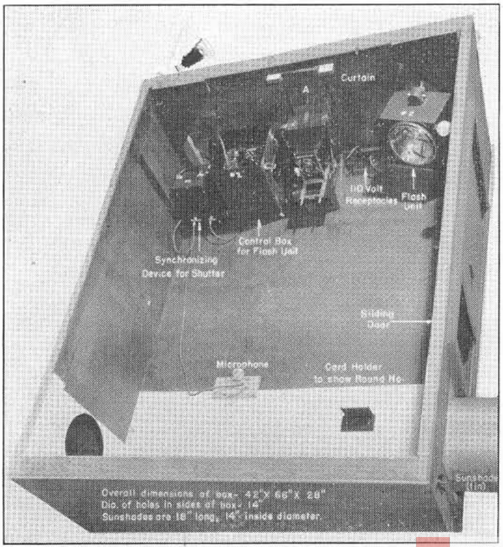


FIGURE 3. Interior of the box, showing Microflash, microphone, synchronizer, and other equipment.

Cambridge, Mass., U. S. A.

While the photograph shows a crystal microphone, this type was found too fragile to stand the terrific concussion from the muzzle blast of the gun and was later replaced. A receiver unit from an ordinary telephone handset has proved to be quite satisfactory.

In order to decrease the amount of light inside the box, a dark curtain is hung in the back, and the inside surfaces of the sunshades on the sides are painted flat black. With super ortho press film, a diaphragm opening of f:6.3 is used.

Results obtained with this technique are shown in Figure 1 and in Figures 6 and 7. In Figure 1 is shown a 155 mm projectile 400 feet from the muzzle of the gun. Figure 4 shows a 3-inch projectile 50 feet from the muzzle of the gun. Here the windshield with the nose cap attached has broken away from the projectile and is approximately 5 inches in front of it.

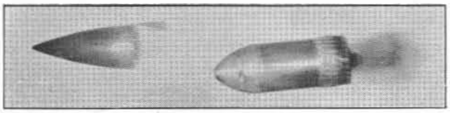


FIGURE 4. Photograph of a defective round showing windshield in front.

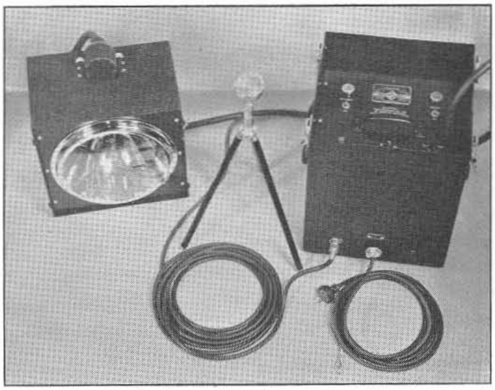


FIGURE 5. View of the Microflash Unit, consisting of light source, power supply, microphone, and connecting cables.

In Figure 6, three views showing erratic behavior of windshields are shown. Figure 7 is a group of photographs of 3-inch projectiles showing excessive yaw.

Work of similar nature has been carried out by the Combined Inspection Board of the United Kingdom and Canada at Valcartier, P. Q. Of particular interest is their use of the shadowgraph technique for the photography of shock waves in air. A diagram of the system is given in Figure 8. The Microflash lamp is converted to a point source (actually about ⅛-inch diameter) and placed some 6 feet from a ground glass screen. The camera is focussed on the side of the screen away from the lamp. The projectile is fired between the lamp and the screen at about 12 inches from

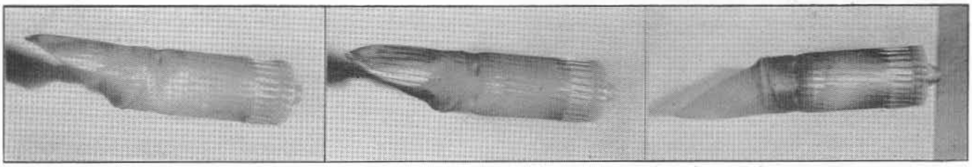
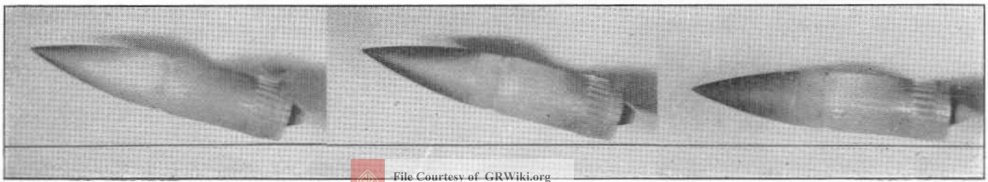


FIGURE 6 (above). Photographs of three rounds in which the windshields have become displaced from their normal positions.

FIGURE 7 (below). These three rounds show excessive yaw. The line below them indicates the line of flight.



the latter, and its shadow is recorded on the film along with the marks made by bow wave and other pressure waves in the air. Definition is limited to the size of the grain of the ground glass surface. Finer definition can be obtained substituting a sheet of film for ground glass, but this method must be used in darkness. The ground glass technique makes it possible to take shadowgraphs of projectiles by firing through the box in daylight.

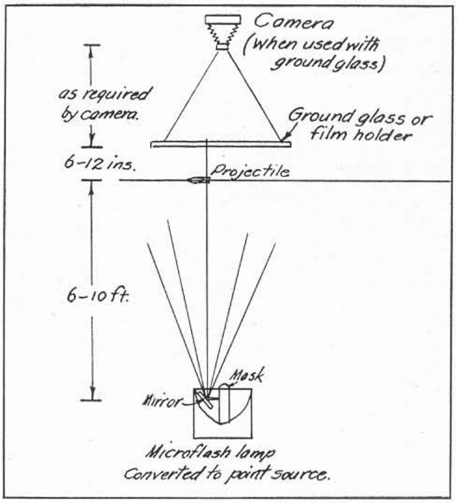


FIGURE 8. Diagram of the equipment used to take shadowgraphs of bullets and projectiles.

MEASURING 0.003 HORSEPOWER WITH THE STROBOTAC

● **MEASUREMENT OF THE VERY SMALL AMOUNT** of power consumed in the gears of a tachometer adaptor unit recently presented a problem at the Barbour-Stockwell Company, manufacturers of Reliance tachometers. Their engineering department solved this problem by means of an ingenious device used in conjunction with the General Radio Strobotac.

The measuring system consists basically of a torsion meter which indicates the torque required to drive the part to which it is coupled. This torsion meter must be capable of rotation at fairly high speeds, and means for reading the meter indications and for measuring the speed must be provided. The TYPE 631-B Strobotac performs these latter functions.

The photograph shows a brass tube, about 15 inches long, coupled to the motor shaft at one end while the other end runs in a bearing and carries a drum-type dial. Within this tube is a straight

FIGURE 1. Mr. Frank Wilkins of the Barbour-Stockwell Company reading the relative positions of the drum dials by means of the Strobotac.

length of 0.037-inch steel piano wire, rigidly attached at the motor end and fixed at the other end to a small shaft that turns freely in a bearing within the end of the tube. This shaft carries a small drum with an index mark on its periphery which indicates the angular displacement against the scale on the adjacent dial attached to the brass tube. The short shaft then passes through the outer bearing and a coupling to the rotating member on which the power loss is to be measured. Thus it is seen that when the motor is stationary, manual rotation of the output coupling shaft results in rotation of the index dial as the piano wire is twisted against its restoring torque.

When the motor is started, the acceleration puts a high torque on the wire, which might be broken except that the index dial has its motion with respect to the other dial limited to 180° by means of stop pins. The load is driven directly, therefore, when starting or stopping. Under running conditions, however, the Strobotac is adjusted to give a stationary image of the dials, and the position of the index with respect to the dial marked in degrees of arc is readily observed. If the motor speed varies enough to make it difficult to obtain a steady image, the contactor socket of the Strobotac may be connected to a cam arrangement on the motor shaft which will insure a steady image of the rotating dials. Since each flash of the Strobotac occurs at the moment that the contactor leads are short-circuited, it is best to arrange the contactor cam so the circuit can be shorted at any chosen point in the rotation of the cam.

The torsion meter is easily calibrated in a stationary condition by comparing applied torques on the output shaft to resulting dial readings. The results should give a linear curve. Power measurements are then made by observing, with the Strobotac, the reading of the torsion dial and the speed of rotation. Calculation of power from the product of torque and speed is then a simple matter.

FIGURE 2. Close-up of the torque meter. The two drum dials, one carrying an index, the other a scale, are shown between the two vertical supports.

The equipment illustrated has been used to measure power losses as small as 0.003 horsepower at speeds of 600 rpm with an accuracy of ±5%. With smaller equipment using a finer wire, there seems to be no reason why this arrangement cannot be used for measuring very much smaller amounts of power.

— KIPLING ADAMS

PHOTOTUBE CAPACITANCE MEASUREMENT WITH THE TYPE 650-A IMPEDANCE BRIDGE

● **SINCE INTERELECTRODE** capacitance has a marked effect upon the frequency characteristics of a phototube, it is important in many applications that the capacitance be accurately known.

The Type 650-A Impedance Bridge has been found quite satisfactory for this measurement when an external Type 602 Decade-Resistance Box is used to give the required precision of balance.

The necessary connections are shown in Figure 2. The bridge controls are set for capacitance measurement. Since for this connection, 1 ohm is equivalent to 0.1 $\mu\mu$f,

$$C = \frac{\Delta R}{10}$$

where ΔR is the change in setting of the resistance box when the phototube is connected.

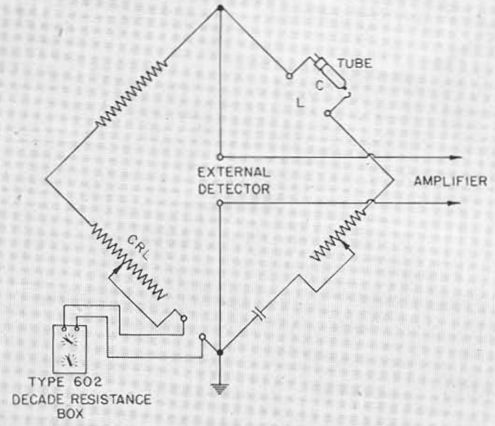
To connect the external decade-resistance box, it is necessary to break the connection between the arm of the CRL potentiometer and ground. This can be done by removing the connecting wire from the potentiometer terminal and bringing out a new lead from the terminal. An equally satisfactory and more convenient method is to insert a slip of paper between the potentiometer arm and the winding. The decade box can then be connected between the *J* terminal of the bridge and ground.

For measurements over a range of 0.6 to 3.0 $\mu\mu$f, balance to 0.1 $\mu\mu$f could be obtained with a decade box providing unit steps in resistance. A tenth-ohm decade gives increments of 0.01 $\mu\mu$f, and with an amplifier as indicated in Figure 2 the bridge is sufficiently sensitive so that balance to 0.01 ohm or 0.001 $\mu\mu$f is easily obtained. Since hundredth-ohm decades are not generally available, it would be necessary to use a slide wire to obtain this degree of precision.

When a wire from the CRL potentiometer is brought out to the decade, the zero capacitance of the bridge, which amounts to approximately 10 $\mu\mu$f, can be balanced out by means of an initial setting of the CRL dial. If the CRL potentiometer is disconnected by insulating the contact arm from the winding, the decade box must be large enough to balance this zero capacitance, and a four-dial box consisting of hundred-, ten-, one-, and tenth-ohm decades should be used.

In order to keep the conductance component small, the phototube should be shielded from light during the meas-

Figure 1. Panel view of the Type 650-A Impedance Bridge.



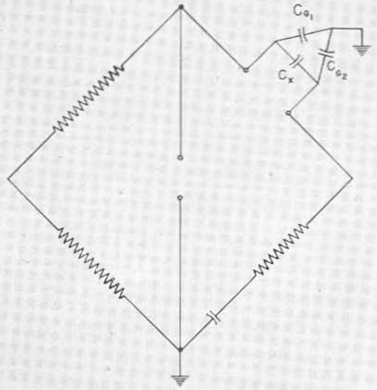


FIGURE 2 (*left*). Circuit diagram of the bridge, showing the decade resistance box connected in series with the CRL dial.

Figure 3 (*right*). By tying the terminal capacitances C_{G1} and C_{G2} to ground, as shown here, the direct capacitance C_x can be measured.

urement. If the tube is exposed to light, an additional decade resistance across the standard condenser is needed for balancing the parallel conductance, in order to avoid a serious sliding balance.

The accuracy obtainable with the TYPE 650-A in the measurement of capacitance of this magnitude is limited largely by the unavoidable connection errors. Since connection errors of the order of 0.1 $\mu\mu$f are difficult to eliminate,* these errors will usually determine the absolute accuracy of the measurement.

It should be noted that this method measures direct capacitance rather than total capacitance and hence is applicable to a number of other problems where small values of capacitance must be measured. It can be seen from Figure 3 that capacitance to ground from the low unknown terminal is in parallel with the detector, while that associated with the high terminal is across the standard arm of the bridge and, when not small enough to be considered negligible, can be corrected for. For measurements of capacitance increments where connection errors do not exist, as, for instance, with plug-in elements, highly accurate measurements can be made.

One possible application is in the measurement of the interelectrode capacitances of vacuum tubes, where the socket is connected to the bridge, and the capacitance increment resulting from plugging in the tube is measured. For these measurements, all unused electrodes should be grounded, so that only the direct capacitance between the two significant electrodes is measured. For accurate measurements of the smaller capacitances such as the grid-to-plate capacitances of screen grid tubes, shielded sockets are necessary to avoid connection errors larger than the capacitance being measured.

— L. E. PACKARD

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*R. F. Field, "Connection Errors in Capacitance Measurement," *General Radio Experimenter*, XII, 8 January 1938.

MISCELLANY

● **DR. A. P. G. PETERSON** of the General Radio Engineering Staff addressed a group from the New York Section, Institute of Radio Engineers at Red Bank, New Jersey, on March 16. His subject was "Wide-Range Tuned Circuits for High Frequencies."

A paper on "High-Frequency Measurements" was delivered by Dr. Donald B. Sinclair, Assistant Chief Engineer, before a meeting of a group of Middle West radio engineers arranged by the Chicago Office of the General Radio Company on March 21. This paper was also presented at the Radio Engineers' Club in Chicago on March 22, at the London, Ontario, Section of the IRE on March 23, and at the Toronto, Ottawa, and Montreal Sections on March 26, 27, and 28, respectively.

● **QUALITY PARTS** sometimes mean the difference between a good job and one that doesn't make the grade. A manufacturer recently completed several hundred equipments on a project that was highly secret and very urgent. They were OK, except for the rotary switches, which failed in use. Several General Radio switches of the type used in our decade resistors were available and these were dismantled and reassembled in a 3-gang combination. These worked satisfactorily and were rugged and reliable. Result — an urgent call for switch parts. Luckily, we were able to scrape up a small quantity for immediate needs and to schedule the balance for production on a high priority.

● **IN WARTIME** expense is often no object if the need is urgent. A secret development project recently needed ten General Radio Precision Forks, and only eight were available. To wait for a delivery of the next production lot was out of the question; the project was too urgent. The last previous delivery, it turned out, was to a foreign ally, and believe it or not, one of Uncle Sam's planes went right over there and brought back two of the units.

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THE General Radio EXPERIMENTER

VOLUME XIX No. 12 MAY, 1945

ELECTRICAL MEASUREMENTS AND THEIR INDUSTRIAL APPLICATIONS

VACUUM-TUBE AND CRYSTAL RECTIFIERS AS GALVANOMETERS AND VOLTMETERS AT ULTRA-HIGH FREQUENCIES

Also

IN THIS ISSUE

• **UNTIL RECENTLY,** the crystal detector of radio's early days has had little, if any, commercial use since the introduction of mass-produced vacuum tubes. It has, however, always found considerable application in ultra-high frequency research[1] and lately has again become commercially available.

Today's crystal units are more stable and more uniform than those of 30 years ago, although in neither respect are they as yet comparable

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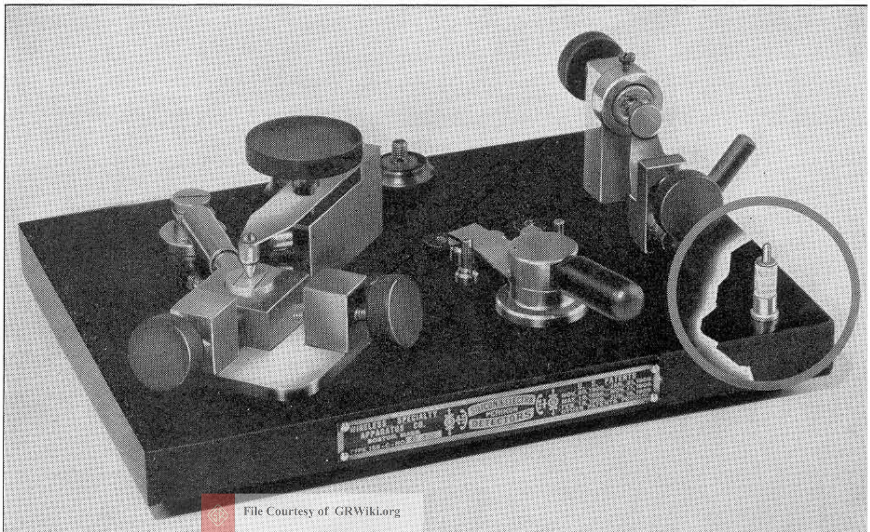
[1] G. C. Southworth, "Beyond the Ultra-Short Waves," *Proc. I.R.E.*, Vol. 31, No. 7, July, 1943, pp. 319-330. G. C. Southworth, "Hyper-Frequency Wave Guides — General Considerations and Experimental Results," *Bell System Technical Journal*, Vol. 15, No. 2, April, 1936, pp. 284-309. W. L. Barrow, "Transmission of Electromagnetic Waves in Hollow Tubes of Metal," *Proc. I.R.E.*, Vol. 24, No. 10, October, 1936, pp. 1298-1328.

Figure 1. Crystal detectors of 30 years ago and (in circle) a present-day unit. Older types were cumbersome and adjustable. Modern units are small, and the adjustment is sealed.



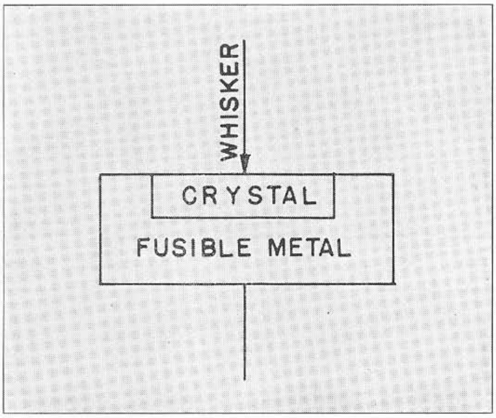


FIGURE 2. Simplified diagram of the construction of a crystal rectifier.

to vacuum tubes. They perform well as detectors and mixers in u-h-f circuits and offer considerable promise as rectifying elements for high-frequency voltmeters. The capabilities and limitations of the crystal as a voltage measuring device can best be shown by a consideration of its characteristics and a comparison with those of the vacuum-tube rectifier.

Nature of the Crystal Rectifier

The crystal rectifier depends for its non-linear behavior on the very interesting properties of the class of materials known as semi-conductors.[2] This class includes silicon, iron pyrites, galena, and many other crystals, which have the characteristic luster of metals but are not quite metals. When contact is made to one of these crystals by a metal, electrons can flow across the boundary, often referred to as the barrier layer, more readily in one direction than in the other, and this behavior is used for rectification. As rectifier elements, the units are usually constructed with the crystal held in a fusible metal alloy, which serves as one terminal of the rectifier. The other terminal is a "cat whisker," such as a fine tungsten wire, which touches the crystal as shown in Figure 2.

Owing to its inherent simplicity, the crystal rectifier can be made in a unit of extremely small physical size. Very small vacuum tubes also have been constructed for use at high frequencies,[3] but the need for an evacuated space surrounding the diode elements makes its manufacture extremely difficult in any size smaller than the familiar acorn tube.

Resonance Effects

The main reason for reducing the physical size of a rectifier is to increase the lowest resonant frequency of the circuit formed by its elements. Below this resonant frequency the voltage that appears at the rectifying element, which is the plate-to-cathode space in the diode and the barrier between whisker and crystal in the crystal rectifier, is greater than the terminal voltage because of series resonance between the lead inductance and the capacitance across the rectifying element.

