the GENERAL RADIO Experimenter

INDEX

TO

GENERAL RADIO EXPERIMENTER

VOLUME 33

JANUARY through DECEMBER, 1959

INDEX BY TITLE

INDEX BY AUTHOR

INDEX BY TYPE NUMBER

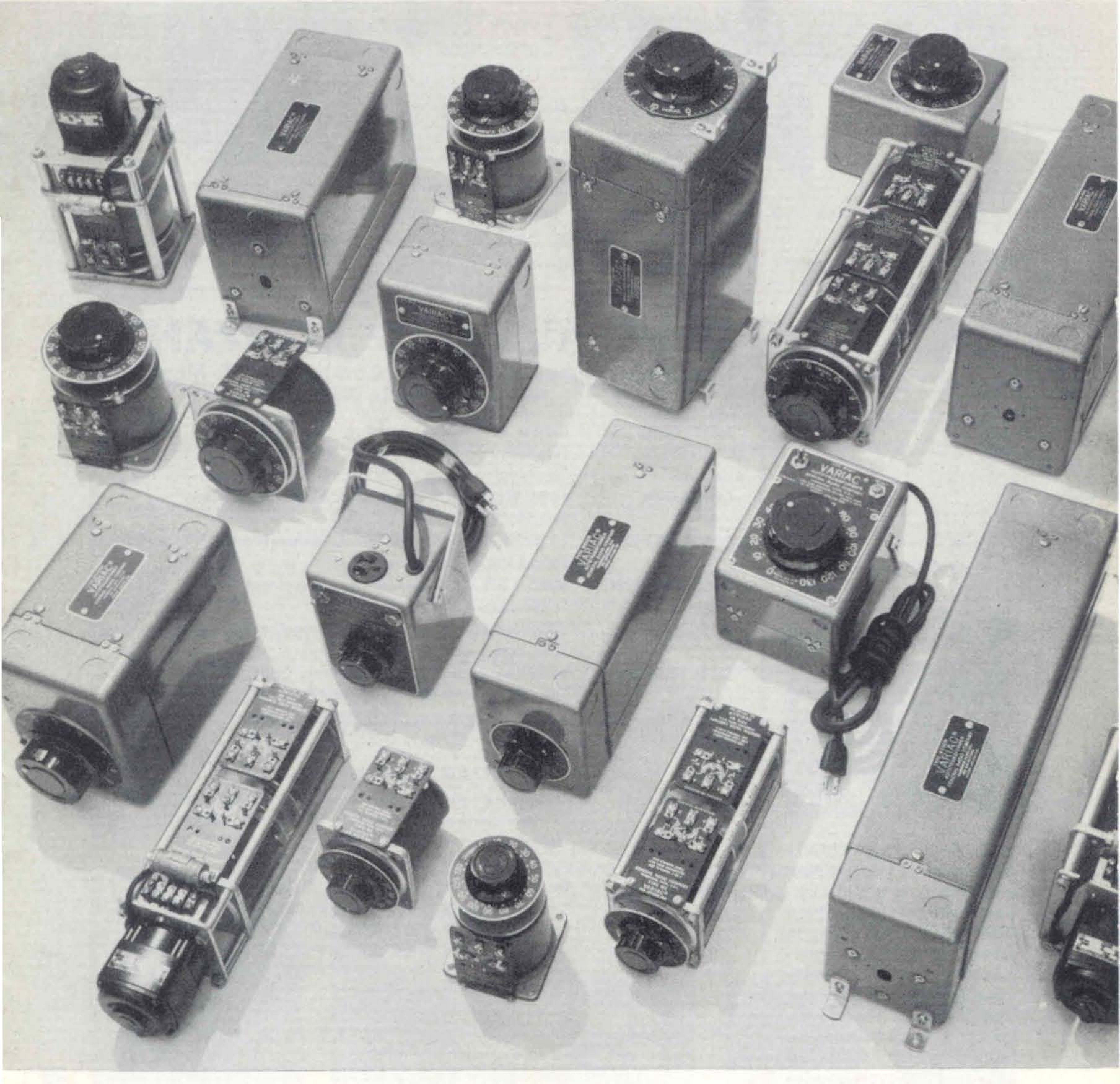
Litho in USA

the GENERAL RADIO Experimenter

© 1959 · GENERAL RADIO Company, Cambridge, Mass., U.S.A.

Since 1915 — Manufacturers of Electronic Apparatus for Science and Industry

VOLUME 33 No. 1 **JANUARY, 1959**



In This Issue

New 10-Ampere Variac®

New Connectors

the GENERAL RADIO Experimenter

Published Monthly by the General Radio Company

VOLUME 33 • NUMBER 1 JANUARY, 1959

CONTENTS

The General Radio EXPERIMENTER is mailed without charge each month to engineers, scientists, technicians, and others interested in electronic techniques in measurement. 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.

GENERAL RADIO COMPANY

275 Massachusetts Avenue, Cambridge 39, Mass.

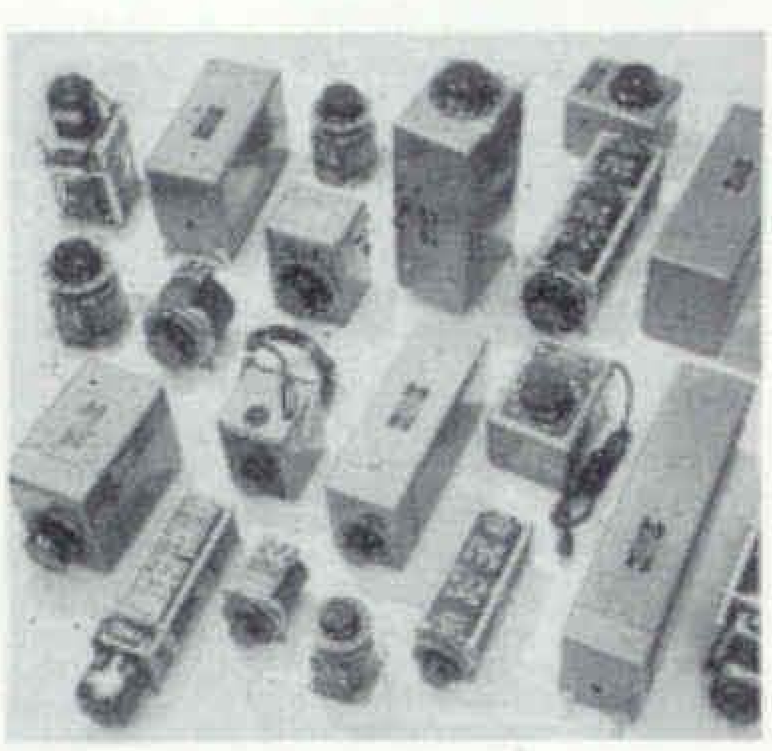
Telephone: TRowbridge 6-4400

NEW YORK:	**Broad Avenue at Linden, Ridgefield, New Jersey** *Telephone — N. Y., WOrth 4-2722* *N. J., WHitney 3-3140*
CHICAGO:	**6605 West North Avenue, Oak Park, Illinois** *Telephone — VIllage 8-9400*
PHILADELPHIA:	**1150 York Road, Abington, Pennsylvania** *Telephone — HAncock 4-7419*
WASHINGTON:	**8055 13th St., Silver Spring, Maryland** *Telephone — JUniper 5-1088*
LOS ANGELES:	**1000 North Seward St., Los Angeles 38, Calif.** *Telephone — HOllywood 9-6201*
SAN FRANCISCO:	**1182 Los Altos Ave., Los Altos, Calif.** *Telephone — WHitecliff 8-8233*
CANADA:	**99 Floral Parkway, Toronto 15, Ontario** *Telephone — CHerry 6-2171*

REPAIR SERVICES

EAST COAST:	**General Radio Co., Service Dept., 22 Baker Avenue, West Concord, Mass.** *Telephone — Concord, EMerson 9-4400* *Lincoln, CLearwater 9-8900*
NEW YORK:	**General Radio Co., Service Dept., Broad Ave. at Linden, Ridgefield, New Jersey** *Telephone — N. Y., WOrth 4-2722* *N. J., WHitney 3-3140*
MIDWEST:	**General Radio Co., Service Dept., 6605 West North Ave., Oak Park, Illinois** *Telephone — VIllage 8-9400*
WEST COAST:	**Western Instrument Co., 826 North Victory Boulevard, Burbank, Calif.** *Telephone — VIctoria 9-3013*
CANADA:	**Bayly Engineering, Ltd., First St., Ajax, Ontario** *Telephone — Toronto EMpire 2-3741*

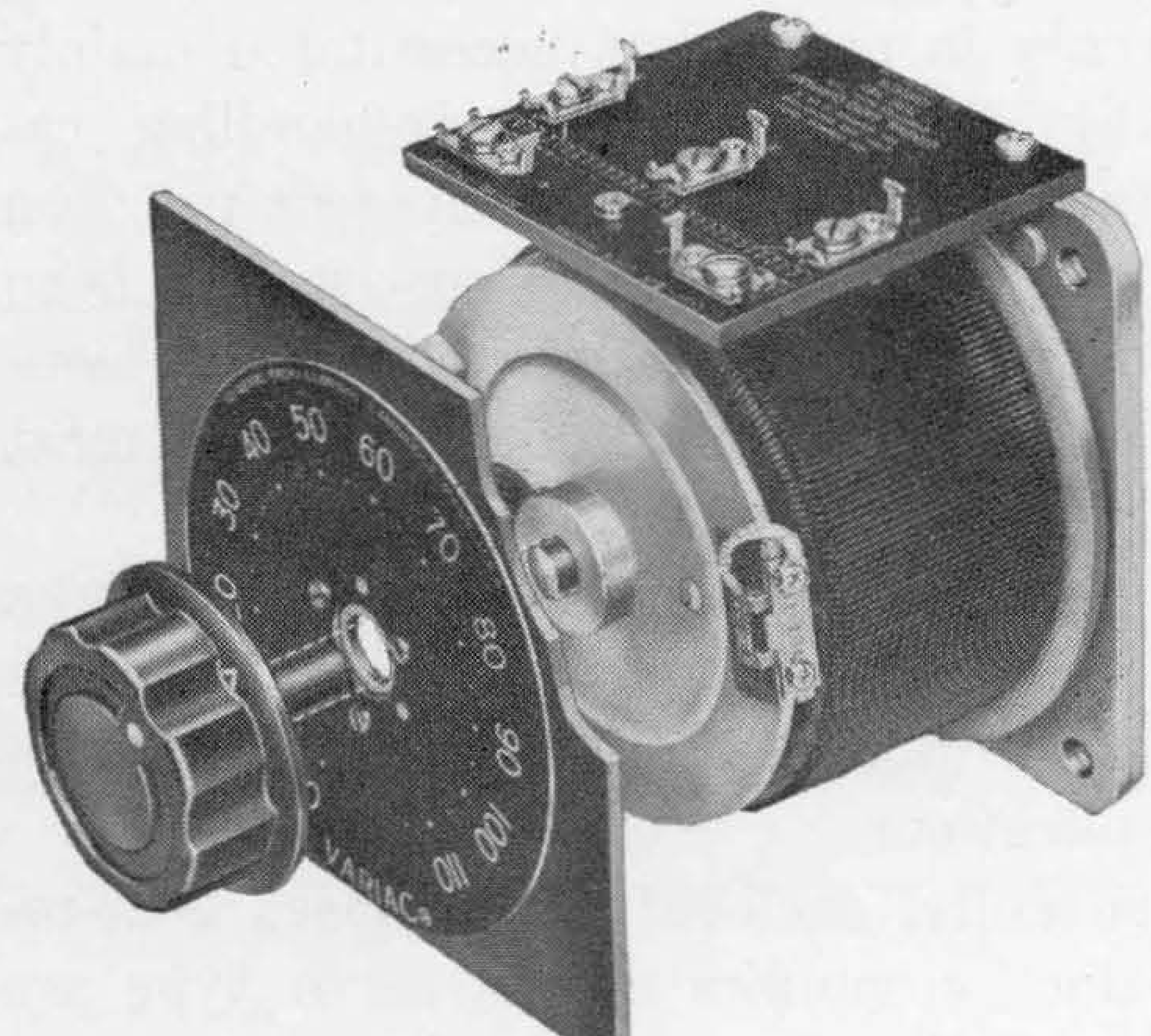
COVER



VARIAC® Adjustable Autotransformers are now available in a uniform design in 60-cycle ratings from 0.36 KVA to 52 KVA, in panel-mounting, wall-mounting, and portable models, with or without cases, and for either manual or motorized operation. High-frequency units for 350- to 1200-cycle service have ratings from 0.34 kva to 10 kva.

NEW TYPE W10 VARIAC® AUTOTRANSFORMER

Type W10M Variac



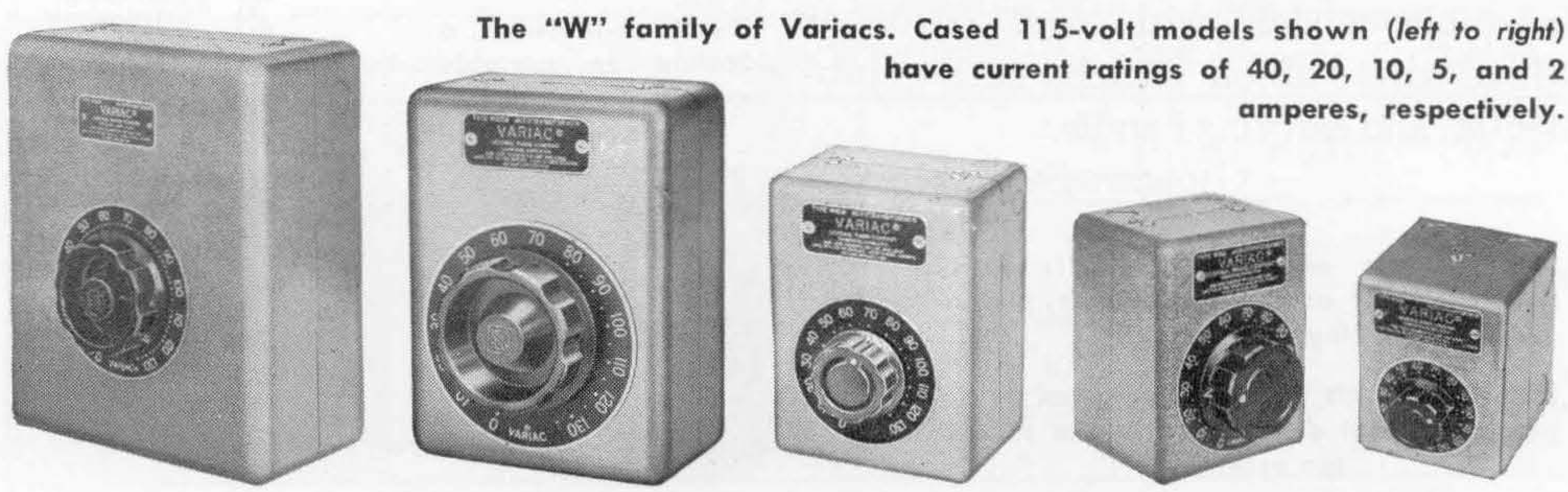
Type W10 Variac

The General Radio Variac® Autotransformer, one of the most widely copied products in the electrical industry, has been constantly improved since its introduction to the industry over 25 years ago. Frequent improvements not noticeable to the user are made to assure greater reliability and better performance while, at intervals of several years, complete model changes are made which incorporate the result of years of development work. Through a continuous program of development, General Radio engineers are constantly seeking new materials, design techniques, and manufacturing methods and applying them to the building of better Variacs.

One of the fruits of this program is the *Duratrak* contact surface; another is the "W" Variac design, of which the 10-ampere Type W10 (115 volts) and 4-ampere Type W10H (230 volts) are the latest examples, replacing the Type V-10 series. The features of "W" Variacs have been described in detail previously.[1] Improved heat transfer, improved insulation for better electrical performance; the substitution of wrought metal for castings to improve mechanical properties; disc radiators to protect the brush track, etc. Now, all General Radio Variacs bear a strong family resemblance

[1] "More New Variacs®," *General Radio Experimenter*, 30, 12, May, 1956, pp. 13-15.
"The Type W5 Variac® — A New and Better Variable Autotransformer," *General Radio Experimenter*, 30, 7, December, 1955, pp. 1-10.
"The Type W20 — A New 20-Ampere Variac® Autotransformer," *General Radio Experimenter*, 32, 15 and 16, August-September, 1958, pp. 3-5.
"New '50' Size Variacs® — Types W50 and W50H," *General Radio Experimenter*, 31, 11, April, 1957, pp. 3-9.

The "W" family of Variacs. Cased 115-volt models shown (*left to right*) have current ratings of 40, 20, 10, 5, and 2 amperes, respectively.



based on the application of the same sound principles to all models, differing only in particulars necessitated mainly by differences in power-handling capacity. That the development program has been a complete success has been amply demonstrated not only by consumer acceptance, but by that most sincere form of flattery, imitation.

Motor drives can be furnished on Type W10 single or ganged Variacs for servo work and for remote positioning applications.

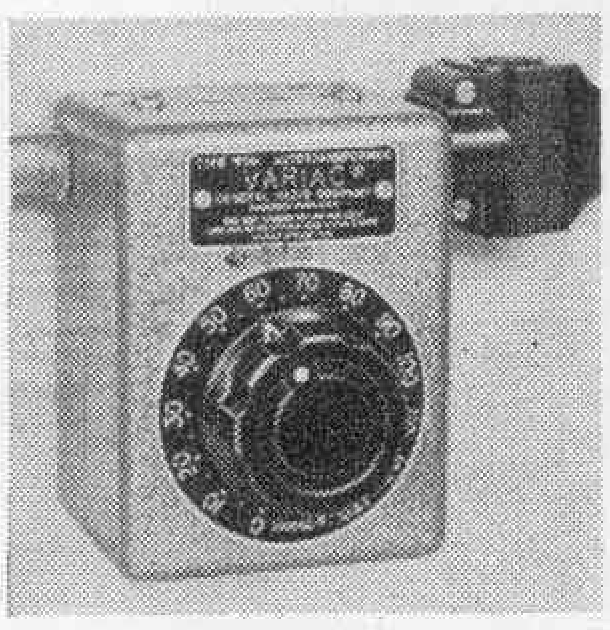
Fully enclosed, two-phase, gear-reduction motors of the servo type are used. For servo applications, the motor has low moment of inertia and high angular acceleration. For remote positioning, the same servo motor assembly with a different shaft speed is used. The low moment of inertia is useful to avoid overshoot.

Single, two-gang, and three-gang units can be equipped to provide traverse rates of 8, 16, 32, and 64 seconds for 320° of travel for either servo or remote positioning applications and 128-second traverse for remote positioning only. The single units (Types W10 and W10H) can also be equipped to provide 4-second traverse rate for servo applications only.

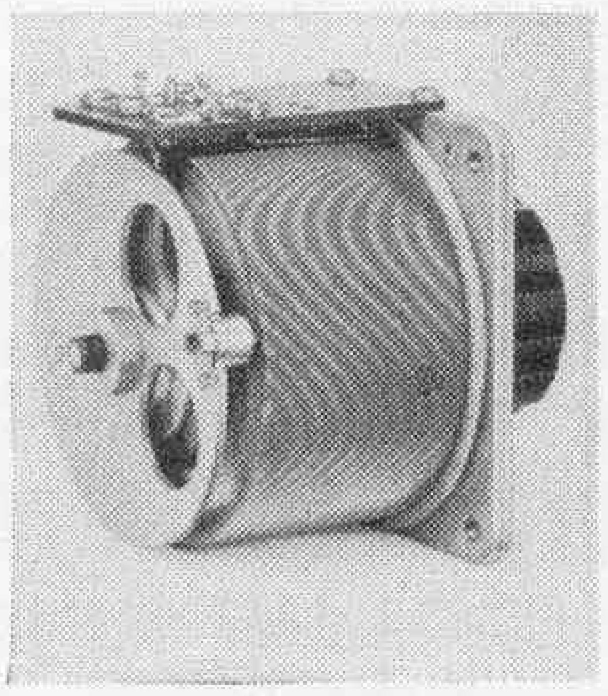
The Type W10 series of Variacs is available in a wide assortment of models, 115- and 230-volt input, line or overvoltage output, single or ganged, open or cased, with or without ball bearings and motor drive as well as cased portable models with cord (two- or three-wire), off-on switch, outlet, protector, and carrying handle.

— Gilbert Smiley

Portable model with convenient handle is available in 2- and 3-wire models.



Cased model for wall mounting has conduit knockouts.



Uncased model for panel mounting.

Overload protector, a feature on portable models, is reset from front panel.

VARIAC RATINGS

SINGLE PHASE

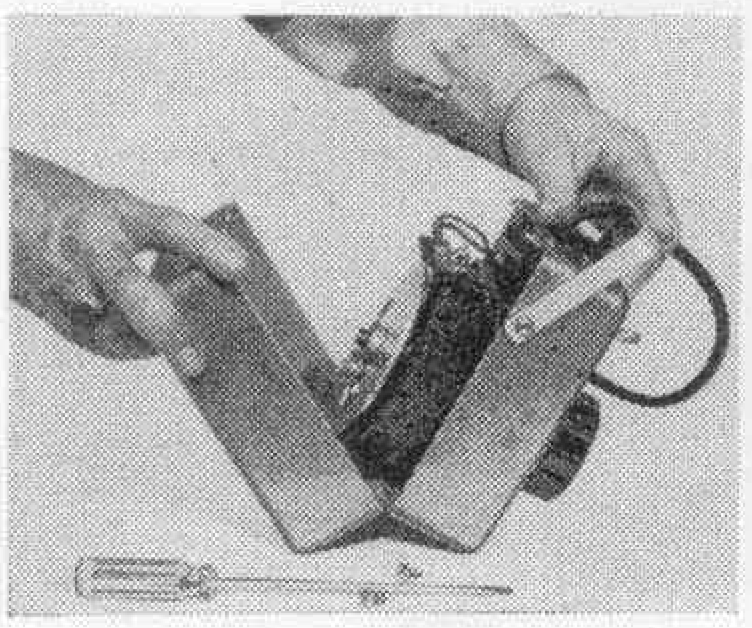
	KVA	Type
115-VOLT INPUT		
	0.36	W2
	0.9	W5
	1.5	W10
	3	W20
	5.75	W50
	6	W20G2
	9	W20G3
	11.50	W50G2
	17.25	W50G3
	23	W50G4BB
	34.5	W50G6BB
230-VOLT INPUT		
	0.6	W5H
		W2G2
	1.2	W10H
	1.8	W5G2
	2.4	W20H
	3	W10G2
	4.8	W20HG2
	6	W20G2
	7.5	W50H
	15	W50HG2
	22.5	W50HG3
	30	W50HG4BB
	45	W50HG6BB
460-VOLT INPUT		
	1.2	W5HG2
	2.4	W10HG2
	4.8	W20HG2
	15	W50HG2
	30	W50HG4BB
	45	W50HG6BB

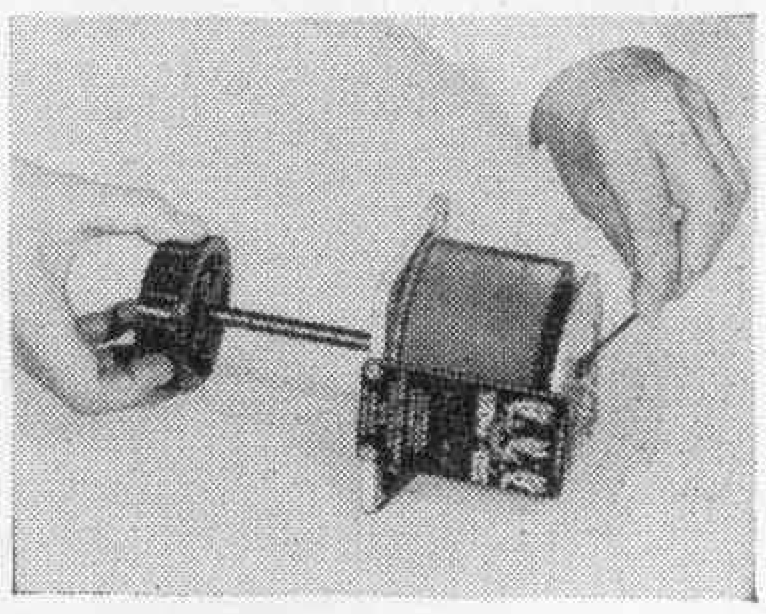
THREE PHASE

	KVA	Type
230-VOLT INPUT		
	1.0	W5HG2
	1.25	W2G3
	2.1	W10HG2
	3.1	W5G3
	4.1	W20HG2
	5.2	W10G3
	10.4	W20G3
	13	W50HG2
	20	W50G3
	26	W50HG4BB
	40	W50G6BB
460-VOLT INPUT		
	2.1	W5HG3
	4.1	W10HG3
	8.2	W20HG3
	26	W50HG3
	52	W50HG6BB

(*Right*) Cover of cased model is easily removable for access to terminals, mounting holes, etc.

(*Far right*) Shaft is easily adjusted or replaced without disturbance to the rest of the assembly.





Type and Mounting	Input Voltage	Line-Voltage Connection: Rated Output Current -Amp.	Output Voltage	Maximum Current -Amp.	Output KVA	Overvoltage Connection: Output Voltage	Rated Output Current -Amp.	60-cycle no-load loss-watts	Driving torque oz.-in.	Net Wt. lbs.	Code Word	Price
W10 Open	115	10	0–115	13	1.5	0–135	10	17	30–60	12½	DOGAL	**$31.00**
W10M With case	115	10	0–115	13	1.5	0–135	10	17	30–60	15	DOGER	**44.00**
W10MT Portable 2-wire	115	See note[1] below				0–135	10	17	30–60	16	DOGIC	**48.00**
W10MT3 Portable 3-wire	115	See note[1] below				0–135	10	17	30–60	16	DOGOM	**51.00**
W10H Open	230	4	0–230	5.2	1.2	0–270	4	17	30–60	12	LUTAL	**33.00**
	115	2				0–270	2					
W10HM With case	230	4	0–230	5.2	1.2	0–270	4	17	30–60	14½	LUTER	**46.00**
	115	2				0–270	2					
W10HMT Portable 2-wire	230	See note[1] below				0–270	4	17	30–60	15½	LUTIC	**50.00**
W10HMT3 Portable 3-wire	230	See note[1] below				0–270	4	17	30–60	15½	LUTOM	**53.00**
VBT-10	Replacement Brush for Type W10, per set											**1.25**
VBT-11	Replacement Brush for Type W10H, per set											**1.25**

[1] MT and MT3 models have overvoltage connection and corresponding dial scales, but can be supplied on special order with line voltage connections and dial scales.

GANGED MODELS

Type		*Load Rating KVA*: *Parallel*	*Series*	*Delta*	*Wye*	*Input Line Volts*	*Code Word*	*Price*
W10G2	**2-gang W10**	3.0		2.6		115	DOGALGANDU	**$ 72.00**
			3.0			230		
W10G2M	**2-gang W10 cased**	Same as W10G2					DOGALBONDU	**93.00**
W10G3	**3-gang W10**	4.5				115	DOGALGANTY	**105.00**
					5.2	230		
W10G3M	**3-gang W10 cased**	Same as W10G3					DOGALBONTY	**128.00**
W10HG2	**2-gang W10H**	2.4		2.1		230	LUTALGANDU	**76.00**
			2.4			460		
W10HG2M	**2-gang W10H cased**	Same as W10HG2					LUTALBONDU	**97.00**
W10HG3	**3-gang W10H**	3.6				230	LUTALGANTY	**111.00**
					4.2	460		
W10HG3M	**3-gang W10H cased**	Same as W10HG3					LUTALBONTY	**134.00**

NEW CONNECTORS FOR THE LABORATORY

PATCH CORDS, SHIELDED PLUGS, ADAPTORS, INSULATORS

Connectors for interconnecting instruments are an important part of any measurement system. These connectors are properly a concern of the instrument designer, because the proper functioning of his product may depend upon the type and quality of the means used to connect it to other devices and circuits.

