THE General Radio EXPERIMENTER

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ELECTRICAL MEASUREMENTS AND THEIR INDUSTRIAL APPLICATIONS

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

Also

IN THIS ISSUE

● 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:

$$L_C = 6.1 \times 10^{-9}\ h$$
$$R_C = 0.026\ \Omega \text{ at } 30 \text{ Mc}$$
$$L'' = 3.15 \times 10^{-9}\ h$$
$$L' = 6.8 \times 10^{-9}\ h$$

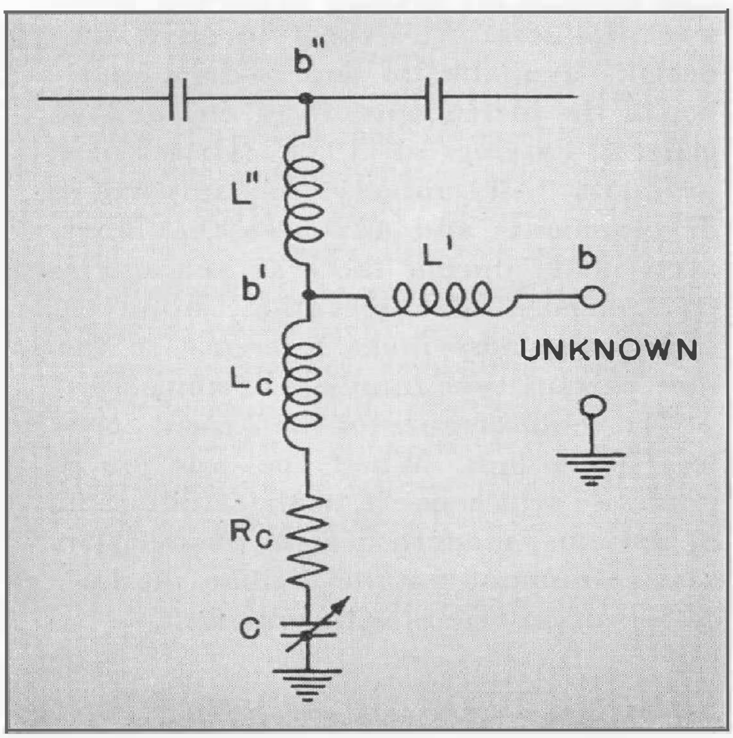


FIGURE 1. Equivalent circuit of the precision condenser used in TYPE 821-A Twin-T, showing the location of residual impedances.

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 capacitance 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

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

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

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

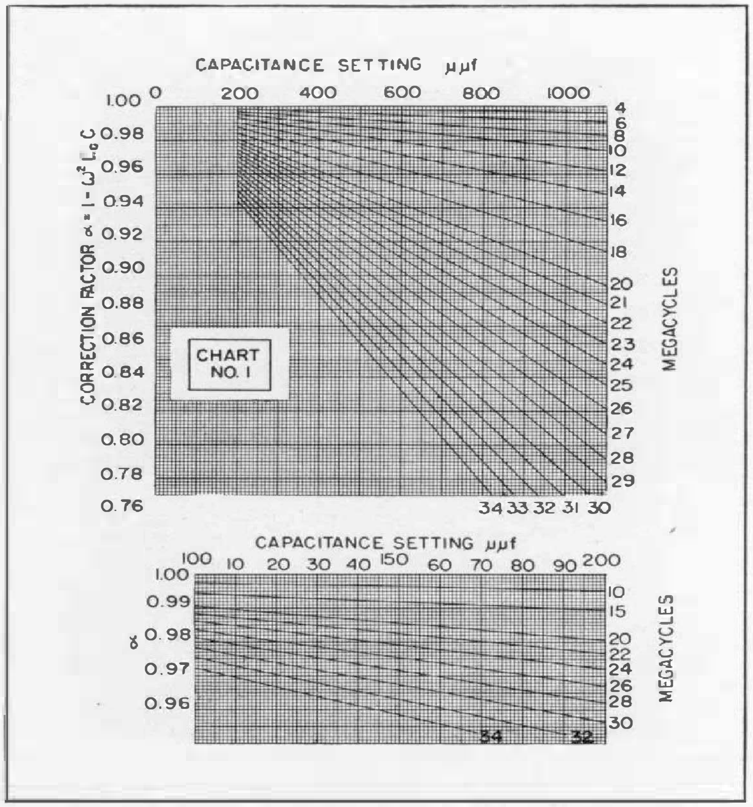


FIGURE 2. Chart No. 1 for determining the quantity ∝. To facilitate reading the chart at low values of capacitance, the portion below 200 μμf is expanded and plotted below the main chart.