When the rectifier is used for measuring the voltage at its terminals, a cor-

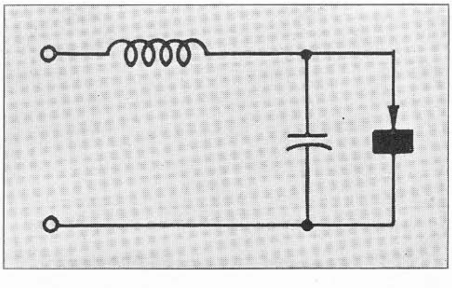


FIGURE 3. Diagram showing the resonant circuit formed by lead inductance and shunt capacitance of a crystal rectifier.

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[2] K. F. Herzfeld, "The Present Theory of Electric Conduction," *Electrical Engineering*, Vol. 53, No. 4, April, 1934, pp. 523-528.

[3] B. J. Thompson and G. M. Rose, Jr., "Vacuum Tubes of Small Dimensions for Use at Extremely High Frequencies," *Proc. I.R.E.*, Vol. 21, No. 12, December, 1933, pp. 1707-1721. Leon S. Nergaard, "Electrical Measurements at Wave Lengths Less Than Two Meters," *Proc. I.R.E.*, Vol. 24, No. 9, September, 1936, pp. 1207-1229.

rection must therefore be made for resonance. As the frequency of the applied voltage approaches resonance the required correction becomes greater, and near resonance the accuracy of measurement becomes very poor because the large correction cannot be accurately determined.

A more serious effect of resonance, for which no numerical correction can be made, is the emphasis of harmonics as compared to the fundamental. When the applied voltage contains harmonic components that are in the vicinity of the series-resonant frequency, the indicated voltage may be almost completely determined by those components even though the fundamental component is appreciably lower in frequency than that of resonance and is many times as large in magnitude at the voltmeter terminals as the sum of all other components.

The resonant frequency can, therefore, be considered as a first upper limit to the frequency at which a given rectifier can be used as a voltmeter. Commercial diodes are available with resonant frequencies in the vicinity of 1500 Mc, and the resonant frequencies of commercially available cartridge crystals are considerably higher. Crystal rectifiers can readily be built with resonant frequencies still higher than those of the commercially available crystals. Thus, in this respect, the crystal rectifier has a marked advantage over the diode.

When a rectifier is used as an indicator of relative voltage level, that is, as an r-f galvanometer rather than as an absolute voltmeter, the resonant frequency is not so important a limitation, for resonance does not produce by itself any effect on voltage ratios. However, harmonic components in the vicinity of resonance may cause considerable error, and the reduction of stray pickup becomes more difficult at frequencies near and beyond the first resonance.

Transit-Time Effects in Diodes

Another reason for reducing the size of a diode rectifier is to reduce the effects of the finite time of transit of the electrons from cathode to plate. When the period of the applied voltage becomes comparable to this transit time, the vacuum tube characteristics are modified from the low-frequency ones. While for some specialized measurements tubes with adjustable transit time are used, the resultant systems are inherently frequency dependent. In the very useful diode peak-type voltmeter, such as the General Radio Type 726-A Vacuum-Tube Voltmeter, the effect of transit time is to reduce the indicated voltage for a given applied voltage as the frequency of that applied voltage is raised.[4] This behavior might be characterized as a reduction in rectification efficiency. Furthermore, since transit time depends on the applied voltage, this reduction is dependent on voltage level, with the result that voltage ratios are not preserved independent of frequency. This behavior is a serious limitation for the diode rectifier, not only for its use as a voltmeter but also as a galvanometer where accurate measurement of ratios may be important even though the absolute level is not. For acorn-type diodes, the reduction in rectification efficiency is noticeable at 30 Mc for voltages of the order of one-half volt or less, and at 500 Mc at the same voltage level the reduction is of the order of 30%.

The effect of transit time in a crystal rectifier is negligible for its present appli-

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[4] L. S. Nergaard, *loc. cit.* Ivan G. Easton, "Radio-Frequency Characteristics of the Type 726-A Vacuum-Tube Voltmeter," General Radio *Experimenter*, Vol. 15, No. 11, May, 1941, pp. 1-5.

cations, but another limitation appears whose effect is similar to that of transit time.

R-C Effect in Crystals

The crystal rectifier with its semiconductor crystal and metallic whisker is a barrier-layer rectifier like the copper-oxide rectifier and has in common with that rectifier a decrease in rectification efficiency with increasing frequency.[5] However, owing to the whisker-type of contact and the nature of the material, the frequency limitations of the crystal are not nearly so serious as those of conventional copper-oxide rectifiers. In fact, the frequencies at which there is an appreciable drop in rectification efficiency for a suitably constructed crystal unit can be thousands of times the corresponding frequencies for copper-oxide instrument rectifiers.

As an illustration of the decrease in rectification efficiency, Figure 4 shows the results of some measurements made on an iron-pyrites crystal rectifier. The crystal in its holder had its lowest resonant frequency at about 3500 Mc. The input voltage to the crystal rectifier was standardized by means of a bolometer, and the effective voltage indicated by the crystal as a function of frequency was noted. The result shows a marked drop in the indication of the crystal as the frequency is raised.

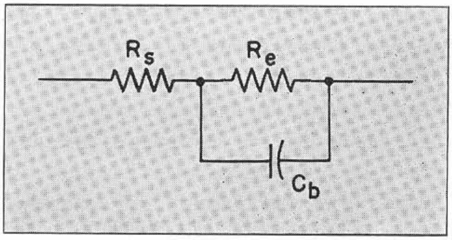

FIGURE 5. Equivalent circuit for interpreting the R-C effect of the crystal rectifier. The resistance R_e of the barrier layer is non-linear.

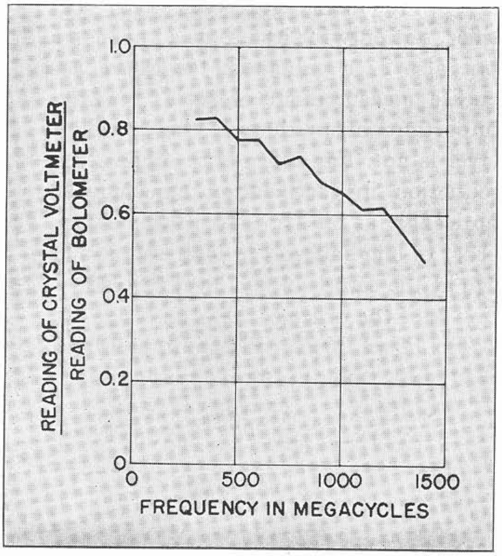

FIGURE 4. Plot showing decrease in rectification efficiency of an iron-pyrites rectifier as a function of frequency.

The equivalent circuit shown in Figure 5, developed by Schottky and Deutschmann,[6] can be used for interpreting this decrease in rectification efficiency. In this circuit R_e represents the non-linear resistance of the barrier layer of the whisker-crystal junction, R_s represents the resistance of the semiconductor between the barrier layer and the fusible metal alloy that holds the crystal, and C_b is the capacitance that exists directly across the barrier layer. At high frequencies this capacitance tends to shunt out the non-linear element so that only a fraction of the

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[5] Joseph Sahagen, "The Use of the Copper-Oxide Rectifier for Instrument Purposes," *Proc. I.R.E.*, Vol. 19, No. 2, February, 1931, pp. 233-246. Karl Maier, *Trockengleichrichter*, München, R. Oldenbourg, 1938, pp. 52f, 198f, 261, and 283ff.

[6] W. Schottky and W. Deutschmann, "Zum Mechanismus der Richtwirkung in Kupferoxydulgleichrichtern," *Physikalische Zeitschrift*, Vol. 30, No. 22, November 15, 1929, pp. 839–846. O. Zinke, *Hochfrequenz Messtechnik*, Leipzig: S. Hirzel, 1938, pp. 100 ff. W. Meyer and A. Schmidt, "Messungen an Sperrschichtgleichrichtern," *Zeitschrift fur technische Physik*, Vol. 14, No. 1, 1933, pp. 11–18.

energy going into the crystal unit appears in the non-linear element where the rectification occurs. The result is a reduction in rectified output at high frequencies compared to that at low frequencies for the same energy input.

It is important to note that the above reduction results from the increased current flow in the resistive element R_s with a resulting increase in dissipation of energy where it is of no value. A capacitance across the complete unit and an inductance in series do not upset the energy relationships, because of their non-dissipative nature. Thus they do not inherently affect the rectification efficiency, even though they do modify the impedance relationships and the relative voltage appearing at the barrier layer compared to that at the input terminals.

A rough measure of the relative energy contributing to the rectification as a function of frequency is given by

$$\frac{1}{1 + (\omega C_b)^2 R_e R_s}.$$

Since R_e is nonlinear, the expression indicates only the order of magnitude and the general nature of the variation of rectification efficiency with frequency. The relative rectified voltage varies with frequency approximately as the square root of the above expression.

Consequently, for small departures from uniformity the reduction in output varies as the square of the frequency. The departure is in a direction opposite to that for resonance, and the two effects tend to cancel at low frequencies, so that the apparent resonant frequency is raised. However, since the barrier-layer resistance depends on the voltage level, the amount of the reduction in rectification efficiency is a function of the voltage, and hence, even in the crystal, the measurement of voltage ratios is not completely independent of frequency.

Fortunately the magnitude of thin reduction in rectification efficiency can be kept small by proper design of the crystal unit and by the choice of the rectifying material. The commercial 1N21B-type crystals are much better in this respect than is the crystal whose characteristic is shown in Figure 4. Actually this crystal was one of the poorest of a large group measured, and the 1N21B-type crystal exhibits no appreciable reduction in rectification efficiency up to 1000 Mc and in many cases even higher frequencies. This frequency is far higher than that at which transit-time effects begin to appear in diodes.

Reverse Rectification in Crystals

Although the rectifier action in crystals is normally expected to be confined to the whisker-crystal junction, rectification also can occur in the junction between the crystal and the other contact.[7] This rectification is in the opposite sense to the desired one, and might be called a reverse rectification. Normally the resistance of this second contact is very small compared to that of the whisker contact so that the desired rectification dominates. But when the

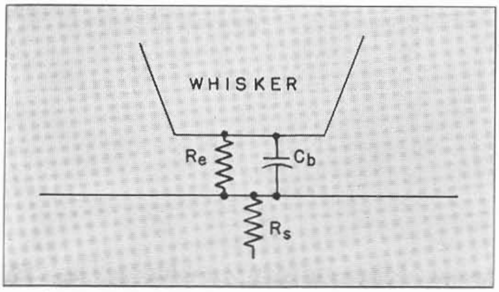

FIGURE 6. Simplified sketch of the whisker-crystal contact greatly enlarged to show the location of the elements of Figure 5.

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[7] J. T. Kendall, "The Rectifying Property of Carborundum," *Proc. Phys. Soc.*, Vol. 56, Pt. 2, No. 314, March 1, 1944, pp. 123-129.

crystal is merely embedded or soldered in its retaining cup, the reverse rectification may be very important.

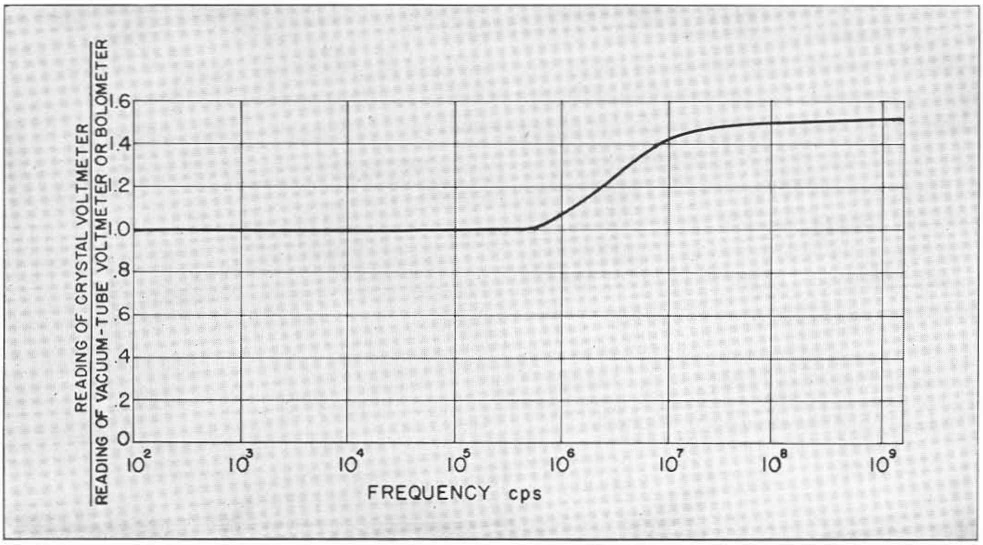
The effect of this rectification at the second contact is highly dependent on frequency. The capacitance across the contact is so large that its reactance rapidly becomes very low compared to the impedance of the main rectifying contact as the frequency is raised. This causes the voltage across the second contact to decrease and the contribution from its rectification to disappear as the frequency is raised. Thus one would expect to observe an increase in rectified output for increasing frequency for a crystal with a noticeable reverse rectification. This behavior is exhibited in Figure 7, which shows the results of some measurements on an iron-pyrites crystal used as a voltmeter.

Even more marked effects of reverse rectification have been observed. One crystal had an output which was reversed from the normal at low frequencies (the reverse rectification dominating), but normal rectification at high frequencies. Another showed no appreciable rectified output at low frequencies but had fairly good output at high frequencies. Most crystals show only a moderate effect from reverse rectification, and the reverse rectification can usually be made negligible by plating the crystal before mounting or by fusing the crystal in place. The 1N21B-type crystal seems to exhibit no appreciable effects of reverse rectification.

Other Limitations

In addition to the frequency characteristic, other factors must be considered in determining whether or not the crystal is satisfactory for use in a given application. One of the most important of these is input impedance. At high frequencies the crystal and the diode have comparable impedances. The input capacitance of a probe containing a crystal unit is usually comparable to that of one using a diode. While the input conductance of a diode voltmeter can be made very low at low frequencies, the conductance increases with increasing frequency, and at ultra-high frequencies the conductance becomes nearly as great as that of a very good crystal unit used as a peak voltmeter.

FIGURE 7. Frequency characteristic of an iron-pyrites rectifier showing the increase in output that occurs as a result of the large capacitance across the second contact.



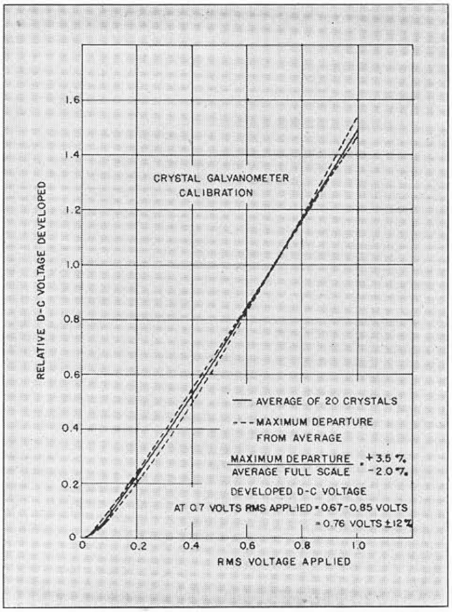


Figure 8. Plot showing the average characteristics of 20 crystals and the maximum departure from average. The output is taken as unity for 0.7 volts, r-m-s, input.

The crystal unit is seriously limited in voltage range, with a 1-volt r-m-s limit for a 1N21-type unit as a peak rectifier. When the crystal is overloaded its characteristics are changed, so that great care must be exercised in many systems to avoid permanently damaging the crystal contact. Higher voltage can be measured, however, by using capacitance multipliers.

The characteristics of crystal rectifiers are somewhat dependent on the operating temperature, so that they should be calibrated at approximately the ambient temperature at which they will be used.

One important disadvantage of the diode compared to the crystal is the need of maintaining a constant cathode temperature to assure constant thermionic emission. Consequently, the crystal, because it requires no heated cathode, has a considerable advantage in simplicity, and can be used at lower voltage levels.

In any measurement system which uses vacuum-tube or crystal rectifiers the uniformity of characteristics of different units of the same type is an important consideration. If replacement of a unit necessitates recalibration of the measuring device, the general usefulness of the device is impaired. Vacuum-tube diodes, particularly the high-frequency types, are not so uniform as is often desired, but even so they are appreciably better in that respect than are the commercial crystal units. For instance, the replacement of the acorn diode in the Type 726-A Vacuum-Tube Voltmeter does not appreciably affect the calibration of the voltmeter with its 2% accuracy rating. If a crystal rectifier is used in a similar circuit, however, the indication of the meter is appreciably dependent on the particular crystal used. Figure 8 shows the average characteristics and maximum departure from average of a group of 20 crystals of the same type used in a peak-reading voltmeter. The extent of the variation in rectified output is appreciable. Furthermore, since the shapes of the curves are different, a single calibration-check point will correct only approximately for the variations among the crystals. Thus for accuracy of the order obtained with the diode voltmeter a complete calibration must be made for each crystal.

The overall stability of modern crystal units is remarkably better than the arrangements used in the early days of radio communication and further improvement can be expected. While lack of uniformity between crystals is at present an important limitation as compared to diodes, this disadvantage is outweighed by their better high-frequency characteristics. — Arnold Peterson

SPARK TIMING WITH THE STROBOLUX

• **AT THE AERONAUTICAL RESEARCH LABORATORY** of the University of Kentucky, research on aircraft engine fuels is carried on under the sponsorship of Pratt and Whitney Aircraft. During a long series of tests on an engine to evaluate its performance with a given type fuel, it is necessary to have an exact knowledge of the degree of spark advance with which the engine is operating.

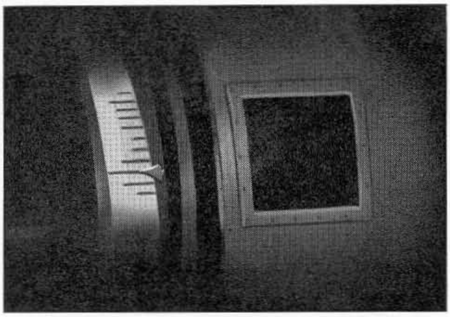
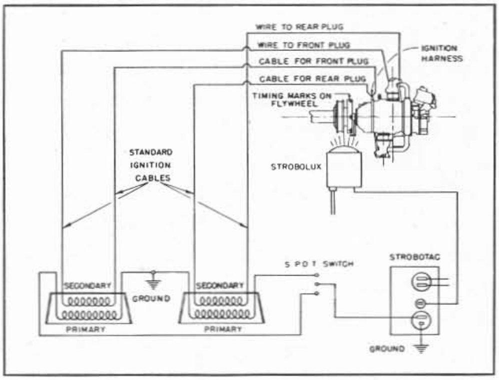


FIGURE 1. Photograph of the drum and scale taken with stroboscopic light. This is a multiple-flash exposure.

Using the General Radio Strobotac and Strobolux, Professor A. J. Meyer, director of the laboratory, and his associates have developed a spark-indicating system that gives accurate and dependable results. Figure 1 is a stroboscopic photograph showing the indicator dial, while the wiring diagram of Figure 2 shows the principle of operation. The high-tension magneto current passes through the secondary winding of a standard automotive spark coil, while the primary winding is connected to the contactor terminals of the Strobotac. The Strobolux is flashed from the Strobotac circuit in the normal manner. Its lamp illuminates the fly-wheel, which carries a scale. When the light flash initiated by the ignition spark occurs, the angular position of the flywheel at that instant can be accurately read from the scale.

FIGURE 2. Diagram showing connections for the spark indicator.



In Figure 2, connections to both front and rear plugs are shown, with a switch in the low-tension circuit to select either plug.

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VOLUME XX No. 1 JUNE 1945

THIRTIETH ANNIVERSARY · 1915-1945

DEVELOPMENT ENGINEERING AT THE GENERAL RADIO COMPANY

EVERY fifth year, on the anniversary of the founding of the General Radio Company, we devote the June issue of the *Experimenter* to a description of some of our company operations and personnel. The subject chosen for this month is the Engineering Department — its organization and personnel, its activities during the war, and the post-war products that may result from war-time developments.

● **THE BUSINESS** of the General Radio Company is producing and selling packaged engineering to solve industry's measurement problems. Primarily responsible for the degree of excellence with which a General Radio instrument does its job is the development engineer. Given a measurement problem, the engineer devises a solution in the form of electrical circuits, and with the cooperation of the mechanical design engineer, puts it in a package that can be manufactured and that can be conveniently used.