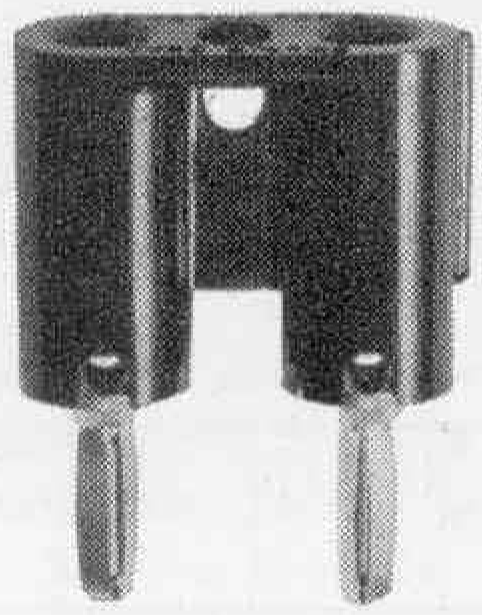
Poor-quality terminal insulators, high-loss or noisy cables, and loose plug-and-jack combinations that make erratic contact can ruin many a measurement, however accurate the measuring instrument may be.

Binding posts, plugs and jacks, patch cords, and similar devices have always been made available by the General Radio Company. These have been used not only with General Radio instruments but also with those of other manufacturers, since nearly all have adopted the General Radio standard of jack-top binding posts, spaced ¾ inch on centers.

The Type 274 Plugs, Jacks, and Patch Cords, together with the Type 938 Binding Posts in their several combinations, are an integrated set of low-frequency connecting devices, which are used on and supplied with General Radio instruments and are also sold separately. A number of these have recently been redesigned to have greater flexibility and adaptability than previous designs.

The well-known Double Plug, Type 274-MB, molded in polymethylstyrene, is now supplied with a cross hole through its center portion to provide strain relief for attached leads or cables up to 0.2 inch diameter.

The Type 274-NK Shielded Double Plug is a new design having an anodized aluminum shell, ceramic insulation, and providing strain relief for coaxial cables



Type 274-MB Double Plug of low-loss, heat-and-impact-resistant polymethylstyrene.

(*At right*) Type 274-NK Shielded Double Plug shown with shielded cable attached. Plugs directly into ¾″ spaced Type 938 Binding Posts with metal housing providing shield.

of 0.200 and 0.250 inch outside diameter. A wide variety of military and other coaxial cables is made in this range of sizes.

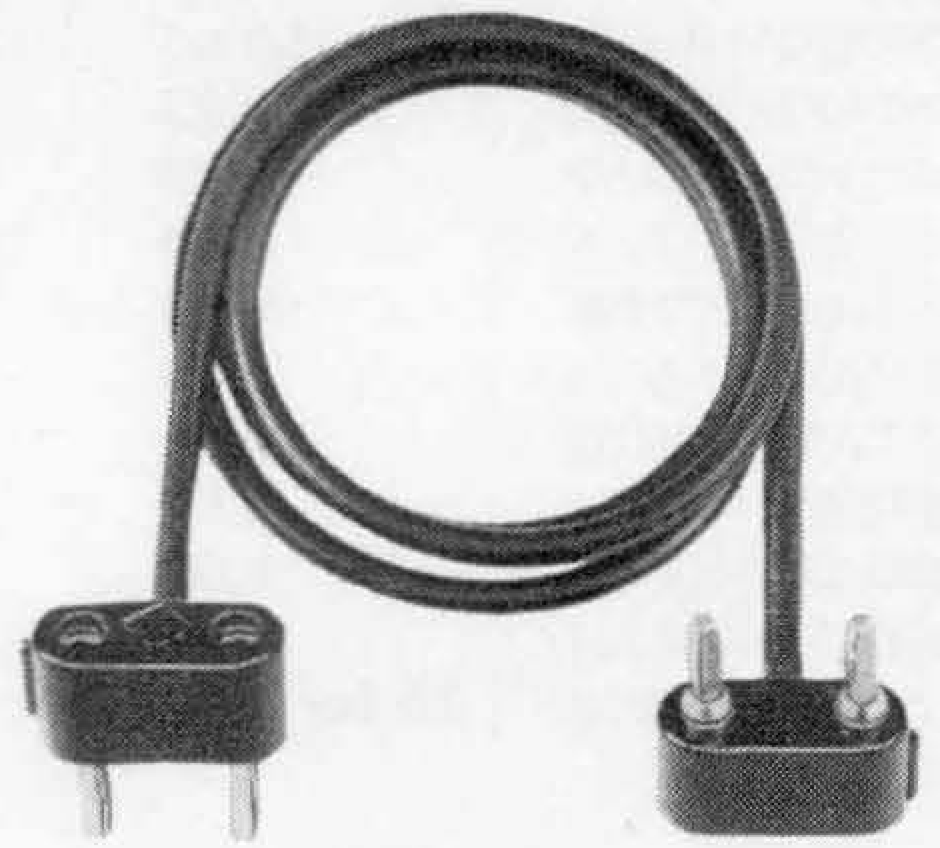
For single-wire connection, the Type 274-DB Single Plugs are still available in both red and black polymethylstyrene.

A combination of four assembled cords with connectors on the ends suitable for the type of connections commonly made, and a versatile cord capable of adaption to many types of terminals, satisfies practically every need met in the laboratory, at frequencies up to several megacycles.

For complete shielding, the Type 274-NL Patch Cord connects two pairs of binding posts, adding less than 100 $\mu\mu f$ to the circuit. If complete shielding is not required and more than one connection is desired at one pair of binding posts, the Type 274-NP serves the purpose. It has high-grade insulating materials throughout and less than 100 $\mu\mu f$ capacitance. The double plugs are molded to the ends and can be stacked for multiple connections. Metal parts are bright-alloy-plated beryllium copper.

Type 274-NL Patch Cord for shielded connection between ¾″ spaced binding posts.

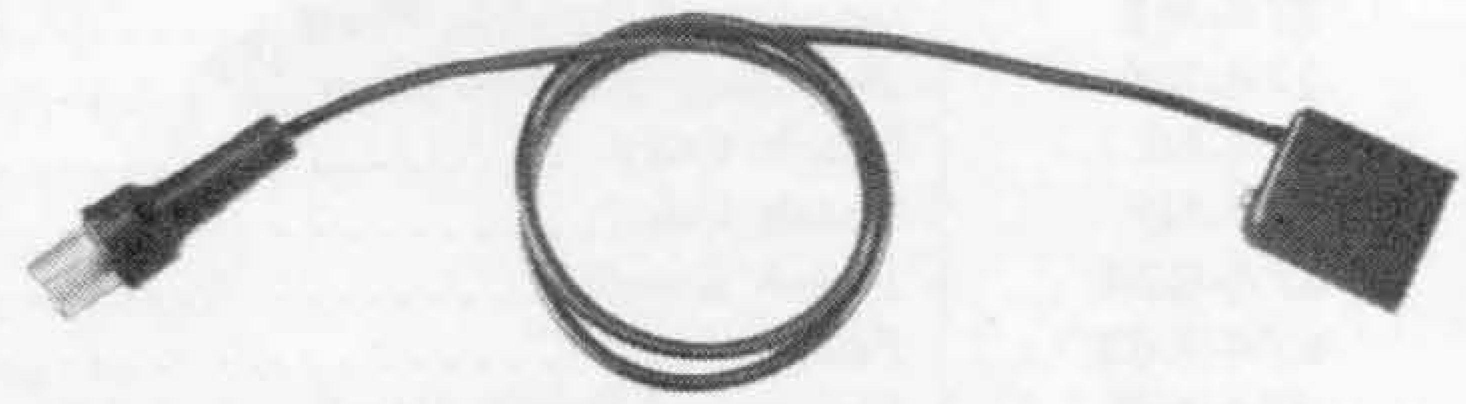
A shielded connection between any combination of binding posts on ¾ inch centers, binding posts at other than ¾ inch centers, "bread boards," and Type 874 Coaxial Connectors can easily be made by use of the Type 274-NO Universal Patch Cord. This cord consists of a coaxial cable, with a Type 274 Plug on each end of the center conductor, a metal



Type 274-NP Patch Cord connects between ¾″ spaced binding posts, allowing for multiple connections.

ferrule on each end of the shield, and a pigtail lead, with Type 274 Plug attached to the ferrule at each end of the cord. These plugs can go directly into jack-top binding posts or jacks spaced up to three inches apart. By addition of the Type 274-NT Shell, a completely shielded connection can be made to a pair of binding posts as in the Type 274-NL Patch Cord. Addition of the Type 874-QN6 to this universal cord adapts it for connection to the widely used Type 874 Coaxial Connectors. Lastly, the addition of Type 838-B Alligator Clips permits connection directly to any point in experimental or other circuits.

Bridging the gap from the Type 874 Coaxial System to the Type 274 Plug-Jack System is the Type 874-R34 Patch Cord. With it a pair of binding posts can be connected to a Type 874 Coaxial Connector with complete shielding. All

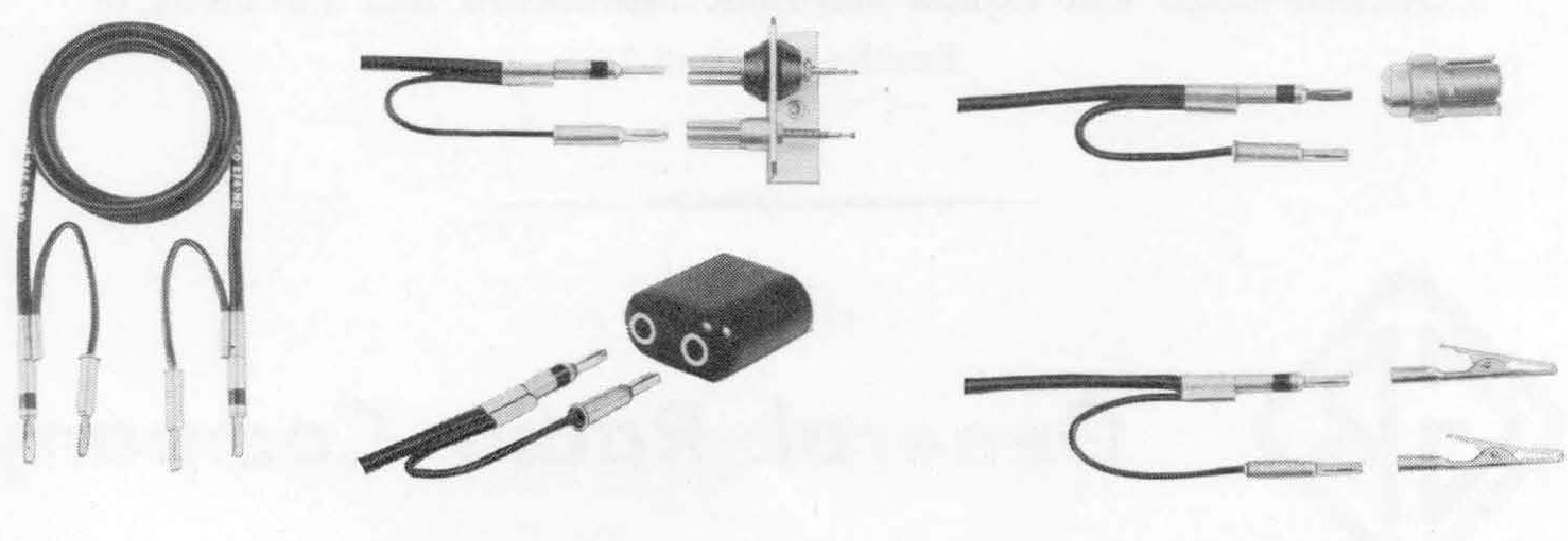


Type 874-R34 Patch Cord

the versatility of the Type 274-NO Cord described above can be had on one end of the Type 874-R33 Patch Cord while the other end is plugged into a Type 874 Connector. This latter cord used with the Type 874-Q line of adaptors will connect virtually anything to anything.

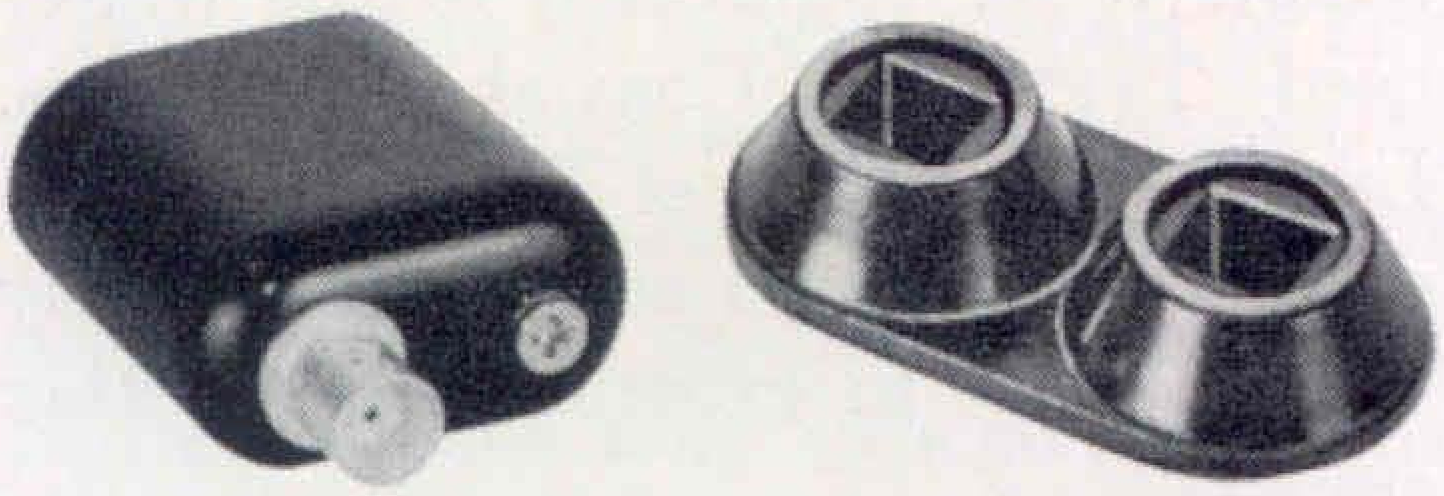
To add still further flexibility to the system, the new Type 274-QBJ Adaptor provides a means of connecting a pair of

(*Far left*) Type 274-NO Universal Patch Cord. (*Below*) shown with (*left*) Type 938 Binding Posts, Type 274-NT Shell; (*right*) Type 874-QN6 Adaptor, Type 838-B Alligator Clips.



jack-top binding posts to the popular BNC-type connector.

Another new design is the Type 938-YB Double Binding Post Insulator. It is



(*Left*) Type 274-QBJ Adaptor to BNC. (*Right*) Type 938-YB Double Binding Post Insulator.

in every way compatible with the well-established Type 938-WR, 938-WB, and 938-P Jack-top Binding Posts, but can be conveniently mounted on panels up to 5/16 inch thickness in two 1/2 inch diameter holes. The black polymethylstyrene material gives it a voltage rating of 4000 peak with less than 1 $\mu\mu f$ capacitance between binding posts.

These new connectors, plus the Type 938 Binding Posts and the Type 874 Coaxial Connectors and Adaptors, provide well-designed, high-quality interconnection systems for all kinds of electronic equipment operating at frequencies from dc up to about 5000 megacycles.

— H. C. Littlejohn

Type		*Code Word*	*Price*
274-MB	Insulated Double Plug	STANPARBUG	$0.65
274-NK	Shielded Double Plug	STAPLUGNUT	1.35
274-NL	Patch Cord	STAPLUGBAT	4.50
274-NP	Patch Cord	STANPARYAK	3.50
874-R34	Patch Cord	COAXFITTER	5.50
874-R33	Patch Cord	COAXLINKER	5.00
274-NO	Universal Patch Cord	STANPARKID	3.25
274-QBJ	Adaptor to BNC	STANPARMUG	2.50
874-QN6	Adaptor to 874	COAXCHOSER	1.00
938-YB	Double Insulators	STANPARPAN	.20
838-B	Alligator Clip	STANPARNIP	10 for 1.50

WINTER MEETING AND EXHIBIT

American Physical Society — American Association of Physics Teachers

HOTEL NEW YORKER -:- NEW YORK, N. Y.

JANUARY 28 to 31

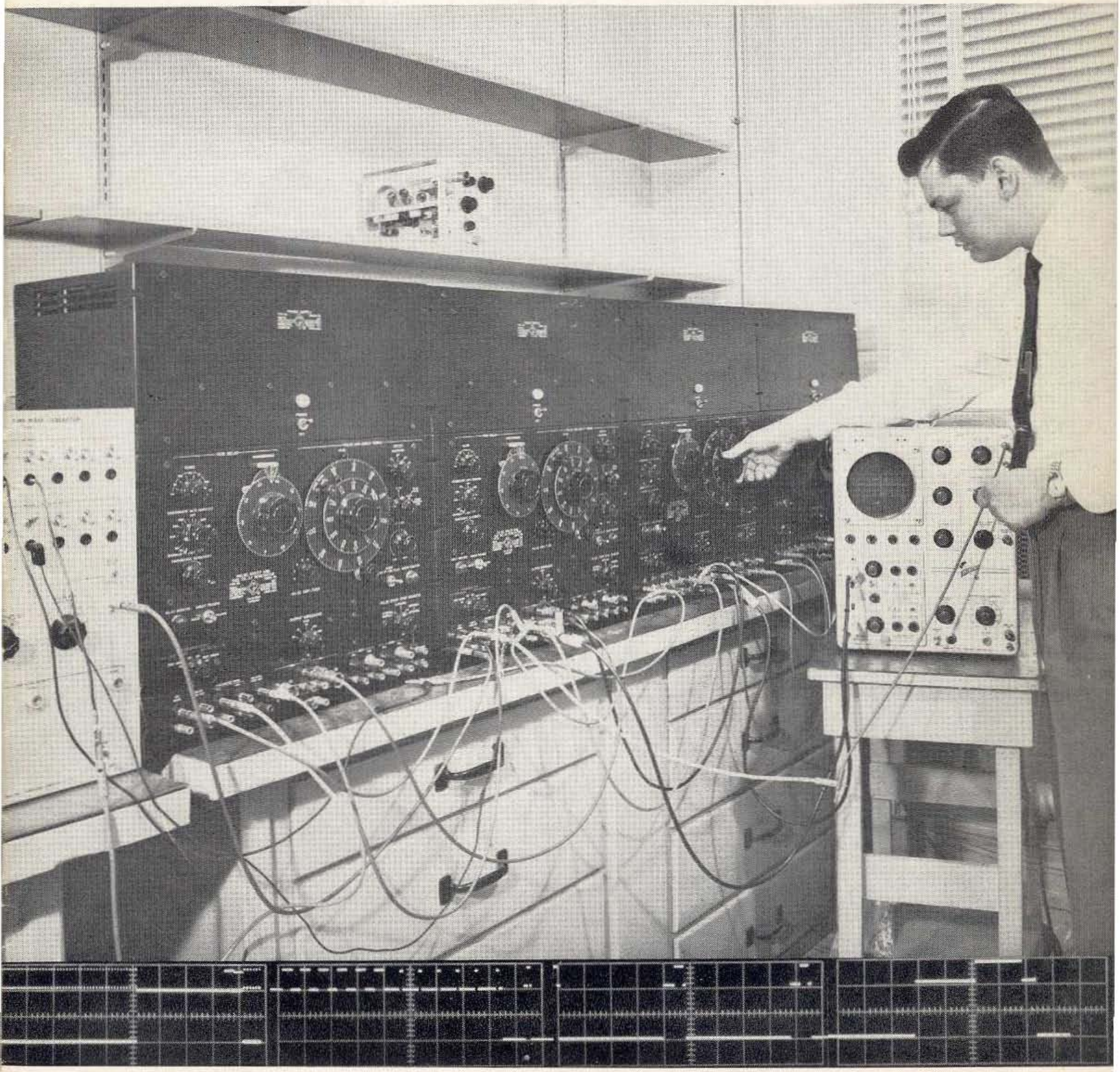
General Radio will exhibit electronic instruments and standards in Booths 14 and 15.

General Radio Company

the GENERAL RADIO Experimenter

Since 1915 – Manufacturers of Electronic Apparatus for Science and Industry

VOLUME 33 No. 2 **FEBRUARY, 1959**



In This Issue

Pulse Generator
Vacuum-Tube Bridge

the GENERAL RADIO Experimenter

Published Monthly by the General Radio Company

VOLUME 33 • NUMBER 2 **FEBRUARY, 1959**

CONTENTS

The General Radio EXPERIMENTER is mailed without charge each month to engineers, scientists, technicians, and others interested in electronic techniques in measurement. 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.

GENERAL RADIO COMPANY

275 Massachusetts Avenue, Cambridge 39, Mass.

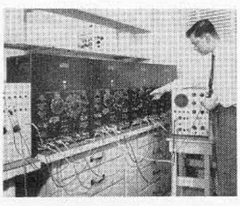
Telephone: TRowbridge 6-4400

NEW YORK:	**Broad Avenue at Linden, Ridgefield, New Jersey** *Telephone — N. Y., WOrth 4-2722* *N. J., WHitney 3-3140*
CHICAGO:	**6605 West North Avenue, Oak Park, Illinois** *Telephone — VIllage 8-9400*
PHILADELPHIA:	**1150 York Road, Abington, Pennsylvania** *Telephone — HAncock 4-7419*
WASHINGTON:	**8055 13th St., Silver Spring, Maryland** *Telephone — JUniper 5-1088*
LOS ANGELES:	**1000 North Seward St., Los Angeles 38, Calif.** *Telephone — HOllywood 9-6201*
SAN FRANCISCO:	**1182 Los Altos Ave., Los Altos, Calif.** *Telephone — WHitecliff 8-8233*
CANADA:	**99 Floral Parkway, Toronto 15, Ontario** *Telephone — CHerry 6-2171*

REPAIR SERVICES

EAST COAST:	**General Radio Co., Service Dept., 22 Baker Avenue, West Concord, Mass.** *Telephone — Concord, EMerson 9-4400* *Lincoln, CLearwater 9-8900*
NEW YORK:	**General Radio Co., Service Dept., Broad Ave. at Linden, Ridgefield, New Jersey** *Telephone — N. Y., WOrth 4-2722* *N. J., WHitney 3-3140*
MIDWEST:	**General Radio Co., Service Dept., 6605 West North Ave., Oak Park, Illinois** *Telephone — VIllage 8-9400*
WEST COAST:	**Western Instrument Co., 826 North Victory Boulevard, Burbank, Calif.** *Telephone — VIctoria 9-3013*
CANADA:	**Bayly Engineering, Ltd., First St., Ajax, Ontario** *Telephone — Toronto EMpire 2-3741*

COVER



The output currents from several Type 1391-B Pulse, Sweep, and Time-Delay Generators can be added to produce very complex waveforms. This photograph shows four generators whose outputs are combined to synthesize across the load resistor of one generator the waveforms shown at the base of the photograph.

AN IMPROVED PULSE GENERATOR WITH 15-MILLIMICROSECOND RISE TIME

The Type 1391-B Pulse, Sweep, and Time-Delay Generator is a general-purpose laboratory tool for the synthesis of pulse waveforms and for controlling the occurrence of those waveforms in time. The Type 1391-A model, originally described in 1953, was the result of an effort to extend the signal generator concept to the field of pulse measurements. Before this time, pulse generators had usually been either cranky "breadboards" or highly specialized (and still cranky) commercial devices. This new model reflects both field experience and an advance in technology which brings it nearer to the status of the standard-signal generator as an accurate, stable, and dependable laboratory tool.

An outstanding feature of the new generator is its improved pulse generating circuit with faster rise time, better pulse shape, and improved reliability. Other outstanding characteristics of the predecessor, Type 1391-A, are retained[1,2]. In particular, the following retained features have been improved:

1. The instrument produces an output signal of 0.15 ampere into any impedance level up to 600 ohms, thus permitting a wide choice of generator source impedance and pulse amplitude.

2. It produces this output signal direct coupled, so that pulses of *any* duration at *any* impedance level do not exhibit ramp-off effects.

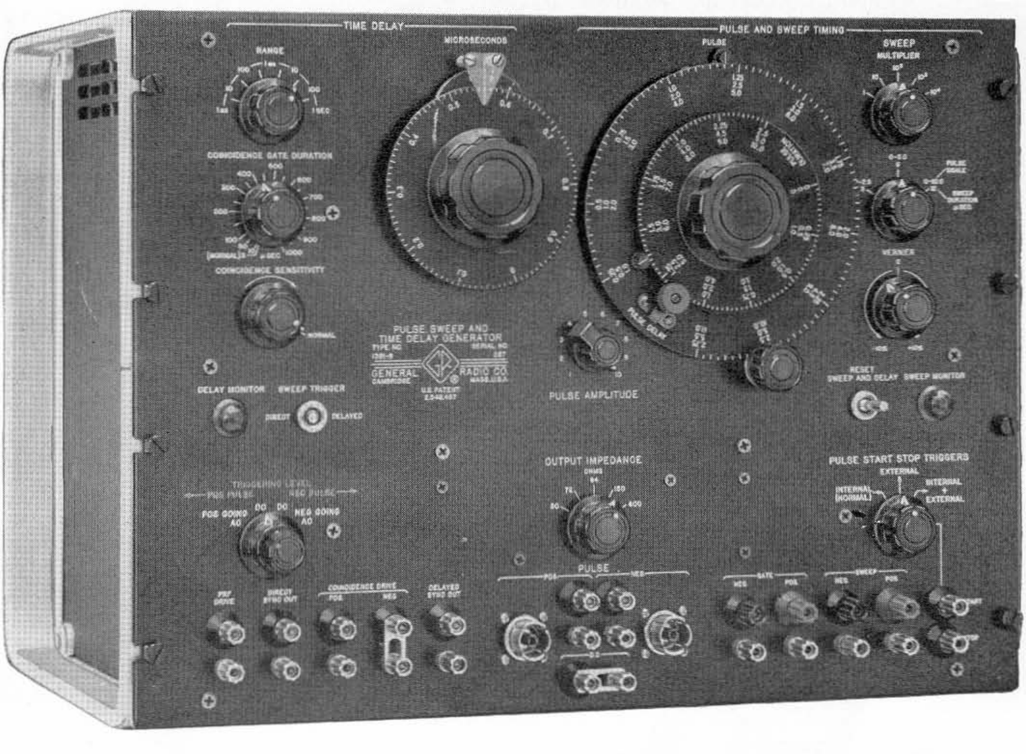
3. It has no duty-ratio restrictions.

4. It permits the user to inject his own dc component.

[1]*Proceedings of the National Electronics Conference, 1953.*

[2]R. W. Frank, "A Versatile Generator for Time-Domain Measurements," *General Radio Experimenter*, Vol. 30, No. 12, May, 1956, pp. 1-13.

Figure 1. Panel view of the Pulse, Sweep, and Time-Delay Generator.