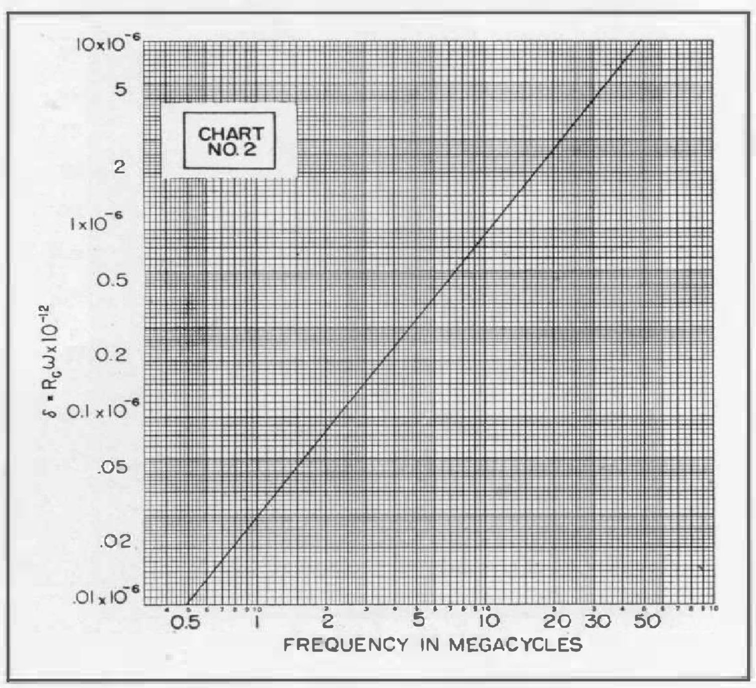


FIGURE 3. Chart No. 2 for determining the quantity δ which is used to calculate the correction term ΔG.

[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.

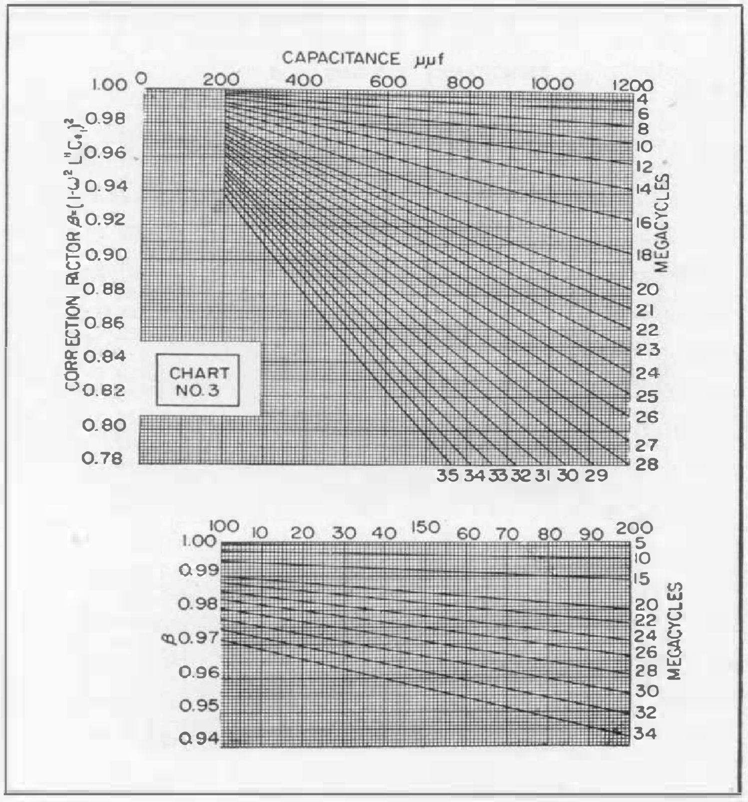
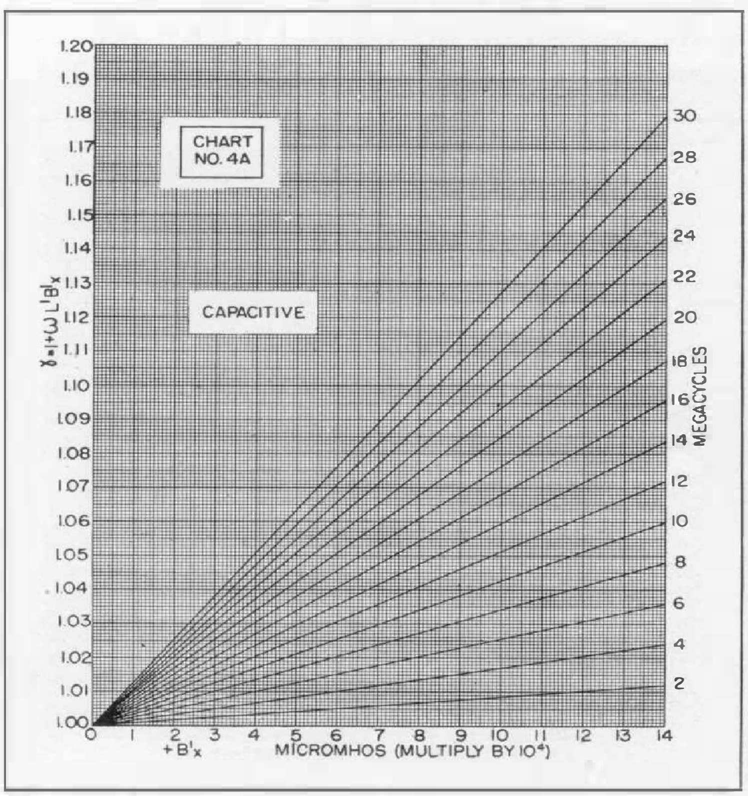