At the General Radio Company, twenty-seven engineers are exclusively engaged in the development and design of electronic instruments. Drafting, model shop and secretarial employees boost the total of de-

FIGURE 1. View of the technical library.

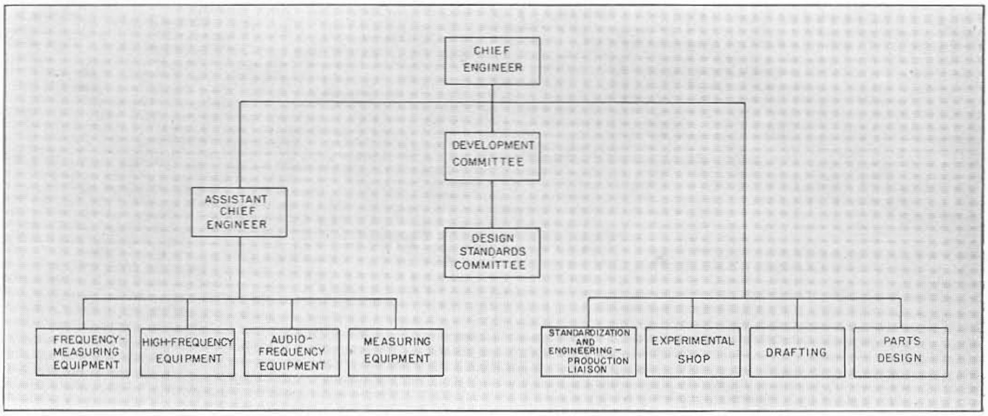

FIGURE 2. Functional diagram of engineering department organization.

PERSONNEL

EXECUTIVE

Chief Engineer — Melville Eastham

Assistant Chief Engineer — D. B. Sinclair

Engineer in Charge of Drafting — L. M. Burgess

Engineer in Charge of Frequency Measuring Equipment Development — J. K. Clapp

Engineer in Charge of Parts Design — Melville Eastham

Engineer in Charge of High-Frequency Development — Eduard Karplus

Engineer in Charge of Standardization — P. K. McElroy

Engineer in Charge of Measuring Equipment Development — D. B. Sinclair

Engineer in Charge of Audio-Frequency Development — H. H. Scott

Engineer in Charge of Experimental Shop — H. W. Wilkins

DESIGN

Paul Hanson
H. C. Littlejohn
Gilbert Smiley
F. W. Williams

DEVELOPMENT

A. G. Bousquet
W. F. Byers
C. A. Cady
D. H. Chute
R. F. Field
E. E. Gross
H. H. Hollis
H. W. Lamson
S. R. Larson
A. P. G. Peterson
D. A. Powers
R. J. Ruplenas
W. R. Saylor
W. R. Thurston
C. A. Woodward

DEVELOPMENT COMMITTEE

Chairman — Melville Eastham

Vice-Chairman — D. B. Sinclair

Secretary — Eduard Karplus

P. K. McElroy
H. H. Scott
C. T. Burke*

---

*Director of Planning

DESIGN STANDARDS COMMITTEE

Chairman — P. K. McElroy

Secretary — L. M. Burgess

H. C. Littlejohn
Gilbert Smiley
F. W. Williams
H. S. Wilkins
D. B. Sinclair†

---

†Designate from Development Committee

velopment engineering personnel to approximately fifty, or one in every eight General Radio employees. These are the people who are responsible for designing the new instruments that will be available to you after war work is completed.

General Radio engineers are specialists in the application of electronic principles to industrial and scientific measurements. Within the general field of electronics, many of the staff specialize in certain types of circuits and measurements, but all have a broad background of general engineering and scientific training.

The organization of the department is outlined in Figure 2. For purposes of administration the engineering department is divided into groups, classified by the major activity of the group personnel. Lines of classification, however, are not rigidly drawn, and it is not unusual to find engineers in the audio-frequency group, for instance, designing u-h-f equipment or the u-h-f group working on power-frequency apparatus.

Group leaders are responsible to the Chief Engineer and Assistant Chief Engineer. Overall administration of the department is the responsibility of the Chief Engineer, who is guided, insofar as decisions on matters of development and design are concerned, by the Development Committee and the Design Standards Committee. It is the function of the Development Committee to set general specifications for a new development and to pass on completed developments before manufacture is started. The Design Standards Committee concerns itself with standard practice in mechanical design: parts, finishes, structural details, etc. It is a sub-committee of the Development Committee.

When new developments are scheduled, the leader in whose group the work is to be done is responsible for the general guidance of the project within the original specifications laid down by the Development Committee. The committee reviews all current projects at frequent intervals, making such changes and improvements in the general specifications as the progress of the development warrants.

The instrument takes form first as a breadboard assembly and next as a working model built in the experimental shop from the design engineer's sketches.

FIGURE 3. The Development Committee in session. Left to right around the circle: C. T. Burke, H. H. Scott, P. K. McElroy, Eduard Karplus, Melville Eastham, D. B. Sinclair

FIGURE 4. A meeting of the Design Standards Committee. Left to right: P. K. McElroy, L. M. Burgess, H. S. Wilkins, F. W. Williams, Gilbert Smiley, H. C. Littlejohn, D. B. Sinclair.

This model is submitted to the Development Committee, who suggest whatever changes seem advisable to improve its general acceptability and its adaptability to established manufacturing methods. Upon approval by the Development Committee, detailed manufacturing drawings are made in the drafting group, and the instrument is ready for manufacture. Before quantity production is started, however, a single unit is built to check the drawings, and a test run of (usually) ten units is made to prove tools and to iron out any production difficulties. Upon successful completion of the trial production lot, the instrument is ready for quantity production.

In addition to the development of instruments, the engineering department is responsible for the preparation of purchase specifications for parts and materials purchased from other manufacturers and for acceptance specifications on new material received.

Facilities

Working facilities in the Engineering Department have been arranged to afford a maximum of adaptability to the work of the department. The working space is a combined office and laboratory, with desk, telephone, and filing facilities, as well as the required laboratory bench space. Senior engineers have, as a rule, individual offices; for junior engineers and assistants one office is shared by two people. There are in all nineteen such offices, all on the same floor, in addition to the departmental facilities, which include the library, secretaries' office, conference room, measurements room, instrument room, frequency standard, and experimental shop.

The library, which is in charge of a full-time librarian, contains over 1000 volumes on general and specialized technical subjects and subscribes regularly to some sixty journals and periodicals.

In the measurements room, standards of resistance, inductance, capacitance and voltage are maintained, and standard equipment is provided for the measurement of impedance over a frequency range of 0 to 100 Mc. This equipment is available for use by engineers at all times. One important function of this laboratory is the determination of the electrical characteristics of new insulating materials and new circuit components. As new types of capacitors, resistors, inductors and dielectrics become available, their properties are measured, and the results are made available to the development engineers for use in instrument design.

The Engineering Department is well equipped with General Radio instruments. These, when not in use, are kept in an instrument room and are available to any engineer needing them. Individual laboratories are canvassed about once a week to pick up unused items for return, so that maximum usefulness can be obtained from the stock available. The instrument room is under the supervision of a technician, and all instruments are kept in repair and are periodically sent to the standardizing laboratory for recalibration and test.

The primary standard of frequency for the whole plant is located in the Engineering Department. It consists of four independent standard-frequency crystal oscillators, with means for intercomparing and recording their frequencies. The output frequency is known at all times to better than one part in ten million. Frequency multiplying and dividing circuits provide hundreds of standard frequencies for use in measurement and calibration work. These are distributed through shielded lines to the engineering laboratories and to various production departments, where they are needed for calibration and test operations.

The experimental shop produces the wide variety of special parts and assem-

FIGURE 5. A view of the Experimental Shop. The total shop personnel is twelve. In the center foreground is K. A. Johnson, Foreman, who is also General Radio's senior employee. H. S. Wilkins, Engineer-in-Charge, is shown in the right foreground.

FIGURE 6. A. G. Bousquet of the High-Frequency Group, who has designed a number of General Radio's signal generators, vacuum-tube voltmeters and power supplies, is shown here testing a preliminary model of a standard-signal generator.

blies needed in engineering development work and constructs the working models of new instruments after development is completed. The shop is equipped with a variety of machines, capable of precision considerably greater than that required in a production shop. Personnel are selected for special skills and include machinists, assembly men, and electrical technicians.

Wartime Development Engineering

During the war, General Radio engineers have been engaged in a variety of war projects. Many new instruments have been developed, among them a number of specialized types of signal generators, test oscillators, high-frequency receivers, and frequency meters. No production by General Radio beyond a few models of these items was possible, because our manufacturing facilities were completely engaged in the production of urgently needed standard items, for most of which deliveries were scheduled by the War Production Board. Millions of dollars worth of equipment, based on these designs was, however, built by other manufacturers. The design of much of this equipment stemmed from the butterfly circuit,* developed by General Radio, which made possible compact tuning assemblies and single-dial control in u-h-f circuits. Developed under the direction of D. B. Sinclair, E. Karplus, and A. P. G. Peterson, all these items except the butterfly itself was classified for security reasons, and descriptions cannot yet be published.

Other one-of-a-kind items have been developed for use in conjunction with development programs carried on by other organizations. In this group directed by H. H. Scott, a total of eighteen separate instruments, many of them for use in f-m systems, have been designed, constructed, and delivered for a single project, which is still secret.

Considerable work has also been done, under the direction of J. K. Clapp, on the design and production of low-frequency quartz bars to meet extreme

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*E. Karplus, "The Butterfly Circuit," *General Radio Experimenter*, Vol. XIX, No. 5, October, 1944.

FIGURE 7. W. F. Byers (left) and S. R. Larson (right) of the Audio-Frequency Group conduct a test run on a finished model.

stability specifications in equipment of considerable urgency. After the engineering work was completed, and a small quantity of bars produced to get the program started, production was turned over to other companies.

In the field of frequency measurement, General Radio has for many years supplied equipment for the ships of the U. S. Navy. Shortly before the war, new designs were completed, and the resulting equipment has been in continuous production since the start of the war. Through close engineering contact with the production process, uniform quality has been maintained and service difficulties have been kept at a minimum.

War research and production in the aircraft, automotive, and ordnance fields have required large numbers of stroboscopes. In addition to our standard types, many of specialized design have been needed. Although the demand for these was limited, the need was urgent, and several small quantity lots have been made under the supervision of H. S. Wilkins. Two items of particular interest are the Microflash, for high-speed, single-exposure photographs, and the Power Stroboscope and continuous-film camera for ultra-speed motion pictures. An interesting example of the use of the Microflash was described in a recent *Experimenter*.* The high-speed movie equipment has been used for aircraft engine research, cavitation studies, and a number of other research programs in mechanics that had immediate application in the design of military equipment.

FIGURE 8. J. K. Clapp (right), in charge of the development of frequency-measuring equipment, looks over a newly developed quartz bar with H. H. Hollis (left).

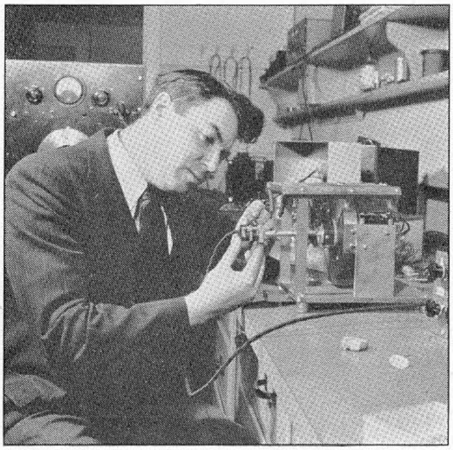

FIGURE 9. W. R. Saylor, who specializes in sound and vibration measurement, testing an experimental vibration pickup.

Owing to our location, in proximity to the Radiation Laboratory of Massachusetts Institute of Technology, the Radio Research Laboratory of Harvard University, and other NDRC organizations, cooperation with these laboratories has been close. In a consulting capacity, the skill and experience of our engineers have been available to them constantly, in most cases without charge. Special parts have been designed for them under the direction of H. S. Wilkins, and standard instru-

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*"Microflash Shows Flight Defects in Projectiles," *General Radio Experimenter*, April, 1945.

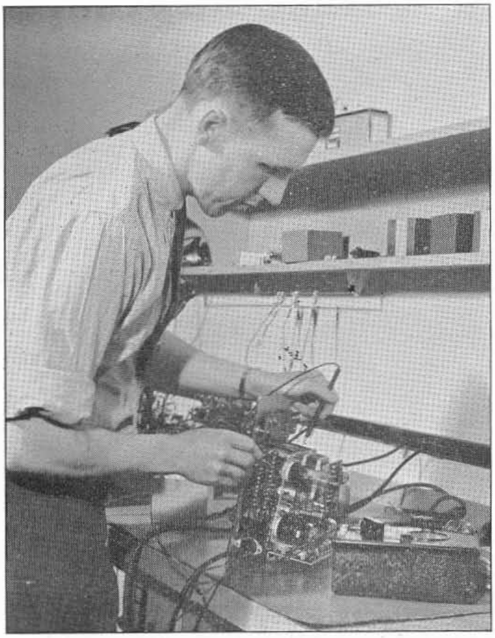


Figure 10. C. A. Woodward, of the Measurement Group, with the preliminary model of a high-frequency voltmeter.

ments have been modified to meet specialized requirements.

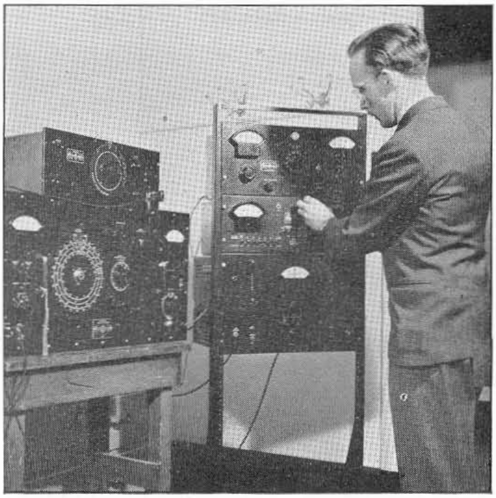
Our chief engineer, Melville Eastham, was on leave of absence for some months, devoting all his time to the administration of a division of the Radiation Laboratory. Dr. D. B. Sinclair, Assistant Chief Engineer, served part time as research associate and consultant at the Radio Research Laboratory and was a technical observer for the AAF in the North African theater at AFHQ for a considerable period. Several other members of the staff are members of the NDRC or have served on NDRC sub-committees.

Post-War Development

The accelerated research of wartime compresses into a short period advances that normally would require several times as long to achieve. The experience gained by General Radio engineers through war work will be reflected in new and better instruments in the post-war period. New developments in circuits, new and better circuit elements, new techniques of measurement, and new methods of construction are available and can be applied to the design of instruments to achieve levels of performance, stability, and accuracy considerably better than were possible before the war.

While war projects leave little time for thinking about post-war products, the trend of wartime development has made it possible to predict with considerable accuracy what advances in the art will mean in terms of new peacetime instruments. Circuits developed for military equipment have obvious applications in industrial instruments. New parts and materials have shown the engineer how to get better overall performance from a given circuit, or to extend the ranges over which acceptable performance can be maintained. New techniques of measurement lead to entirely new instruments, and improved

Figure 11. C. A. Cady, of the Audio-Frequency Group, checks the distortion in a newly-developed oscillator.



methods of construction can mean more economical designs, greater convenience of operation, easier maintenance, or longer life.

In the field of broadcast monitoring equipment, for instance, new models will be smaller, will require less r-f power, and will be easier to install and operate. Frequency monitors will operate directly from an amplitude-modulated signal. The frequency range and sensitivity of distortion meters will be increased.

Improved tuned circuits, output systems, and dial drives will make possible a considerable improvement in the accuracy and reliability of standard-signal generators. Both a-m and f-m models are now planned and will collectively cover frequencies from the low-radio range to the u-f-h bands, a total frequency span of about 100,000:1. U-h-f models will use the new butterfly and cylinder-type tuning units.

In instruments for voltage measurement, the upper frequency limit will be extended for vacuum-tube types and a d-c voltage measuring feature included.

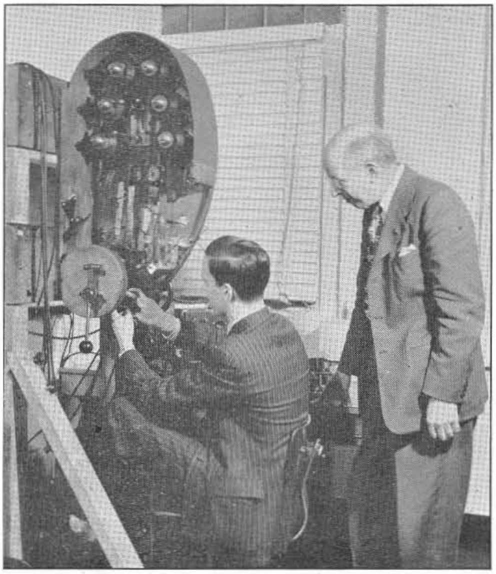


FIGURE 12. R. F. Field (right) and D. A. Powers, with a machine for winding polystyrene capacitors, a new type developed under Mr. Field's supervision.

FIGURE 13. View of the Drafting Department. The total personnel of this department is eleven, in addition to L. M. Burgess, Engineer-in-Charge and A. C. Rohmann, Supervisor

FIGURE 14. E. E. Gross (left) and W. R. Thurston, of the High-Frequency Group, working on a u-h-f oscillator of the coaxial butterfly type.

Smaller circuit elements, particularly vacuum tubes, and refinement of mechanical design, direct outgrowths of war developments, make it possible to produce a probe of higher resonant frequency than heretofore. Where high-frequency performance is not important, sensitivity can be considerably increased. Beyond the useful upper frequency of vacuum-tube types, crystal rectifiers will be used.

Both better constructional methods and circuit design are factors which will simplify some of the more complex instruments. Frequency standards, in particular, will be smaller and more compact, while auxiliary frequency measuring equipment will be more flexible in application and more convenient to operate.

Ranges of frequency measurement have of necessity been extended to higher frequencies during the war, and both wavemeters and heterodyne frequency meters in compact, portable models for the u-h-f and v-h-f ranges will be available for post-war use.

Improvements in oscillators will include lower distortion, wider ranges, and higher power output. A double-beat-type of instrument is also planned for use in the measurement of distortion resulting from cross-modulation.

Unit construction offers possibilities for inexpensive and flexible laboratory equipment. Simple oscillators and amplifiers made to plug into a power supply unit will avoid unnecessary duplication of equipment and will be priced at a level within the reach of the smaller laboratories.

The advances made over the past several years in our understanding of the nature of dielectrics have indicated that measurements should be made over wide ranges of frequency in order to predict accurately the electrical properties of insulating materials. Consequently, wide-range bridges will be available for the measurement of dielectric constant and dissipation factor. Another new instrument for insulation testing is a high-voltage, direct-reading megohm-meter for taking current-time curves.

FIGURE 15. A. P. G. Peterson (right) and R. J. Ruplenas with an experimental u-h-f signal generator.

FIGURE 16. H. W. Lamson makes a few check measurements on his newly-developed magnetic test set.

In the v-h-f and u-h-f bands, transmission lines are now widely used for impedance, voltage, power, and attenuation measurements. One drawback to their use has been that a given length of line is usable over only a narrow range of frequency. A set of coaxial connectors is under development, which will permit the necessary line elements for any given frequency to be assembled quickly and conveniently.

Other new standard parts will include variable air condensers, rheostat-potentiometers of improved linearity and accuracy, and a completely new line of Variacs. New core materials and improved mechanical and electrical design have produced a Variac that is smaller, more efficient, more rugged, and easier to service.

The increasing use of radio-active tracer isotopes, produced in the cyclotron, for analyzing chemical, physiological and metallurgical processes has produced a need for various types of counters. One projected new instrument is a counting-rate meter for use with a Geiger-Muller counter tube.

New and improved stroboscopes will result from war designs, for both visual and photographic use. Among the possible new features are higher-intensity lamps, shorter flash duration, and higher repetition rates.

In broad outline, these are some of the general improvements that can be expected in post-war instruments. Designs must await the completion of war engineering work, and production, the release of materials.

FIGURE 17. D. H. Chute, in charge of the measurements room, balances a precision capacitance bridge.

FIGURE 18. Paul Hanson of the Design Group examines a model of a new wire wound variable resistor.

VOLUME XX

● **THIS ISSUE** of the *Experimenter* is Volume XX, Number 1, and marks the start of the twentieth year of continuous publication. Volume I, Number 1 was a four-page 9- x 12-inch paper and was dated June 1926. At that time, an important part of the General Radio Company's business was the manufacture of parts for home-built radio receivers, although a considerable line of laboratory measuring instruments was also produced. Articles of interest to the amateur and home experimenter were published, therefore, as well as a considerable amount of more technical material.