Improvements

A completely new principle was used in the design of the dc coupled stages of the pulse generator and output system to increase their bandwidths with a consequent reduction in rise time. The improved rise time makes this pulse generator compatible with the fastest standard oscilloscopes.

A future article is planned in which the theoretical increase in bandwidth for these dc-coupled pulse circuits will be derived. The decrease in rise time is better than two-to-one. In this instrument we chose not to press for the full theoretical increase in bandwidth, but instead to design circuits of increased stability and reliability. Negative-feedback principles and reduced plate dissipation (most of the pulse-amplifier tubes run at less than half their maximum plate dissipation) make the characteristics of the pulse essentially independent of tube aging and line-voltage variations.

In addition to the extensive modification of the pulse generating and output system, important changes have been made in the input circuits, and improvements have been made in the switching system for starting and stopping the main pulse.

The changes in the input circuit now permit (1) either ac or dc connection from the external systems to the trigger circuit and (2) an adjustment of the triggering threshold voltage. This increases the adaptability of the instrument in laboratory systems, since the sensitivity for brief pulses can be optimized, the input circuits can be gated, and some range of phasing for slowly varying waveforms can be had. These possibilities are explored further under *Input Circuits*, below.

A change in the switch which routes the "start" and "stop" triggering pulses determining the duration of the main pulse has been made. With this new arrangement it is possible to mix internally produced pulses with pulses generated by outside systems or with pulses produced by the input and delay circuits of the TYPE 1391 itself. With the pulse timed by both the normal system and the delay circuits, the user can produce an accurately timed double pulse. If externally generated pulses are mixed with those produced internally, multiple pulses or even pulses having different repetition rates will be produced by the pulse-generating circuits.

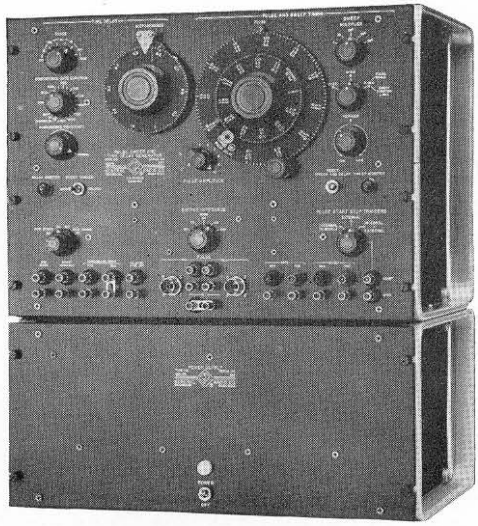


Figure 2. View of generator and power supply.

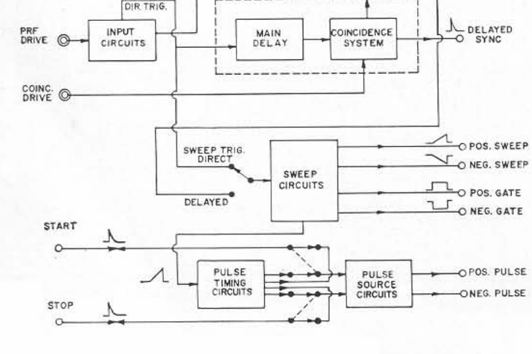


Figure 3A. System block diagram showing major circuit groups and their interconnections.

The newly designed pulse-generating circuits permit some simplification of the power-supply circuitry. Along with the changes necessary for the new circuitry, the selenium rectifiers used in the power supply have been replaced with silicon types, resulting in a reduction of volume required for components and permitting a reduction in the height of the power supply panel.

System

The TYPE 1391-B Pulse, Sweep, and Time-Delay Generator (Figures 1 and 2), as its lengthy name implies, is a combination of three instruments in one. It consists (Figure 3) of a precision delay generator, a saw-tooth sweep generator, and a pulse generator. A versatile input circuit is included, which is capable of driving the three corresponding generating circuits at any recurrence rate from zero to their maximum capabilities. The timing waveform to set the PRF can be sine waves, square waves, or pulses, and it can be provided either by a periodic signal source such as the General Radio TYPE 1210-C Unit R-C Oscillator, or by a one-shot, or random, change in voltage. Alternatively, an output signal from the generator can be fed back into the input terminal to provide a timing period set by the internal circuits themselves. Used in this way, the instrument is a self-contained timing generator of good accuracy and stability.

To provide for the utmost in applicability, many input and output terminals and switches permit interconnection of the major units among themselves and to and from external circuitry. These connections and switching are shown in Figure 3 and will be discussed in connection with the individual circuit groups below.

Input Circuits

The input circuits (Figure 4) provide a triggering pulse to initiate the action of the various circuit systems comprising the generator. They also provide a master synchronizing pulse to synchronize other equipment with the generator. These triggering signals are nearly invariant in slope and duration, irrespective of the slope and amplitude of the driving signal.

The new input switch and dc threshold control make it possible to select either positive-going or negative-going portions

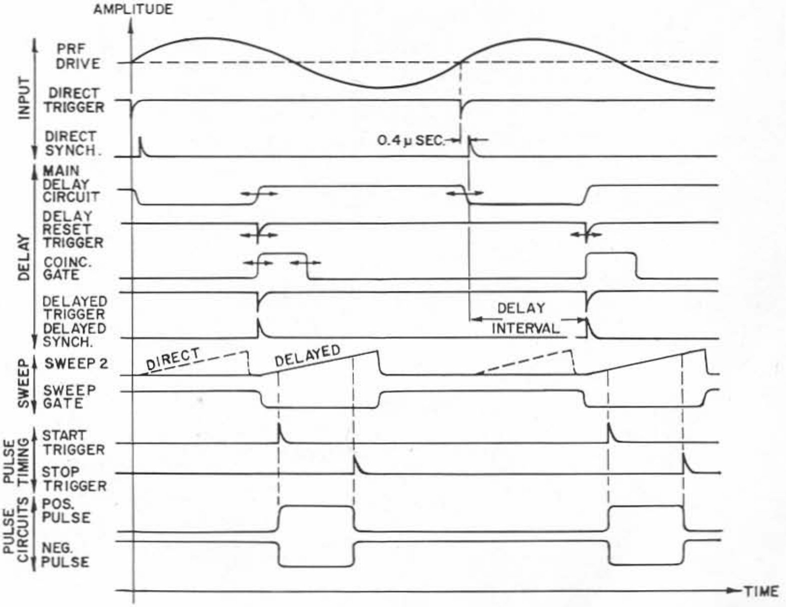


Figure 3B. Timing diagram for the complete system.

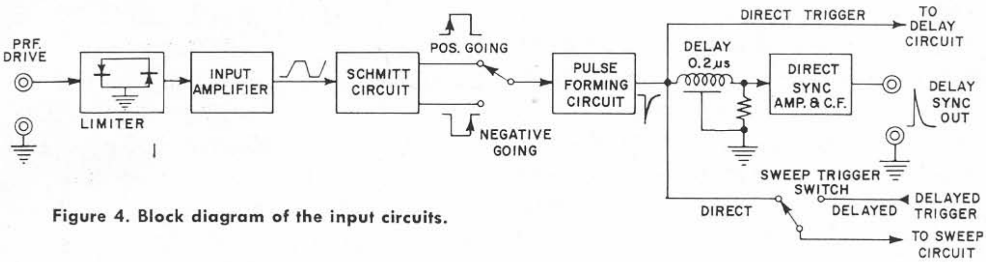


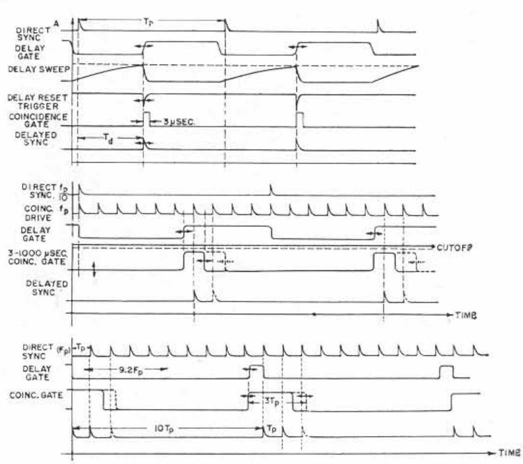
Figure 4. Block diagram of the input circuits.

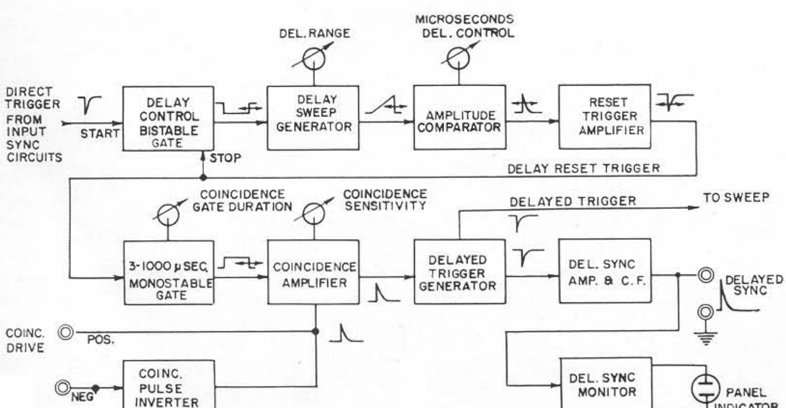
of the input signal to trigger the synchronizing circuits. The switch couples the input signal either directly or capacitively to the trigger circuits, and the threshold control selects, over a limited range, the actual voltage at which the trigger circuits will fire. This control enables the user to optimize the sensitivity to input pulses of either polarity and to initiate the trigger at voltages corresponding precisely to the zero crossings of any waveform.

The cover photograph illustrates a unique and important feature of the new input circuits. The input circuits themselves serve as a very efficient "and" gating circuit, which can, for instance, be used to produce pulse bursts. Another Type 1391 Generator (or any other dc coupled source of pulses, for that matter) is connected to the input terminals in addition to the normal driving signal. The pedestal thus added can, depending upon its polarity, either enable or disable the input circuit. This operation permits the construction of very complex timing sequences like part of those shown on the cover, in which, for example, a "vertical" blanking pedestal will automatically inhibit the formation of "horizontal" synchronizing pulses.

Delay Circuits

The direct trigger initiates the operation of the delay circuits (Figure 5), which normally produce the delayed synchronizing pulse at an accurately controlled time after the direct sync pulse. This time interval can be varied





(Left) Figure 5A. Block diagram of the delay circuits.

(Above) Figure 5B. Delay-circuit timing. (Top) Coincidence circuit set for normal operation. (Center) Multiple-pulse timing. (Bottom) Delay circuit used as a prf divider.

from 1 microsecond to 1 second by the 10-turn delay control and the 6-decade range switch, with an absolute accuracy of delay relative to the direct sync pulse of better than $\pm 3\%$ over the entire range. The usefulness of the 1-μsec-to-1-second delay circuit is increased by the 3- to 1000-μsec coincidence gate system (Figure 5B). Through the use of this circuit, multiple pulses, precision delays, and accurate delay-circuit calibration can be accomplished. The similar circuits

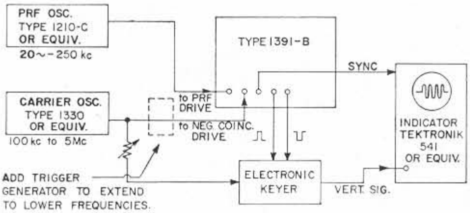


Figure 7. Block diagram of system for generating tone bursts.

of the 1392-A Time-Delay Generator were discussed both in theory and in application in the December, 1958, *Experimenter*. The system, shown in Figure 5, breaks down the various functions of gating, sweep generation, amplitude comparison, and reset of the gating circuits in such a way that accuracy, stability, and resolution are all assured.

One example of the versatility of the delay system is shown in Figures 6 and 7. The output pulse is made coherent with a high frequency to produce tone bursts.

Sweep Circuits

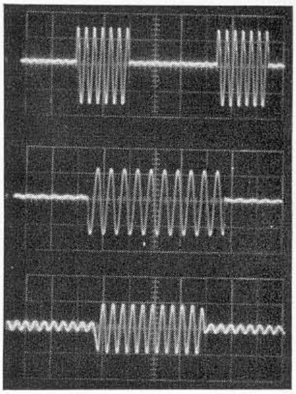
The primary function of the sweep generator is to time the pulse both in

Figure 6. Coherent tone bursts.

(a) 200-kc signal 10-kc burst rate.

(b) 1-Mc signal 10-kc rate.

(c) 5-Mc signal: note increased crosstalk in keyer; note also absence of switching transients.

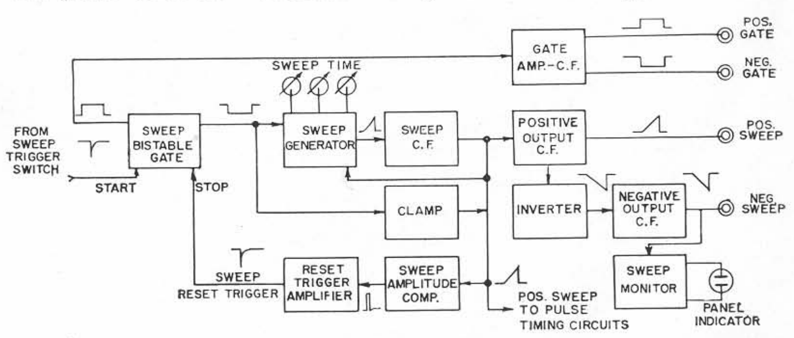


duration and delay relative to the direct synchronizing pulse or the delayed synchronizing pulse, either of which can be used to start the sweep circuits. The sweep-generating circuits as shown in Figure 8 consist of a bistable gate, "bootstrap," linear sweep circuit, amplitude comparator, and resetting circuits. The push-pull, linear, saw tooth produced by this group of circuits is fed at 135-volt amplitude through isolating cathode followers to output terminals for use with external systems. Positive and negative gate pulses corresponding in time to the start and the stop times of the sweep are also provided at output terminals. The duration of the sweep is nominally 3, 6, or 12 μsecs with a five-decade multiplier so that the longest sweep is 0.12 second.

Pulse Timing

The sweep circuits drive the pulse-timing circuits which comprise a pair of amplitude comparators used to start and to stop the output pulse. The principles of pulse timing are shown in Figure 9.

Figure 8. Block diagram of sweep circuits.



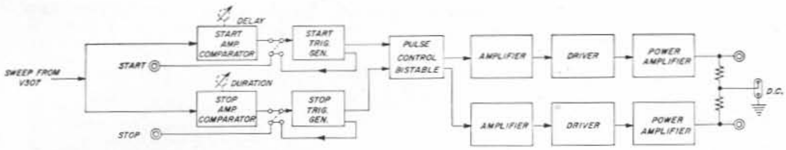


Figure 9. Block diagram of pulse timing and output circuits.

The pulse-timing amplitude-comparison circuits are followed by trigger-forming circuits which produce high-speed pulses to start and stop the pulse generator. Between the amplitude-comparison circuits and the trigger-forming circuits switching is inserted to provide:

(1) Normal operation, in which the amplitude comparators delay the pulse and time its duration relative to the sweep as described above. In this position the trigger pulses, which correspond to "start" and "stop" time, are fed to front-panel binding posts labeled "start" and "stop," respectively.

(2) Means to start and stop the pulse generator using externally generated and timed signals.

(3) For the addition of both internally produced and externally generated timing signals to start and stop the pulse.

These three possible methods of driving the pulse generating circuits contribute to the versatility of the instrument. In normal operation, the start-and-stop triggering pulses available at the trigger-pulse output terminals can be used for making time measurements in external systems, for checking flip-flop resolution, etc. In (2) above, the application of an external signal will permit the pulse generator to be operated at rates far in excess of the 250-kc maximum repetition rate set by the 3-μsec sweep in the self-contained timing system. Using a General Radio Type 1330-A Bridge Oscillator (10 volts at 3 Mc) and Type 314-S86 Delay Line,[3] for example, it is possible to produce pulses at repetition rates up to about 3 Mc (Figure 10).

With the pulse triggering switch set as in (3) above, any number of start-and-stop pulses can be superimposed upon those generated internally. As a particular example of this application, the generator becomes a useful tool for generating pulse pairs.[3] By addition of the direct and delayed synchronizing pulses to the internally produced timing pulses with the network shown in Figure 11, a double pulse having the following characteristics can be produced:

1. First pulse duration, 1 μsec to 1 second.
2. Delay between first and second pulse, 0.25 μsec to 0.1 second.
3. Duration of second pulse, 0.025 μsec to 0.1 second.

Pairs of pulses produced by this method are shown in Figure 12.

Pulse Generating and Output Circuits

A simplified schematic diagram of the newly designed pulse generating and output circuit is shown in Figure 13. The circuits comprise a bistable multivibra-

[3] F. D. Lewis, R. M. Frazier, "A New Type of Variable Delay Line," *General Radio Experimenter*, Vol. 31, No. 5, October, 1956, pp. 1-8.

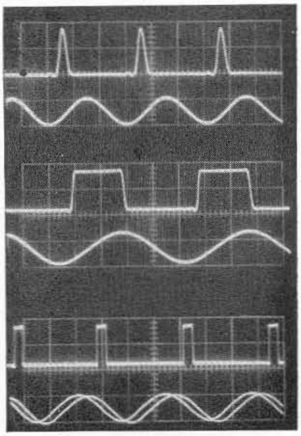


Figure 10. Pulses at high repetition rates; external timing.

(a) 0.03 μsec pulse. 3.3-Mc timing signal.

(b) 0.4 μsec pulse. 1-Mc timing signal.

(c) Pulses timed by 500-kc signal. Direct and delayed sine waves at START and STOP terminals.

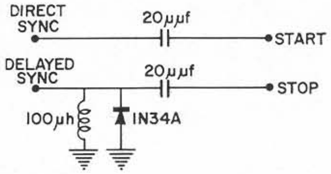


Figure 11. Adding network for producing pulses.

tor, started and stopped by timing pulses, a pair of pulse amplifiers, and an output stage. The output stage consists of a pair of push-pull 6550 beam tubes driven by a pair of 6AV5's. The circuits from the bistable multivibrator onward are push-pull and direct-coupled by a unique method in which the loss in gain characteristic of the conventional dc coupling methods is eliminated. This new coupling system uses high-μ triodes as current sources, and makes practical an increase in bandwidth of about 3:1 in a circuit like that in Figure 13. This circuit can be viewed as a video amplifier flat from dc to about 25 Mc.

All stages, including the output tubes, work well below their maximum cathode-

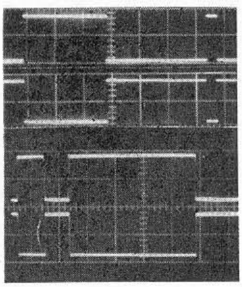


Figure 12. Double pulses.
(a) First pulse, 30 μsec; 30-μsec delay; second pulse, 5 μsec. Generator self-timed at 10 kc.
(b) First pulse, 1 μsec; 1-μsec delay; second pulse, 5 μsec.

current and plate-dissipation ratings, and all stages in the "on" state operate well into the negative grid region, under self-biased conditions, permitting the stabilization of plate current during the life of the tube. The 6550 output tubes supply about 150 ma to the variable source resistors across which the pulse is produced. The common transmission-line impedances of 50, 72, 94, 150, and 600 ohms are provided internally, and any impedance lower than 600 ohms can be obtained by the connection of an appropriate resistor in parallel with the internal resistors. Examination of Figure 13 shows that the pulse of voltage developed across these resistors contains a dc component which is negative with respect to ground at the output terminals. Only by preservation of the dc component can pulses of long durations at low-impedance levels be delivered to the outside world without deterioration of waveform. The dc component can be changed over about a $\pm$ 50-volt range by the addition at the dc-insertion binding post of either a resistor for negative translation or a dc voltage for positive translation.

Pulse amplitude can be changed over a decade range by use of the built-in step-amplitude control switch. This switch reduces pulse amplitude in ten steps. Pulse amplitude is stabilized against variations or transients in line voltage. A 20% change in line voltage will produce no visible transient in either pulse shape or duration, and only a very small long-

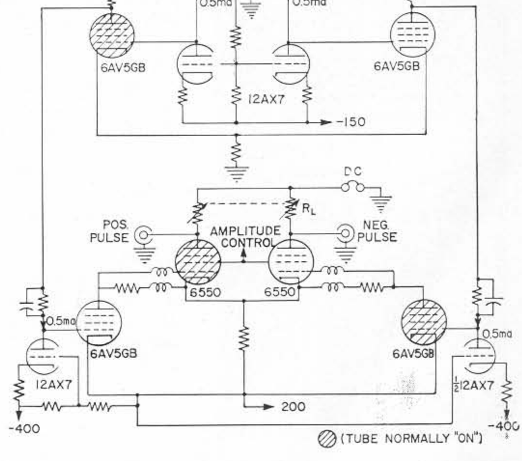


Figure 13. Simplified schematic of the pulse generating circuits.

term variation in pulse amplitude, which is due entirely to cathode temperature variation with heater-supply voltage.

Figure 14 consists of unretouched photographs of output pulses under various conditions. Careful examination of these pictures for the characteristics of rise time, overshoot, and flatness will convey a better feeling for the over-all quality of the pulses produced by this generator than can the words used to describe them or their specifications. The reader should note particularly Figure 14 (C and D) which shows the pulse applied directly on the deflecting plates of a Tektronix 541 Oscilloscope and the same pulse passed through the 53/54-C plug-in unit and oscilloscope amplifiers. With the 53/54-C plug-in unit this oscilloscope has a rated rise time of 14 mμ seconds.

Summary and Applications

Since the TYPE 1391-B is such a general-purpose device, it is very difficult to make a complete listing of applications. To the reader the applications to his work will probably be obvious.

The following specialized applications will help to emphasize the versatility of this new generator:

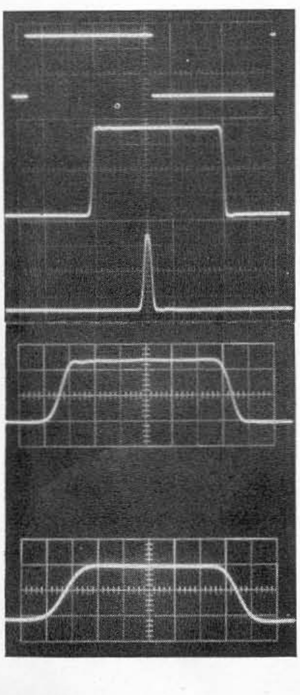


Figure 14. Pulse waveforms; connections directly to deflection plates of Tektronix 541 Oscilloscope.
(a) 50-μsec pulse; scale 10 μsec/cm.
(b) 0.5-μsec pulse; 0.1 μsec/cm.
(c) Minimum pulse; 0.1 μsec/cm.
(d) 0.12-μsec pulse, 94 Ω termination, 0.02 μsec/cm.
(e) Same pulse as in (d), passed through vertical amplifier of oscilloscope.

1. Use of the input circuits as an "and" gate, in which one generator can produce bursts of pulses from another. This possibility is amply shown on the front cover.

2. The delay and coincidence circuits can produce pulses capable of timing bursts of high frequency coherent with any frequency within the generator's specified range of PRF's.

3. The linear sweep produced at the sweep output terminals can be used to produce a multiplicity of pulses, all of individually variable duration and delay. Use of the amplitude comparator described in the January, 1959, *Experimenter* is recommended.

4. Since the pulse output circuit consists of a current source and load resistor, the currents from several 1391-B's can be added to produce a very complex waveform without the usual adding circuit; again, note the front cover illustration where the complex waveform developed by four instruments appears across the load resistor of one instrument.

5. Only the resolution of the bistable circuit in the pulse-generator assembly establishes an upper limit on the repetition rate of this unit. By the use of externally timed start and stop pulses, or when the pulse is timed by any other external device, the output pulse generating circuit can be driven at repetition rates above 3 Mc.

6. For the testing of high-speed computer devices, such as flip-flops, even where the clock rate is in the megacycle range, it is usually the pulse-pair resolution which is of interest. The brief start-stop pulses used to time the main pulse can be continuously varied from coincidence to 0.1 second apart and form a useful pair of signals for such resolution testing.

— R. W. FRANK

SPECIFICATIONS

Input Synchronizing Signal: Signals of almost any shape will trigger the input timing circuits.

Typical input signal minimum amplitudes are:

(1) Sine wave 0.1 volt, rms.
(2) Square waves 0.3 volt, peak-to-peak.
(3) Brief positive pulse 1.0 volt, peak-to-peak.
(4) Brief negative pulse 1.0 volt, peak-to-peak.

Switch for a-c or d-c input and triggering threshold controls are provided.

Direct Synchronizing Pulse

Polarity-positive amplitude: 75 volts.
Duration: (½ amplitude) 1 μsec.
Output Impedance: 600 ohms.
Repetition Rate: Amplitude constant to 300 kc; down 20% at 500 kc.

Time-Delay Circuit

Range: 1.0 μsec to 1.1 sec in six ranges.
Delay Dial Calibration: 1.00 to 11.00 in 1000 divisions.
Delay Dial Resolution: 1 part in 8800.
Accuracy: Absolute, ±2% of full scale, or ±3% of scale reading + 0.05 μsec, whichever is larger; incremental delay, ±(1% + .05 μsec).
Maximum PRF: 400 kc.
Duty Ratio Effects: Less than 2% error in delay for duty ratios up to 60%, at the low end of each range, and up to 90% at the high end of each range.
Delayed Synchronizing Pulse Characteristics: Positive, 60 v, 1.0-μsec half-amplitude duration, 600-ohm cathode-follower output.
Stability:

	Low End of Dial	*High End of Dial*
Time Jitter	1:10,000	1:50,000
10% Line Change	2:1000	2:10,000
Sudden 10% Line Transient	3:1000	3:10,000

Concidence Circuits

Gate Duration: 3 to 1000 μsec.
Gate Accuracy: ±15% or ±1 μsec, whichever is larger.

Coincidence driving circuit will accept either positive or negative input pulses. Source impedance should be low, have rise time less than 0.2 μsec. Amplitudes between 5 and 20 volts are acceptable for negative pulses, and between 10 and 100 for positive pulses.

Sweep Circuit

Sweep Duration: 3, 6, 12 μsec with 5-decade multiplier.
Sweep Linearity: Determined by the accuracy of pulse timing. On longer ranges, where time delay effects are absent, the linearity is better than 1%.
Sweep Amplitude: Push-pull, each phase, 135 volts, nominal.
Cathode-Follower output, 1-μf blocking capacitors.
Sweep Gate Amplitude: Push-pull, each phase 40 volts nominal.
Positive sweep gate is cathode-follower output circuit with a 1-μf coupling capacitor. Negative gate is amplifier output with 1-*uf* blocking capacitor.
Duty Ratio and Repetition Rate Effects: Maximum repetition rate, 3-μsec sweep, 250 kc.