FIGURE 4. The correction factor β is determined from Chart No. 3, shown here. Full-size reproductions of these charts are available to users of the Twin-T upon request to the General Radio Company.

by the resistance R_C and is given by

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



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

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

and

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

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'.

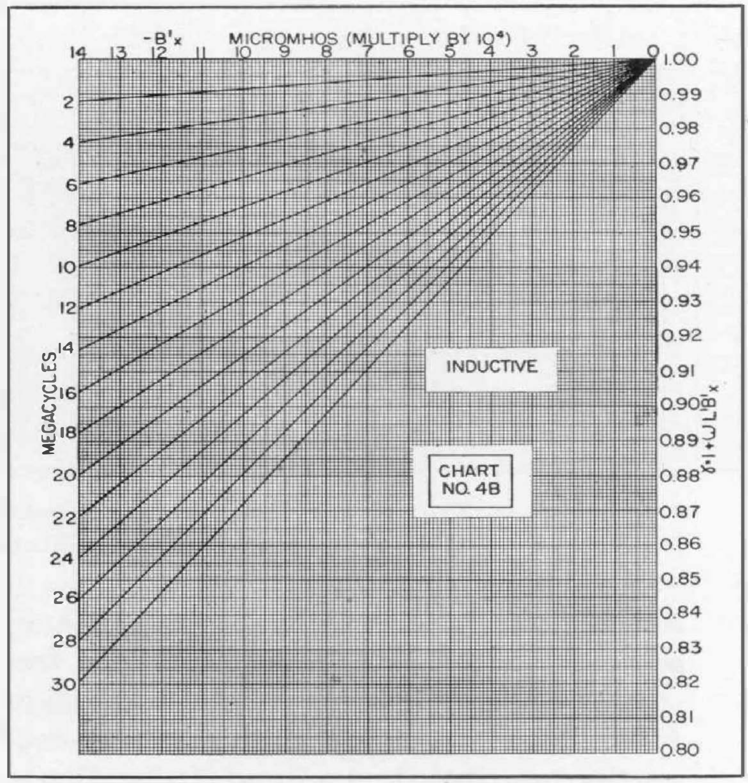


FIGURE 6. For negative susceptances (inductive) Chart No. 4B, above, is used.