As measuring equipment became the predominant part of our business, nearly all of the articles in the *Experimenter* were directed to technical men. In 1929, beginning with Volume IV, Number 1, the present 6- x 9-inch, 8-page format was adopted.

The present circulation is approximately 24,000 copies, of which 20,000 go to the United States and Canada.

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 address, type of business company is engaged in, and title or position of individual.

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THE General Radio EXPERIMENTER

VOLUME XX Nos. 2 and 3 JULY and AUGUST, 1945

ELECTRICAL MEASUREMENTS AND THEIR INDUSTRIAL APPLICATIONS

A HETERODYNE FREQUENCY METER FOR 10 TO 3,000 MEGACYCLES

Also

IN THIS ISSUE

● TO MEASURE FREQUENCIES, power from an unknown source can be absorbed in a calibrated resonant circuit and made to operate an indicator. The indicator can be an incandescent lamp, a glow tube or a galvanometer preceded by a detector. This simple and straightforward method requires appreciable power and is limited to frequencies for which resonant circuits are available.

In a heterodyne frequency meter, the power required from the unknown source to produce beat notes with a calibrated oscillator is smaller by several orders of magnitude, and the frequency range that can be covered with a single oscillator, spanning a two to one range, extends continuously over several decades.

If the unknown frequency is lower than the lowest frequency of the heterodyne oscillator, harmonics of the unknown are used to produce beats with the oscillator fundamental. If the unknown is higher than the highest frequency of the heterodyne oscillator, harmonics of the oscillator are used. In either case the harmonics are produced in a nonlinear element of the heterodyne frequency meter.

Experience has shown that harmonics up to the twentieth order can be used in an instrument of this type with a corresponding spacing of 5% between frequencies which

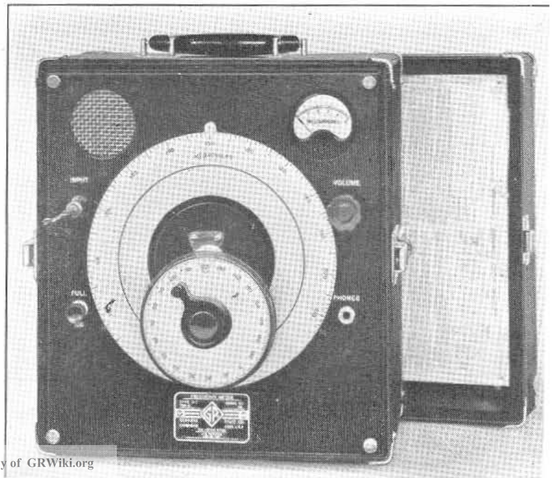

Figure 1. View of the Type 720-A Heterodyne Frequency Meter with cover removed.

produce adjacent beats. It follows that the calibrated oscillator should have a range of approximately 100 to 200 megacycles if unknown frequencies up to 3,000 megacycles are to be measured.

The chief obstacle to producing a heterodyne frequency meter for this range has been the erratic performance of oscillators using conventional tuned circuits. Sliding contacts produce erratic variations in frequency and amplitude, while changes in tubes and supply voltages have much greater effects than at lower frequencies. The newly developed Butterfly Circuit,* however, has made it possible to avoid most of these difficulties. With the new TYPE 720-A Heterodyne Frequency Meter, which uses the Butterfly Circuit, a frequency of 3000 Mc can be measured as conveniently and as accurately as those in the broadcast range. The low-frequency limit for normal use is about 10 Mc, but lower frequencies can be measured if more than 1 volt at the unknown frequency is available at the detector input.

The TYPE 720-A Heterodyne Frequency Meter is a portable battery-operated instrument of small size and light weight, with unusually high sensitivity. The panel view of the new instrument is shown in Figure 1. A complete set of operating instructions is mounted in the removable cover. The functional elements of the instrument are a calibrated oscillator, a detector, and an audio amplifier as shown in the schematic diagram of Figure 2. An internal view of the instrument is shown in Figure 3.

Oscillator

The frequency of the heterodyne oscillator is continuously variable between 100 and 200 megacycles. The frequency-determining element is a tuned circuit of the butterfly type, with rotor plates shaped to give an approximately logarithmic frequency distribution. The rotor is mounted in ball bearings. No sliding contacts are used, and no current flows through the bearings. Smooth adjustment of frequency and stability of calibration are therefore assured.

The main dial of the frequency meter is calibrated directly in megacycles. The scale is 15″ long and approximately logarithmic. The gear ratio between the tuned circuit and the vernier dial is over 200 : 1. Over most of the frequency range one-half turn of the vernier dial corresponds to 1% variation in frequency, and one division of the vernier dial to a frequency change of 100 parts per million. Unknown frequencies are measured by producing beats with the calibrated heterodyne oscillator. Beats may be produced between the fundamentals of the unknown source and the

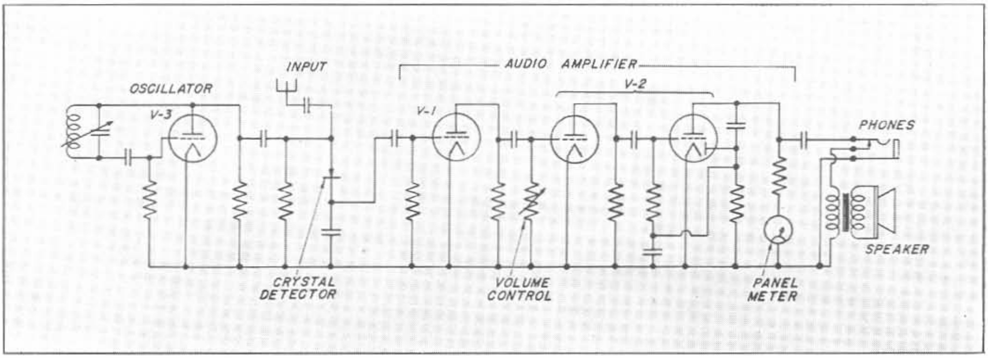

FIGURE 2. Schematic circuit diagram of the heterodyne frequency meter.

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*E. Karplus, "The Butterfly Circuit," General Radio *Experimenter*, Volume XIX, No. 5, October, 1944.

heterodyne oscillator, between harmonics of the unknown frequency and the heterodyne fundamental, between the unknown fundamental and harmonics of the heterodyne oscillator, or between harmonics of both the unknown source and the heterodyne oscillator.

Detector

The detector, in which the harmonics of the known and unknown frequencies and their beats or difference frequencies are produced, is a standard 1N21B-type crystal detector, consisting of a silicon crystal and a tungsten wire, mounted in a small ceramic cartridge. The detector cartridge is located near the antenna input terminal and is held in place by a ring-shaped spring. A spare detector is furnished with the instrument, but, since the cartridge used has standard dimensions, different makes and types of detectors can be substituted.

Adequate input to the detector is usually obtained if the instrument is placed in the vicinity of the oscillator whose frequency is to be measured. An input antenna of adjustable length is permanently mounted on the front panel. This adjustment is used to improve signal strength when working with frequencies above 1000 Mc. For frequencies below 100 Mc, it may be necessary to connect an additional wire to the "input" terminal.

Amplifier

The three-stage audio amplifier has an effective band width of 50 kc and is connected to produce a deflection of the panel meter when a strong signal is impressed on the detector. This feature is particularly useful when the frequency under measurement is not sufficiently stable to produce a steady audible beat. Audible beats are simultaneously heard in the small dynamic speaker mounted on the front panel. Weak beat notes are best observed with a pair of headphones plugged into the PHONES jack.

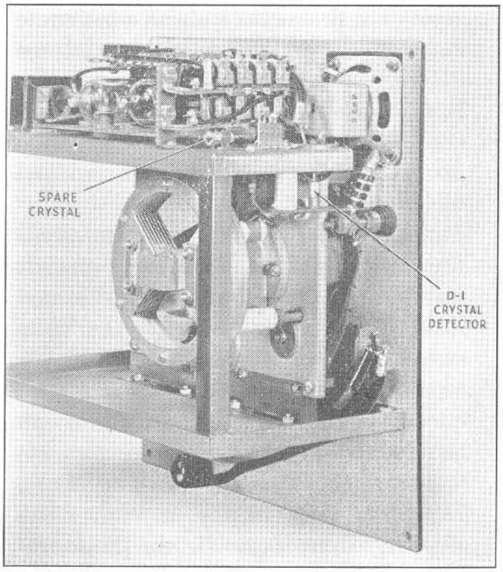

FIGURE 3. Interior view showing the butterfly-type tuned circuit and the location of the working and spare crystals.

Power Supply

One Burgess TYPE 6TA60 Battery is used to supply 90 volts to the plates and 1.5 volts to the filaments of the three vacuum tubes used. All necessary connections are made by a battery plug attached to a short cable. The filament and plate loads are well balanced, and the battery will give long service in intermittent use. Since the heating up time of the tubes is very short, the instrument can be turned off if appreciable time elapses between measurements. The instrument can also be operated from a rectifier power supply, and a compact a-c power unit to fit the battery compartment will be available later.

Making Frequency Measurements

The process of making frequency measurements by the heterodyne method consists fundamentally of three steps. The first is to establish a beat note between the unknown source and the heterodyne oscillator. The second step is to determine the order of the beat observed, and the third step is to determine the frequency of the heterodyne oscillator.

With the Type 720-A Heterodyne Frequency Meter the last step consists merely in reading the directly-calibrated main dial of the instrument. The accuracy thus obtained is 0.1%. If higher accuracies are desired, the true frequency of the heterodyne oscillator can be measured in terms of a more accurate low-frequency standard. The Type 720-A then is merely a convenient stepping stone between the high unknown frequency and the low standard frequency, which are too far apart to produce beat notes by themselves. The best procedure to establish beat notes and to determine their order depends on whether the unknown frequency is in the range of the fundamental oscillator frequency or above or below. In general, if the "unknown" frequency is known approximately, a single beat is sufficient to determine the frequency accurately. On the other hand, if the approximate value is not known, it will be necessary to note successive beats until their pattern can be determined.

Frequencies between 100 and 200 Mc. When the frequency to be measured lies within the fundamental range of the Type 720-A Heterodyne Frequency Meter, the unknown frequency is read directly from the main dial when a strong beat is obtained. In addition to this beat note, other weaker beat notes may be heard. For example, if a fundamental frequency of 150 Mc is measured, a strong beat will be obtained at a dial setting of 150.0 Mc, and weaker beats may be heard at dial settings of 100 and 112.5 Mc. These weaker beats are produced between the 2d and 3d harmonics of the unknown frequency and the 3d and 4th harmonics of the Type 720-A Oscillator, respectively; 2 × 150 Mc = 3 × 100 Mc and 3 × 150 Mc = 4 × 112.5 Mc.

Frequencies over 200 Mc. For frequencies which lie above 200 Mc the procedure is to start at the high end of the frequency range and to note the successive settings of strong harmonic beats as the frequency of the heterodyne oscillator is progressively reduced. If the frequency at which one beat occurs is divided by the frequency difference between it and a successive beat, the result must be an integer and is the harmonic number of the successive beat. *Example:* A high frequency is measured and strong beats are obtained at 200.0 and 160.0 Mc. Subtracting the second beat from the first gives 200.0 — 160.0 = 40.0. Dividing the first beat by this difference gives 200.0/40.0 = 5, which is the harmonic number of the second

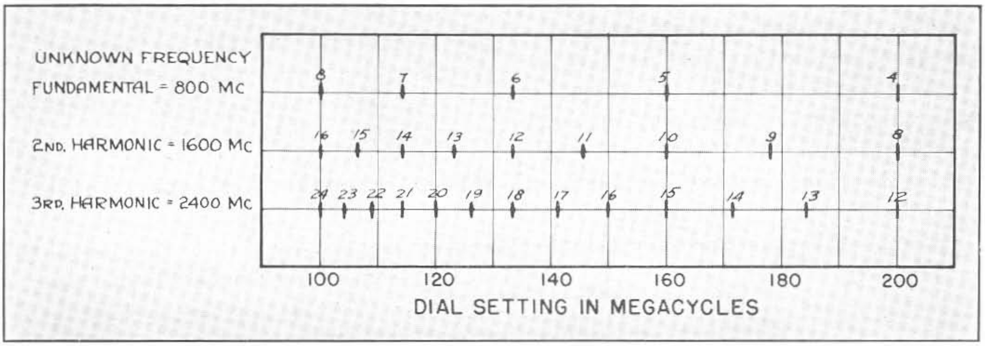

Figure 4. Chart showing pattern of harmonic beats for an unknown frequency of 800 megacycles.

beat. Hence, the unknown frequency is 5 × 160.0 = 800.0 Mc.

In many cases it will be possible to produce beats between harmonics of the unknown frequency and harmonics of the heterodyne oscillator. These beats will usually be much weaker than the beats produced between the unknown fundamental and the heterodyne harmonics. The chart of Figure 4 gives the possible beats up to the 3d harmonic of the unknown used in the example above.

Frequencies under 100 Mc. For frequencies which lie below 100 Mc, the procedure is to start at the low end of the frequency range and to note the successive settings of beats as the frequency of the heterodyne oscillator is progressively increased. The frequency difference between two successive beat settings is equal to the unknown frequency. *Example:* A low frequency is measured and beats are observed at 105.0, 120.0 and 135.0 Mc. The frequency difference between successive beats is 15.0 Mc, which is the frequency being measured.

Wavelength. The wavelength in centimeters is obtained with sufficient accuracy by dividing 3×10^{10} by frequency. In most applications electromagnetic waves are characterized by their frequency, but in some problems the use of wavelength may be more convenient. It has been shown in the paragraph entitled "Frequencies over 200 Mc" above, for instance, how an unknown frequency over 200 Mc can be determined from the two frequencies of the heterodyne oscillator which produce successive beat notes. If all frequencies are converted into wavelength, the wavelength of the unknown is simply the difference between the two wavelengths which produced the successive beat notes. *Example:* 160 and 200 Mc in the example above correspond to 187.5 and 150 cm. The difference of 37.5 cm corresponds to 800 Mc.

— EDUARD KARPLUS

SPECIFICATIONS

Frequency Range: The fundamental frequency range is from 100 to 200 Mc. This range is covered in a single band with approximately logarithmic frequency distribution. By harmonic methods, frequencies between 10 Mc and 3000 Mc can be measured.

Calibration: The main dial is calibrated in frequency, each division corresponding to 1 Mc. The vernier dial is geared to the tuning unit to make one-half turn of the dial correspond to 1% change in frequency over the major part of the tuning range. The vernier dial carries 200 uniform divisions.

Accuracy: The overall accuracy of measurement is 0.1%. Changes in tubes or battery voltages and variations of temperature and humidity over the range of laboratory conditions normally encountered do not affect the accuracy of the instrument.

Detector: One cartridge-type crystal detector (1N21-B) is used and is supplied with the instrument.

Vacuum Tubes: The following tubes are used and are supplied with the instrument:

1 — TYPE 1N5GT
1 — TYPE 1D8GT
1 — TYPE 958

Battery: A single-block Burgess TYPE 6TA60 Battery is used and is supplied with the instrument. The power required is approximately 80 volts, 6 ma and 1.4 volts, 250 ma.

Case: The TYPE 720-A Heterodyne Frequency Meter is mounted in a shielded carrying case of durable airplane luggage construction.

Spare Parts: One 1N21-B-type detector is supplied as a spare in addition to the one in the instrument.

Accessories: Headphones which can be plugged in on the front panel and stored in the cover of the instrument are recommended.

Dimensions: Overall, (width) 12½″ × (height) 13½″ × (depth) 10½″. Panel, (width) 10¾″ × (height) 11¾″.

Net Weight: Including battery, 27¾ pounds.

Type		*Code Word*	*Price*
720-A	Heterodyne Frequency Meter	FANCY	$250.00

This instrument is manufactured and sold under (1) patents of the American Telephone and Telegraph Company, and (2) U. S. Patent No. 2,367,681.

HOW HUMIDITY AFFECTS INSULATION

PART I—D. C. PHENOMENA

The present increasing use of electrical equipment in tropical climates has made necessary a better understanding of the behavior of insulation under extreme conditions of humidity. General statements such as "At 100% relative humidity and a frequency of 60 cycles, increases as much as 50% in capacitance, of a millionfold in conductivity, and up to a dissipation factor of 1.0, are quite possible for such porous materials as filled and laminated thermo-setting plastics, many thermoplastics and natural fibers like cotton, wool, and silk"[1] are quite inadequate. How long does it take to produce these changes; how much less is the effect at lower humidities; what happens at other frequencies; are there any really good insulators that are unaffected? It is the object of this article to give some sort of answer to each of these questions and to make a beginning at sorting out present commercial insulating materials according to their resistance to moisture.

Electrical Properties

The electrical property most affected by moisture is insulation resistance. This is made up of two parts, surface resistance and volume resistance, which exhibit vastly different behavior, especially with respect to time. Volume resistivity is an inherent property of a material, which is at a maximum under dry conditions, and decreases rapidly as water is absorbed. Surface resistivity is infinite for a clean dry surface, but decreases very rapidly as any foreign conducting material adheres to the surface. Water adheres to the surface of most insulators and is absorbed by them under conditions of immersion or high relative humidity. This water film, even though pure initially, becomes ionized from carbon dioxide in the atmosphere, from solution of salts on the surface or in the water on immersion, and from slight solution of the insulating material itself.

The relative importance of these two modes of conduction, surface and volume, depends greatly on the shape of the sample under test. For the slab of insulation shown in Figure 1 the surface and volume resistances are, respectively,

$$S = \sigma \frac{l}{2(w+t)} \quad \text{and} \quad R = \rho \frac{l}{wt}$$

where σ = surface resistivity (independent of units)

ρ = volume resistivity

Since the ratio of surface to volume resistance

$$\frac{S}{R} = \frac{\sigma}{\rho}\frac{wt}{2(w+t)}$$

is independent of path length, it can be minimized by making the slab as thin as possible. The samples used for studying insulation resistance are between $\frac{1}{16}$ and $\frac{1}{8}$ inch thick and have bar electrodes so placed that the surface area is usually a square, so that surface resistivity is approximately twice the insulation resistance (volume resistance being assumed negligible). The electrodes are attached by a center bolt through a hole in the specimen or by two end bolts.[2] Resistance is measured on a TYPE 544-BS8 Megohm Bridge,[3] on which, at 500 volts, a resistance of 10 MMΩ can be distinguished from infinite resistance. The sample is mounted on the metal top of a glass desiccator jar. The terminals

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[1] R. F. Field, "The Effect of Humidity on Electrical Measurements," *General Radio Experimenter*, Vol. XVIII, No. 11, April, 1944, p. 5.

[2] ASTM D257–38, Insulation Resistance of Electrical Insulating Materials, Figures 1 and 2.

[3] This model has a resistance range 10 times greater than that of the standard bridge.

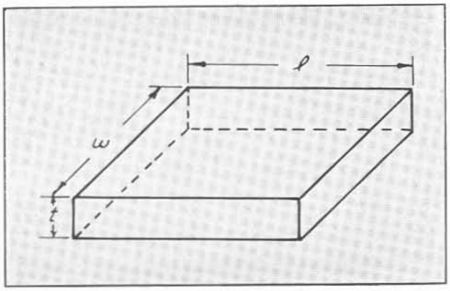


FIGURE 1. Dimension sketch of test slab of insulation.

are mounted on TYPE 138-UL Binding Post Assemblies with the metal top connected to the guard terminal of the bridge. Except for a few of the poorest materials, the insulation resistance of the sample when dry is greater than 10 MMΩ.