Range	*Maximum Frequency for 5% Error in Sweep Slope*		
Sweep Time	3 μsec	6 μsec	12 μsec
× 1	150 kc	100 kc	60 kc
× 10	16 kc	12 kc	7 kc
× 10^2	1.6 kc	1.2 kc	700 c
× 10^3	160 c	120 c	70 c
× 10^4	16 c	12 c	7 c

Pulse Generating Circuit

Pulse Duration: (Timed by sweep) 0.025 to 2.5, 0.05 to 5.0, and 0.05 to 10.0 between half amplitude points, with decade multipliers to a maximum of 100,000 μsec. Pulse can be extended to 1.1 seconds if pulse is timed by delay circuit.
Pulse Duration Accuracy: After sweep calibration, ±1% of dial reading or ±0.02% μsec whichever is the larger.
Pulse Position Accuracy: 0.5 μsec ±1% of dial reading.
Pulse Rise Time: Where the load R_LC_S is negligible with respect to 15 × 10^{-9} sec, the rise time will be faster than 15 mμsec. Higher load impedances or higher shunt C_S will result in increased rise time.
Typical rise times in mμsec are as follows:

Load Impedance	*Positive Pulse* Rise	*Positive Pulse* Decay	*Negative Pulse* Rise	*Negative Pulse* Decay	
50 Ω terminated	15	12	13	15	overshoots
600 Ω with 8 μμf oscilloscope probe	40	40	38	38	approx. 3%

Pulse Shape: Overshoots and other defects are less than 3% of pulse amplitude when the pulse generator is correctly terminated. Pulse ramp-off does not exist, owing to direct coupling of output circuits.
Pulse Duty Ratio: Push-pull circuit with unity duty ratio possible.
Output Impedance: 50, 72, 94, 150, 600 ohms, all ±10%.
Output Pulse Amplitude: 150-ma current source; voltage from each phase of push-pull channel, 0.15 Z_O ±20%.

Typical nominal amplitudes, 50 ohms, 7.5 v; 72 ohms, 10 v; 94 ohms, 14 v; 150 ohms, 22 v; 600 ohms, 90 v.

D-C Component Insertion: Binding posts provided for this purpose. DC can be moved ±25 volts for all output impedance except 600 ohms.

Accessories Supplied: Interconnecting cables, Type CAP-35 Power Cord, 2 Type 874-C58 Cable Connectors, spare fuses.

Other Accessories Available: Type 1219-A Unit Pulse Amplifier for higher power output.

Accessories Required: Trigger source; practically any laboratory oscillator of the appropriate frequency range is adequate; the Type 1210-C Unit R-C Oscillator is recommended.

Tube Complement: Generator:

1-5963	4-6AV5GA	1-6AU8
1-6BQ7A	2-12BH7	
3-6U8	5-5965	Power Supply
8-6485/6AH6WA	2-5687	1-OC3
3-6AN5	1-OA2	1-6AK5
6-12AX7	2-6550	1-6AS7

Power Supply Input: 105 to 125 (or 210 to 250) volts, 50 to 60 cycles, 385 watts.

Power input receptacle will accept either 2-wire (Type CAP-35) or 3-wire (Type CAP-15) power cord. Two-wire cord is supplied.

Dimensions: Generator, 19 (width) x 14 (height) x 12½ inches (depth) over-all; Power Supply, 19 (width) x 8¾ (height) x 12½ (depth) over-all.

Net Weight: Generator, 30 pounds; power supply, 62 pounds.

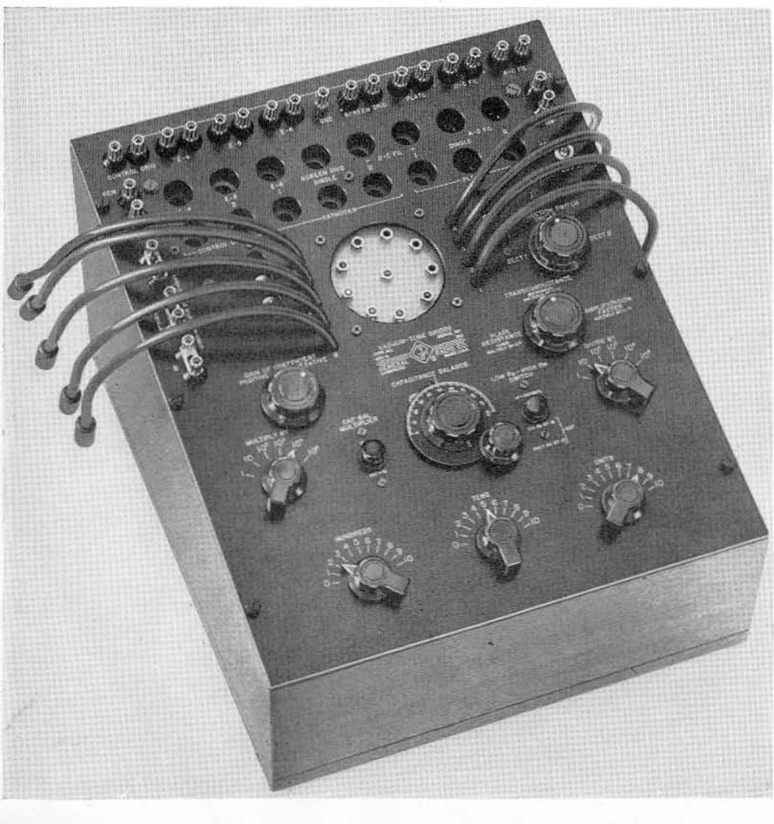
Type		*Code Word*	*Price*
1391-BM*	**Cabinet Model (incl. Power Supply)**	EDIFY	**$1975.00**
1391-BR*	**Relay-Rack Model (incl. Power Supply)**	EBONY	**1975.00**

*U. S. Patent No. 2,548,458.

A NEW AND IMPROVED VERSION OF THE VACUUM-TUBE BRIDGE

The Type 561 Vacuum-Tube Bridge has for many years been the industry standard for determining to a high degree of accuracy the low-frequency coefficients of vacuum tubes. It meets the requirements of the IRE Standards on Electron Tubes[1] and has also proved useful for transistor measurements.[2] Its ruggedness is more than adequate for many production-testing applications.

The basic circuitry, devised by Dr. W. N. Tuttle,[3] replaces the usual resistive ratio arms of a bridge by low-impedance voltage sources from transformer secondaries. While phase and amplitude specifications



Panel view of the new Type 1661-A Vacuum-Tube Bridge.

[1]Standards on Electron Tubes: Methods of Testing, 1950.

[2]A. G. Bousquet, "Transistor Measurements with the Vacuum-Tube Bridge," *General Radio Experimenter*, Vol. 27, No. 10, March, 1953.

[3]W. N. Tuttle, "Dynamic Measurement of Electron Tube Coefficients," *Proc. IRE*, No. 21, pp. 844-857, June, 1933.

require close manufacturing tolerances, the novel circuit successfully meets requirements peculiar to tube and transistor measurements. The common electrode of the device under test and the power supplies can all be connected to a common ground, and the voltage drop due to electrode currents is negligible. The bridge indicates directly the real component of the coefficient as plate resistance, transconductance, or amplification factor. The out-of-phase component due to interelectrode capacitance is balanced out without affecting the real component value.

The basic design has not changed in successive models, but the method of connecting the device under test has occasionally been modified to adapt to the growing list of tube-base types and to transistors.

A new and improved version, the TYPE 1661-A Vacuum-Tube Bridge, incorporates many small but significant features.

The general panel layout and the sloping-front cabinet have been retained. The cabinet depth has been reduced somewhat, but other dimensions are left unchanged to permit the new bridge to be mounted in the consoles that many users have found convenient for laboratory use and for production testing with previous models.

Twin Triodes

Perhaps the most welcome new feature is a switching arrangement that permits measurement sequentially of both sections of twin triodes, twin pentodes, etc., without the need for reconnection of the patch cords. This feature will be most appreciated in production testing where formerly two-section tubes had to be run through test twice because the patch-cord connection system was adequate only for one tube section at a time.

Self-Bias

Tests with self-biasing cathode resistors in the circuit are now required for several tube types, and connections for such tests have heretofore been quite difficult to set up. In the new design, the panel switch that selects the tube section also connects the cathodes to a system of three pairs of binding posts that permit the connection of self-biasing resistors to the separate cathodes or to the two cathodes in parallel.

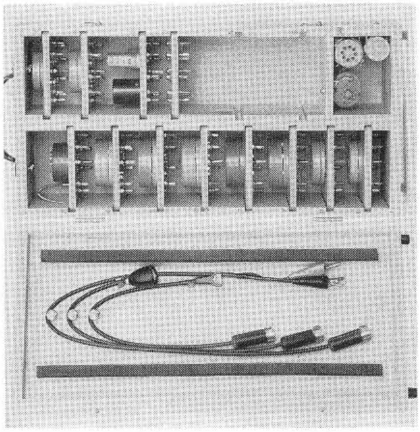
Tube and Transistor Base Adaptors

In spite of the multiplicity of tube and transistor bases, the bridge has been kept up to date relatively simply, because an adaptor plate is provided for each kind of base. With the adaptor plugged into the panel, the tube electrodes can be connected to the appropriate power-supply and bridge terminals by means of the nine doubly shielded coaxial cables. Four grounded connectors have been added to simplify the grounding of any tube terminals. These connectors and two ungrounded connectors provide convenient anchor points to hold the unused patch cords securely out of the way. The patch cords have been lengthened to insure that they will not interfere with the envelope of a large tube.

A new adaptor plate carries three sockets for transistors. One is for JETEC-30 based transistors; a second is for 3- or 4-in-line long-lead transistors (or tubes); the third is for 3- or 4-in-cluster long-lead transistors. There are now a total of thirteen adaptor plates including the "universal" plate to which any unusual socket or tube can be soldered. The adaptor plates and other accessories are supplied in a convenient accessory box.

Voltage and Current Limits

The 1500-volt limit has been retained as the maximum allowable "plate" voltage but, because of the growing list of relatively high-current tubes, the "plate" current limit has been raised from 150 to 400-milliamperes dc. Because some transistors show a frequency effect even at 1000 cycles, the redesign has extended the operating frequency to include the 270 to 400-cycle range in addition to the 1000-cycle point.



View of storage box, opened to show accessory adaptors and cables.

Other Changes

Operation at lower frequencies and at higher currents has necessitated a redesign of the transformers. Magnetic shielding has been improved by mounting the transformers in μ-metal shields. The input transformer has been eliminated and the input impedance has been reduced (550-2100 ohms).

A new oscillator and a new filter have been designed (see below) to provide both bridge power and detector selectivity at 270 and 1000 cycles.

For the resistance and transconductance measurements, the resistance standard has been 100,000 ohms. A panel switch now permits a choice between a 10,000-ohm and a 100,000-ohm standard. The use of the lower resistance standard improves the sensitivity of balance and the signal-to-noise ratio by a factor approaching 10 when low "plate resistance" or high "transconductance" devices are measured. By the same token, for a given signal-to-noise ratio the range of resistance or transconductance measurements is extended.

Many of the new features are the direct result of suggestions from the users of the bridge who, after all, are in a much better position than is the instrument designer to evaluate the virtues and the foibles of the equipment.

— A. G. Bousquet

SPECIFICATIONS

Range: Amplification factor (μ), 0.001 to 10,000. Dynamic internal plate resistance (r_p), 50 ohms to 20 megohms.

Transconductance (g_m), 0.02 to 50,000 micromhos.

Under proper conditions, the above ranges can be exceeded. The various parameters can also be measured with respect to various elements, such as screen grids, etc. Negative as well as positive values can be measured.

Accuracy: Within $\pm 2\%$ for resistances (r_p switch position) from 1000 to 1,000,000 ohms. At lower and higher values the error increases.

The expression $\mu = r_p g_m$ will check to $\pm 2\%$ when the quantities are all measured by the bridge, and when r_p is between 1000 and 1,000,000 ohms.

Tube and Transistor Mounting: Adaptors are provided for 3- and 4-lead transistors (including JETEC 30) and for tubes of 4-pin, 5-pin, 6-pin, small 7-pin, large 7-pin, octal, loctal, miniature button 7-pin, miniature button 9-pin (noval), acorn (5- and 7-pin), flat-press sub-miniature up to 7 wires, and 8-wire sub-minar. In addition, a universal adaptor, with nine soldering lugs, is provided so that unbased transistors, unmounted tubes, or tubes with non-standard bases can be measured conveniently. For short-lead sub-miniature tubes and for transistors, sockets are supplied which can be mounted on the universal adaptor. Thus all standard commercial receiving tubes and transistors can be measured. The panel jack plate and the adaptors are made of low-loss (natural) phenolic, reducing to a minimum the shunting effect of dielectric losses on the dynamic resistance being measured.

Current and Voltage Ratings: Maximum allowable plate current, 400 ma; maximum plate voltage, 1500 volts.

Electrode Voltage Supply: Batteries or other suitable power supplies are necessary for providing the various voltages required by the device under test.

Bridge Source: Type 1214-E Oscillator is recommended.

Null Detector: The Type 1212-A Unit Null Detector with the Type 1951-E Filter is recommended.

Accessories Supplied: Adaptors as listed above, all necessary plug-in leads, and shielded patch cords for connecting generator and detector.

Mounting: The instrument is mounted in a hardwood cabinet. A wooden storage case is provided for the adaptors and leads. Storage space is provided for a spare Universal adaptor, on which any type of socket can be permanently mounted.

Dimensions: (Length) 18½ x (width) 15¾ x (height) 11 inches.

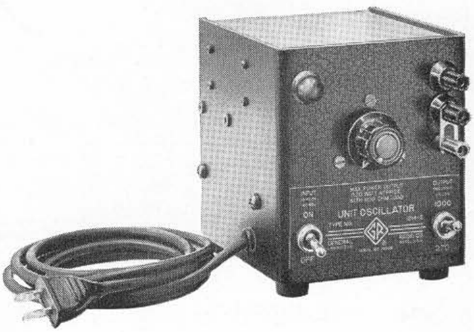
Net Weight: Type 1661-A weighs 40 pounds. The accessories supplied and the accessory box weigh 14 pounds.

Type		*Code Word*	*Price*
1661-A	**Vacuum-Tube Bridge**	BEIGE	**$975.00**

TYPE 1214-E UNIT OSCILLATOR

The Type 1214-E Unit Oscillator was designed to meet the bridge-source requirements of the Type 1661-A Vacuum-Tube Bridge described above. It is small, self-contained, sufficiently well shielded, adequate in power output, and of appropriate impedance level. Output is available at 1000 cycles and at the low-audio frequency of 270 cycles, which is desirable for tests on some transistors.

Like the other Type 1214 Oscillators, this instrument includes a transformerless power supply, and isolation from the power line is obtained by inductively coupling the output circuit to the oscillator tank.



The impedance level presented by the Type 1661-A Bridge is in the range of 550 to 2100 ohms, and the power delivered by a typical Type 1214-E over this range is at least 300 milliwatts.

SPECIFICATIONS

Frequency: 270 and 1000 cycles per second.

Accuracy: $\pm 2\%$.

Output: 300 milliwatts into 800 ohms.

Output Impedance: Approximately 200 ohms at 270 cycles; approximately 500 ohms at 1000 cycles; both at maximum setting of output control.

Harmonic Distortion: 3% with 800-ohm load.

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

Power Input: 16 watts at 115 volts.

Accessories Supplied: Spare fuses.

Tube Complement: One 117N7-GT.

Dimensions: Panel, (width) 4¾ x (height) 5¼ inches; depth behind panel, 5⅛ inches.

Net Weight: 4½ pounds.

Type		*Code Word*	*Price*
1214-E	**Unit Oscillator**	ASSAY	**$75.00**

TYPE 1951-E FILTER

The null detector recommended for the TYPE 1661-A Vacuum-Tube Bridge is the TYPE 1212-A Unit Null Detector. It is essentially a three-stage amplifier with the null indicated on a panel meter. The response is quasi-logarithmic. For maximum sensitivity and selectivity, it is suggested that an impedance-matching filter be placed between the bridge and the amplifier. For 400- and 1000-cycle operation, the TYPE 1951-A Filter has proved adequate. Since provision has been made for 270-cycle operation of the vacuum-tube bridge, a new filter has been designed to include the new frequency. The TYPE 1951-E Filter has a panel switch to permit operation at either 270 or 1000 cycles. Like the TYPE 1951-A model, it provides four input connections for optimum impedance matching over the nominal ranges of 0-5 kilohms, 5-50 kilohms, 50-500 kilohms, and 500 kilohms and higher.

The filter is a tuned circuit with a capacitive voltage divider to provide the impedance matching. The inductor is a toroid with permalloy shielding. As a consequence, external coupling is negligible and the filter can be connected to the input of an amplifier of microvolt sensitivity without introducing spurious pickup.

SPECIFICATIONS

Frequency: 270 and 1000 cycles.

Second Harmonic Rejection: At least 30 db.

Accessories Supplied: One each TYPE 274-MB Double Plug, TYPE 274-NK Shielded Plug, TYPE 874-Q6 Adaptor.

Dimensions: $3\frac{1}{2}$ x $3\frac{3}{4}$ x $4\frac{3}{8}$ inches, over-all.

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

Type		*Code Word*	*Price*
1951-E	**Filter**	FURRY	**$80.00**

General Radio Company

PRINTED IN U.S.A.

the GENERAL RADIO Experimenter

Since 1915 – Manufacturers of Electronic Apparatus for Science and Industry

VOLUME 33 No. 3 MARCH, 1959

In This Issue

New Impedance Bridge
Regulated Power Supply
Radio Engineering Show

the GENERAL RADIO
Experimenter

Published Monthly by the General Radio Company
VOLUME 33 • NUMBER 3 MARCH, 1959

CONTENTS

The General Radio EXPERIMENTER is mailed without charge each month to engineers, scientists, technicians, and others interested in electronic techniques in measurement. 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.

GENERAL RADIO COMPANY

275 Massachusetts Avenue, Cambridge 39, Mass.
Telephone: TRowbridge 6-4400

NEW YORK:	**Broad Avenue at Linden, Ridgefield, New Jersey** *Telephone — N. Y., WOrth 4-2722* *N. J., WHitney 3-3140*
CHICAGO:	**6605 West North Avenue, Oak Park, Illinois** *Telephone — VIllage 8-9400*
PHILADELPHIA:	**1150 York Road, Abington, Pennsylvania** *Telephone — HAncock 4-7419*
WASHINGTON:	**8055 13th St., Silver Spring, Maryland** *Telephone — JUniper 5-1088*
LOS ANGELES:	**1000 North Seward St., Los Angeles 38, Calif.** *Telephone — HOllywood 9-6201*
SAN FRANCISCO:	**1186 Los Altos Ave., Los Altos, Calif.** *Telephone — WHitecliff 8-8233*
CANADA:	**99 Floral Parkway, Toronto 15, Ontario** *Telephone — CHerry 6-2171*

REPAIR SERVICES

EAST COAST:	**General Radio Co., Service Dept., 22 Baker Avenue, West Concord, Mass.** *Telephone — Concord, EMerson 9-4400* *Lincoln, CLearwater 9-8900*
NEW YORK:	**General Radio Co., Service Dept., Broad Ave. at Linden, Ridgefield, New Jersey** *Telephone — N. Y., WOrth 4-2722* *N. J., WHitney 3-3140*
MIDWEST:	**General Radio Co., Service Dept., 6605 West North Ave., Oak Park, Illinois** *Telephone — VIllage 8-9400*
WEST COAST:	**Western Instrument Co., 826 North Victory Boulevard, Burbank, Calif.** *Telephone — VIctoria 9-3013*
CANADA:	**Bayly Engineering, Ltd., First St., Ajax, Ontario** *Telephone — Toronto EMpire 2-3741*

COVER

An important feature of the Type 1650-A Impedance Bridge, described in this issue, is its unique cabinet design. The cover photographs illustrate its many aspects, from carrying case to operating setup.

A NEW UNIVERSAL IMPEDANCE BRIDGE

Accuracy, versatility, and convenience are combined to an unusual degree in the new General Radio TYPE 1650-A Impedance Bridge. Successor to the well-known and widely used TYPE 650-A,[1] the new bridge incorporates the many desirable features of its predecessor, plus a host of improvements that contribute greatly to its accuracy and operating convenience.

The older bridge has long been a standard fixture in laboratories, plants, and schools. Rugged and reliable, it is undoubtedly the best-known instrument in General Radio's extensive line. Many of the early models are still in use — an example of the quality and long life of General Radio instruments — but time has shown many improvements to be both practical and desirable. These, together with several completely new features, make an impressive list of reasons why the new bridge is even more useful and reliable than its predecessor.

Two of the improvements stand out in importance:

(1) Increased accuracy. Measurements of D and Q can be made with an accuracy of 5%, which, together with the basic accuracy of 1% for R, L, and C, holds over the entire range of the bridge.

(2) The patented *Orthonull* feature, which eliminates sliding balances, permitting the measurement of low-Q inductors and high-D capacitors.

Two completely new features contribute greatly to convenience in use and portability:

(3) Unique cabinet, which allows the bridge panel to be tilted and held at any convenient angle and which, when

[1]Robert F. Field, "The Convenient Measurement of R, L, and C," *General Radio Experimenter*, Vol. 7, Nos. 11 and 12, April-May, 1933.

Figure 1. Panel view of the Type 1650-A Impedance Bridge. Note the many new features: Orthonull; built-in generator and detector; single *D-Q* dial; single pair of UNKNOWN terminals; bias terminals. For other external features, see cover.

closed, forms a protective cover and carrying case.

(4) Completely transistorized generator and detector.

Still other improvements and extensions of original features include:

(5) A single dial for all D and Q readings.

(6) A single pair of terminals for all measurements.

(7) A full decade extension of the upper limit of R, L, and C measurement.

(8) Increased upper frequency limit (20 kc).

(9) Meter null indication for both ac and dc measurements, eliminating the need for earphones.

(10) Built-in generator and detector.

(11) The ability to measure 3-terminal components in the presence of large terminal capacitances.

(12) Externally supplied dc polarizing voltage or current can be used.

A more detailed discussion of these features will help to emphasize their utility and desirability.

THE BRIDGE CIRCUITS

While specialized and unusual circuits often have advantages for single-purpose bridges, no satisfactory replacements have been found for the simple, classical circuits in a general-purpose bridge. Their accuracy and simplicity are difficult to surpass for direct measurements of inductance, capacitance, storage factor, dissipation factor, and both dc and ac resistance. In this bridge, therefore, the well-known circuits are used, but, in order to maintain the desired accuracy over wide ranges, several refinements have been introduced. In addition, the so-called sliding balance, which has been the main disadvantage of the classic circuits when used to measure D and Q directly, has been eliminated by the *Orthonull* feature.

The several circuits are shown schematically in Figure 2. Note that a parallel-capacitance bridge is now included as well as the series type; this makes possible not only the measurement of parallel capacitance, but also the extension of the range of accurate D measurements.

The range of measurement of each bridge configuration has been extended upward by one decade to give maximum limits of 1000 microfarads, 1000 henrys, and 10 megohms.

Careful compensation of phase angle in the bridge arms has greatly improved the accuracy of D and Q measurement and has made possible accurate measurements of L and C at frequencies from 20 c to 20 kc.[2]

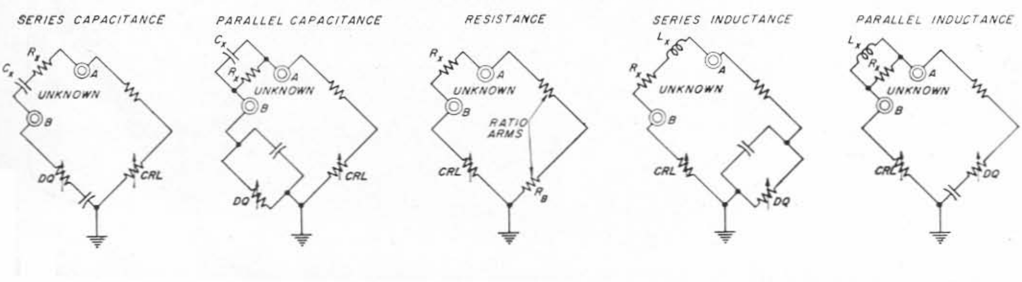
Residual bridge errors have been greatly reduced; the limiting factors are the inductance, resistance, and capacitance of the UNKNOWN terminals themselves. These are equal to or less than the smallest measurable quantities (one micromicrofarad, one microhenry, and one milliohm).

STANDARDS AND COMPONENTS

The standard capacitor is a 0.1-μf silvered-mica unit of General Radio manufacture. A shunt capacitance of

[2] With external generator.

Figure 2. The five circuits used in the bridge.



1000 $\mu\mu$f across this capacitor causes an error of only 1%, and, therefore, 3-terminal direct capacitances can be measured accurately when the smaller of the stray terminal capacitances is well below this value.

The fixed resistors are General Radio precision, wire-wound types except for the one megohm ratio arm, which is a precision film unit. The phase angles of these resistors are sufficiently small to permit ac resistance measurements on high valued resistors. The variable resistors are General Radio potentiometers with exponential tapers and logarithmic scales. The *D-Q* potentiometer covers a total span of 54 db, which makes possible a wide range of measurement and provides complete *D* and *Q* coverage at measurement frequencies down to 100 cycles and, with only a small gap in coverage, down to 60 cycles.

GENERATOR AND DETECTOR

The generator and detector are completely transistorized, making possible the light weight and low power consumption desired in a portable instrument. The LC oscillator and the three-stage transistor amplifier draw a total current of less than 10 ma, which makes possible the long battery life with readily available "D" cells. For measurements on nonlinear elements, such as iron-cored inductors, where the applied signal should be small, an oscillator level control is provided. The amplifier, which has a voltage gain of over 64 db, can be made selective at 1 kc with over 20 db second-harmonic rejection or flat for measurements at other frequencies. The amplifier drives the panel meter to give a visual ac null indication so that headphones are not necessary, although they can be used if desired. A meter sensitivity control is also provided.

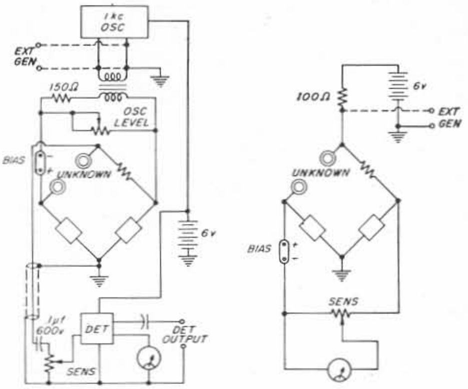


Figure 3. Block schematic of the bridge generator and detector. External-generator connections are shown by dashed lines.

The internal dc source is 6 volts. Provision is made for the connection of external ac and dc sources. External ac generators can be connected to the bridge through the internal isolating transformer provided, thus effectively eliminating the measurement errors that can result from generator-to-ground capacitances.

Block schematics of the complete instrument are given in Figure 3.

ORTHONULL

Those who have tried to balance low-*Q* components on a conventional bridge have experienced the frustrating "sliding balance," which is the slow balance convergence resulting from the interdependence between the two balance adjustments. This phenomenon makes balances tedious when *Q* is less than 2 and virtually impossible when *Q* is less than ½.

"Sliding balance" occurs in any bridge that measures impedance in a nonorthogonal coordinate system. Balances made with controls that balance inductance on one dial, for instance, and *Q* on another inherently slide, because reactance

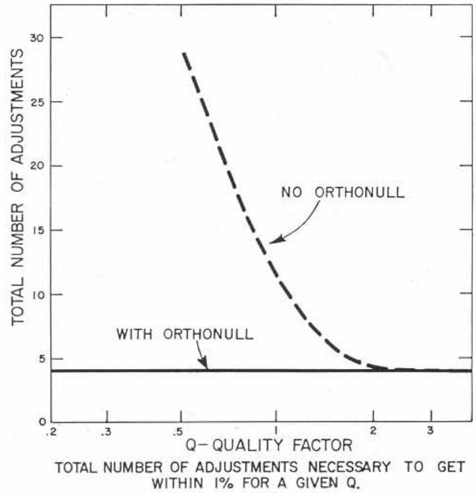


Figure 4. Plot of total number of balances required to achieve final balance, with and without *Orthonull*, as a function of Q.