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

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

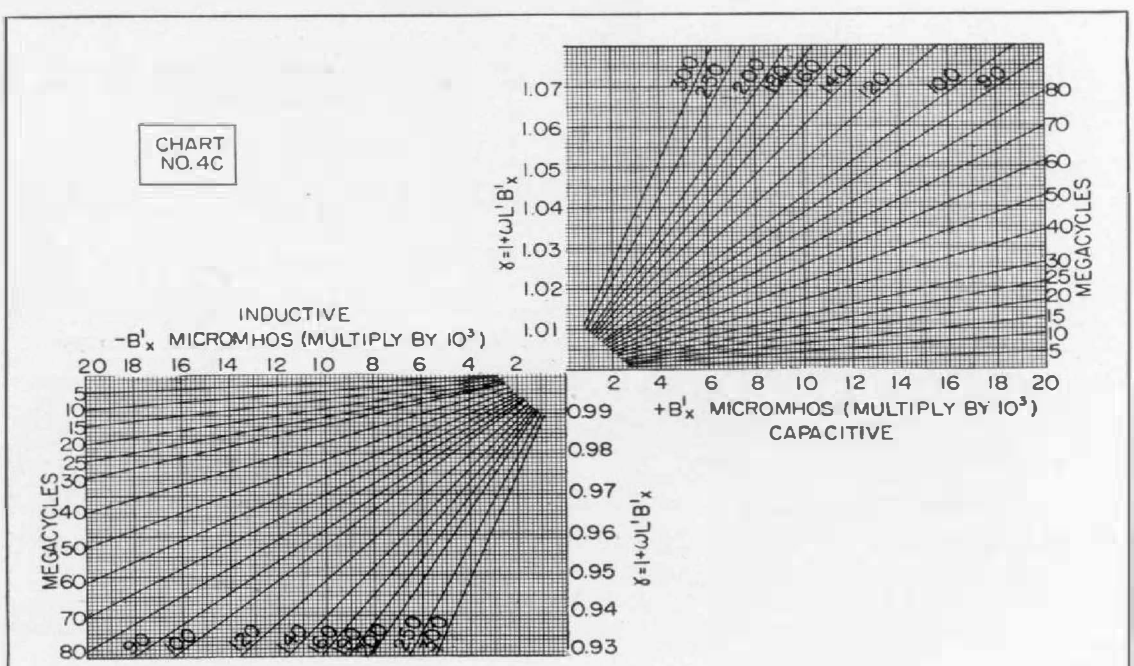


FIGURE 7. Chart No. 4C shows expanded the crowded portions of Charts 4A and 4B. For use in determining lead corrections (see text) a much wider range of frequency is shown.

f_{Mc}	ω	C_1	C_2	α_1	α_2	C_{e_1}	C_{e_2}	$C_{e_1}-C_{e_2}$	B'_x	$C_{e_1}+C_{e_2}$	δ	ΔG	G''	β	$G''\beta$	G'_x	γ	B_x	G_x	L_x	Q_x	C_x	D_x
30	188.5	100.0	388.1	.978	.917	102.2	.423	-320.8	-69,500	525.2	4.8×10⁻¹⁵	-152.5	300	.977	293	140.5	.923	-65,600	165	.081μh	398	—	—
30	188.5	250.0	121.5	.946	.967	264.2	156.8	107.4	29,250	421.0	4.8 "	40.9	22	.946	52	92.9	1.026	19,750	88.3	—	—	104.8	.00447
25	157.0	100.0	139.8	.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	.989	1025	447	578	36,300	1472	.92 "	49.2	80	.975	78	127.2	1.015	35,800	123.5	—	—	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 non-symmetrical 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.

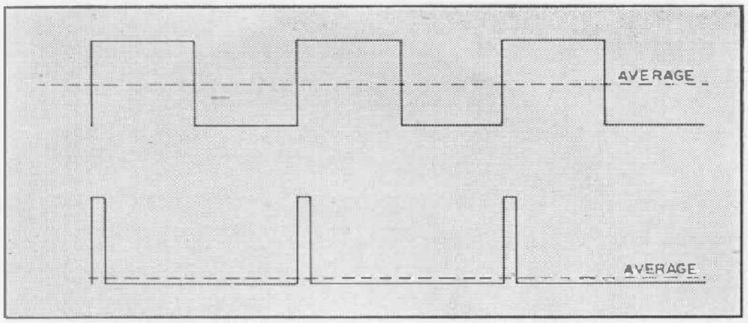


FIGURE 2. (*above*) Square Wave and (*below*) Pulse Wave.

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

WHEN YOU TELEPHONE

With thousands of orders continuously in process, it takes time to check up on the details of any one order. To answer questions about orders already placed, we must have (1) order number, (2) date of order, and (3) list of material ordered.

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