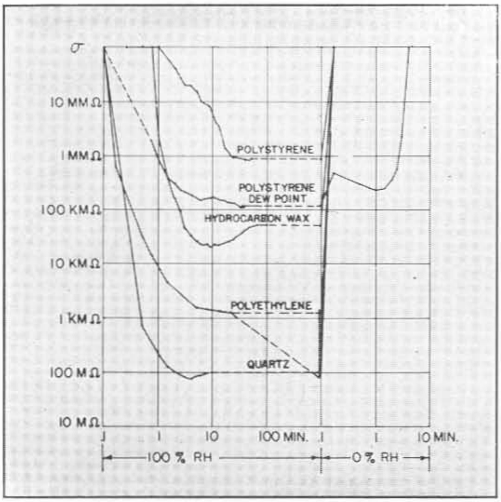
Effect of 100% Relative Humidity

When any sample is placed in an atmosphere of 100% relative humidity,[4] an ionized conducting film of water forms within a few seconds. Within one minute its resistance drops to a value about a decade above its final equilibrium value in the manner shown in Figure 2 for four materials which either have no volume absorption or a negligible amount within the time indicated. The quantity plotted is surface resistivity. For some materials the equilibrium value is steadily approached, while for others there is a minimum value and a slow rise. These different forms result from the divergent effects produced by the applied voltage in sweeping ions to the electrodes and in forming new ions by collision, a process which results in a voltage coefficient of resistance. When the bridge voltage is not applied continuously but only momentarily for a reading, the measured resistance is decreased, but returns to its larger value when the voltage is maintained. Thompson and Mathes[5] have reported a similar effect. This behavior is shown by polyethylene for which the voltage was removed for 16 hours with a tenfold decrease in resistance when the voltage was reapplied. But within 15 minutes its resistance was up to the earlier value, showing that the water film did not change with time. If, however, dew point condensation is produced by initial cooling of the sample, the water film is both more conducting and thicker, as shown by the two curves for polystyrene. Proof that the film is thicker will appear in the next paragraph.

Recovery at 0% Relative Humidity

The degree of permanence of the water film is demonstrated by transferring the sample to an atmosphere of 0% RH.[6] For the materials of Figure 4 the initial resistance is recovered within 10 seconds.[7] Even this short recovery time

FIGURE 2. Plot of surface resistivity vs. time for four materials having negligible volume absorption within the time indicated. The left-hand portion of the plot shows the surface resistivity under the condition of 100% relative humidity for time up to 1000 minutes, where the time scale repeats for the right-hand portion, which shows the recovery time at 0% relative humidity.



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[4] Obtained by filling the base of the desiccator jar with water and having a cover on for four hours previously.

[5] B. H. Thompson, K. N. Mathes, "Electrolytic Corrosion — Methods of Evaluating Insulating Materials used in Tropical Service", AIEE Transactions, Vol. 64, June 1945, p. 297.

is probably set more by the natural diffusion rate of water vapor outward to the silica gel than by any specific property of these materials. For the thick film produced on polystyrene by dew point condensation, the rapid rise in resistance is halted after a few seconds because the relative humidity immediately surrounding the specimen is no longer 0%. The film is redistributed, and only after one minute does resistance start to rise again to regain its initial resistance after 4 minutes. The use of forced ventilation, even at a room humidity of 30% RH, removes the film in 10 seconds.

This shape of the recovery curve, in which there is a rapid rise, a slow drop during redistribution and a final rise to initial value, seems to be characteristic of those materials having no volume absorption within the time of the measurements, when by various means the film is made sufficiently thick. Curves for two grades of mica-filled phenolic are given in Figure 3. Sample A recovers within 10 seconds after an exposure of 90 minutes to 100% RH but requires 14 minutes after a 16-hour exposure. Sample B shows a much lower surface resistivity and the typical recovery curve after only 20 minutes exposure to 100% RH. Forced ventilation removes the films from both materials in 10 seconds. Several other materials show this effect, as shown in Table I, which will be discussed later. The exact shape of the recovery curve can extend from that of vinyl chloride acetate, which rises above 10 MMΩ before the drop, to that of quartz after dew point condensation, which remains at its 100% RH value for 2 minutes before the final rise to initial value.

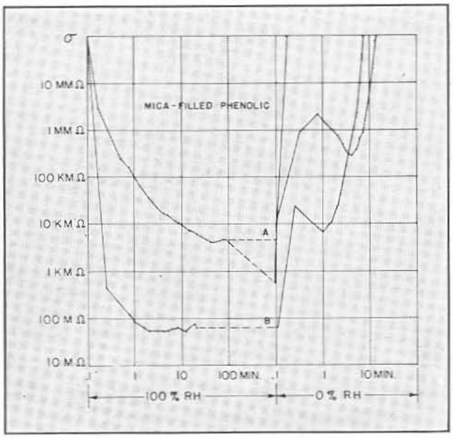


Figure 3. Exposure and recovery curves for 2 grades of mica-filled phenolic. Apparently, small differences in surface finish result in large differences in surface resistivity.

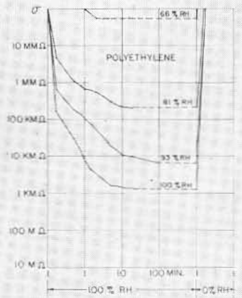
Effect of Other Relative Humidities

When materials are placed in humidities less than 100% RH, their equilibrium resistances are higher and the water films presumably thinner. Curves obtained for polyethylene are shown in Figure 4.[8] The relation between the equilibrium surface resistivity and relative humidity is exponential, as shown in Figure 5, where the plot of the loga-

Figure 4. (*left*) Plot showing how relative humidity affects the exposure curve for polyethylene.

Figure 5. (*right*) Equilibrium surface resistivity for polyethylene as a function of relative humidity. The exponential relationship is characteristic of all insulating materials.

4



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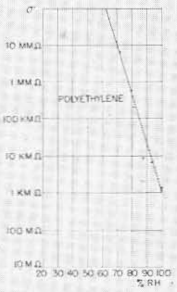

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[6] Obtained by filling the base of the dessicator jar with silica gel and having a cover on for four hours previously.

[7] The bridge is preset at infinite resistance and the time to return to balance is measured by a stop watch.

[8] Definite humidities are obtained by placing saturated solutions of various salts in the desiccator jar. The salts used are as follows:

%RH	32	43	52	66	81	93
Salt	$CaCl_2$	K_2CO_3	$Na_2Cr_2O_7$	$NaNO_2$	$(NH_4)_2SO_4$	$NaSO_4$

rithms of resistivity against percent relative humidity is a straight line. This agrees quite well with the work done by Curtis in 1915[9] on the available insulation of that day. His plots were nearly linear from 100% RH down to about 50% RH and then flattened to a constant value of resistance defined by the volume resistivity of the sample. The greater sensitivity of his apparatus allowed him to measure 100 kMMΩ and to carry the observations down to 0% RH. Surface resistivity at any relative humidity, H%, is best defined by stating the surface resistivity, σ_{100} at 100% RH and the change in relative humidity h which changes the resistivity by one decade. Then

$$\log \sigma = \frac{100 - \mathrm{H}}{h} - \log \sigma_{100} \qquad (3)$$

Effect of Volume Absorption

Volume absorption of water into the body of an insulator provides both a volume conductance and a storage of water, which on drying out must pass out through the surface. Long before enough water has been absorbed to reduce volume resistance to a value at all comparable to surface resistance, the shape of the recovery curve is changed, because the absorbed water tends to maintain the surface film. Surface resistivities for four materials having appreciable volume absorption are shown in Figure 6. Their recovery curves rise slowly and require more than 10 minutes to attain initial values. Something more than amount of water absorbed determines the rate of recovery, since the laminated paper and asbestos-filled phenolics absorb much more water than glass-bonded mica or sheet mica. This may be the molecular force which holds the water film to the surface.

For high rates of volume absorption of water volume resistance at 100% RH becomes comparable with surface resistance before the equilibrium value of surface resistance is attained. The resistance-time curve then continues downward at a rate dependent upon the rate of water absorption. This effect will first appear in the curves for the lower humidities, because the rate of water absorption is probably independent of relative humidity so long as a surface film exists, while the surface resistance in-

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[9] H. L. Curtis, "Insulating Properties of Solid Dielectrics", Bulletin of Bureau of Standards, Vol. II, No. 3, May 1915, pp. 359–420.

FIGURE 6. Exposure and recovery curves for four materials having appreciable volume absorption. Such materials show, in general, a smoother recovery curve, extending over a time comparable to the exposure time.

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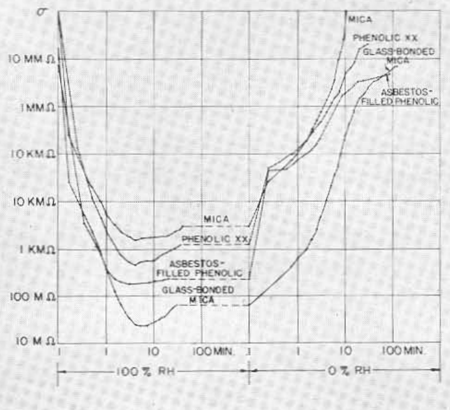

FIGURE 7. Exposure and recovery curves for two materials having so large a volume absorption that an equilibrium value of surface resistivity cannot be observed.

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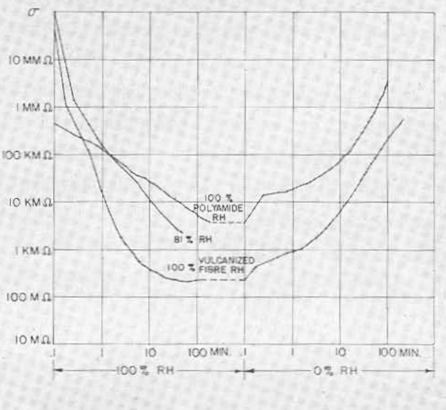

creases with lowered humidity. These distinctions are shown in Figure 7. The surface resistivity of vulcanized fibre at 100% RH is so low that equilibrium is attained at 90 minutes before volume resistance can have an effect, while at 81% RH volume resistance becomes comparable to surface resistance within 10 minutes, prevents equilibrium, and causes insulation resistance to decrease directly with time. Polyamide has a relatively high surface resistivity, so that even at 100% RH its volume resistance becomes comparable to surface resistance within 10 minutes and prevents any equilibrium value being attained.

On continued exposure to high humidity extending over days and weeks rather than hours, volume conductivity steadily increases in proportion to the water absorbed and in most materials dominates over surface conductivity even at 100% RH. Kline[10] has given a list of the times necessary to reach saturation for 22 materials. The values extend from 2 days to 2 years. They depend both on the structure of the material and the shape of the sample, particularly the ratio of surface to volume. Scheer[11] has measured the insulation resistance of several insulators over a period of 30 days and finds that resistance equilibrium is usually attained within that time. It is important to note that of the total decrease (6 to 7 decades) in insulation resistance from the initial dry value surface resistance accounts for the major part, which is usually sufficient to render useless any instrument in which the material is used. Volume resistance only accounts for the last one or two decades, but makes the reduction permanent to the extent that the recovery time will be at least as long as the exposure time.

Collected Data

Some 40 materials are arranged in Table I in the order of decreasing surface resistivity after exposure to 100% RH, ranging from greater than 20 MMΩ to 30 MΩ. The position of certain materials is most surprising and may not be typical. All samples were washed in grain alcohol to remove dirt, but some grease and other substances may remain. At least they were as clean as they would be in actual use. Only one sample of a kind was tested so that there is no measure of the magnitude of normal variations. However, the results are repeatable on the same specimen within 50%. Where more than one sample of a kind is given, they are known to differ or are made by different manufacturers. It is known that very small amounts of plasticizer can greatly change the surface behavior and none of the samples was furnished for this particular test.

The slope of the straight line plot of surface resistivity against relative humidity is given in the second column, and in the third column the relative humidity at which the surface resistivity is 20 MMΩ. Since for most of the materials this value of relative humidity is greater than 50% RH, it is easy to see why relative humidities less than 50% RH are considered to have little effect on insulation and also why that value is a good standard room humidity. Materials with volume absorption may be conditioned at that humidity without having any appreciable surface resistance.

The last three columns give the recovery times in minutes after 1 hour and 16 hours exposure to 100% RH and

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[10] G. M. Kline, A. R. Martin, W. A. Crouse, "Sorption of Water by Plastics", Proceedings of American Society for Testing Materials, 1940, pp. 1273–1282.

[11] F. H. Scheer, "Study of Moisture Proofing Treatment for Phenolic Boards," Company Report 1943–4, Colonial Radio Corp.

				Recovery time in minutes after		
		%RH		100% RH for		Dew point
Material	σ	per decade change of σ	%RH for 20 MMΩ	1 hr	16 hrs	condensation
	MMΩ					
Hydrocarbon wax, modified	>20		100	.0	.0	
Cellulose acetate butyrate	>20		100	.0	.0	.0
Silicone rubber	10			.13		
Polytetrafluoroethylene	3.6			.17	.17	
	kMΩ					
Polystyrene (sheet)	840		93	.13	.13	4*
Polydichlorostyrene 2–5	29	7	79	.17		
Hydrocarbon wax	20	13	56	.17		
Ethyl cellulose	13	9	70	.33	.5	
Cellulose acetate	7.0	6	77	1.0	6	
Polyvinyl chloride acetate	5.7	12	58	6*		
Polystyrene (plasticized)	5.0	4	83	.17	62*	
Phenolic, mica-filled	5.0	9	66	.17	13*	
Aniline formaldehyde	4.2	4	82	.17	20*	
Polyamide	3.8	14	48	200		
Porcelain, glazed	3.7	15	42	2.5*		
Glass (high K)	3.4	10	59	17*	20*	
Mica	3.0	12	50	11		
Polystyrene (molded)	2.4	10	58	.17	.17	
Polystyrene (plasticized)	2.4	8	64	.11	.17	
Steatite (L-3)	1.6			.17	.75	
Quartz	1.4					
Polyethylene	1.3	9	63	.17	.17	
Phenolic, XX	1.3	16	45	80		
Phenolic, asbestos filled	1.2	9	61	1.5*	100*	
	MΩ					
Phenolic, XXXP	660	15	25	300		
Steatite (L-4)	640			.5	1	
Phenolic, LE	500	18	16	400		
Phenolic, mica-filled	320	8	58	40*		
Steatite (L-4)	280			.33		4*
Polydichlorostyrene 3–4	240	6	71	.33	5.3*	
Phenolic, cellulose filled	240	10	49	400		
Aniline formaldehyde, glass matte	240	9	50	14	1000	
Phenolic, C	220	16	20	300		
Vulcanized Fibre	220		0	6000		
Aniline formaldehyde, glass cloth	200	12	57	3		
Quartz	190					
Phenol formaldehyde (plasticized)	100	12	34	25		
Glass (sintered)	90					
Glass bonded mica	64	18	31	400		
Melamine, glass cloth	38	14	14	300		
Phenolic, mica filled	30	11	32	7*		

after dew point condensation. Any time up to 0.25 minute (15 seconds) indicates no volume absorption. Any longer time which is starred (*) refers to the shape of recovery curve characteristic of nonporous materials, for which forced ventilation will give a recovery time of less than 0.25 minute. Other large times indicate volume absorption under the condition noted.

Many interesting facts may be gleaned from this table. The high position of cellulose acetate-butyrate is surprising when it is realized that this material will absorb about 1% of water in 24 hours at 100% RH. This water must be kept in unconnected pockets to prevent conduction. A sample with 4% of water still has a resistance greater than 10 MMΩ. Eventually the water in the isolated pockets joins and provides normal volume resistance. Glass, quartz, steatite and mica are well down in the list and probably would be lower if their surfaces had been made perfectly clean by high temperature baking. Silicone rubber is third from the top and illustrates the valuable water-repellent property of all silicone resins. Treatment of materials containing silicon, such as glass and quartz, by the special silicone resins which produce a molecular layer several hundred molecules thick makes the treated surface completely water-repellent, even under hot salt spray and salt water immersion. A similar treatment of steatite affords great improvement, but is not always entirely successful. A non-porous ceramic properly treated with silicone resin is unaffected by moisture and is as nearly a perfect insulator as exists at present. It is quite possible that certain plastics, especially the silicone resins, will also meet this specification.

— Robert F. Field

Part II on A. C. Phenomena will appear in an early issue.

MISCELLANY

● At Oregon State College on June 10, the honorary degree of Doctor of Engineering was conferred upon Melville Eastham, founder and former president of the General Radio Company, now Chief Engineer in charge of research and development.

● **A PAPER** entitled "Wartime Problems of a Manufacturer of Engineering Products" was delivered by A. E. Thiessen, Vice President of the General Radio Company, before the Cedar Rapids, Iowa, Section of the Institute of Radio Engineers on April 19, and at a meeting of the Chicago Section on April 20.

On April 27, Horatio W. Lamson, of the General Radio Engineering Staff, addressed the Boston Section of the Institute of Chemical Engineers on the subject of "Time and Time Measurement."

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THE General Radio EXPERIMENTER

VOLUME XX No. 4 SEPTEMBER 1945

ELECTRICAL MEASUREMENTS AND THEIR INDUSTRIAL APPLICATIONS

A PRECISION TUNING FORK WITH VACUUM-TUBE DRIVE

Also

IN THIS ISSUE

● **THE LOW-FREQUENCY TUNING FORK** has been widely used as a standard both for frequency measurement and control and for chronographic work. In May, 1936, the General Radio Company announced[1] the Type 815 Precision Fork which is supplied to operate at 50, 60, or 100 cycles per second.

This readily-portable instrument is a double-button microphone-driven fork, which is energized by a battery of from 4 to 6 volts. The fork itself is made from a stainless-steel alloy having a low temperature coefficient, so that the operating frequency remains within 0.01% of its rated value under all normal fluctuations of ambient temperature and battery

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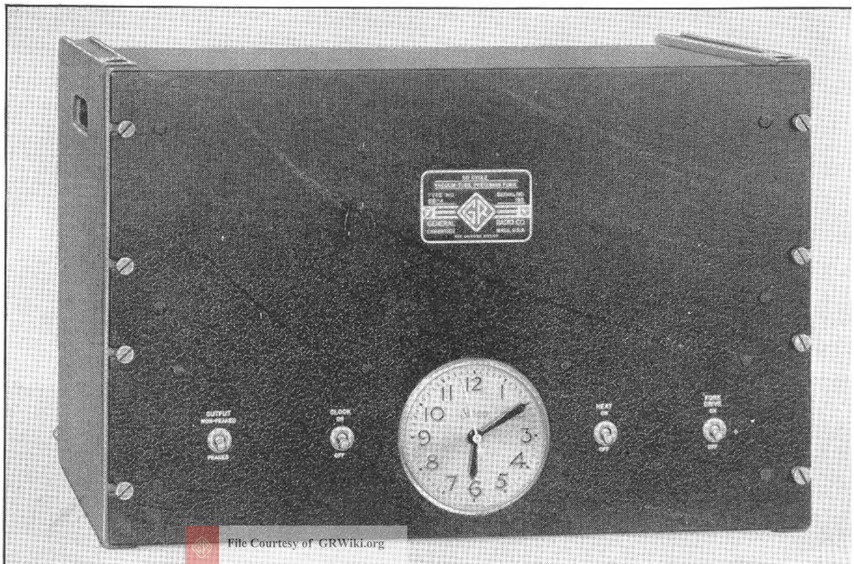
[1] General Radio *Experimenter*, Vol. X, No. 12.

Figure 1. Panel view of the Type 816 Vacuum-Tube Precision Fork.



voltage. In later tests[2] under controlled conditions of temperature and driving voltage, one of these forks stayed within 0.002% of its nominal value during a two-months' period of continuous operation.

Subsequent studies showed that the fork itself, because of its high value of Q (about 19,000), was ultimately capable of still greater precision. Accordingly, a modified form of this tuning-fork standard, designated as TYPE 816[3], was developed to minimize some of the limitations inherent in the original instrument.

Next to temperature variations, the chief source of erratic residual fluctuations in the frequency of the microphone-driven fork is the microphone button used in the driving circuit. The amplitude and phase characteristics of a loose pocket of granular carbon are not constant, but are subject to considerable random variation. Consequently, the microphones were removed, and the fork was driven by generating from the tine motion a small emf in a polarized electromagnet, L_1, amplifying this emf, and subsequently driving the fork by a second polarized electromagnet, L_2. This permitted a smaller tine motion, which itself increased the inherent stability of the fork.

Another limitation of the microphone-driven fork for some applications is the appreciable but unavoidable variation in power output, again caused by the erratic behavior of a carbon microphone. This is essentially eliminated in the new amplifier-driven fork.

In order to reduce the effect of ambient temperature fluctuations, the fork is built into a temperature-controlled box regulated automatically by a thermostat so that the actual temperature of the fork is kept to within about 0.1° Centigrade of an optimum mean value.