($j\omega L$) is a component in a Cartesian coordinate system while Q ($=\frac{\omega L}{R}$) is a measure of angle in a polar coordinate system, and they are consequently non-orthogonal.[3]

To eliminate this difficulty, the TYPE 1650-A Impedance Bridge is equipped with an exclusive, patented feature, known as *Orthonull*.[4] This name was chosen because the null is obtained by balances which are essentially orthogonal and therefore converge rapidly. *Orthonull* gangs the two adjustments non-reciprocally in such a manner as to cancel the electrical interdependence, leaving the two adjustments independent of one another. As a result the full Q range is useful and balances are easily made. (This device will be described in detail in an early issue of the *Experimenter*.) Figure 4 shows a comparison of the number of successive balances required for low-Q measurements, with and without *Orthonull*, and is a striking illustration of the advantages of the *Orthonull* feature.

MECHANICAL FEATURES

Another novel development is the unique carrying case and tilting arrangement shown in Figure 5. The cover may be latched closed to form a protective cover for carrying or storage, it may be latched with the bridge open, or it may be used as a support which allows the bridge to be tilted and operated at any convenient angle. This type of case approaches the ideal for portable instruments. You will see it on other General Radio products in the future.

The panel controls (see Figure 1) are arranged for the convenience of the operator, and the terminals are placed for efficient use. The switching arrangement and panel engraving make the operation of the bridge self-explanatory to the user.

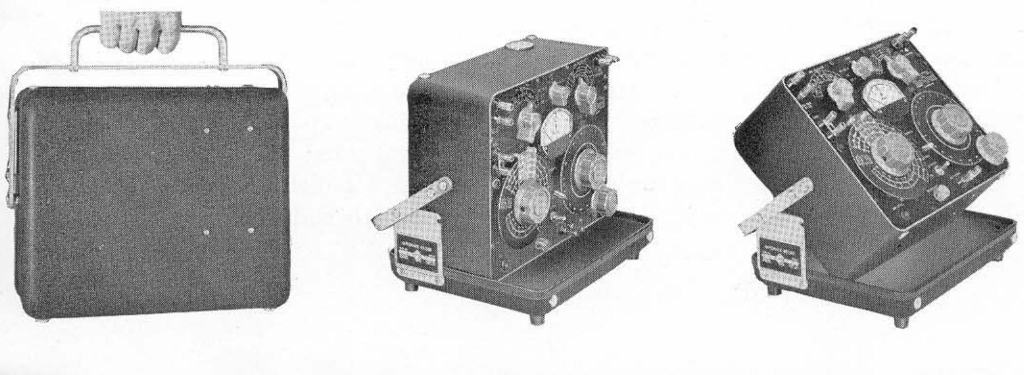
APPLICATIONS

The basic use of this type of bridge is in the everyday measurements of re-

[3] G. B. Hoadley, "The Science of Balancing an Impedance Bridge," *Journal of the Franklin Institute*, Vol. 228, No. 6, pp. 733-754; December, 1939.

[4] U. S. Patent No. 2,872,639.

Figure 5a (*Left*). Bridge cabinet when closed is an easily carried, protective case. Figure 5b (*Center*). Bridge, when cabinet is opened, can be used with panel vertical or, as shown in Figure 5c (*right*), tilted at any desired angle.



sistors, capacitors, and inductors, and for this application the wide ranges, efficient layout, and uniform accuracy of the TYPE 1650-A Impedance Bridge are important.

These same features, however, make possible additional types of measurement that illustrate the inherent versatility of the bridge.

Frequency Characteristics — The wide frequency response facilitates studies of the variations in component parameters over the entire audio-frequency range. An example of this is shown in Figure 6. The recommended external source for these measurements is the TYPE 1210-C Unit R-C Oscillator.

DC Bias — Panel terminals are provided for the application of a dc polarizing voltage to the element under measurement. Up to 600 volts of dc bias voltage can be applied to a capacitor being measured on any of the bridge ranges. DC current can be supplied to inductors or resistors by either of two methods. One permits currents ranging from 100 ma for 0.01 ohm or 0.01 henry to 0.5 ma for one megohm or one henry; the other permits 40 ma under any conditions.

Voltage Coefficients — DC bias makes possible the study of the variation in the capacitances of a ceramic or electrolytic capacitor as a function of voltage as shown in Figure 7. In measurements of this sort the very low values of dissipation factor which can be measured greatly extend the field of applications of the bridge.

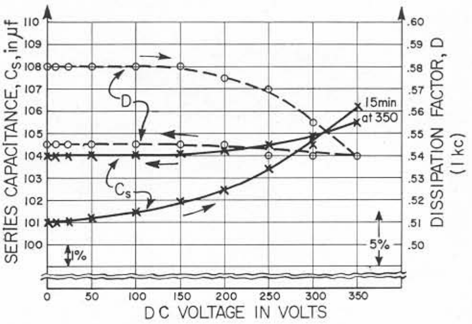


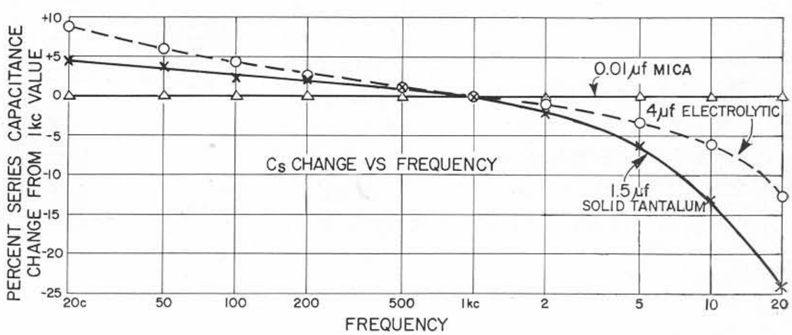
Figure 7. Measured capacitance and dissipation factor of a new electrolytic capacitor as a function of impressed dc voltage as it is passed to its rated voltage, then returned to zero bias.

Iron-Core Inductors — In the measurement of iron-cored coils, the ability to adjust the generator voltage and the high selectivity of the detector are useful in the measurement of inductance as a function of voltage. The data thus obtained can then be extrapolated to zero voltage to determine the inductance at zero permeability.

In such measurements as the determination of inductance of a radio-frequency choke, which usually has low Q's at 1 kc, the *Orthonull* mechanism makes possible accurate measurements which otherwise would be impossible.

Resistance — DC resistances up to 100 kilohms can be balanced with a precision of 1%. Above this magnitude, an external dc source should be used for maximum precision. With an external source, measurements can be made with standard EIA test voltages over most of the resistance range. Alternatively, the resistance at 1 kc can be measured. The

Figure 6. Plots of capacitance vs. frequency for three types of capacitors, as measured on the Type 1650-A Impedance Bridge. The 1210-C Unit R-C Oscillator was the external, variable-frequency generator.



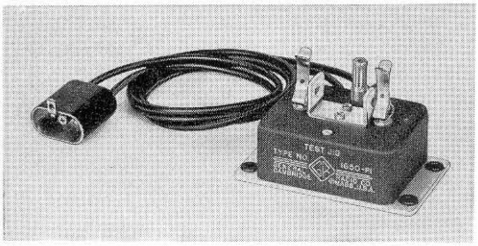


Figure 8. View of the Type 1650-P1 Test Jig.

greater sensitivity available for the ac measurement permits higher resistance magnitudes to be measured with the internal 1-kc generator. For most types of resistors, there is no appreciable difference between dc and 1-kc values. With an external ac generator, the behavior of resistive elements that vary with frequency can be studied. If an appreciable reactance is associated with the ac resistance, it can usually be cancelled by an external capacitor.

The resonant frequency of tuned circuits can also be determined through the measurement of ac resistances over a range of frequencies (up to about 5 kc) supplied by an external oscillator.

AC resistance measurements with dc bias can be used to study the characteristics of diodes, varistors, thermistors, and other nonlinear resistive elements.

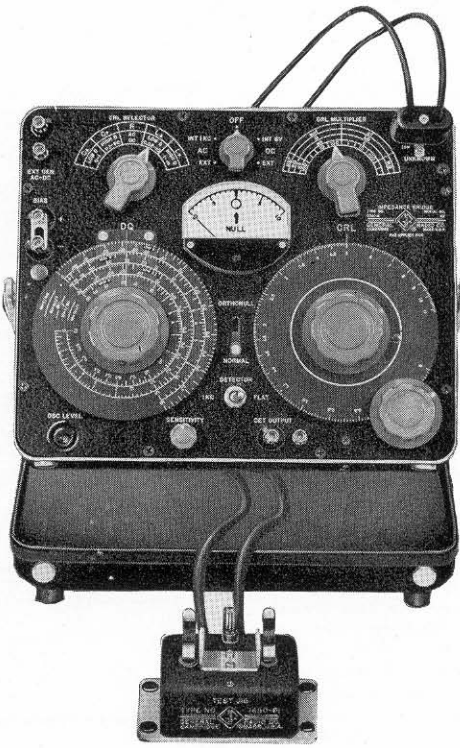
3-Terminal Capacitors — As previously mentioned, the high capacitance of the standard capacitor makes possible the measurement of direct capacitance even when the associated terminal capacitances are of considerable magnitude. One of the terminal capacitances appears across the detector and has no effect upon the measurement. The other appears across the standard capacitor. Here, a terminal capacitance of 1000 $\mu\mu$f produces an error of only 1% in the capacitance measurement. Thus the measurement of shielded 3-terminal components and of remote capacitances with shielded leads is quite feasible. In the latter class is the measurement of elements in conditioning chambers; in this application small changes can be determined to a degree of accuracy limited only by the resolution of the dial scales.

Limit Testing — A test jig, Type 1650-P1, facilitates the routine testing of identical components. The sensitivity of the bridge can be set to give a conveniently read deflection of the null indicator for any given tolerance.

ACKNOWLEDGMENTS

The well-integrated electrical and mechanical design of this bridge is the result of the combined efforts of many individuals. Every effort has been made to produce an accurate, convenient, flexible, and attractive instrument. Par-

Figure 9. Bridge with Test Jig connected.



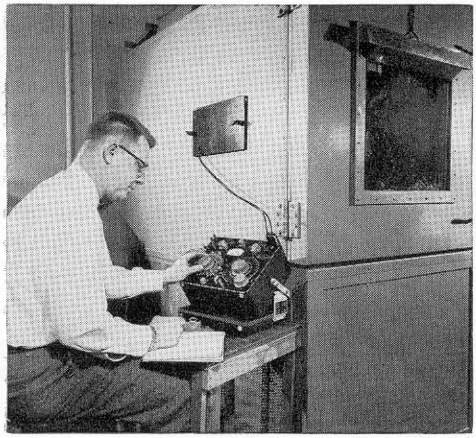


Figure 11. Bridge in use for 3-terminal measurements of sample in conditioning chamber.

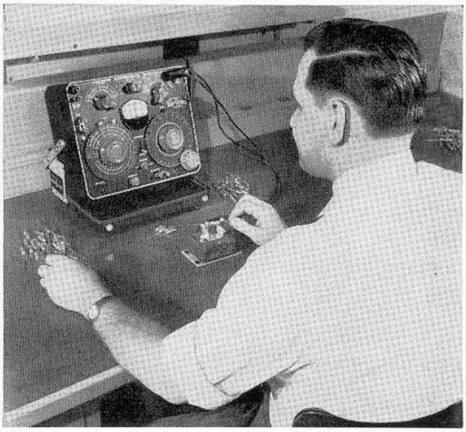


Figure 10. With the Test Jig, as shown here, the bridge can be set up for go-no-go testing to preset limits.

ticular credit should go to H. C. Littlejohn for developing the tilting case; to G. A. Clemow for working out the mechanics of the *Orthonull* mechanism; to H. G. Sterling and G. C. Oliver for layout; and to R. G. Fulks for helping with the testing. The instrument also embodies the suggestions of D. B. Sinclair, I. G. Easton, and R. A. Soderman, all of whom followed the project with interest and enthusiasm.

— Henry P. Hall

SPECIFICATIONS

Ranges:

Resistance, 1 mΩ to 10 MΩ, 8 ranges, ac or dc

Capacitance, 1 μμf to 1000 μf, 7 ranges, Series or Parallel

Inductance, 1 μh to 1000 h, 7 ranges, Series or Parallel

D (of series capacitance), 0.001 to 1 at 1 kc

D (of parallel capacitance), 0.1 to 50 at 1kc ($C_s = C_p$ within 1% if $D < 0.1$)

Q (of series inductance), 0.02 to 10 at 1 kc

Q (of parallel inductance), 1 to 1000 at 1 kc ($L_s = L_p$ within 1% if $Q > 10$)

Accuracy:

Resistance*, ± 1% ± 1 mΩ (Residual $R \approx$ 1 mΩ)

Capacitance, ± 1% ± μμf (Residual $C \approx$ 0.5 μμf)

Inductance, ± 1% ± 1μh (Residual L <0.2 μh)

D ± 5% ± .001 at 1 kc or lower

$1/Q$, ± 5% ± .001 at 1 kc or lower

Frequency Range: (1 kc supplied internally) 1% accuracy for L and C, 10 c to 20 kc; for R, 10 c to 50 kc. (D and Q ranges are functions of frequency.)

Internal Oscillator Frequency†: 1 kc ± 2%.

Internal Detector: Response, flat or selective at 1 kc; sensitivity control provided.

Internal DC Supply: 6 v, 60 ma max.

Power Supply: 4 "D" cells, supplied. Current drain (ac measurements) 10 ma.

DC Polarization: 600 volts may be applied (from external source) for series capacitance measurements.

Accessories Supplied: One Type 274-MB Double Plug.

Other Accessories Available: Type 1650-P1 Test Jig.

Other Accessories Required: None. Earphones may be used where high precision is required at the extremes of the bridge ranges.

Mounting: Aluminum cabinet, with captive cover.

Dimensions: 7¾ x 12¾ x 12½ inches including handle.

Weight: 17 pounds.

Type		*Code Word*	*Price*
1650-A	**Impedance Bridge‡**	BATON	**$440.00**

‡U. S. Patent No. 2,872,639.
*External DC Supply required for 1% accuracy above 100 kΩ.
†External ac and dc sources can also be used.

TYPE 1650-P1 TEST JIG

This test-jig adaptor provides a way to connect components quickly to a pair of terminals which can be placed on the bench directly in front of the operator. Thus the test jig and 1650-A Bridge make a rapid and efficient component sorting device when the panel meter of the 1650-A is used as a limit indicator.

The test jig makes a three-terminal connection to the bridge, so that the residual zero capacitance is negligible. The lead resistance (0.08 ohm total) has effect only when very low impedances are measured, and the lead capacitance affects only the measurement of the Q of inductors, introducing a small error in D (or $\frac{1}{Q}$) of less than 0.007.

Type		*Code Word*	*Price*
1650-P1	**Test Jig. . . . .**	LOCAL	**$19.00**

TYPE 1205-B ADJUSTABLE REGULATED POWER SUPPLY

A new idea in voltage regulation has made possible the high efficiency of the TYPE 1205-B Adjustable Regulated Power Supply. This new instrument, which delivers 120 watts, has an over-all volume of less than ⅕ that of conventional supplies.

The features of the series regulator and the controlled rectifier are combined in this instrument. The fast-acting series regulator provides a low output impedance over a wide bandwidth, while the high-efficiency controlled rectifier maintains constant voltage drop across

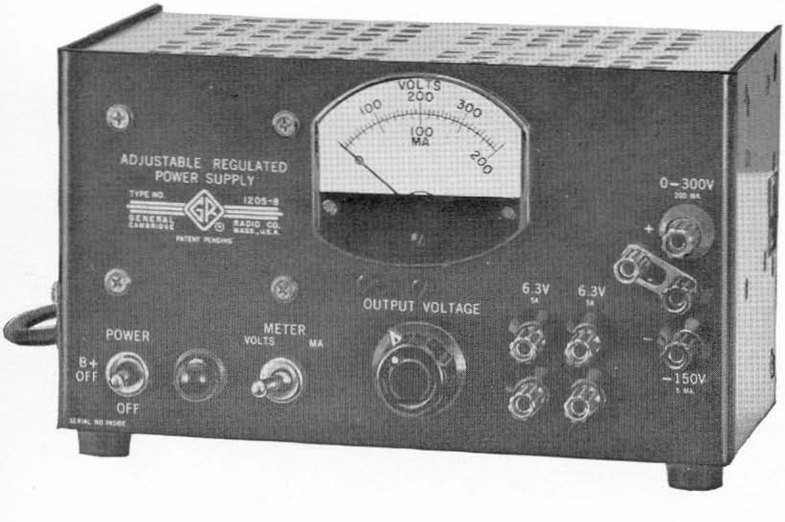


Figure 1. Panel view of the Adjustable Regulated Power Supply.

the series regulator. Thus the series regulator always operates at the optimum operating point, and the power dissipation is held to the same minimum value regardless of the output voltage setting or of line voltage variations. Furthermore, the regulator performance is the same at any output voltage from 0 to 300 volts.

A pair of thyratrons is used as a high-efficiency full-wave rectifier. Control is obtained by variation of the thyratron bias through a dc feedback path (Figure 2) from the regulated output to the thyratron grids. Superimposed on this dc feedback voltage is an ac bias voltage, phase shifted 90° with respect to the thyratron plate voltage, to provide smooth control of the thyratron firing angle. The dc feedback path includes a voltage source which determines the voltage drop across the series regulator. Any variation in the voltage drop across the series regulator changes the thyratron bias and therefore the firing angle. The change in firing angle varies the voltage applied to the series tube to maintain constant drop across it.

The series regulator uses a differential cascode amplifier for low drift and high gain. A cathode follower between the high-impedance cascode amplifier and the grids of the series tubes increases the bandwidth and improves the transient response of the regulator. Positive feedback within the over-all negative feedback loops is used to provide infinite amplifier gain and, therefore, essentially zero output impedance. To assure stability, the positive feedback is effective only at low frequencies. An oil capacitor across the regulated output terminals maintains the low output impedance at frequencies beyond the bandwidth of the amplifier.

Excellent regulation, high output, and low hum level make this power supply suitable for the most exacting applications.

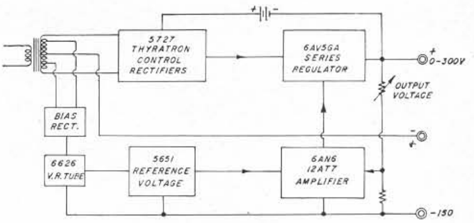


Figure 2. Block schematic of the power supply.

SPECIFICATIONS

DC Output Voltage: 0 to 300 volts, continuously adjustable at 200 ma, max.

Regulation: No load to full load, 0.1 volt; 0.75 volt change for ± 10% change in line voltage.

120-Cycle Ripple: 1 millivolt.

Internal Impedance: Approximately 0.3 Ω + (3 μh in parallel with 4 μf).

Regulated Bias Voltage: −150 volts, dc, fixed at 5 ma, max.

Regulation: No load to full load, 0.5 volt ± 10% line-voltage change, 2 volts. Unregulated AC Voltage: 2 circuits, 6.3 volts at 5a.

Meter Accuracy: Voltage, 2%; current, 5%.

Input: 105 to 125 volts, 60 c, 250 watts.

Tube Complement: 2-6AV5-GA, 2-5727, 1-12AT7, 1-6AN8, 1-6626, 1-5651, 1-6BZ7.

Dimensions: Panel, (width) 9½ x (height) 5¼ inches; depth behind panel, 8⅛ inches.

Net Weight: 15 pounds.

Type		*Code Word*	*Price*
1205-B	**Adjustable Regulated Power Supply**.............	APPLY	**$290.00**

NEW SERVICE LABORATORY FOR NEW YORK

A new service facility has been established at our Metropolitan New York Office —

General Radio Company
Broad Avenue at Linden
Ridgefield, New Jersey
Telephone:
WHitney 3-3140 (New Jersey)
WOrth 4-2722 (New York)

The new service laboratory has complete facilities for the repair, reconditioning, and recalibration of General Radio products. Certification of GR standards will also be handled. A stock of replacement parts will be available for those customers who wish to make their own repairs. Mr. Donald W. Brown, a factory-trained service engineer, is in charge of the new operation.

Our customers in New York State, Northern New Jersey, and Southwestern Connecticut are asked to write the New York Office Service Department for instructions when GR products are to be returned for calibration or repair. This office will also continue to provide these customers with application, engineering, and commercial information.

GENERAL RADIO AT THE IRE SHOW

NEW YORK COLISEUM — MARCH 23 - 26

BOOTHS 3302 — 3312

See the TYPE 1650-A Impedance Bridge and the TYPE 1205-B Power Supply at our booths, together with 15 other new instruments announced in 1958 or scheduled for announcement in 1959, including:

Graphic Level Recorder
Pulse Generator
Time-Delay Generator
Sound-Level Meter
Microwave Frequency Standard
Dielectric Measuring Line
Transfer Function and Immittance Bridge
Vacuum-Tube Bridge
Precision Inductance Bridge
Low-Frequency, 3-Phase Oscillator
W10 and W20 Variacs
3-Terminal Capacitance Standards

The Best Instruments in Electronics

General Radio Company

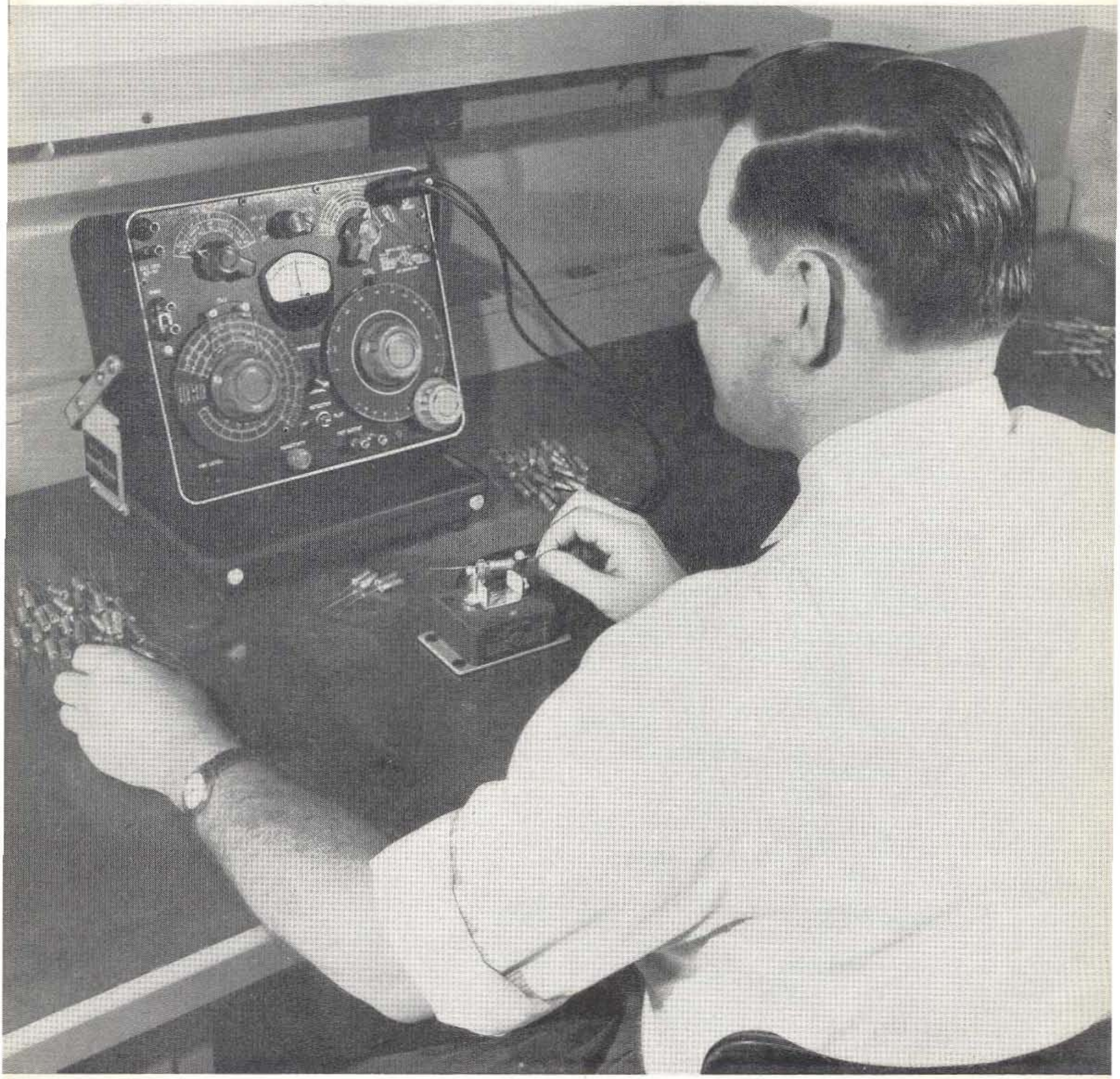
PRINTED IN U.S.A.

the GENERAL RADIO

Experimenter

Since 1915 – Manufacturers of Electronic Apparatus for Science and Industry

VOLUME 33 No. 4 APRIL, 1959



In This Issue

the GENERAL RADIO Experimenter

Published Monthly by the General Radio Company
VOLUME 33 • NUMBER 4 **APRIL, 1959**

CONTENTS

The General Radio EXPERIMENTER is mailed without charge each month to engineers, scientists, technicians, and others interested in electronic techniques in measurement. 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.

GENERAL RADIO COMPANY

West Concord, Massachusetts

Telephone: (Concord) *EMerson 9-4400;* (Boston) *CLearwater 9-8900*

NEW YORK:	**Broad Avenue at Linden, Ridgefield, New Jersey** *Telephone — N. Y., WOrth 4-2722* *N. J., WHitney 3-3140*
CHICAGO:	**6605 West North Avenue, Oak Park, Illinois** *Telephone — VIllage 8-9400*
PHILADELPHIA:	**1150 York Road, Abington, Pennsylvania** *Telephone — HAncock 4-7419*
WASHINGTON:	**8055 13th St., Silver Spring, Maryland** *Telephone — JUniper 5-1088*
LOS ANGELES:	**1000 North Seward St., Los Angeles 38, Calif.** *Telephone — HOllywood 9-6201*
SAN FRANCISCO:	**1186 Los Altos Ave., Los Altos, Calif.** *Telephone — WHitecliff 8-8233*
CANADA:	**99 Floral Parkway, Toronto 15, Ontario** *Telephone — CHerry 6-2171*

REPAIR SERVICES

EAST COAST:	**General Radio Co., Service Dept., 22 Baker Avenue, West Concord, Mass.** *Telephone — Concord, EMerson 9-4400* *Boston, CLearwater 9-8900*
NEW YORK:	**General Radio Co., Service Dept., Broad Ave. at Linden, Ridgefield, New Jersey** *Telephone — N. Y., WOrth 4-2722* *N. J., WHitney 3-3140*
MIDWEST:	**General Radio Co., Service Dept., 6605 West North Ave., Oak Park, Illinois** *Telephone — VIllage 8-9400*
WEST COAST:	**Western Instrument Co., 826 North Victory Boulevard, Burbank, Calif.** *Telephone — VIctoria 9-3013*
CANADA:	**Bayly Engineering, Ltd., First St., Ajax, Ontario** *Telephone — Toronto EMpire 2-3741*

COVER

Go-no-go testing is easy with the new Type 1650-A Impedance Bridge and its accessory Test Jig. This photo shows the bridge set up for the rapid testing of capacitors.

The patented *Orthonull* feature of this bridge, which eliminates sliding balances when high-loss capacitors or inductors are measured, is discussed in this issue.

A MILITARIZED, THREE-PHASE, LINE-VOLTAGE REGULATOR

The TYPE 1570-AS25 Line-Voltage Regulator is a completely militarized servo-controlled three-phase regulator. The inherent advantages of no distortion, large power rating, and high efficiency of this type of regulator, combined with its high accuracy and excellent transient response, make it especially attractive for many applications. In addition to the military environmental requirements of shock, vibration, temperature, humidity, and so forth, the unit is designed with particular emphasis on flexibility, ease of maintenance, reliability, and long life.

This regulator is similar in construction to the single phase TYPE 1570-AS15 Line-Voltage Regulator.[1] For adaptability and ease of maintenance, it is built in two units (Figure 1). The control unit contains all the electronic circuitry and is identical with the control unit of the single-phase model. The regulator unit consists of a three-gang W5 Variac, a servomotor, and three "buck or boost" transformers.

Because all three phases are controlled together in response to the variations on one control phase, only a single servo is required, and considerable space and price savings are possible over the use of three separate regulators. While the performance of this type of regulator is independent of load or load balance, any input voltage unbalance that results cannot be corrected, since each phase is not controlled independently. Thus, for accurate regulation, a balanced input voltage is necessary.

Ease of maintenance was a prime consideration in the original design of the regulator. If service of the electronic circuitry is required, only the small control unit need be removed. The larger unit with all its power wiring can stay in service supplying uninterrupted (but unregulated) power while the control unit is being replaced or repaired. Manual control of output voltage is possible during these intervals by means of the Variac® dial on the front panel.

Tubes can be replaced without the removal of any covers other than tube shields. Removal of a single dust cover exposes all other components. Component wiring is accomplished with an etched circuit to provide a high degree of uniformity between units. Each component is marked with its magnitude and rating and is identified by a com-

[1] M. C. Holtje, "Militarized Line-Voltage Regulator," *General Radio Experimenter*, 31, 6, November, 1956.

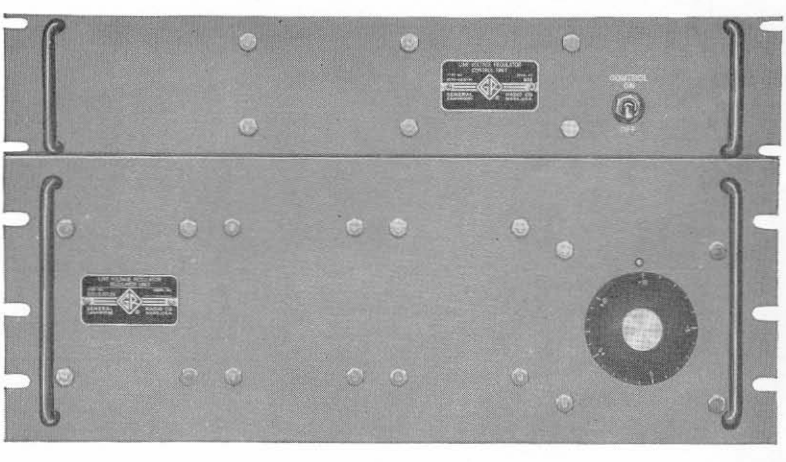


Figure 1. Panel view of the Type 1570-AS25 Three-Phase, Automatic, Line-Voltage Regulator.

ponent number printed on the mounting board. The removal of the bottom cover plate exposes all etched wiring. The complete circuit diagram is silk screened on the inside of this plate. For protection against the effects of moisture and fungus growths, the etched board is sealed with a fungus-resistant varnish.

Reliability and long life have been assured by conservative ratings and the use of the best materials and components in simple circuits that have proved reliable in long field experience.

For maximum versatility, a switch is provided inside the control unit for 50-cycle operation of the regulator. In the 50-cycle switch position, the range of operation is 45 to 55 c; in the 60-cycle position, it is 55 to 65 c. Space is also provided for the installation of a separate output-voltage-sampling transformer to permit control of 400-cycle power, although 50- or 60-cycle power must be available to operate the control unit.

To provide adequate strength for military shock and vibration requirements, the regulator unit is built on a seven-inch, U-shaped, extruded-aluminum channel. The smaller control unit mounts on a 3/8″ aluminum panel. Both units will withstand the standard 1200-ft.-lb. shock test, and they show no significant mechanical resonances up to 55 cycles per second.

The regulator is designed to meet or to exceed the general requirements of MIL-E-4158B and MIL-E-16400B. It will operate at full load over the ambient temperature range from —29°C. to +52°C. (—20° to +125° F.) and for non-operating storage from —54°C. to +85°C. (—65° to +185°F.). With special motor lubricants, operation is possible at far lower temperatures. Operation is possible with relative humidity up to 100 percent, including condensation caused by temperature changes.

While these military specifications are generally more severe than those encountered in most industrial applications, the increased reliability and ease of maintenance may often justify the use of the militarized regulator in critical industrial applications. This is particularly true for applications at high ambient temperatures or for portable installations where mechanical shock or vibration is encountered.

— M. C. Holtje

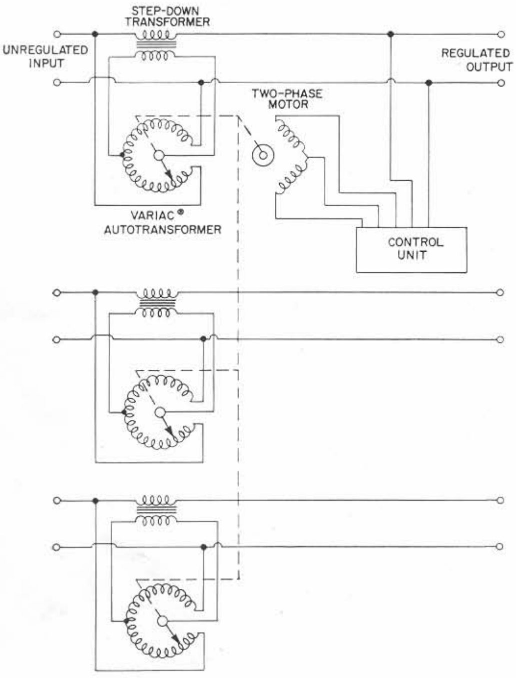


Figure 2. Functional block diagram of the regulator.

SPECIFICATIONS

Terminals: Multipoint connector strips.

Frequency: 45-55 cycles or 55-65 cycles, as selected by a switch.

Waveform Distortion: None.

Waveform Error: The average value of the output voltage is held constant, and a loaded dc power supply operated from the output of the regulator will give constant output voltage regardless of the harmonic distortion present in the power line. The rms output voltage will also remain constant, regardless of the harmonic distortion present, as long as the phase and amplitude of these harmonics are constant. If the harmonic content changes, the rms value will change by an amount less than $\Delta R/n$, where ΔR is the change in the harmonic amplitude and n is the harmonic number.

Ambient Temperature: Full ratings apply over a temperature range of $-29°$ to $+52°$C.

Power Consumption: No load, 35 watts. Full load, 140 watts.

Dimensions: Control Unit, panel, 19 x 3½ inches; depth behind panel, 7 inches. Regulator Unit, panel, 19 x 7 inches; depth behind panel, 16¾ inches.

Net Weight: 97 pounds.

Ratings

	1570-ALS25		1570-AHS25	
*Output Voltage per phase	115 ± 10%		230 ± 10%	
**Input Voltage as a percent of Output Voltage	91% to 109%	82% to 118%	91% to 109%	82% to 118%
Output Current per phase	25	12.5	10	5
Approx. KVA (wye***)	8.6	4.3	6.9	3.5
†Accuracy in % of output voltage	0.5	1.0	0.5	1.0
††Speed of response, volts per second	10	20	20	40

***Delta rating is $1/\sqrt{3}$ times wye rating. *Internal adjustment.
**Instruments are shipped connected for ±9% range unless ±18% range is specified on order.
†Applies only to measured phase. Other phases depend on input voltage balance.
††Slightly less for very small voltage corrections.

Type		*Code Word*	*Price*
1570-ALS25	**3-phase Regulator, 115 volts**	DICKY	**$865.00**
1570-AHS25	**3-phase Regulator, 230 volts**	DAILY	**885.00**

POLYSTYRENE CAPACITOR DECADE

100 $\mu\mu$f per step

Supplementing the three polystyrene decades previously announced,* a new decade with capacitance steps of 100 $\mu\mu$f is now available. Like its companion units of 0.001, 0.01, and 0.1 μf per step, this new decade is admirably suited for applications that call for high insulation resistance, low dielectric absorption, and constancy of capacitance and dissipation factor as a function of frequency.

Four capacitors are used in the decade, with their magnitudes in the ratio 1-2-2-5. Parallel combinations, as selected by the switch, yield all integral values from 1 to 10. The switch is rigidly constructed and includes a detent mech-

*"New Decade Capacitors with Polystrene Dielectric," *General Radio Experimenter*, 31, 2, July, 1956.

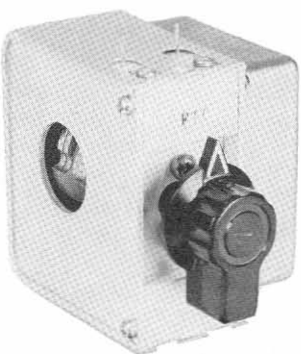


Figure 1. View of the Type 980-D Decade Capacitance Unit.

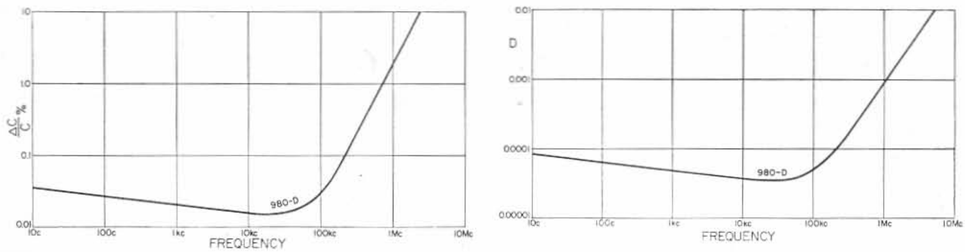


Figure 2 (*left*). Change in capacitance as a function of frequency. Since the capacitors are adjusted to their rated accuracy at 1 kc, the 1-kc value should be used as a reference for an estimate of the frequency error. (*Right*) Typical plot of dissipation factor as a function of frequency.

anism for positive location of position. The switch insulation, including the shaft, is heat-resistant, cross-linked polystyrene. Contact is made by cams bearing on phosphor-bronze springs, and the whole contact structure is heavily silver plated.

The individual capacitor units are wound from continuous interleaved tapes of polystyrene and metal foil. The foils projecting at each end of the roll are soldered together to minimize inductance and series resistance.

The tape used for the dielectric is specially prepared of purified high-molecular-weight polystyrene, having very high insulation resistance and freedom from unwanted polarizations. Hermetic sealing with Teflon feed-through insulators assures high performance, even under adverse humidity conditions. All capacitor units are heat stabilized, so that their long-time stability approaches that of the best silvered-mica capacitors.

Terminals are provided for both 2-terminal and 3-terminal connections.

SPECIFICATIONS

Capacitance: Total range, 0.001 μf; per step, 0.0001 μf.

Zero Capacitance: 2-terminal connection, approximately 11 $\mu\mu$f; 3-terminal connection, $<1\mu\mu$f.

Accuracy: 2-terminal, $\pm$ (1% + 2 $\mu\mu$f); 3-terminal, + 1%, − (2% + 4 $\mu\mu$f). Capacitance increment from zero setting is within this percentage of the indicated value for any setting.

Dissipation Factor: <0.0002.

Insulation Resistance: $>10^{12}$ ohms at 100 v, 25° C., 50% RH.

Temperature Coefficient of Capacitance: Approximately − 140 ppm/°C.

Maximum Operating Voltage: 500 volts, dc or peak, at frequencies up to 10 Mc.

Maximum Operating Temperature: 65° C.

Dielectric Absorption: See Voltage Recovery.

Voltage Recovery: <0.1% of original charging voltage after a charging period of one hour and a 10-second discharge through a resistance equal to one ohm per volt of charging.

Dimensions: See sketch.

Net Weight: 2 pounds, 2 ounces.

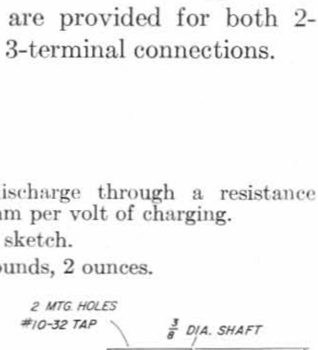


Figure 3. Dimensions of the Type 980-D Decade Capacitance Unit.

Type		*Code Word*	*Price*
980-D	**Decade Capacitor Unit.........................**	ALIEN	**$57.00**

ORTHONULL — A MECHANICAL DEVICE TO IMPROVE BRIDGE BALANCE CONVERGENCE

Impedance bridges can generally be divided into two classes, depending upon the location of the two adjustable components in the bridge circuit. These adjustments may be either in the same bridge arm or in different arms, and their positions determine what the bridge will read and how the balance will converge on the null.

The familiar Maxwell inductance bridge may take either of these two forms as shown in Figure 1. The balance equations are the same for both forms. However, dial reading must, in general, be proportional to only one variable element, so that the quantities indicated on the dials are different for these two circuits as shown.

The bridge that reads L and Q has several important advantages: (1) It reads Q, which is generally a more desired quantity than R because it gives a measure of the purity or quality of the inductor without calculation; (2) because the standard capacitor is fixed, it can more easily be made large to permit higher L and Q values to be measured; and (3) both adjustments are variable resistors, which can be continuously adjustable over a wide range.

The L-Q bridge has one disadvantage, however: when low-Q components are measured, the balancing procedure becomes tedious and often impossible, owing to slow convergence of the balance. This condition, often referred to as a "sliding null," can be remedied by a mechanical unilateral ganging called *Orthonull*, a patented device used for the first time on the GR Type 1650-A Impedance Bridge described last month.[1]

Cause of Sliding Null

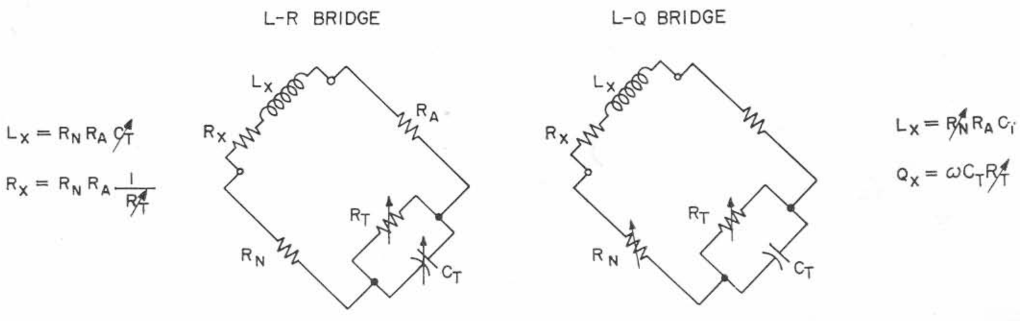
The output voltage of an unbalanced Maxwell bridge may be written in the form

$$\frac{E_O}{E_{IN}} = \frac{R_X + j\omega L_X - \left(\dfrac{R_N R_A}{R_T} + j\omega R_N R_A C_T \right)}{\text{Denominator}} \quad (1)$$

The denominator is a complicated function of the bridge arms and generator and detector impedances, and, for the purposes of this analysis, one can assume that it is constant in the region near the null. The numerator is made up of the difference between the "unknown" impedance and a function of the bridge components, which we will call the "bridge impedance." At null, these two impedances are equal. Off null, the output voltage is proportional to the difference between these two quantities, which is the distance between them on the complex plane. In balancing the bridge, one adjusts the variable components

[1] Hall, H. P., "A New Universal Impedance Bridge," General Radio *Experimenter*, March, 1959, Vol. 33, No. 3, pp. 3-9.

Figure 1. Two types of Maxwell inductance bridge.



alternately to give a minimum output voltage, repeating the process until a satisfactory balance is reached.

In the *L-Q* bridge, the two adjustable components are R_N and R_T. From the equation above it can be seen that an adjustment of R_T varies only the real part of the bridge impedance and therefore would move this impedance horizontally on the complex plane as shown in Figure 2. Both the real and imaginary parts are proportional to the other adjustment, R_N, so that a variation of this quantity causes the bridge impedance to move radially from the origin. When Q is high, these two adjustments have loci that are almost orthogonal, but when Q approaches zero, the loci become more and more nearly parallel. It is obvious that, at low Q values, a variation in only the imaginary (vertical) direction involves adjustments of both variable quantities. The process of balancing is somewhat analogous to that of tacking with a sailboat that won't point close to the wind.

Examples of two balance loci are given in Figure 3. Many adjustments are needed to obtain a balance, and it can be seen that each adjustment makes so small an improvement in the output voltage that in practice it is often unnoticeable, especially if an aural null indication is used. In this plot, the Q of the unknown is 0.5 which isn't very low. The situation is much worse if the Q is lower.

Orthonull Mechanism

Orthonull[2] makes it possible to get an independent adjustment of the imaginary part of the bridge impedance and hence rapid convergence. To do this, the ratio R_N/R_T in the real part of Equation (1) is kept constant as R_N is varied by a ganging of the two adjustments. However, when R_T is varied, R_N and R_T are not ganged so that only the real part is varied.

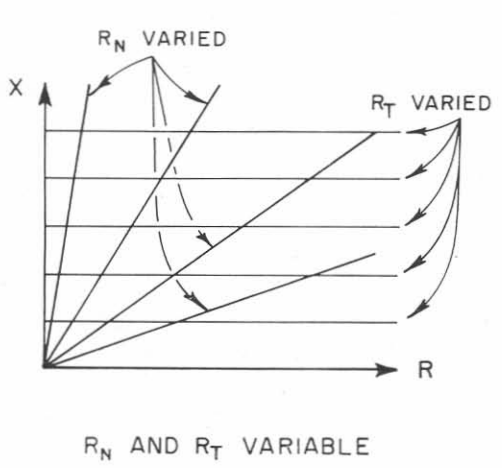
The mechanism to obtain the unilateral ganging on the Type 1650-A Bridge is shown in Figure 4. The friction clutch which is engaged when *Orthonull* is active has sufficient friction to drive easily the low-friction *D-Q* resistor (R_T). However, the CRL resistor, R_N, is loaded by a vernier adjustment and by a mechanical justifying mechanism[3] so that its friction is high enough to prevent coupling in the reverse direction.

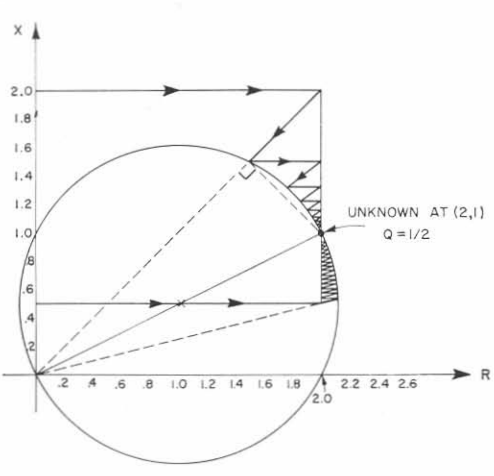
If the two resistors were always ganged, the ratio R_N/R_T could be made constant

[2] U. S. Patent No. 2,872,639.
[3] This justifying mechanism is an adjustable cam and cam follower, which varies the position of the potentiometer rotor with respect to the shaft and dial to compensate for variations in the winding.

Figure 2 (*left*). Loci of adjustments on the Z plane.

Figure 3 (*right*). Idealized balancing loci; Q = ½.





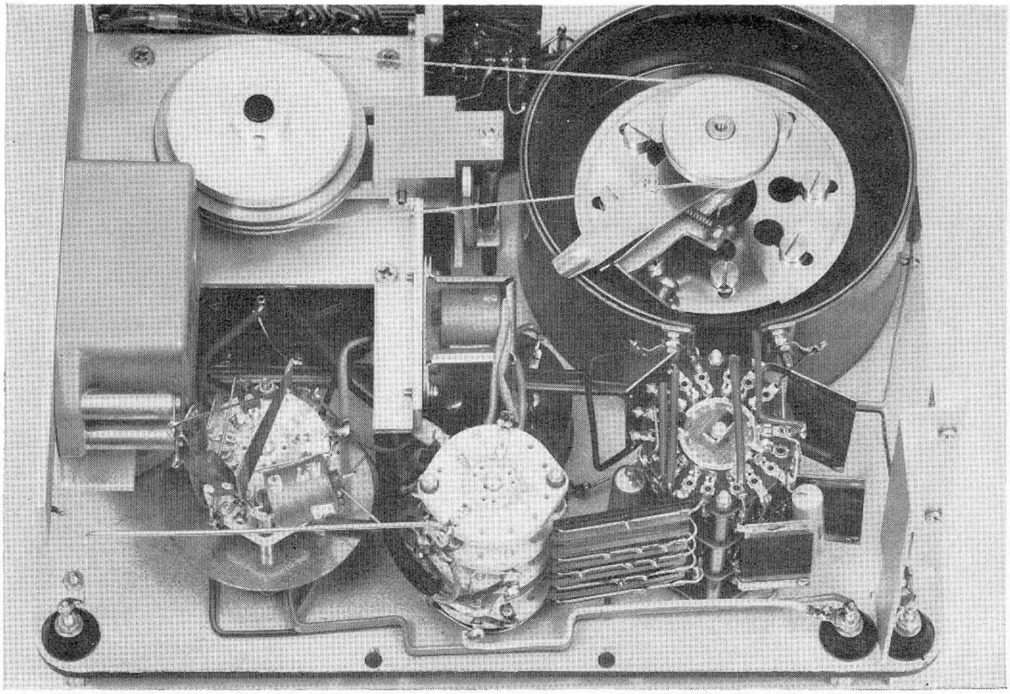
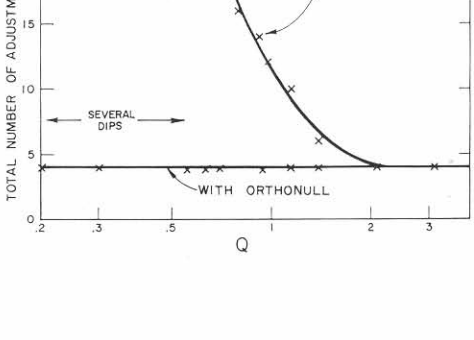


Figure 4. Interior view of the Type 1650-A Impedance Bridge, showing the ganged drive for *Orthonull*. The clutch lever, which is operated from the front panel, is between the two potentiometers; the clutch face is between the two pulleys on the left-hand potentiometer.

by use of resistors of any similar characteristic. However, since R_T must be moved independently of R_N, an exponential R vs. θ characteristic is necessary in order that a given angular change will always produce the same fractional resistance change. Fortunately, resistors with exponential windings have logarithmic dials, which are desirable for constant percentage bridge accuracy. The *D-Q* resistor of the TYPE 1650-A Impedance Bridge is a 54-db potentiometer and the CRL dial is logarithmic over a 21-db range. The difference in exponential span of the two resistors results in a pulley ratio that is favorable to torque transmission in the direction required. The pulleys are connected by a wire cable with spring take-up to prevent backlash in the adjustments, and two ball bearings are used to reduce drag.

Figure 5. Plot of total number of balances required to achieve 1% final balance, with and without *Orthonull*, as a function of Q.



Advantages

The advantages of *Orthonull* operation can most easily be illustrated by the experimental plot, Figure 5, of Q vs. the number of adjustments necessary to get a 1% balance. At high Q's, four adjustments, two of each potentiometer, are generally required whether *Orthonull* is used or not. Below a Q of 2, however, the curve for "no *Orthonull*" quickly rises while the number of adjustments necessary has not increased for balances with *Orthonull*.

False Null

Without *Orthonull* it is impossible to obtain a 1% balance down to Q values of about ½ if the usual balancing procedure is used. Under these conditions, a false null is reached where an adjustment of either variable element only causes a larger bridge unbalance. The phenomenon is due to the finite resolution of the R_T resistor and may be explained with the aid of Figure 6. Let us assume that the R_N adjustment is varied, moving the locus of the bridge impedance along the radial line as shown. The best minimum output voltage occurs at point P, which is the closest point on the line to the unknown. The operator would then make a horizontal, R_T, adjustment, but since the resolution R_T is finite, the locus must jump to either P' or P'', both of which are further from the unknown than P. Therefore, an adjustment of either variable increases the bridge output voltage, and the operator would

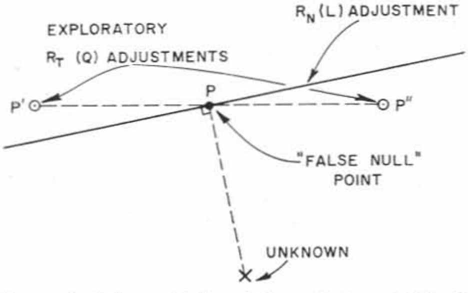


Figure 6. False null. Resolution of $R_T = 0.5\%$; if $Q = 0.2$, the error in L can be as great as 6.25%.

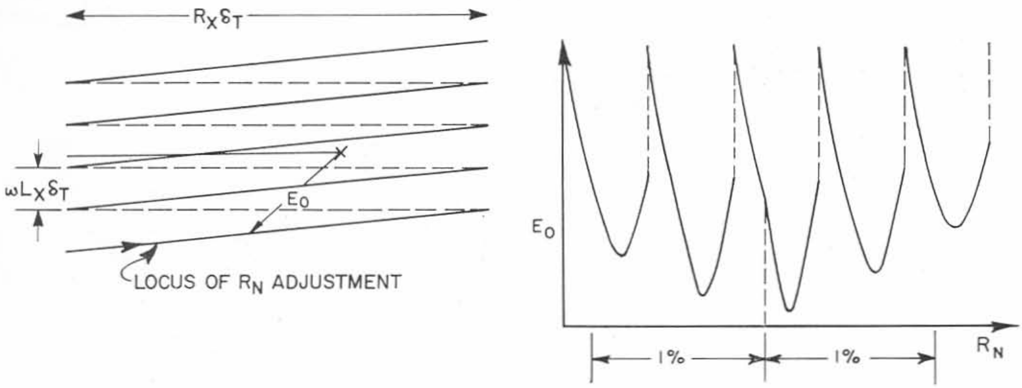
assume this point to be the best null. It can be shown that this balance can result in an error of as much as $\frac{\delta_T}{2Q_X^2}$ where δ_T is the percent resolution of R_T. For the 1650-A, $\delta_T \approx 0.5\%$, so that the error would be 1% when $Q = ½$ and 25% when $Q = 0.1$.

It should be noted that the "false null" error described above can be avoided by a trial-and-error method. In this procedure one starts with various R_N values and makes successive balances, each of which will be a "false null." The best balance may eventually be obtained in a logical manner if the detector indication is used as a guide in the choice of the succeeding initial R_N value. Needless to say, this is a time-consuming procedure.

Multiple Dips

The finite resolution of the R_T resistor also has an effect on balances made with *Orthonull*, but does not limit the ac-

Figure 7. Effect on output voltage, E_O, of limited resolution of R_T, assuming that R_N is ideal, R_T has 0.5% resolution, and $Q = 0.1$.