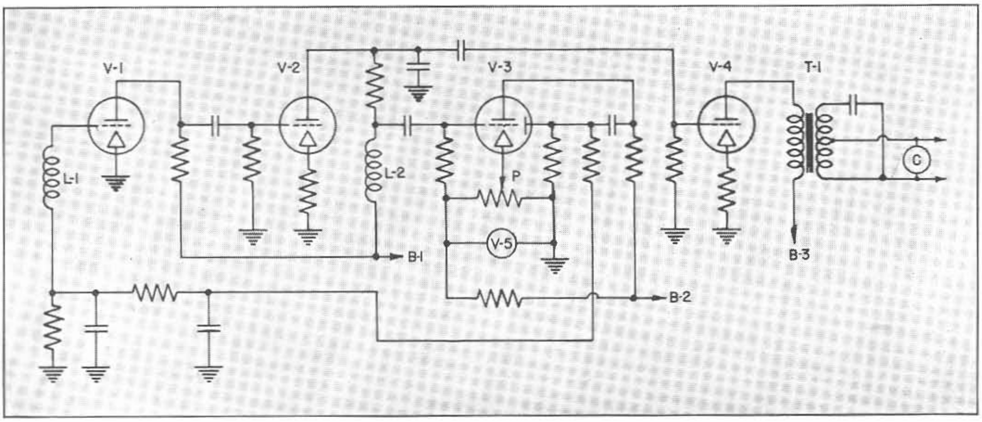
To provide for universal operation the circuits are so designed that power for energizing both the heater elements and the amplifier system may be obtained from either of two sources:

(1) A single-phase a-c power line supplying from 100 to 130 volts at any commercial frequency, or

(2) A d-c power line of 100 to 130 volts.

While this method of driving a tuning fork is not basically novel, several features have been introduced into the amplifier system, all of which contribute to the ultimate stability. The input tube, V_1, of the amplifier is heavily

FIGURE 2. Schematic circuit diagram of the TYPE 816-A Vacuum-Tube Precision Fork.



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[2] General Radio *Experimenter*, Vol. XIII, Nos. 4, 5.

[3] Although the TYPE 816 Vacuum-Tube Precision Fork has been available for war use for some time, it has not hitherto been described in the *Experimenter*.

biased by means of an a-v-c tube, V_3, whose control potential is regulated in turn by a gaseous discharge tube, V_5, thus providing a rigid control of tine amplitude, independent of supply line fluctuations. The amplifier design is such that phase shifts in the output of the driving tube, V_2, are reduced to a very low minimum. These features, combined with the high Q of the fork and its low temperature coefficient, produce a tuning-fork standard whose residual variations, when temperature controlled, aggregate less than 0.001%, and can, to a considerable degree, be attributed directly to diurnal fluctuations in barometric pressure.

If a less precise standard will suffice for any particular application, the heater power source may be omitted, and the frequency stability of the fork will be determined chiefly by ambient temperature fluctuations.

OPERATING CHARACTERISTICS

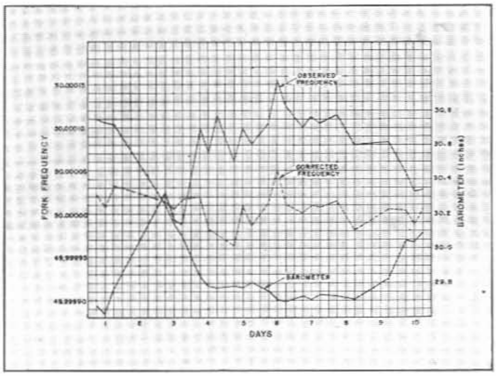
Because of the high thermal capacity of the fork, the actual temperature remains within 0.1° Centigrade of the optimum controlled value of about 60° Centigrade during successive cycles of thermostat operation. At 60° the temperature coefficient of frequency is less than two parts per million per degree. When the temperature control is not used, the effective temperature of the fork will follow, with considerable time lag, the fluctuations of ambient temperature, and the frequency will be subject to a negative temperature coefficient[4] of the order of 10 to 20 parts per million per degree Centigrade.

The a-v-c bias potential, and hence the fork amplitude, is adjustable by means of the potentiometer, P, thus permitting an electrical control of the fork frequency over a range of about 0.001%. With a minimum value of this bias potential the supply-line-voltage coefficient of frequency is positive and is less than 0.03 parts per million per volt change of line voltage. At the mid-value of this bias potential, the coefficient is less than 0.01 parts per million per volt; while at the maximum bias potential the coefficient is negative and less than 0.1 parts per million per volt change.

When one of these forks was checked against a piezo-electric primary standard having a still higher degree of precision, it was found that the major part of the minute fluctuations of the fork frequency could be attributed to variations in barometric pressure. Increase of pressure caused a greater effective loading on the tines of the fork and a corresponding reduction in frequency. The resultant negative coefficient is about 2.5 parts per million per inch of mercury change in the barometer reading. Since the fork is maintained at a fixed temperature above ambient, it would appear that fluctuations in ambient humidity would have no appreciable effect upon its frequency.

These coefficients are each so small that under all normal variations encountered in practice the unmonitored

FIGURE 3. Typical frequency variation for a nine-day interval. Note that when corrected for barometric pressure the frequency remained within one part in a million of its nominal value.



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[4] The measured temperature coefficient is supplied with each fork.

frequency will remain stable within conservative limits of 10 parts per million or 0.001% which, as a chronometer, means an error of less than one second per day. If corrections for barometric pressure are applied by adjustment of the potentiometer, *P*, a precision of better than five parts per million may be expected for this standard when set up and run continuously.

The data plotted in Figure 3 were taken on a 50-cycle fork during a typical nine-day interval of continuous operation and show how the residual variation of the frequency of one of these tuning-fork standards follows inversely the variation of barometric pressure. The observed frequency values were measured with a precision of one part in five million. The second curve gives these data corrected to a mean barometer value of 30.2 inches. It will be seen that, during this interval, the *corrected* data did not depart by more than one part in a million from the nominal value of 50 cycles per second.

CONSTRUCTIONAL FEATURES

The Type 816 Precision Fork and its associated circuits are completely housed in a metal cabinet. The instrument is adapted either for relay-rack mounting or for standing upon a laboratory bench and, if kept approximately horizontal, is readily portable for field use. Input and output leads are attached through plugs on the rear of the cabinet.

The fork and associated magnets are mounted on a spring-supported subpanel to minimize damping. This assembly, in turn, is contained in a metallic box carrying the heater units and is surrounded by a balsa wood box for thermal insulation. The box and the amplifier tubes are mounted upon a horizontal shelf beneath which are the various elements of the amplifier circuits. If desired, a thermometer may be inserted through the side wall of the cabinet into the fork box. The instrument panel carries various control switches and a synchronous clock, *C*, which can be driven from the fork-controlled output and used for calibrating the standard over long-time intervals in terms of radio time signal observations. This clock may be reset by a knob on the rear of the cabinet.

The necessary circuit changes for accommodating the two different sources of power supply are made at the input power jack.

Coarse adjustments of the fork frequency may be made by setscrews in the extremities of the fork tines, and fine adjustments by means of the a-v-c bias control, *P*.

OUTPUT

Output power at the controlled frequency is obtained by the use of a separate output tube, V_4, furnishing about two watts without and one watt with the synchronous clock in operation. This output power may be obtained at three different generator impedance values. The output voltage may be nearly sinusoidal or, for certain chronographic uses, may be sharply peaked in character, as selected by a switch on the panel. This peaked waveform being rich in harmonics is frequently useful in measuring unknown frequencies of higher value than the standard. The use of an output transformer, *T*, permits the output signal circuit to be ungrounded and free from d-c polarization.

The original Type 815 Precision Fork still retains its advantage of being light in weight and of minimum bulk, together with its ability to be driven by three small dry cells, and possesses an accuracy which makes it reliable to 0.01%. On the other hand, the new TYPE 816-A Vacuum-Tube Precision Fork has at least a tenfold higher precision, better than 0.001%, gives a higher and an unvarying output power, is equipped with a synchronous clock for time keeping and calibration, and may be operated either from an a-c or a d-c power line. Each instrument therefore has a field of application in which it proves most advantageous. — HORATIO W. LAMSON

SPECIFICATIONS

Frequency: 50 or 60 cycles per second.

Calibration: The frequency is adjusted within 0.0005% of its rated value and is measured to 0.0001% in our standardizing laboratory.

Stability: When the temperature-control system is operated, the frequency is within one part in 100,000 (0.001%) of its mean value thus timing to better than one second per day. Without temperature control, the frequency will follow (with a considerable lag) variations in ambient temperature. At ordinary room temperatures, the temperature coefficient of frequency is negative and is between − 10 and − 20 parts in 10^6 per degree Centigrade. Frequency changes with supply voltage and atmospheric pressure are usually negligible in comparison to the rated accuracy of the fork.

Power Supply: The amplifier circuit and the heaters for temperature control are arranged to operate on either of two types of power supply, selection being made by plug and jack terminals:

(1) a-c line, 100 to 130 volts, 50 to 60 cycles.
(2) d-c line, 100 to 130 volts.

Power Input: For temperature control, 30 watts; for fork and amplifier, 45 watts.

Output: Peaked or sinusoidal, as selected by a switch. When the synchronous clock is operated, maximum output is 1 watt. When clock is not used, maximum output is 2 watts. Output circuit is not grounded and is free from any d-c polarization. Various output impedances between 200 and 30,000 ohms are provided.

Maximum peaked open-circuit output voltage is 350 volts.

Vacuum Tubes: Supplied with Instrument,

2 — 6A7G
1 — 6Q7G
1 — 25L6GT
1 — 25Z6
1 — 139-949A

Accessories Supplied: Spare fuses; 2 Multipoint Connectors; 1 line connector cord.

Mounting: The entire assembly is mounted on a standard 19-inch relay-rack panel, which can be adapted for table mounting by the use of the wooden end frames supplied. The instrument is readily portable in an operating condition if kept in approximately its operating position.

Dimensions: Panel, 19 x 12¼ inches; depth, 12½ inches.

Net Weight: 49½ pounds.

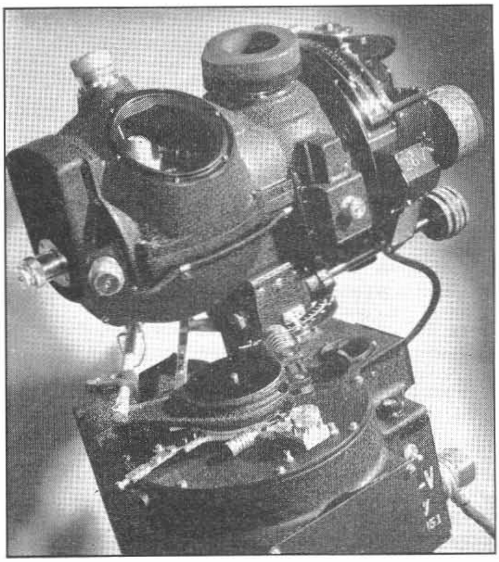
Type		*Code Word*	*Price*
816-A	Vacuum-Tube Precision Fork.....	FERRY	$385.00
816-B	Vacuum-Tube Precision Fork.....	FABLE	385.00

[6] Licensed under patents of the American Telephone and Telegraph Company.

BUSMAN'S HOLIDAY

● EVEN WHEN ON VACATION, the engineer seldom loses interest in research. Mr. Robert F. Field of the Engineering Staff, while vacationing at his Meredith, New Hampshire, summer home, recently conducted an investigation of the variations in water depth and temperature over parts of Winnepesaukee and Squam lakes. The results were reported to the Meredith Rotary Club at their weekly luncheon on August 15.

BALANCING TO 0.000070 INCH WITH THE AID OF THE STROBOTAC



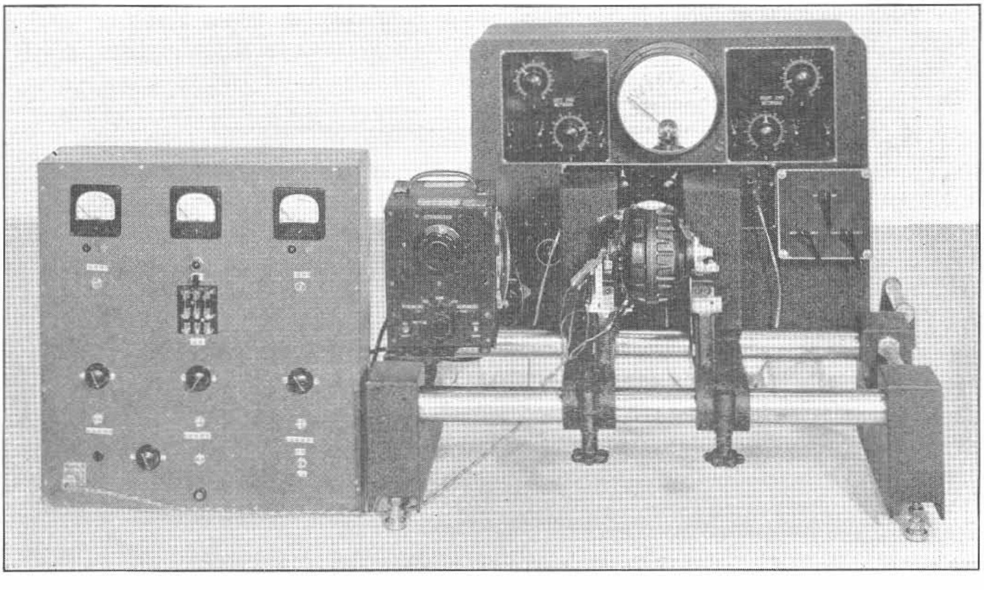
(*Above*) The famous Norden Bombsight.

● **THE FAMOUS NORDEN BOMBSIGHT**, until recently a complete military secret, is probably one of the most precise instruments made by man, yet it is being built in mass production by a number of manufacturers.

The bombsight consists of two main units: the stabilizer, which controls the horizontal flight of the plane during the bombing run; and the sighting mechanism, which contains the telescope and computer. Each of these main units contains a gyro, which must be balanced to the unheard-of accuracy of 70 millionths of an inch. At the plant of the Victor Adding Machine Company, one of the manufacturers of the Norden bombsight, this balancing is accomplished on a "Dynetric" balancing machine, manufactured by the Gisholt Machine Company. This machine uses as one of its elements a General Radio Strobotac.

The accompanying photograph shows the balancing machine with a gyro and its housing in the test position. The Strobotac, which is shown at the left of

(*Below*) The Dynetric balancing machine showing the Strobotac and a gyro in test position.



the gyro, has two functions: first, to determine the rotational speed of the gyro wheel; and second, to indicate the angular position of unbalance.

The Strobotac is set to the desired speed, and the gyro is then brought up to this speed by means of the electronic speed controller in the cabinet at the extreme left. When the desired speed is reached, the rotor, as viewed in the light from the Strobotac, appears stationary. A precise setting and control of the speed is necessary because the balancer includes a sharply tuned filter.

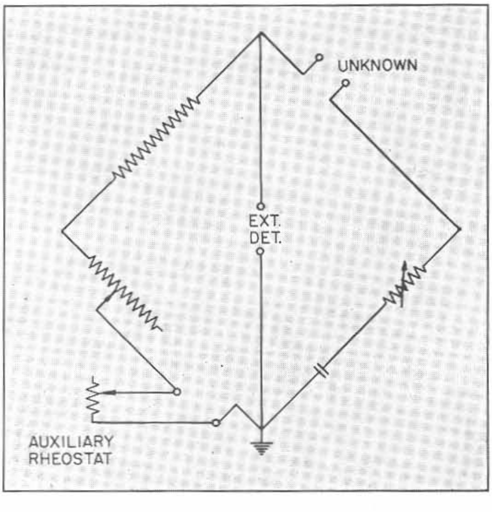
In the balancing operation itself, the machine determines the amount and angular position of the unbalance in each of two planes, which are the faces of the gyro wheel. The angular position at which unbalance occurs is shown opposite a stationary pointer when the Strobotac flashes. On the meter behind the gyro is shown directly the weight that must be removed at the indicated position to remove the unbalance. The sequence of these operations is selected by switches, shown at the right of the gyro rotor. One switch selects the plane of observation, i.e., left or right; another selects either the meter indication of amount of unbalance, or the Strobotac indication of angular position; while a third provides two orders of meter sensitivity.

PRODUCTION TESTING WITH IMPEDANCE BRIDGES

● **WHEN THE TYPE 740-B CAPACITANCE BRIDGE** and the TYPE 650-A Impedance Bridge are used for the production testing of capacitors, inductors, and resistors, uneven wear of the potentiometers in the bridges may occur as a result of continued operation over narrow ranges of the dials. This can be avoided by connecting in series with the potentiometer an external unit covering the tolerance range necessary for the measurement, and making balances entirely on this unit. The calibration of the auxiliary potentiometer can be made experimentally by comparison with the bridge dial, or can be calculated from the bridge constants. Our TYPE 471, 371, or 314 and 214 Potentiometers will be found quite satisfactory for this application.

As an example, consider the measurement on the TYPE 650-A Impedance Bridge of 500-$\mu\mu$f capacitors with an acceptance tolerance of $\pm 5\%$. With the CRL Multiplier set at 100 $\mu\mu$f, the balance point for 500 $\mu\mu$f is at 5 on the CRL dial, corresponding to a resistance of 5000 ohms on the CRL rheostat. At the balance point for the lower limit of 475 $\mu\mu$f (500 $\mu\mu$f less 5%), the resistance of the CRL dial is 4750 ohms, and at the upper limit is 5250 ohms.

Consequently, a 500-ohm rheostat



can be used, with its dial marked zero at the center and marked +5% and —5% at the ends. The CRL dial should be set at 4750 ohms, or 4.75 on the scale, to make the auxiliary rheostat balance at center scale for 500 $\mu\mu$f.

To connect the auxiliary rheostat, it is necessary to break the connection between the arm of the CRL rheostat and ground, and to insert the auxiliary at this point.

ATTENTION: MIDWEST

● **MR. ROBERT F. FIELD** of our Engineering Department will present a paper entitled "The Behavior of Dielectrics over Wide Ranges of Frequency, Temperature, and Humidity" at the following local sections of the Institute of Radio Engineers:

Cedar Rapids	September 19
Chicago	September 21
Kansas City	September 24
Minneapolis	September 25
Milwaukee	September 26
South Bend	September 27

A Technical Conference on r-f coil design is being arranged by our Chicago office. At this meeting Mr. Field will lead the discussion and present the results of some of his recent work on this subject. This meeting will be held the afternoon of September 18 and engineers interested in attending and participating are invited.

Mr. Kipling Adams of the Service Department will be in Chicago during the last two weeks of September and the first week of October. The purpose of his visit is to offer owners of General Radio equipment in the Chicago area greater assistance in service and maintenance problems than would be possible by correspondence. Mr. Adams will be available for consultation, and arrangements are being made by our Chicago office.

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VOLUME XX No. 5 OCTOBER 1945

ELECTRICAL MEASUREMENTS AND THEIR INDUSTRIAL APPLICATIONS

A WAVEMETER FOR 240 TO 1200 MEGACYCLES

Also IN THIS ISSUE

● **TO STATE THE RANGE** of a wavemeter in megacycles appears to be an inconsistency, but since today "frequency" rather than "wavelength" is used to define the period of oscillations, the only alternative would be to discard the designation "wavemeter." However, a wavemeter is such a useful and time-honored piece of equipment that it hardly seems advisable to change its name. Moreover, the modern frequency meter is usually a heterodyne instrument (see General Radio *Experimenter* of July and August 1945), and the term implies a degree of accuracy that is not necessarily required for all measurements in the laboratory.

The new TYPE 1140 Wavemeter is intended for applications where

FIGURE 1. Two views of the TYPE 1140-A U-H-F Wavemeter. At the front, the butterfly is seen through a transparent window; at the rear, both the resonance indicator and the frequency scale can be read as the tuning control is turned.

ease of operation and small size are more important than high accuracy, and where direct reading indications over a wide frequency range are most desirable.

The new wavemeter has a single range from 240 to 1200 megacycles. The tuned circuit is of the butterfly type (see General Radio *Experimenter* of October 1944 and *Proceedings of the Institute of Radio Engineers* for July 1945). The inductive and capacitive elements are built integrally, and tuning is achieved by simultaneous variation of both. No sliding contacts are used.

Resonance is indicated on a microampere meter preceded by a crystal detector. Coupling between tuned circuit and indicator is relatively close, and the wavemeter is designed to make effective coupling to the unknown source possible without direct connections. Some accuracy has thus been sacrificed for high sensitivity. If sufficient power is not available to deflect the indicating meter, resonance can still be observed by the reaction of the wavemeter on plate or grid current of an oscillator of unknown frequency.

The detector, which consists of a silicon crystal and a tungsten wire, is contained in a ceramic cartridge and is easily replaced. Crystal detectors of this kind have recently been standardized, and the most suitable types are designated 1N21 and 1N22. The crystal detector is shunted by the indicating meter and, therefore, well protected against overload, since it cannot be damaged without producing several times full scale deflection.

The resonant frequency of the detector circuit is around 1600 megacycles. This high resonant frequency has been obtained by mounting the detector cartridge in a metal block and providing only a small loop for coupling to the butterfly circuit. The metal block, seen at the bottom of Figure 2, is part of the casting which supports the butterfly circuit on one side and the gear-drive and indicator drum on the other side.

The scale on the indicator drum is about 9 inches long. Three turns of the tuning knob are required to cover the full range corresponding to a 90° rotation of the butterfly rotor. The tuning unit and the indicating meter are mounted in a plastic housing which can be held conveniently in one hand. Two views of the complete wavemeter are shown in Figure 1. A transparent window in the housing shows the butterfly

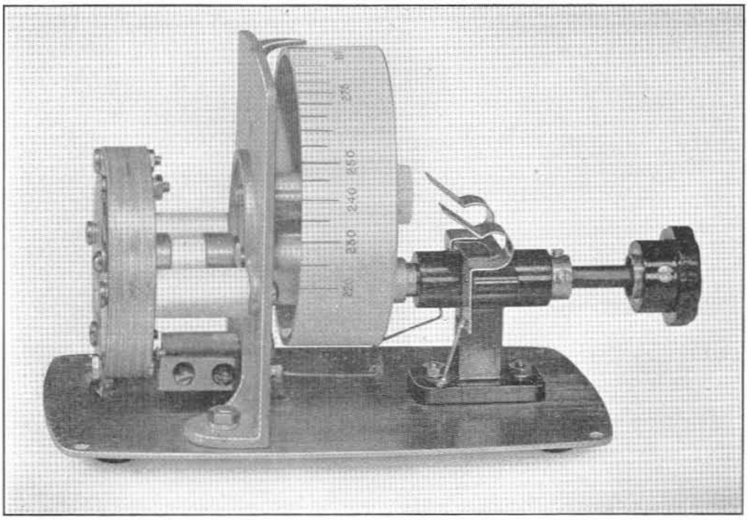


FIGURE 2. View of the interior of the wavemeter with case removed. The cartridge-type crystal detector is mounted in the metal block near the base at the rear of the butterfly. The two clips above the shaft bearing make contact with the terminals of the microammeter, so that both original assembly and removal for servicing are easily accomplished.

circuit and facilitates proper coupling to the unknown source which has to be measured. The interior construction is shown in Figure 2.

A certain amount of care is required to avoid erroneous readings and spurious responses, which are not encountered with similar instruments at low frequencies. Misleading indications can be produced by resonance of the detector circuit with harmonics of the unknown frequency and by spurious responses of the tuning element. Spurious responses or modes, only too familiar to anyone working in the microwave regions, are caused by the fact that dimensions of the circuit elements are no longer small compared to wavelengths, and that current paths through these elements are possible in different directions. Fortunately circuit losses in spurious modes are ordinarily larger than the losses in the desired mode, and consequently the meter deflection will be higher and more sharply dependent on tuning if the wavemeter is set to the correct frequency.

— EDUARD KARPLUS

SPECIFICATIONS

Frequency Range: 240–1200 Mc.

Accuracy: ±2% of the indicated frequency.

Temperature and Humidity: The accuracy of this wavemeter is independent of temperature and humidity effects over the range normally encountered in the laboratory.

Detector: A TYPE 1N22 Crystal Detector is furnished with the instrument.

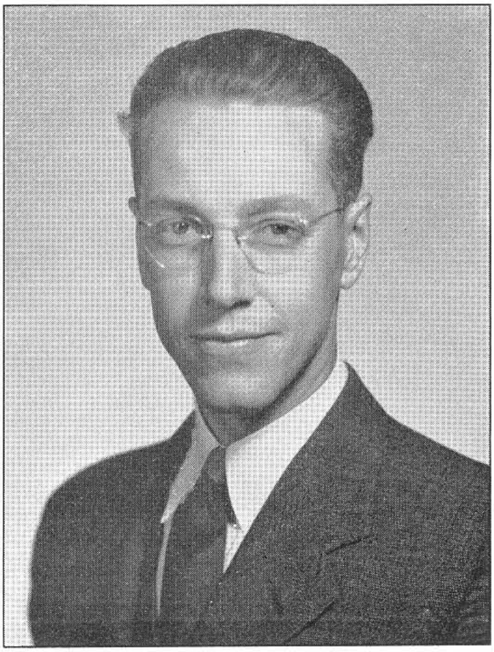
Dimensions: $3\frac{7}{8}$ x $7\frac{1}{4}$ x $4\frac{1}{2}$ (height) inches overall.

Net Weight: $3\frac{1}{4}$ pounds.

Type		*Code Word*	*Price*
1140-A	U-H-F Wavemeter..............	WAGER	**$65.00**

MISCELLANY

● **ADRIAN W. CLEVELAND** has been appointed Purchasing Agent of the General Radio Company, succeeding the late Walter H. Sherwood. Mr. Cleveland was born at Oxbow, New York, and received his early education in the public schools of that state. He studied electrical engineering at Northeastern University, from which he was graduated in 1934 with the degree of Bachelor of Science. Coming to the General Radio Company the same year, he became thoroughly familiar with manufacturing operations by working in every branch of the production department before assignment to the purchasing department in 1937. He was appointed Assistant Purchasing Agent in 1939, and became Purchasing Agent in August, 1945.



A LIGHT SOURCE FOR MICROSECOND PHOTOGRAPHY

● **THE MICROFLASH,** a highly specialized type of stroboscopic light source has been added to General Radio's line of stroboscopic equipment. This device was perfected at the beginning of the war, and it has rendered good service in a score or so laboratories during the emergency. Now the Microflash is available for peacetime use in research work where short photographic exposures or flashes of light are required.

Commercially available stroboscopes, before General Radio offered the first Edgerton Stroboscope in 1932, were mainly shutter-type instruments, which operated by periodically interrupting the user's vision, so that illumination was low and only moderately high-speed motion could be arrested. The development of highspeed light sources for stroboscopy by Edgerton, Germeshausen and Grier of M. I. T. opened up new fields of usefulness for visual work and resulted in the well-known Strobotac and Strobolux. The latter instrument produces a flash of high intensity and of relatively high speed, and hence has been used as light source for photography. Its flash duration of 30 microseconds ($\frac{30}{1,000,000}$ of a second), however, is a limitation which makes it unsuitable for many applications where close-ups or even enlargements must be made of objects moving at very high speeds, as for instance, bullets and other projectiles. Flash durations of only 1 or 2 microseconds are necessary for this work.

These flash speeds have been obtainable for a number of years by means of spark discharge equipment, which is extremely cumbersome. Owing to the limitations of the spark as a light source, most spark photography was done in silhouette. Stroboscope design technique, however, offers a means of obtaining short, high-intensity flashes in a small compact unit, with only a small power demand.

Since the power required to operate a stroboscopic lamp varies directly with the flashing rate, much less power is necessary for flashing at intervals of

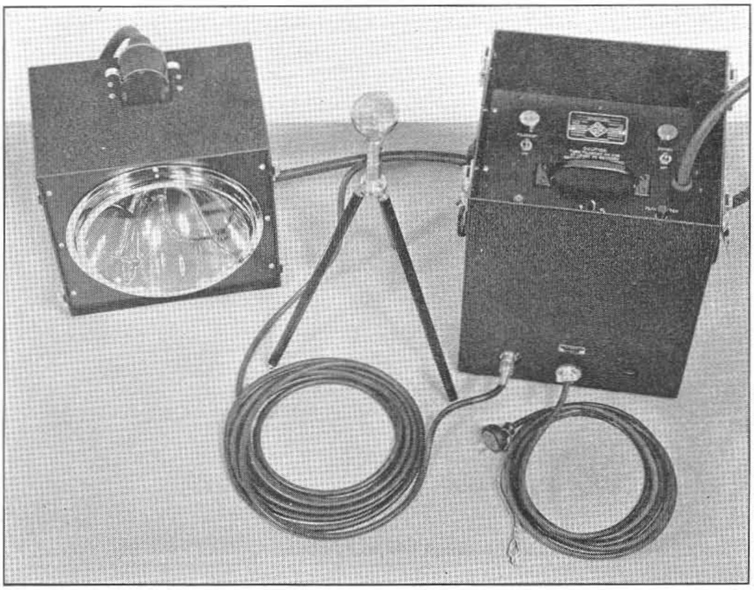


FIGURE 1. View of the Microflash unpacked and ready for operation.

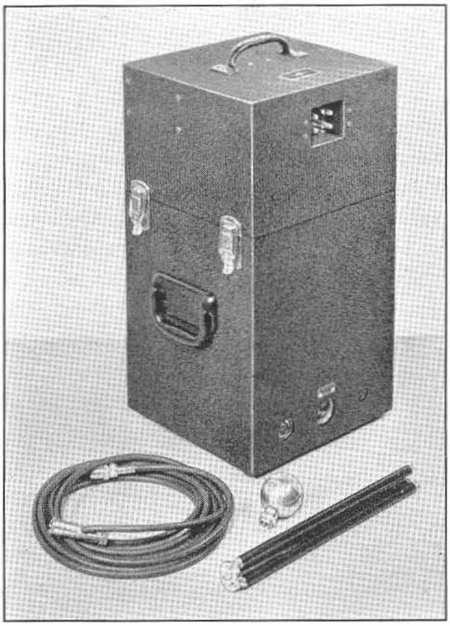


FIGURE 2. Lamp housing and power supply lock together in a convenient assembly for transportation.

several seconds or minutes than for the high repetition rates used for visual work. The duration of flash can be greatly reduced by proper design of the lamp and by using a smaller condenser and charging it to a higher voltage.

A preliminary design of the Microflash, TYPE P-509, was described in the *Experimenter* a few years ago.[1] The new TYPE 1530-A Microflash is now available for general sale and provides a means of photographing objects in much faster motion than was possible with equipment designed primarily for stroboscopy.

Functionally, the electrical circuit of the Microflash is simple, consisting of a rectifier power supply, a condenser which is charged to about 7500 volts from the power supply, and a lamp through which the condenser is discharged to produce the flash. The flash is "tripped" by an impulse from a spark coil which ionizes the gas in the lamp sufficiently to initiate the condenser discharge. The spark coil is excited by a thyratron, which in turn may be tripped by making or breaking an external contact, by pressing a button on the panel, or by an impulse from a microphone which picks up sound from the phenomenon to be photographed. A built-in amplifier with a manual sensitivity control is provided.

The external appearance of the Microflash is shown in Figures 1 and 2. The view of Figure 1 shows the instrument set up for operation with the microphone arranged to trip the flash. For transportation, the lamp and power supply cases lock together, as shown in Figure 2.

Two sockets are provided for plugging in the tripping circuits, one for the microphone, the other for a contactor. A two-position switch permits a choice of either make or break contactor-trip.

When the microphone is used, the time of the flash depends upon the distance the sound wave travels before reaching the microphone. As can be seen from Figure 1, the microphone is provided with a cable of considerable length so that the timing of the flash can be adjusted over a considerable range by moving the microphone with respect to the object being photographed.

In adjusting the time of flash, it is necessary to take into consideration an initial minimum delay of 10 to 15 microseconds. Although varying between these limits among different instruments, the delay is practically constant for any one unit.

The duration of the flash is about 2 microseconds, with a faint trailer lasting about 15 microseconds, as indicated in

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[1] "A Light Source for Ultra-High-Speed Photography," General Radio *Experimenter*, Volume XVI, No. 4, September, 1941.

Figure 4. To eliminate any effect of the trailer, film should be under-exposed and over-developed.

Since the Microflash was originally developed for war research, its uses thus far have been largely in the testing of ammunition, particularly new types. A previous article[2] discussed a number of these tests.

The Microflash has many other applications in this field, among them investigations of the impact of bullets, of artificially induced yaw to deflect projectiles, and of the action of rotating bands on shells. It has also proved useful in studying the behavior of wads in shotgun shells, and resulted in radical changes in the design of the shells.

Other studies include the effects of underwater explosions on models; icing on airplane propellers; the disintegration of rotors at very high speeds, particularly turbine rotors and rayon buckets; the bursting of fluid containers under extreme pressure conditions, and the mechanism of self-sealing in bullet-proof fuel tanks for airplanes.

Other projected uses include the study of the propagation of fractures in materials, and of the mechanism of wear in automobile tires at high speeds. The Microflash also has possibilities for studying cutting and grinding operations with machine tools. For industrial research where the behavior of rapidly moving objects must be recorded, it offers a means of saving both time and money, and for many problems offers the only method of obtaining a satisfactory solution.

— H. S. WILKINS

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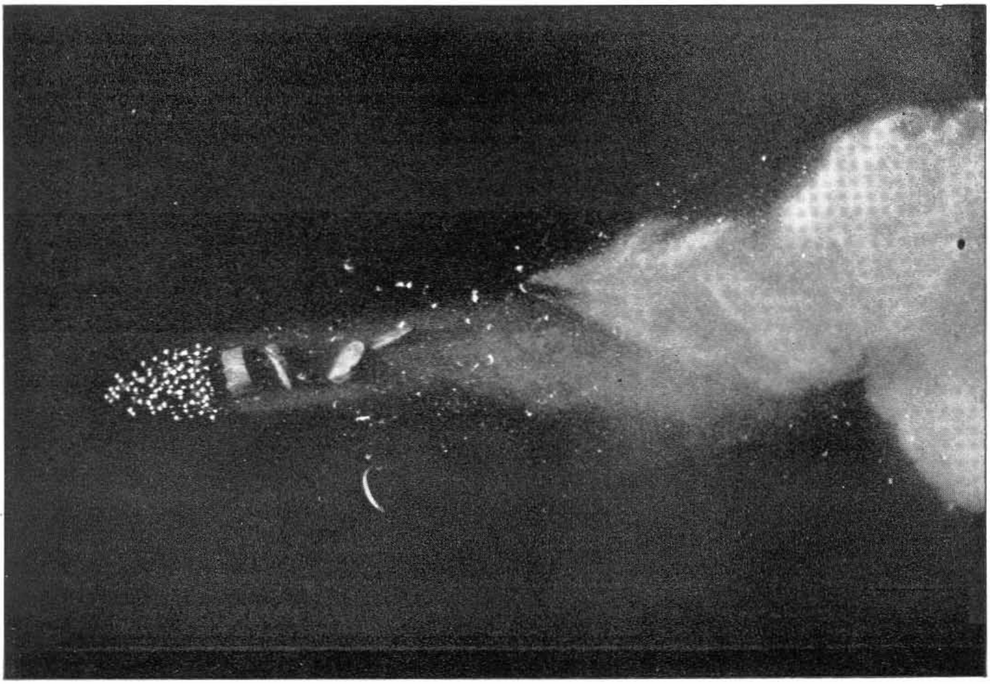
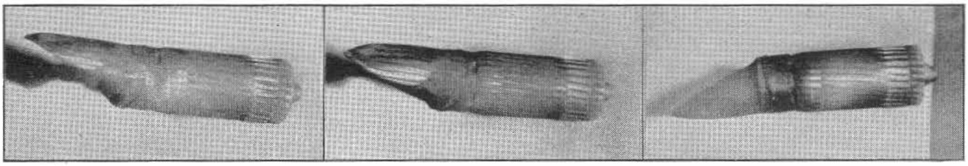
[2] "Microflash Shows Flight Defects in Projectiles," General Radio *Experimenter*, Volume XIX, No. 11, April, 1945.

FIGURE 3. Microflash photo of the explosion of a shotgun shell as it leaves the muzzle of gun, which is out of the picture at the right. Note that the wads can be seen as well as the cluster of shot.



— H. E. Edgerton



—Courtesy Jefferson Proving Ground, Ordnance Department, U. S. Army.

FIGURE 4. Photographs of three rounds of ammunition showing both yaw and erratic behavior of windshields.

The photographs shown below were taken by H. E. Edgerton and F. E. Barstow and are reproduced through the courtesy of the Hartford-Empire Company

FIGURE 5. Uncompleted fracture in an experimental bottle. The heavy line is drawn with gold on the glass, which, when interrupted by a crack, opens the circuit to trip the Microflash. Note the faint lines at the ends of the cracks which indicate the direction the fracture lines will take. The velocity of propagation of the fracture has been determined by Microflash photography to be approximately 5000 feet per second.

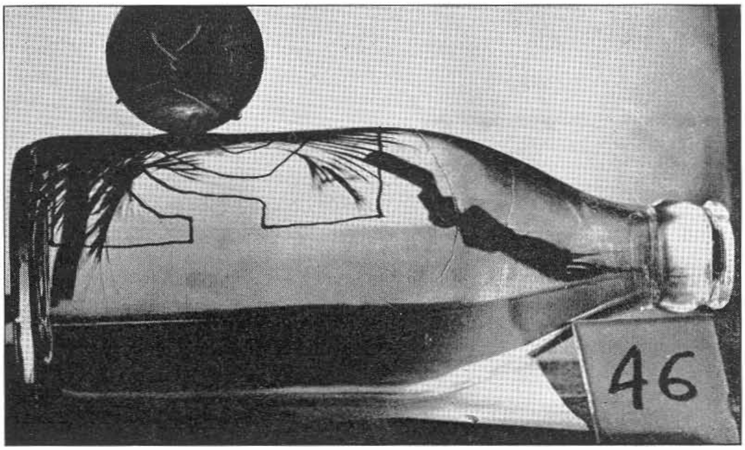
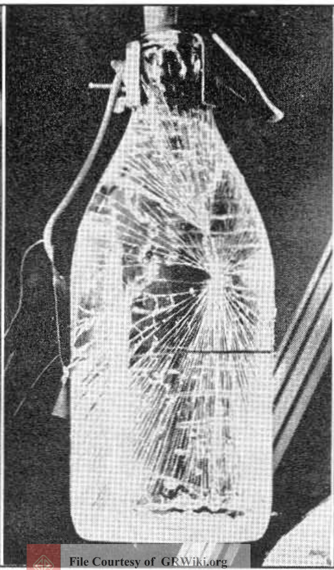
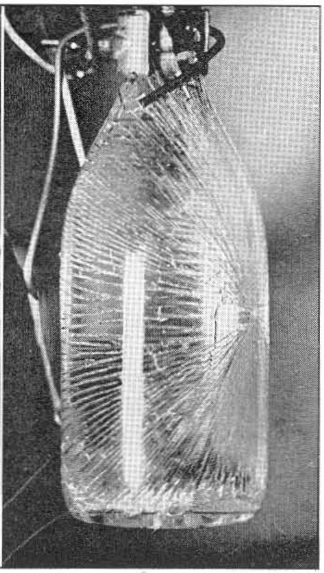


FIGURE 6. Experimental bottle breaking by severe impact on a steel plate. The Microflash tripping circuit is closed by a sheet of tinfoil driven against the steel by the bottle.

FIGURE 7. Fracture of an experimental bottle under 520 lb./sq. in. water pressure. The fracture started at the center of the radiating pattern. The Microflash was tripped by a crystal phonograph pickup with needle bearing against the glass.

FIGURE 8. Fracture of an experimental bottle under 730 lb./sq. in. water pressure. The tripping mechanism was the same as that used for Figure 10.





SPECIFICATIONS

Duration of Flash: Approximately 2 microseconds.

Power Supply: 105 to 125, 210 to 250 volts, 50 to 60 cycles.

Power Input: 70 watts.

Tubes:
1 — 5T4 (RCA) 1 — FG-17 (GE)
1 — 2V3G(RCA) 1 — 6AC7 (1852) RCA

Accessories Supplied: Microphone with cable; tripod; all tubes; spare pilot lamps and fuses; 2 spare flash lamps Type 1530-P1; plug for connection to contactor-trip jack.

Mounting: The power supply and trigger circuits are assembled in one metal case, the lamp in another. The two cases lock together for transportation, completely protecting the lamp and controls.

Dimensions: 24⅛ x 13¼ x 11¾ inches, overall.

Net Weight: 72 pounds.

Type		*Code Word*	*Price*
1530-A	Microflash	TAFFY	$525.00*
1530-P1	Replacement Flash Lamp	TONIC	15.00*

*Plus current Federal tax on photographic equipment.

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ERRATUM

● **IN THE SPECIFICATIONS** for Type 816 Vacuum-Tube Precision Fork, described in the September *Experimenter*, the frequency designation was inadvertently omitted from the price list. The listing should have read as follows:

Type	*Description*	*Frequency*	*Code Word*	*Price*
816-A	Vacuum-Tube Precision Fork	50 c.p.s.	FERRY	$385.00
816-B	Vacuum-Tube Precision Fork	60 c.p.s.	FABLE	385.00

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, address, type of business company is engaged in, and title or position of individual.