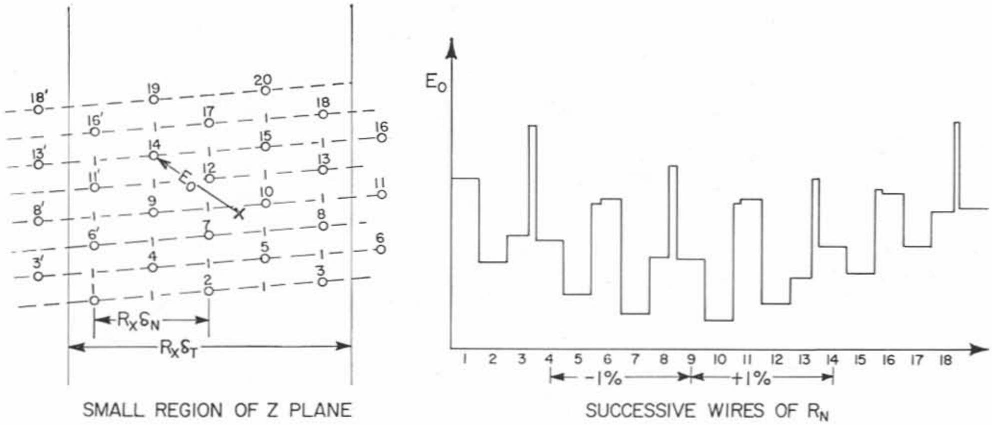


Figure 8. Effect on output voltage, E_0, of limited resolution of R_N and R_T, assuming $\delta_N = 0.2\%$, $\delta_T = 0.5\%$, and $Q = 0.1$.

curacy. Instead, the limited resolution causes the output voltage to make repeated dips as R_N is varied, and the best dip can be chosen to give a more accurate reading. If both resistors were perfectly continuous, a variation in R_N would move the locus of the bridge impedance vertically on the complex plane, due to *Orthonull* action. However, if R_T has finite resolution, an adjustment of R_N results in a zigzag locus, as shown in Figure 7a, where each line corresponds to the variation of R_N for one particular wire of R_T. Since the output voltage is the distance between the unknown, Z_X, and the zigzag line, this voltage will go through a series of dips as R_N is varied, as shown in Figure 7b. If the best null is chosen, the error is always less than $\delta_T/2$, which is ¼% for the Type 1650-A Impedance Bridge, and thus the error of the false null of Figure 6 is avoided.

Actually, of course, both R_T and R_N have finite resolution since both are wire-wound potentiometers. The R_N (CRL resistor) resolution is about 0.2%. As a result, the locus of R_N variation is not a series of curves as indicated in Figure 7, but a step from one wire to another as shown in Figure 8. This latter figure is idealized in that the ratio of resolutions of the two potentiometers, $\frac{\delta_N}{\delta_T}$, is assumed to be exactly 2/5, which results in an even pattern of possible balance points. As R_N is varied, the output jumps in discrete steps, with large jumps coming as the setting of the coarser potentiometer, R_T, changes from wire to wire.

The most important limit on accuracy

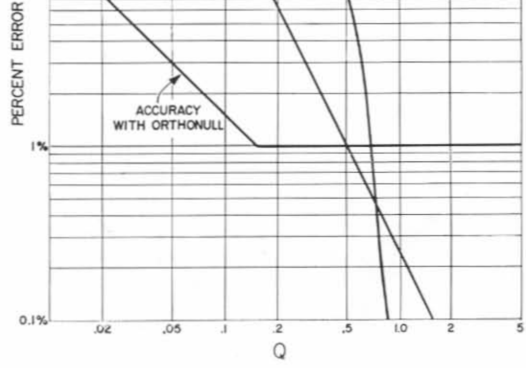


Figure 9. Accuracy to be expected in measurement as a function of Q, with and without *Orthonull*. "False null" error is also shown.

is that it is possible to get a bridge balance that is in error by approximately $\delta_N/4Q$ but which is as good as the best possible balance. This occurs when the unknown is in the worst possible location, in the complex plane, *i.e.*, where it is farthest from any balance point.

Other, less important, limits on the accuracy are backlash, which is small, and reduced sensitivity, both of which cause errors proportional to $1/Q$.

Many experimental balances were made to see what sort of accuracy could be expected, and it would seem that, with reasonable care, one should be able to get balance of 1% or $0.15/Q\%$, whichever is larger. This is plotted in Figure 9. Also on this plot is the possible error occurring as a result of the "false null" when conventional balancing technique is used as described above. A more practical limit for operation without *Orthonull* is the line which shows the approximate accuracy possible with 20 balance adjustments starting with a $+100\%$ unbalance in inductance.

Conclusion

Orthonull makes possible rapid balances at low Q values, avoiding the "sliding null." The basic bridge accuracy is not affected since *Orthonull* only affects the manner in which the balance is made. Effectively the accuracy at very low Q values is improved by avoidance of "false nulls."

It should be pointed out that on the TYPE 1650-A Impedance Bridge the *Orthonull* mechanism can be used for high D capacitance measurements as well as low Q inductance measurements. The device can be disengaged so that high Q (low D) balances can be made in the usual manner.

Acknowledgments

The idea for *Orthonull* was prompted by a suggestion from Dr. D. B. Sinclair for making an orthogonal L-R bridge (Figure 1) give a Q reading by appropriate adjustment of logarithmic scales. The mechanical design of the mechanism was worked out by G. A. Clemow.

— H. P. HALL

GENERAL RADIO EXHIBITS IN CANADA

Our Canadian friends will have an opportunity to see the latest General Radio instruments for acoustic measurements at the exhibit to be held at the meeting of the Acoustical Society of America at Ottawa, May 14-16.

A General Radio traveling display will be in Ontario and Quebec from May 11 to May 28. It will be at the Seaway Hotel in Toronto on May 16 and at the Capri Hotel in Montreal on May 24, from 12 to 6 P.M.

ERRATA—TYPE 1650-A IMPEDANCE BRIDGE

Please note the following corrections to the specifications for this instrument appearing in our March issue:

Capacitance Accuracy: $\pm 1\% \pm 1\ \mu\mu$f.

Frequency Range for R: 20 c to 5 kc.

On page 7, under **Iron-Core Inductors,** the last line of the first paragraph should read "at initial permeability."

THE GENERAL RADIO EXPERIMENTER

VOLUME 33 No. 5

MAY, 1959

IN THIS ISSUE

Transfer-Function and Immittance Bridge

Metered Variacs

THE GENERAL RADIO

EXPERIMENTER

©1959—GENERAL RADIO COMPANY, WEST CONCORD, MASS., U.S.A.

Published Monthly by the General Radio Company

VOLUME 33 • NUMBER 5 **MAY, 1959**

CONTENTS

The General Radio EXPERIMENTER is mailed without charge each month to engineers, scientists, technicians, and others interested in electronic techniques in measurement. 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.

GENERAL RADIO COMPANY

West Concord, Massachusetts

Telephone: (Concord) *EMerson 9-4400;* (Boston) *CLearwater 9-8900*

NEW YORK:	**Broad Avenue at Linden, Ridgefield, New Jersey** *Telephone — N. Y., WOrth 4-2722* *N. J., WHitney 3-3140*
CHICAGO:	**6605 West North Avenue, Oak Park, Illinois** *Telephone — VIllage 8-9400*
PHILADELPHIA:	**1150 York Road, Abington, Pennsylvania** *Telephone — HAncock 4-7419*
WASHINGTON:	**8055 13th St., Silver Spring, Maryland** *Telephone — JUniper 5-1088*
LOS ANGELES:	**1000 North Seward St., Los Angeles 38, Calif.** *Telephone — HOllywood 9-6201*
SAN FRANCISCO:	**1186 Los Altos Ave., Los Altos, Calif.** *Telephone — WHitecliff 8-8233*
CANADA:	**99 Floral Parkway, Toronto 15, Ontario** *Telephone — CHerry 6-2171*

REPAIR SERVICES

EAST COAST:	**General Radio Co., Service Dept., 22 Baker Avenue, West Concord, Mass.** *Telephone — Concord, EMerson 9-4400* *Boston, CLearwater 9-8900*
NEW YORK:	**General Radio Co., Service Dept., Broad Ave. at Linden, Ridgefield, New Jersey** *Telephone — N. Y., WOrth 4-2722* *N. J., WHitney 3-3140*
MIDWEST:	**General Radio Co., Service Dept., 6605 West North Ave., Oak Park, Illinois** *Telephone — VIllage 8-9400*
WEST COAST:	**Western Instrument Co., 826 North Victory Boulevard, Burbank, Calif.** *Telephone — VIctoria 9-3013*
CANADA:	**Bayly Engineering, Ltd., First St., Ajax, Ontario** *Telephone — Toronto EMpire 2-3741*

COVER

Entrance to the General Radio plant at West Concord. Please be sure our new address is in your records.

TYPE 1607-A TRANSFER-FUNCTION AND IMMITTANCE BRIDGE

NEW FUNCTIONS, NEW NAME, AND NEW TEST MOUNTS

An unusual new instrument, identified as the TYPE 1607-A Transfer-Function Meter, was described in this publication a little over one year ago.[1] It could measure all the complex transfer functions[2] of three- and four-terminal[3] devices and networks, such as transistors, vacuum tubes, amplifiers, filters, and attenuators, over the 60:1 frequency range from 25 Mc to 1500 Mc.

New Functions

Stimulated by comments of people seeing the instrument for the first time, e.g., "That's fine, but isn't there some way of making it measure *two*-terminal impedances and admittances, too? Then it would measure everything," we looked further and found a simple way to do just this.[4] Although the changes necessary to incorporate the added functions involved cutting a fourth set of slots in the instrument's main junction block and the addition of a new indicator assembly, we were fortunately able to catch the first production lot of instruments just in time to include these new features, starting with the first instrument sold. Therefore, all instruments in use are up to date, except that on the earliest units the engraving shows the old name. The instrument will now measure the input or output impedance or admittance of two-, three-, or four-terminal networks with dc bias supplied to all terminals and with three- and four-terminal networks terminated in either an rf short or open circuit.

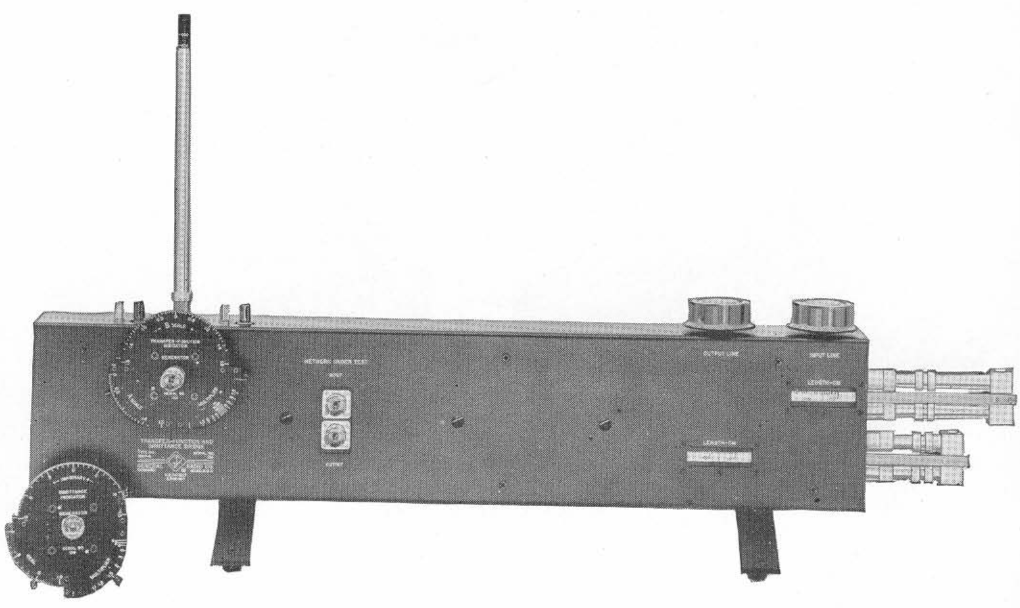
[1]W. R. Thurston, R. A. Soderman, "A Transfer-Function Meter for the VHF-UHF Range," *General Radio Experimenter*, Vol. 32, No. 10, March, 1958, pp. 3-15.

[2]Forward and reverse transadmittance, transimpedance, transfer voltage ratio, and transfer current ratio.

[3]Having one input terminal and one output terminal grounded.

[4]Not "everything," of course — just 2, 3, and 4-terminal networks.

Figure 1. View of the Transfer-Function and Immittance Bridge with Transfer-Function indicator in place. Interchangeable Immittance Indicator is shown in foreground.



New Name

With the capabilities of the instrument increased to cover many additional applications, the old name, "Transfer-Function Meter," was not completely descriptive. The new name is "Transfer-Function and Immittance Bridge," the word "Immittance" denoting both *im*pedance and ad*mittance*. Because of its convenience, this word is gradually coming into more common use in connection with transmission lines, networks, and certain types of measuring instruments, such as the slotted line.

The change of the last word from "Meter" to "Bridge" is intended to improve further the descriptive accuracy of the name. Passive, null-type circuits used with generator and detector to measure accurately the real and imaginary components of an unknown in terms of resistive and reactive standards are commonly called "bridges," whether or not the classic, bridge, diamond form is apparent without topological juggling.

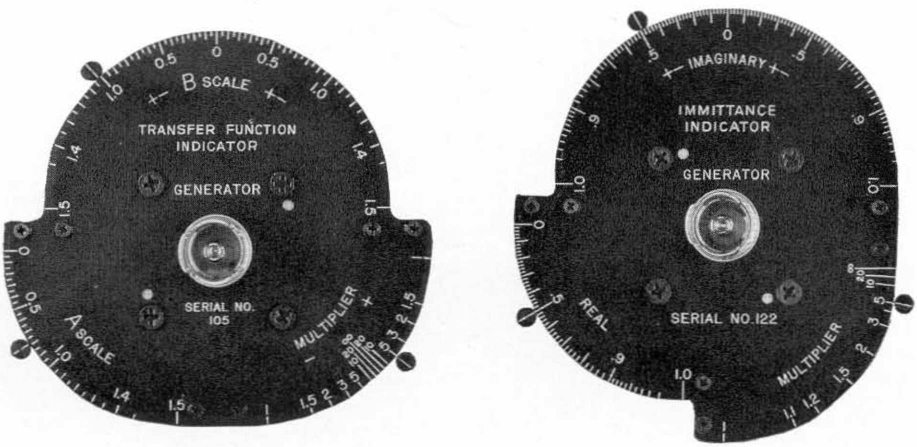
Interchangeable Indicators

Two different indicator units, shown in Figures 2 and 3, are furnished with the bridge, one for transfer-function measurements and the other for immittance measurements. Each is an assembly of a casting with three rotatable loop units, control-indicator arms, and calibrated scales. They are held in place by four screws and are easily interchanged. Locating pins permanently preserve alignment and factory calibration.

Circuit for Immittance Measurements

The operating principles and circuit for transfer-function measurements were fully described in the earlier article,[1] to which reference is made for basic description and features. For immittance measurements with the Immittance Indicator (Figure 4), there are still three loops coupled to three coaxial lines, two of which are terminated, respectively, in a standard conductance and a standard susceptance, but the third loop couples to the bottom line (labeled "Network Output") instead of to the right-hand line (labeled "Network Input"). In the schematic diagram of Figure 4, the circuit is set up for measuring the output immittance of a four-terminal network. To measure network input im-

Figure 2. View of the two indicators. Calibrations are normalized with respect to coaxial line characteristic impedance (50 ohms) and admittance (20 millimhos).



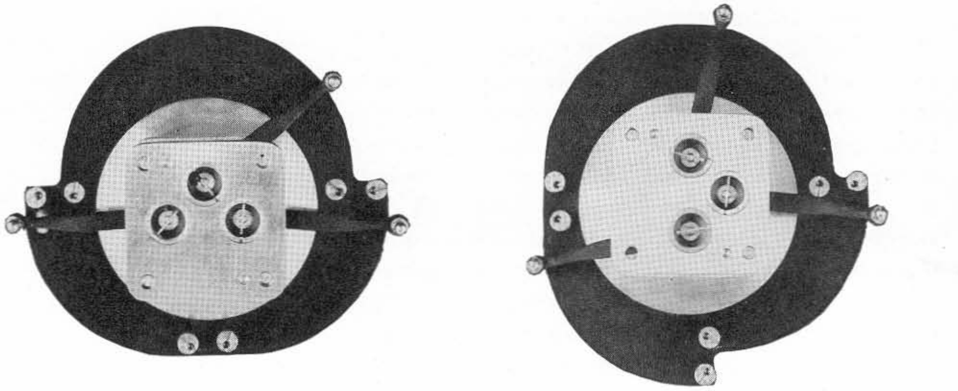


Figure 3. Rear view of indicator units showing different loop locations and consequent differences in scale plate shape.

mittances, the network is simply reversed. Note that the lower line, though labeled "Network Output" because of its use during transfer-function measurements, actually drives the network during immittance measurements. The upper line, labeled "Network Input" because of its use during transfer-function measurements, acts as either a short or open circuit at the other end of the network during immittance measurements and has no other coupling to the circuit, except to provide dc bias if required.

For measurements on two-terminal, grounded immittances, the unknown network is connected to the lower ("Output") terminals, and the upper line (labeled "Network Input") is not used at all.

This circuit for immittance measurements is the same as that used in the Type 1602-B Admittance Meter.[5] With the lower line (labeled "Network Output") set to a half wavelength or an integer multiple thereof, the instrument measures admittance. With the line set to a quarter wavelength or odd multiple,

[5] W. R. Thurston, "A Direct-Reading Impedance-Measuring Instrument for the U-H-F Range," *General Radio Experimenter*, Vol. 24, No. 12, May, 1950, pp. 1-7.

R. A. Soderman, "Improved Accuracy and Convenience of Measurements with Type 1602-B Admittance Meter in VHF-UHF Bands," *General Radio Experimenter*, Vol. 28, No. 3, August, 1953, pp. 1-6.

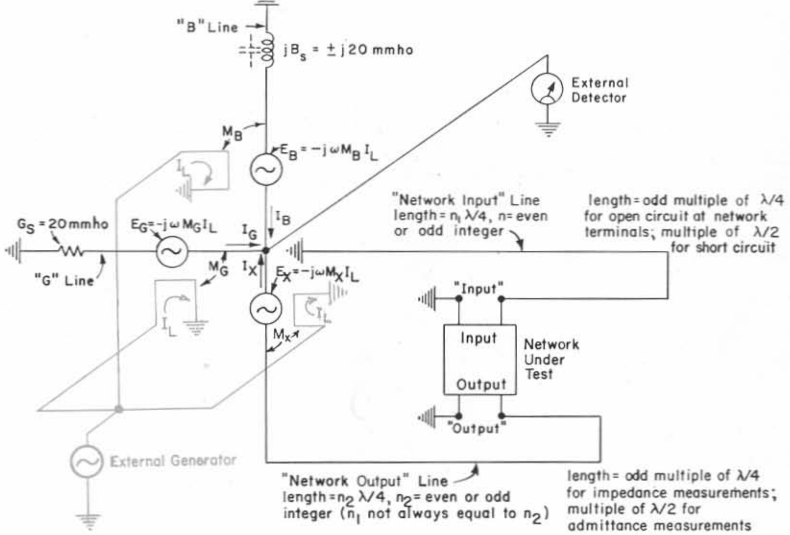


Figure 4. Schematic diagram of the circuit for immittance measurement. For a diagram of the circuit for transfer-function measurement, see previous article.[1]

the instrument measures impedance. The scales are calibrated in normalized components, from 0 to 1, with a multiplier from 1 to ∞. For impedance measurements, the reference is 50 ohms, and for admittance measurements, 20 mmhos. The Transfer-Function and Immittance Bridge can measure everything that the Admittance Meter can measure, including reflection coefficient and VSWR of transmission lines and antennas. In addition, it has the built-in, calibrated, adjustable line for direct-reading immittance measurements, the second, short-circuited, calibrated, adjustable line for proper termination of four-terminal networks during input and output immittance measurements, and provisions for biasing active devices or networks. However, the Admittance Meter will, no doubt, still be preferred in a number of instances for two-terminal measurements because of its lower price, smaller size, and somewhat better basic accuracy (3% vs. 5%).

New Transistor Mounts

At very-high and ultra-high frequencies, the method of connecting an unknown device to a measuring instrument of any kind is critical. Reproducible answers can be obtained in different measurements by different people using different equipment only if the same, standard method of making connections is used in all cases, with details of configuration and dimension being precisely the same. Furthermore, the necessity of

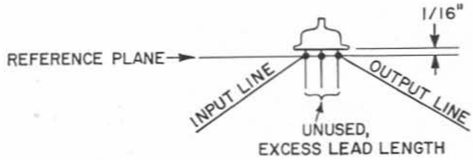


Figure 6. Sketch of connections to transistor, showing the reference points of measurement.

applying bridge voltages or currents to transistors or other active devices, of accurately compensating stray capacitances and inductances, and of suppressing spurious oscillations makes the design of suitable mounts more than a minor job, even for an engineer skilled in vhf-uhf design techniques.

To help avoid these problems in transistor measurements, standard mounts have been designed, two of which are presently available and two more which are approaching completion in development. Additional types will be added from time to time in response to user demand. Those available now are for JETEC basings, 0.200-inch-pin-circle triode with common base (1607-P101) or common emitter (1607-P102). Those in development are for 0.200-inch-pin-circle tetrodes and 0.100-inch-pin-circle triodes with common base. Leads of units to be measured can be any length between $\frac{3}{32}$ and $\frac{5}{16}$ inch, and lead diameters up to 0.035 inch can be accommodated. In the Transfer-Function and Immittance Bridge all characteristics of a given transistor with a given common electrode are measured with a single mount, thus insuring consistency of results at high frequencies.

These transistor mounts incorporate several refinements that result in accurate and reproducible measurements:

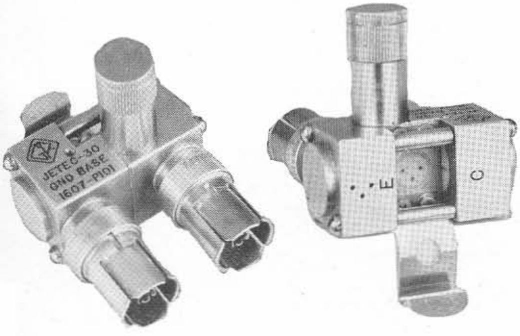


Figure 5. Two views of the Type 1607-P101 Transistor Mount showing the damper unit projecting from the side. In the right-hand view the lead alignment holes can also be seen.

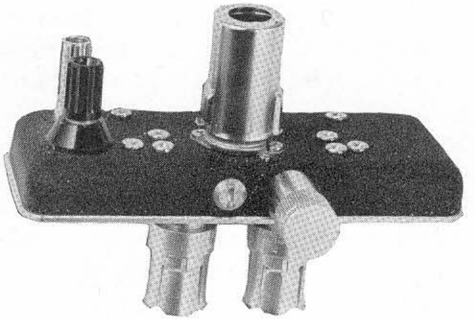


Figure 7. View of the Type 1607-P201 Tube Mount with tube and shield installed and damper unit projecting from side. Binding posts at left are for heater connections.

(a) The reference point of measurement on the transistor leads is only 1/16″ from where they emerge from the header, as shown by Figure 6. Therefore, the measured characteristics are those of the transistor elements in their housing and with 1/16″ leads. This measurement environment is very close to the best that can practically be done in actual circuit use of transistors.

(b) The input and output lines leading to the reference plane are accurately compensated to maintain a 50-ohm characteristic impedance level with very low reflections due to discontinuities.

(c) A removable 50-ohm resistor, with bias blocking capacitor, is supplied to suppress spurious oscillations. This resistor is shunted across either the input or the output of a transistor, depending on the type of measurement being made, and has no adverse effect on measurement accuracy.

(d) The input and output circuits within the mounts are very well shielded, so that coupling between them external to the transistor is negligible.

Transistors with 0.072-inch-pin circles will be easily measurable in the 0.100-inch-pin-circle mount (available later) if the leads are bent the slight amount required, by use of the lead alignment holes provided in the top of the mount.

Figure 5 is a photo of Type 1607-P101 Transistor Mount.

Tube Mount

One tube mount is available so far. It is designed for common-cathode measurements on seven-pin miniature tubes such as 6AF4, 6AF4A, 6AN4, 6T4, and other tubes having the same pin connections. The tube is measured in the socket of the mount, so that measured values will include socket effects and will be those of greatest use in circuit design. The Type 1607-P201 Tube Mount, with tube and shield installed, is shown in Figure 7.

Typical Measurements

With this instrument direct measurements can be made of the parameters of commonly used transistors, vacuum tubes, and passive networks. Transistors can be measured in either the common-base or common-emitter connection; and a *complete* set of measurements can be made in either connection without calculation of any of the parameters from measurements made in another connection. This factor is important at high frequencies, where connection changes can cause changes in the effects of stray capacitances and inductances.

The chart on page 8 shows a typical set of measurements made on a high-frequency transistor. All the values were directly measured with the exception of the h_o parameters. For the h_o measurement, the output admittance must be determined with the input circuit open circuited, a condition which is easily obtained with the bridge. However, with the open-circuit connection, the damping units cannot be used, and in some cases regeneration or oscillation can occur. In these cases, h_o can easily be calculated from the formula:

$$h_o = Y_{22} + \frac{h_f h_r}{h_i}$$

The variations in some of the above transistor parameters with collector voltage are plotted in Figure 8. Figure 9 shows measured values of forward current-transfer ratio for a diffused-base transistor. Figure 10 shows the results of measurements of the short-circuit output admittance, Y_{22}, on a similar transistor.

The extrinsic base resistance, $r_{bb'}$, of a transistor is often determined[6] from measurements of the common-emitter input impedance with the collector short circuited, h_{ie}. In this case, the $r_{bb'}$ is approximately equal to the input resistance obtained at a frequency at which the reactance is zero. Figure 11 shows a plot of h_{ie} measured on a relatively low-frequency transistor, indicating a base resistance of 27 ohms. At frequencies above the zero-reactance point, the reactance becomes positive owing to the inductance of the leads inside the transistor body and that of the short length of pin between the seal and the point at which the measurements are made. At much higher frequencies, this lead inductance can be in paralled resonance with the stray capacitance to the shell and ground, as shown in Figure 11.

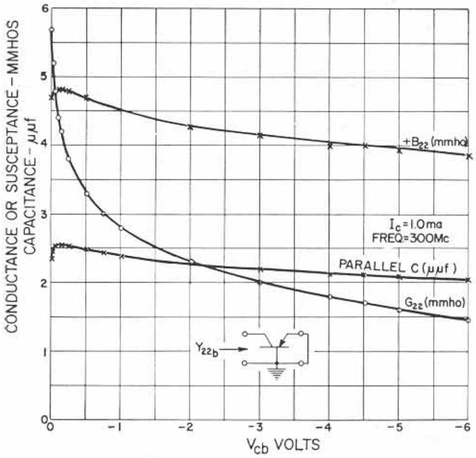
In high-frequency transistors, the zero-reactance point occurs at a much higher frequency, and the impedance at this point may be affected by stray lead reactances. A typical measurement is shown in Figure 12. Measurements were also made on a slotted line in order to check the values measured on the Transfer-Function and Immittance

[6] R. P. Abraham and R. J. Kirkpatrick, "Transistor Characterization at VHF," *Proc. Nat. Elec. Conf.* 13, pp. 385-402, 1957.