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THE General Radio EXPERIMENTER

VOLUME XX Nos. 6 and 7 NOVEMBER and DECEMBER, 1945

ELECTRICAL MEASUREMENTS AND THEIR INDUSTRIAL APPLICATIONS

AN IMPROVED MEGOHMMETER FOR A-C OPERATION

Also

IN THIS ISSUE

Page

THE MEGOHMMETER, since the introduction of the Type 487-A instrument in 1936,[1] has become a familiar piece of laboratory equipment. The measurement of high-valued resistors and of leakage resistance up to several thousand megohms becomes, with the megohmmeter, as simple as low-resistance circuit testing, and many special applications have developed.

The Type 1861-A Megohmmeter is a redesign of the Type 487-A instrument. The principal changes are the addition of a range at the low-resistance end with a center scale value of 0.1 megohm, stabilization of the voltage applied to the unknown, and provision of a switch and an additional scale on the meter so that the high resistance tube voltmeter used in the megohmmeter circuit can be made available for d-c voltage measurements from 0–100 volts. Other changes from the original Type 487-A design in-

Figure 1. Panel view of the Type 1861-A Megohmmeter. Superseding the Type 487-A, this new instrument measures resistances from 2000 ohms to 50,000 megohms and can also be used as a d-c voltmeter.

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[1] F. Ireland "An Ohmmeter for the Megohm Ranges," *G. R. Experimenter*, Vol. 9, Nos. 4 & 5, September-October 1936.

clude elimination of the zero-setting knob and rearrangement of the panel so that the long dimension is from top to bottom. The size of the instrument is unchanged.

The new low range, also incorporated in the Type 729-A Battery-Operated Megohmmeter,[2] makes possible a deflection of at least a full division for resistances from 2,000 ohms to 50,000 megohms, a range of 25 million to one. The wide range and the addition of the voltmeter scale greatly increase the utility of the instrument in trouble shooting.

The stabilized circuit not only makes unnecessary a preliminary zero adjustment before use, but also eliminates fluctuations in the meter reading resulting from line voltage variations. As a result, accurate measurements in the very high ranges of resistance can be made very rapidly and conveniently.

The instrument is applicable to general high resistance and leakage testing except where specified test voltages must be applied, or where the high-value standard resistances employed in the circuit would result in an excessively large time constant. The latter limitation means that the equipment is suitable for the rapid testing of condensers up to only a few thousandths of a microfarad in capacitance. The Type 544-B Megohm Bridge is recommended for leakage testing of higher valued condensers. For applications not subject to special requirements of this kind and for resistances up to 10,000 megohms, the new Type 1861-A Megohmmeter will be found equally accurate and far more rapid and convenient in use.

The standard resistances of 0.1, 10, 100, and 1,000 megohms employed in the megohmmeter circuit can be connected across the voltmeter as desired, so that the voltmeter resistance can have the four corresponding values from 1,000 ohms per volt up to 10 megohms per volt. For applications where the voltage drop of 100 volts can be tolerated, the instrument can also be used as a microammeter having a maximum full-scale sensitivity of 0.1 microampere.

The instrument, like its predecessor, is suitable for many special applications such as determination of the moisture content of wood, paper, dehydrated products, and similar materials. The additional scale makes such determinations possible for a wider range of materials and for higher moisture contents.

— W. N. Tuttle

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[2] W. N. Tuttle, "A Portable Megohmmeter," *G. R. Experimenter*, Vol. 15, No. 2, July 1940.

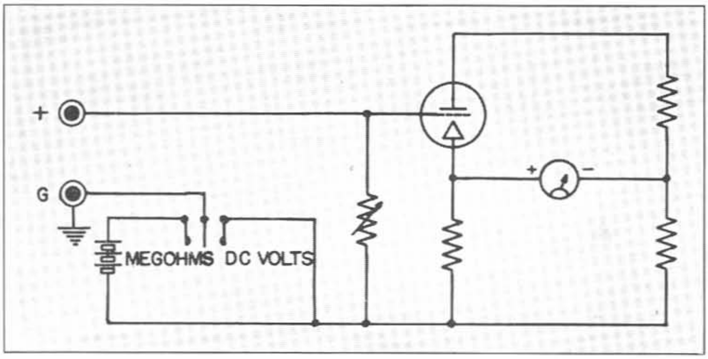

Figure 2. Elementary schematic circuit diagram of the megohmmeter. The circuit is similar to that of the conventional ohmmeter, but a vacuum-tube voltmeter is used as the indicator.

SPECIFICATIONS

Range: 2,000 ohms to 50,000 megohms in five overlapping ranges; zero to 100 volts, dc.

Scale: The standard direct-reading ohmmeter calibration is used; center scale values are 0.1, 1, 10, 100, and 1000 megohms. Length of scale, 3¼ inches; center decade, 1⅝ inches. The scale is illuminated by a lamp in the indicating meter. The voltage scale is linear.

Accuracy: Within ±5% of the indicated value between 30,000 ohms and 3 megohms, and within 8% between 3 megohms and 3000 megohms when the central decade of the scale is used. Outside the central decade the error increases because of the compressed scale. For voltage measurements the accuracy is ±2% of full scale.

Input Impedance: For voltage measurements the input impedance in megohms is indicated by the selector switch.

Temperature and Humidity Effects: Over the normal range of room conditions (65° Fahrenheit to 95° Fahrenheit; 0 to 95% relative humidity) the accuracy of the instrument is substantially independent of temperature and humidity.

Voltage on Unknown: The applied voltage on the unknown does not exceed 105 volts and varies with the indication.

Tubes: The necessary tubes, one type 1-v, one type 85, and one OC3/VR-150 are supplied.

Power Supply: 105 to 125 (or 210 to 250) volts, 40 to 60 cycles ac. The power required is 10 watts.

Accessories Supplied: A seven-foot connecting cord.

Mounting: The instrument is supplied in a walnut case and is mounted on an engraved black crackle-finish aluminum panel.

Dimensions: (Width) 10 x (height) 8 x (depth) 5½ inches, over-all.

Net Weight: 8¼ pounds.

Type		*Code Word*	*Price*
1861-A	Megohmmeter	ONION	$95.00

AN ANALYZER FOR VIBRATION MEASUREMENTS

● **MEASUREMENT** of the effective amplitude of vibration acceleration, velocity, or displacement with a vibration meter and vibration pickup is in some instances adequate for complete solution of a vibration problem. This is true when the vibration is known to be essentially sinusoidal in waveform.

A complex vibration, on the other hand, involving a number of components of differing frequency and amplitude, while measurable in its overall effect by the vibration meter, can be handled completely only if broken down into its various components by some form of analyzer.

The Type 762-A Vibration Analyzer[1] was designed to work with the Type 761-A Vibration Meter over an extended frequency range of 2.5 to 750 cps (150 to 45,000 rpm). The frequency band from 2.5 to 25 cps, covered by two ranges in the instrument, provides a most important extension to the spectrum which can be analyzed. The major components in a complex vibration will often be found here, and it is seldom that an analysis does not reveal at least one component in this region of the spectrum.

Modified to permit faster analyses and a wider range of application over the same frequency range, the instrument now in production is known as the Type 762-B Vibration Analyzer. Its important characteristics and its use in analyzing complex vibration and voltage waves are described in succeeding para-

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[1] This analyzer was described in "An Analyzer for Sub-Audible Frequencies" by H. H. Scott, *Journal of the Acoustical Society of America*, Vol. XIII, No. 4, pp. 360–362, April, 1942.

graphs. The panel arrangement is shown in Figure 1.

As in the sound analyzer, the circuit of the vibration analyzer includes a linear amplifier with a resistance-capacitance-tuned feedback network, resulting in high selectivity over the entire frequency range. The selectivity provided is similar to that of a constant Q, constant impedance-level, resonant circuit in the vicinity of the tuning peak.

Two band widths, one corresponding to an effective Q of about 50 and the other to an effective Q of 10, are available with panel switching. Figure 2 shows typical selectivity curves in three regions of the spectrum and includes for comparison similar curves obtainable with a heterodyne analyzer such as the TYPE 736-A Wave Analyzer, which is designed primarily for electrical wave analysis and has a constant band width in cycles. The advantages of the constant percentage band width of the degenerative analyzer are illustrated clearly in this figure. The broad selectivity feature is extremely helpful in locating components quickly in a fast sweep over the spectrum, the final determination of frequency and amplitude being made with the sharper network.

As frequently occurs in vibration work, a component may be drifting back and forth or warbling by several percent about a mean frequency. Under such conditions the high Q network would provide unstable or unreliable indications of amplitude because of its sharply peaked characteristic. Here the broad selectivity network finds another important use in making final determination of mean frequency and amplitude of components. The flat topped character of the broad selectivity curve as compared with the peaked characteristic of the sharp selectivity curve in the immediate vicinity of a tuning peak is shown in Figure 3.

The voltmeter of the instrument has an approximately logarithmic scale calibrated in linear units, so as to provide usable indications of relative amplitude of components down to about 1% of the largest component without switching. Two scales are furnished to match those on the indicating meter of the TYPE 761-A Vibration Meter.

FIGURE 1. Panel view of the TYPE 762-B Vibration Analyzer.

In an analysis to determine the relative amplitudes of the components of a complex wave (vibration acceleration, velocity, or displacement as determined by vibration meter switching), a preliminary sweep over the spectrum is made to determine the component of greatest amplitude. With the analyzer tuned to this component, the SENSITIVITY control is adjusted to an indication of 100 on the upper (black) scale. This control is left fixed at the above setting for the remainder of the analysis and a final sweep over the spectrum is made. As each component is tuned in, its amplitude and frequency are recorded. Amplitudes are then direct reading in percent of the amplitude of the largest component. The upper (black) scale is the only analyzer scale used for this type of analysis.

A complete analysis of a complex vibration, which yields the amplitudes of the various components in terms of their normal units (i.e., inches per second per second for acceleration, microinches per second for velocity, and microinches for displacement), may be made with only one modification of the procedure just outlined — the method of setting the SENSITIVITY control of the analyzer. For this adjustment a sinusoidal signal must be applied to the vibration meter and the analyzer adjusted to give the same indication as that of the meter. This may be most simply done by using the 110-volt, 60-cycle, signal applied through the power cord to the vibration meter as in the normal calibration of this instrument. With the CALIBRATION-1 button depressed, the METER READS switch set for acceleration, and the METER SCALE switch of the vibration meter adjusted to give an indication greater than one-third of full scale, the SENSITIVITY control of the vibration analyzer is adjusted to give an analyzer indication identical with that of the vibration meter. This makes the analyzer direct reading for all components, in the units determined by the subsequent switch settings on the vibration meter. The SENSITIVITY control must, of course, not be shifted throughout succeeding analyses, and corresponding scales are read on both the analyzer and meter indicating instruments.

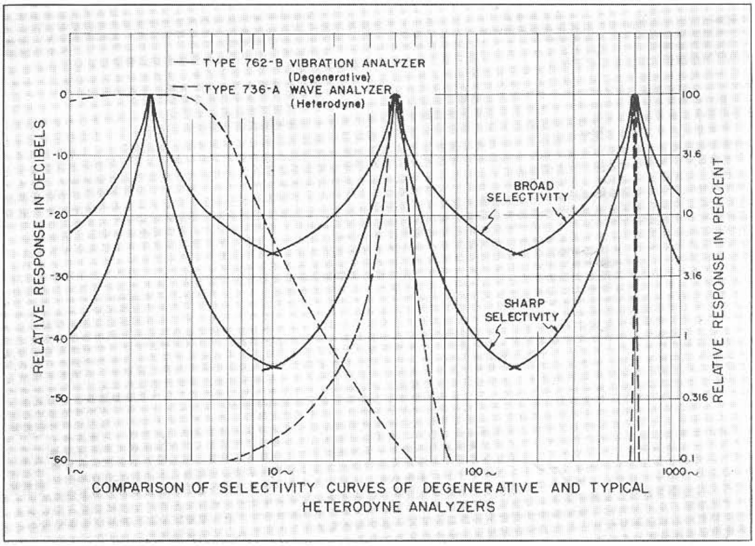


FIGURE 2. Comparison of selectivity curves of the degenerative and heterodyne analyzers. For vibration analysis, the degenerative type is preferable because it has a constant percentage band width.

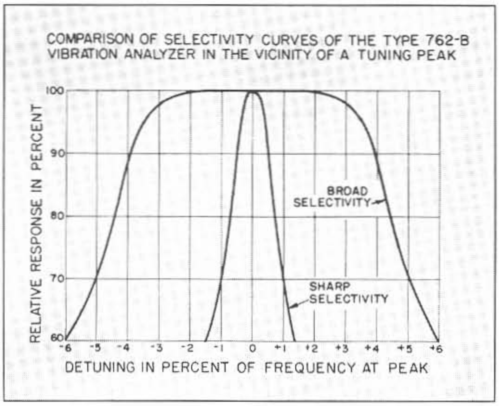


FIGURE 3. Plot of the relative band widths for BROAD and SHARP selectivity positions.

Many applications in the field of wave analysis in the low audio- and subaudio-frequency regions are possible with the instrument used directly as a voltage analyzer. As a tuned detector in low-frequency bridge applications it is probably best used again in conjunction with the TYPE 761-A Vibration Meter. Here the vibration meter is used as a high-input-impedance, high-gain, linear amplifier (the acceleration characteristic of the meter is that of a linear amplifier over approximately the frequency range of the analyzer), and is inserted between the bridge and the analyzer. The input impedance of the vibration analyzer varies from 20,000 to 30,000 ohms depending upon the setting of the SENSITIVITY control. With the SENSITIVITY control set at a maximum, full scale indication is obtained with an input voltage of about 0.1 volt. Under circuit conditions where these input characteristics are satisfactory, the instrument may be used directly as a voltage analyzer or tuned voltmeter. The procedure to be followed in making the instrument direct reading in volts or in percent of the major component is identical with that outlined for vibration analysis.

— W. R. SAYLOR

SPECIFICATIONS

Frequency Range: 2.5 to 750 cycles, covered in five ranges as follows: 2.5 to 7.5, 7.5 to 25, 25 to 75, 75 to 250, 250 to 750.

Band Width: For the sharp selectivity position, the relative attenuation is approximately 30% (3 db) at a frequency differing by 1% from that to which the analyzer is tuned. For the broad selectivity position, the attenuation is 30% for a frequency difference of 5%. At one octave from the peak, the relative attenuations are 98% (35 db) and 90% (20 db), respectively.

Frequency Calibration: The accuracy of frequency calibration of the sharp selectivity network is ±1½% or ±1½ cycles, whichever is the larger, over the three highest ranges (25 to 750 cycles); on the two lower ranges (2.5 to 25 cycles), the accuracy is ±5% or ±0.2 cycle, whichever is the larger. The frequency as determined with the broad selectivity network deviates on the average by less than ±2% from that determined with the sharp selectivity network.

Frequency Response: The response of the sharp selectivity network is flat within ±2 db over the entire range. At points where two ranges overlap, the sensitivity is the same on either range within ±1 db. The sensitivity of the broad selectivity network is the same as that of the sharp selectivity network to within ±2 db.

Voltage Range: The analyzer will give usable indications on input voltages ranging from 1 millivolt to 10 volts. The meter scale is calibrated for reading directly component tones down to 1% of the fundamental or strongest component. Accordingly, to make full use of this feature, the input voltage at the strongest component or fundamental should be 0.1 volt or higher.

Input Impedance: The input impedance is between 20,000 and 30,000 ohms, depending upon the setting of the sensitivity control. A 3-μf blocking condenser is in series with the input.

Temperature and Humidity Effects: Under very severe conditions of temperature and humidity only slight, and generally negligible, shifts in calibration, sensitivity, and band width will occur.

CIRCUIT: The circuit consists of a three-stage amplifier made selective by the use of degeneration, and an approximately logarithmic vacuum-tube voltmeter circuit, which allows a range slightly in excess of 40 decibels, or 100 to 1, to be read on the meter scale.

Meter: The indicating meter is calibrated down to 1% of the fundamental or strongest component.

Telephones: A jack is provided on the panel for plugging in a pair of head telephones, in order to listen to the actual component of the sound to which the instrument is tuned. This is also useful when using the analyzer as a bridge-balance indicator.

Tubes: Three 1H4-G and one 1F7-GV tubes are required. A neon regulator tube (type T-4½) is also used. A complete set of tubes is supplied with the instrument.

Batteries: The batteries required are four Burgess No. F2BP 3-volt batteries, or the equivalent, and three Burgess No. Z30N 45-volt batteries, or the equivalent. A compartment is provided in the case of the analyzer for holding all batteries, and connections are automatically made to the batteries when the cover of this compartment is closed. A set of batteries is included in the price of the instrument.

Accessories Supplied: A shielded cable-and-plug assembly for connecting the analyzer to the vibration meter.

Case: The analyzer is built into a shielded carrying case of airplane-luggage construction. In addition to the handle on the carrying case, a handle is provided on the panel of the instrument for convenience in moving the instrument about while it is in operation.

Dimensions: (Length) 18 x (width) 10 x (height) 11½ inches, over-all.

Net Weight: 34 pounds, with batteries; 27¼ pounds, without batteries.

Type		*Code Word*	*Price*
762-B	Vibration Analyzer	AWARD	$275.00

MISCELLANY

● **PAPERS** — H. B. Richmond, Chairman of the Board, spoke at the conference on "Instrumentation and the University," held at Carnegie Institute of Technology on October 17. His subject, "Educational Preparation for an Instrumentation Career in the Electronic Industry."

On November 12, E. E. Gross of the Engineering Department spoke at the Rochester Fall Meeting on "A Coaxial Modification of the Butterfly Circuit."

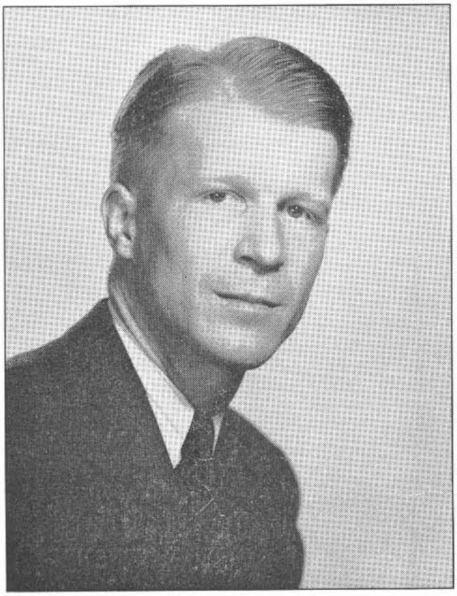
Dr. A. P. G. Peterson of the Engineering Department spoke at the Cincinnati Section of the I.R.E., November 20, on "High-Frequency Measurements."

Ivan G. Easton of the Sales Engineering Department delivered a paper entitled "The History and Technology of the Stroboscope" at a meeting of the Textile Division of the American Society of Mechanical Engineers in New York, November 29.

● **WE HAVE ALWAYS BEEN PROUD** of the broad distribution of GR products in industry. A good illustration has just come to our attention. In the October, 1945, issue of *Electronics*, scattered among the advertisements and articles there are fourteen pictures of GR equipment in as many different uses. We thank the users for their confidence.

● **DON'T MISS** the General Radio exhibit at the Winter Technical Meeting of the I.R.E., to be held at the Hotel Astor, New York, January 23–26, 1946. New designs will be displayed and General Radio engineers will be on hand to answer your questions.

EASTON TO NEW YORK ENGINEERING OFFICE



● **EFFECTIVE** about December 1, Ivan G. Easton becomes manager of the New York Engineering and Sales Office of the General Radio Company. Martin A. Gilman, manager of this office for the past two years, returns to the sales engineering staff at the Cambridge office.

Mr. Easton was born in 1916 and attended the public schools of Rockport, Massachusetts. He received his B. S. degree in electrical engineering from Northeastern University in 1938 and his M. S. degree from Harvard in 1939. Upon completion of his graduate work at Harvard, he joined the engineering staff of the General Radio Company and has worked in both the development engineering and sales engineering groups. Readers of the *Experimenter* will recall his many articles on bridge circuits and impedance measurements.

Mr. Easton is a senior member of the I. R. E. and for the past two years has been Program Chairman for the Boston Section. He is also a member of the A. I. E. E., a member of the Society for Experimental Stress Analysis, and company representative of the American Society for Testing Materials. During the war Mr. Easton has taught ESMWT courses in radio engineering at Northeastern University.

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