NETWORK PARAMETER MEASUREMENTS ON A HIGH-FREQUENCY TRANSISTOR AT 300 Mc

FREQUENCY = 300 Mc, V_{cb} = -4.5 v, I_c = 1.0 ma, SHELL GROUNDED

COMMON BASE			COMMON EMITTER		
	HYBRID	SC ADMITTANCE mmhos	HYBRID	SC ADMITTANCE mmhos	
α_f 0.79 − j 0.53	h_{fb} −0.79 + j 0.53	Y_{21b} −3.4 + j 10.2	h_{fe} −0.68 − j 1.5	Y_{21e} 2.0 − j 12.0	β_f −0.68 − j 1.5
α_r 0.32 − j 0.18	h_{rb} 0.04 + j 0.14	Y_{12b} −1.4 − j 1.0	h_{re} 0.12 + j 0.09	Y_{12e} −0.4 − j 1.0	β_r −0.215 − j 0.02
	h_{ib} 67.0 + j 53.8 ohms	Y_{11b} 9.1 − j 6.9	h_{ie} 115 − j 75 ohms	Y_{11e} 5.9 + j 4.1	
	h_{ob} 0.2 + j 4.25 mmhos	Y_{22b} 1.8 + j 4.2	h_{oe} 3.2 + j 3.0 mmhos	Y_{22e} 1.9 + j 4.3	



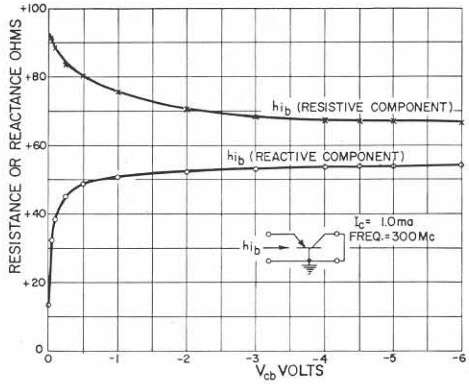


Figure 8. Variation of parameters of a diffused-base transistor as a function of collector voltage.

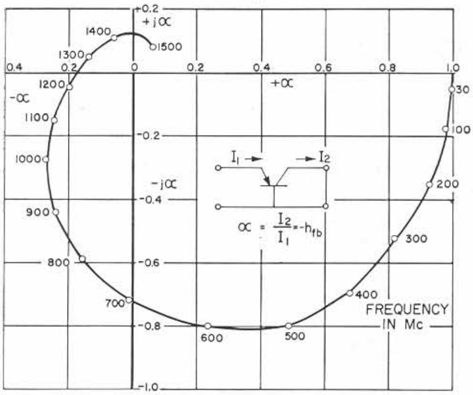


Figure 9. Plot of α, or $-h_{fb}$, versus frequency for a diffused base transistor.

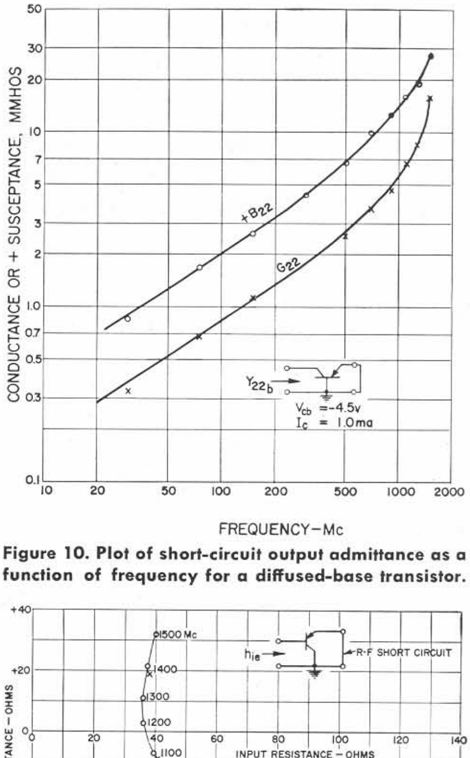


Figure 10. Plot of short-circuit output admittance as a function of frequency for a diffused-base transistor.

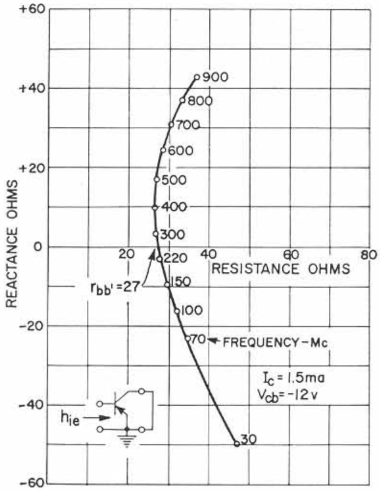


Figure 11. Plot of input reactance versus input resistance, with output short circuited, for a low-frequency transistor.

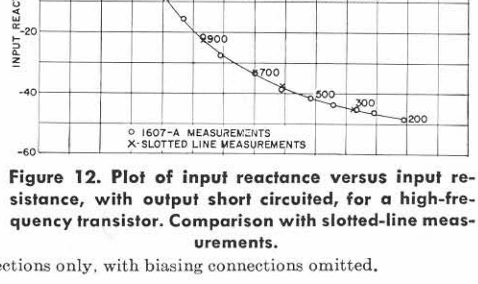


Figure 12. Plot of input reactance versus input resistance, with output short circuited, for a high-frequency transistor. Comparison with slotted-line measurements.

NOTE: All schematics on this page show *rf* connections only, with biasing connections omitted.

Bridge. These measurements are plotted on the same figure, and it is evident that they agree very closely with the Transfer-Function and Immittance Bridge measurements.

Advantages of the Transfer Function and Immittance Bridge

The Transfer-Function and Immittance Bridge has a number of very important advantages over other methods of measuring transistor characteristics in the VHF-UHF range.

(a) All measurements are made *directly*, with the transistor operating in the *proper environment* as defined by the parameter being measured. In most cases no calculations are required to obtain any desired short-circuit or open-circuit input, output, or transfer function. Direct measurements save time and avoid deterioration of measurement accuracy.

(b) All input, output, and transfer measurements on a given transistor with a given common electrode are made with the *same* mount, so that consistency between these different functions is assured. Furthermore, standard mounts are *available* and are not a design problem to the user.

(c) The unusually wide frequency range from 25 Mc to 1500 Mc is valuable in most applications and is of particular interest for today's new commercial transistors.

(d) The bridge can be operated with a very low rf level on the unknown, which is essential for the measurement of transistors and other nonlinear devices.

(e) First impressions notwithstanding, the bridge is *very simple*. The initial appearance of complexity is due to the *large number of different things that it can measure*, but each of these things *by itself* is measured in a straightforward and simple manner.

The bridge is completely passive, with stability of calibration dependent only on permanent, physical dimensions.

Finally, the instrument makes *basic* measurements of circuit characteristics that have been in use since the beginning of radio and that will continue to be used indefinitely into the future of electronics. Currently its most popular use is for the measurement of transistors, but its ability to measure any network, active or passive, indicates a much wider field of application.

Acknowledgment

The authors wish to acknowledge the contributions of Peter D. Strum to the development of this instrument.

—W. R. Thurston
R. A. Soderman

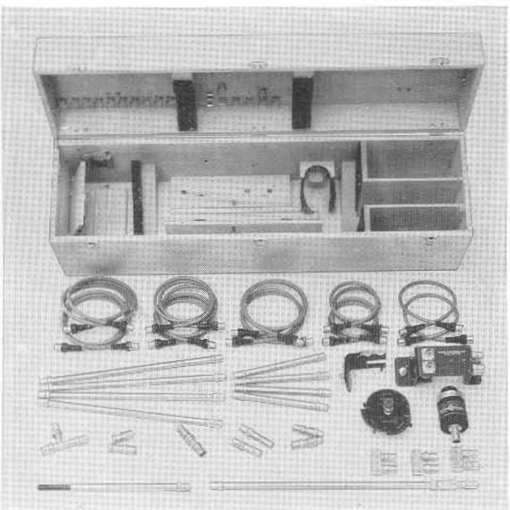


Figure 13. View of the instrument storage box with accessories that are supplied with the Type 1607-A Transfer-Function and Immittance Bridge.

SPECIFICATIONS

Frequency Range: 25 to 1500 Mc, with reduced accuracy above 1000 Mc and when flexible cable is used in the lines. The use of this cable is required at frequencies below 150 Mc and is optional at other frequencies.

Measurement Range: **Accuracy:** (up to 1000 Mc)

Voltage and Current Ratios
(R) 0–30 $2.5\,(1+\sqrt{R})\% + 0.025$

Transimpedance (Z_{21})
0–1500 ohms $2.5\left(1+\sqrt{\frac{Z_{21}}{50}}\right)\% + 1.25$ ohms

Transadmittance (Y_{21})
0–600 mmhos $2.5\left(1+\sqrt{\frac{Y_{21}}{20}}\right)\% + 0.5$ mmho

Impedance (Z_{11})
0–1000 ohms $2.0\left(1+\sqrt{\frac{Z_{11}}{50}}\right)\% + 1.0$ ohm

Admittance (Y_{11})
0–400 mmhos $2.0\left(1+\sqrt{\frac{Y_{11}}{20}}\right)\% + 0.4$ mmho

DC Bias: Terminals are provided for introducing dc bias from external sources. Maximum bias current, 100 ma; maximum bias voltage, 400 volts.

Accessories Supplied: Range-Extension Unit; Transfer-Function Indicator; Immittance Indicator; 6 terminations (open, short, matched, etc.); standards; 10-db attenuator; 8 air lines (21.5 and 43 cm); 3 U-line sections; constant-impedance adjustable line; a special tee; 10 patch cords; carrying case with storage space for instrument and accessories.

Accessories Required: Generator, detector, and mount for unknown device. Unit Oscillators and Type DNT Detectors are recommended. For coaxial adaptors, see latest General Radio Catalog. See below for mounts available.

Other Accessories Available: Type 1607-P101 Transistor Mount for JETEC-30 base arrangement, grounded base. Type 1607-P102 Transistor Mount for JETEC-30 base arrangement, grounded emitter. Type 1607-P201 Tube Mount, 7-pin miniature, grounded-cathode, for 6AF4, 6AF4A, and other tubes with same connections.

Case: The instrument, with accessories, is mounted in a wooden carrying and storage case.

Dimensions: Case — 11¼ x 14½ x 40 inches.

Net Weight: 63 pounds.

Type		*Code Word*	*Price*
1607-A	Transfer-Function and Immittance Bridge	HYDRA	$1665.00
1607-P101	Transistor Mount (JETEC-30, grounded base)	TRANSMOUNT	60.00
1607-P102	Transistor Mount (JETEC-30, grounded emitter)	TOPICMOUNT	60.00
1607-P201	Tube Mount, 7-pin miniature, grounded cathode	TUBESMOUNT	75.00

U. S. Patent No. 2,548,457.

NEW *METERED* VARIACS, TYPES W5MT3A, W5MT3W

The usefulness of the Variac® autotransformer as a laboratory tool can be considerably enhanced by the inclusion of meters in the assembly so that voltage, current, or power measurements can be made directly without the necessity of finding, and connecting, external meters. To this end, General Radio offers two instruments, similar in appearance and construction, and differing only in one respect. The Type W5MT3A Metered Variac reads volts and *amperes;* the Type W5MT3W Metered Variac reads volts and *watts;* both are metered in the output or load circuit.

The metal case houses a Type W5 Variac, the meters, a current transformer, and the necessary switching and meter shielding. This latter is sufficiently effective to reduce the Variac stray field to a point permitting an over-all accuracy of 3% (full scale) with 2% meters. Connections are made through a three-wire cord (line) and a three-wire outlet (load). A double-pole off-on switch disconnects the instrument from both sides of the line in the off position. A make-before-break range switch permits switching under load of the dual scale ammeter or wattmeter, as the case may be, from 1 ampere to 5 amperes, full scale, or from 150 watts to 750 watts, full scale,

respectively. Current-coil circuit and, hence, load circuits are fused for 1 and 5 amperes in the W5MT3A (ammeter) model and for 2 and 5 amperes in the W5MT3W (wattmeter) model.

The finish matches standard W-line Variacs. The case is equipped with a convenient carrying handle. A net weight of 11¾ pounds assures ready portability.

SPECIFICATIONS

Frequency: 50-60 cycles.

Input Voltage: 115.

No Load Loss (60 cycles): 9 watts.

Output Voltage: 0-135 (0-150 voltmeter).

Output Current: (W5MT3A) Two ranges 0-1, 0-5 amperes.

Output Watts: (W5MT3W) Two ranges — 0-150, 0-750 watts.

Meter Accuracies: ±3% of full scale.

Switching: OFF-ON, two-pole switch disconnects assembly from line in "OFF" position.
Meter RANGE, HIGH-LOW, make-before-break to permit switching under load.

Terminals: Line — 3-wire cord and plug.
Load — 3-wire outlet receptacle (will accept parallel 2-wire plug).

Fusing: W5MT3A — 1 ampere, low range.
5 amperes, high range.
W5MT3W — 2 amperes, low range.
5 amperes, high range.

Angle of Rotation: 325°.

Driving Torque: 30-60 oz.-in.

Case Dimensions: 9$^{15}/_{16}$" high, 6¾" wide, 6⅜" deep and handle.

Net Weight: 11¾ pounds.

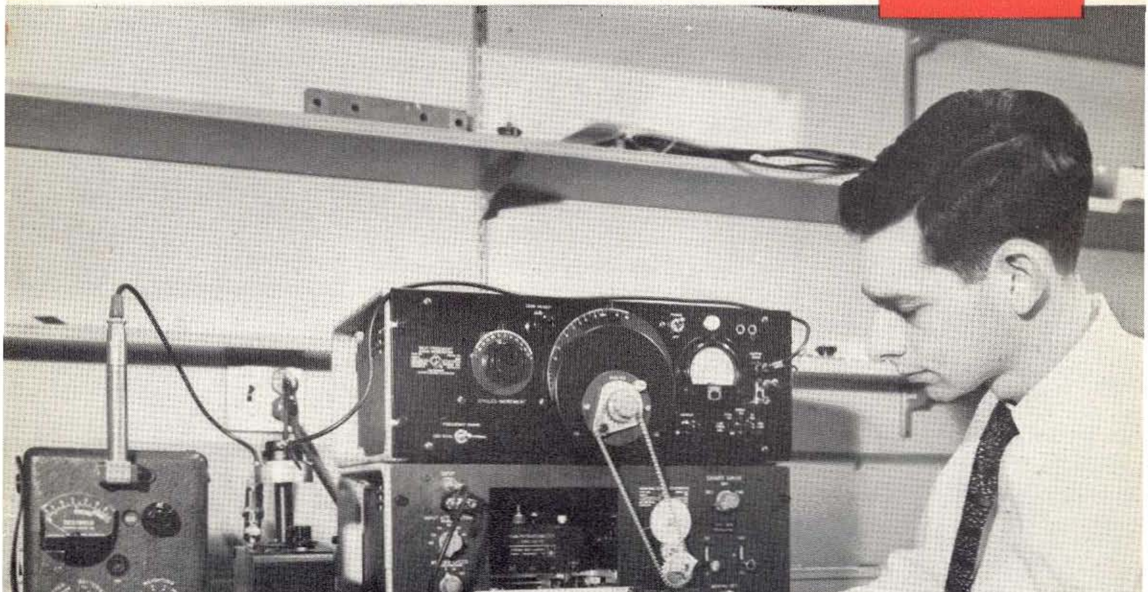
Type		*Code Word*	*Price*
W5MT3A	**Metered Variac (voltmeter, ammeter)**	CABAL	**$ 85.00**
W5MT3W	**Metered Variac (voltmeter, wattmeter)**	CABOB	**110.00**

Patent applied for.

General Radio Company

PRINTED IN U.S.A.

THE GENERAL RADIO
EXPERIMENTER



VOLUME 33 No. 6

JUNE, 1959

IN THIS ISSUE

Graphic Level Recorder

THE GENERAL RADIO

EXPERIMENTER

Published Monthly by the General Radio Company

VOLUME 33 • NUMBER 6 **JUNE, 1959**

CONTENTS

The General Radio EXPERIMENTER is mailed without charge each month to engineers, scientists, technicians, and others interested in electronic techniques in measurement. 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.

GENERAL RADIO COMPANY

West Concord, Massachusetts

Telephone: (Concord) *EMerson 9-4400;* (Boston) *CLearwater 9-8900*

NEW YORK: **Broad Avenue at Linden, Ridgefield, New Jersey**
Telephone — N. Y., WOrth 4-2722
N. J., WHitney 3-3140

CHICAGO: **6605 West North Avenue, Oak Park, Illinois**
Telephone — VIllage 8-9400

PHILADELPHIA: **1150 York Road, Abington, Pennsylvania**
Telephone — HAncock 4-7419

WASHINGTON: **8055 13th St., Silver Spring, Maryland**
Telephone — JUniper 5-1088

LOS ANGELES: **1000 North Seward St., Los Angeles 38, Calif.**
Telephone — HOllywood 9-6201

SAN FRANCISCO: **1186 Los Altos Ave., Los Altos, Calif.**
Telephone — WHitecliff 8-8233

CANADA: **99 Floral Parkway, Toronto 15, Ontario**
Telephone — CHerry 6-2171

REPAIR SERVICES

EAST COAST: **General Radio Co., Service Dept., 22 Baker Avenue, West Concord, Mass.**
Telephone — Concord, EMerson 9-4400
Boston, CLearwater 9-8900

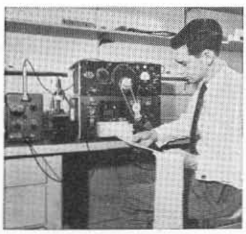
NEW YORK: **General Radio Co., Service Dept., Broad Ave. at Linden, Ridgefield, New Jersey**
Telephone — N. Y., WOrth 4-2722
N. J., WHitney 3-3140

MIDWEST: **General Radio Co., Service Dept., 6605 West North Ave., Oak Park, Illinois**
Telephone — VIllage 8-9400

WEST COAST: **Western Instrument Co., 826 North Victory Boulevard, Burbank, Calif.**
Telephone — VIctoria 9-3013

CANADA: **Bayly Engineering, Ltd., First St., Ajax, Ontario**
Telephone — Toronto EMpire 2-3741

COVER



The new General Radio Graphic Level Recorder plotting automatically the frequency response of an earphone. The earphone is driven by the Type 1304-B Beat-Frequency Audio Generator and is coupled to the Type 1551-P1 Condenser Microphone System through a standard ASA coupler. The output of the Condenser Microphone System is fed to the Type 1551-B Sound Level Meter, which drives the recorder.

A GRAPHIC LEVEL RECORDER WITH HIGH SENSITIVITY AND WIDE RANGES

A graphic level recorder has a wide variety of uses in electronics, acoustics, and other branches of physical science and engineering. It records on a logarithmic scale the rms magnitude of an ac voltage, rather than the instantaneous value and can plot the output of an ac device as a function either of time or of some other parameter that can be made time dependent, such as frequency. The TYPE 1521-A Graphic Level Recorder,* an accurate and versatile instrument for recording from 20 c to 200 kc, has an input sensitivity of one millivolt. It has been designed to meet the requirements of many different applications and has a number of outstanding electrical, mechanical, and operational features.

In this recorder, a high-speed servomechanism of novel design positions an input potentiometer and a pen to produce an ink trace on rectilinear paper. Potentiometers for ranges of 20, 40, and 80 db are available and can be interchanged easily and quickly.

An additional feature is an accessory linear potentiometer, which converts the instrument from a level recorder to a general-purpose dc recorder with adjustable zero level and 0.8-volt full-scale sensitivity.

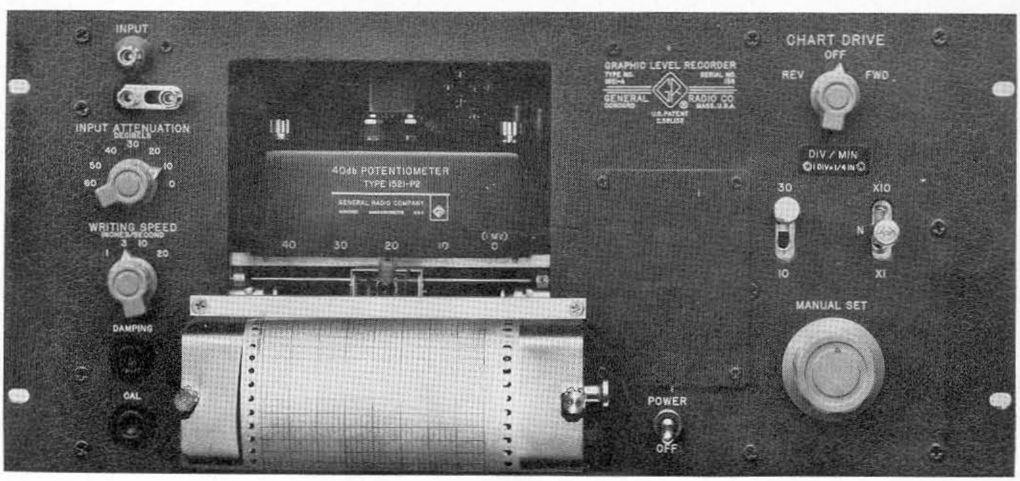
Transistors are used throughout the electronic circuitry, which eliminates warm-up delay and reduces power consumption and over-all size.

Controls are simple and have been reduced to a minimum: input amplitude, writing speed, and paper speed. These are separated into two groups: input signal and writing speed on the left-hand side of the panel; chart drive on the right.

The input and writing speed controls can be seen at the left of Figure 1. A constant impedance calibrated input attenuator is used to adjust the input level. The input terminal can be used with the low terminal either tied to the instrument chassis or floating for dc. The writing speed switch sets the maximum speed of the pen to one of four values from 1 inch per second to 20 inches per second, which, on the 80-db range, corresponds to 400 db per second.

*A completely new design based upon the Model SL-4 Recorder of Sound Apparatus Co.; U. S. Patent 2.581.133, now owned by General Radio Company.

Figure 1. Panel view of the Graphic Level Recorder with 40-db potentiometer and CTP-505 Chart Paper installed.



An adjustable damping control is also provided to allow setting of the overshoot for step inputs. This control is normally set for a 1-db overshoot at the maximum writing speed. A calibration control is also provided for setting the gain of the recorder in conjunction with an external ac reference voltage, so that the recorder will plot absolute level.

Four chart speeds are available with the motor supplied with the instrument: 2.5 in/min, 7.5 in/min, 25 in/min, and 75 in/min. Speed changes are easily made while the motor is running by means of two gear-shift levers shown at the right of Figure 1. A neutral position is also provided. The chart paper can be driven either forward or backward or controlled manually. By the use of a different motor, which is easily interchangeable (see the price table, page 12), these speeds can be reduced by a factor of 60. Chart paper is easily installed. Paper width is 5 inches and has a 4-inch recording range.

The recorder plots rms voltage level *vs.* time for frequencies between 20 and 200,000 cycles per second. Accessories are available to couple the chart drive to the dial of the Type 1304-B Beat-Frequency Audio Generator, the Type 1554-A Sound and Vibration Analyzer, or the Type 760-B Sound Analyzer to produce a plot of level *vs.* frequency. Chart paper with frequency scales is available for use with each of these instruments.

When coupled to the Beat-Frequency Audio Generator, the recorder produces plots having a true logarithmic frequency scale and is ideal for plotting the frequency response of analyzers, recording systems, networks, filters, and equalizers, as well as of loudspeakers, microphones, earphones, vibration pickups, and other transducers.

The combination of the recorder and either the Type 1554-A Sound and Vibration Analyzer[1] or the Type 760-B Sound Analyzer makes possible the automatic analysis of sound spectra and complex waveforms. When the network or device under test is excited by the Type 1390-A Random Noise Generator, a continuous spectrum response of that network to white noise can be plotted.

The high writing speed available with the 80-db potentiometer permits the recorder to be used for the measurement of reverberation time as short as approximately 0.5 second.

The wide range of paper speed facilitates long-period studies of the noise produced by traffic, office machinery, industrial processes, and potential hearing damage environments, as well as the measurement of short-duration transients.

PRINCIPLES OF OPERATION

The Type 1521-A Graphic Level Recorder utilizes a null-seeking servo system, which positions the pen on the chart paper.

The block diagram of the servo loop is shown in Figure 2. The input signal is applied through the input attenuator to the logarithmic potentiometer. The output of the potentiometer is amplified

[1]To be described in a forthcoming issue of the *Experimenter*.

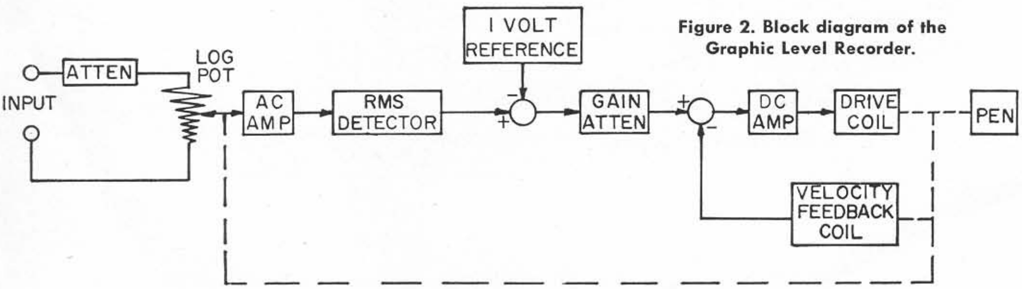


Figure 2. Block diagram of the Graphic Level Recorder.

and then rectified to produce a dc voltage proportional to the rms level of the ac input voltage. This dc voltage is compared with a 1-volt reference voltage, and their difference, which is the error signal, is used ultimately to position the drive coil.

Input Circuit and AC Amplifier

The input attenuator has a 60-db range in 10-db steps. It provides a constant 10,000-ohm input impedance, which can be increased, at corresponding sacrifice in sensitivity, by the addition of a resistor in series with the input. The sensitivity will, however, still be greater than that usually encountered in recorders of this type. The 10,000-ohm resistance of the potentiometer is a compromise between the desire for a high input impedance, the wire size required for the potentiometer, and the loading effects of the ac amplifier.

The ac amplifier consists of an emitter-follower input, four stages of gain, and a phase-inverter stage for driving the detector circuit. The high input impedance of the emitter follower minimizes its loading effect on the potentiometer. The gain of the amplifier is approximately 1000. It can be set to exactly 1000 in terms of an external ac reference voltage when it is desired to measure absolute level. Since the input attenuator is calibrated, the reference voltage can have any value between 1 mv and 10 volts. The gain of the amplifier is stabilized by a sufficient amount of inverse feedback to insure its stability of calibration. A regulated power supply is used to minimize the effects of line-voltage variations. The dynamic range of the amplifier is 15 db, which allows faithful reproduction of input signals with a peak-to-rms ratio of 5:1 — a feature of considerable importance in the recording of noise.

Detector

The detector has a quasi-rms response,[2] which closely approximates true rms for commonly encountered waveforms. The output is within 0.25 db of true rms for sine waves, multiple sine waves, square waves, and noise.

Since the output of the potentiometer is linear in db rather than in volts, the change in input voltage to the detector is significantly different for increasing and decreasing input signals. For example, a 10-db increase would momentarily produce 3.16 volts, a change of 2.16 volts from its normal 1-volt value, compared with 0.316 volt, or a change of −0.684 volt, for a 10-db decrease. In order to maintain comparable step responses in the two directions for these vastly differing signals, diode limiters are incorporated at the output of the detector. The level of limiting is set to produce similar transient responses for increasing or decreasing levels.

[2]E. E. Gross, "Improved Performance Plus a New Look for the Sound-Level Meter," *General Radio Experimenter*, Vol. 32, No. 17, October, 1958.

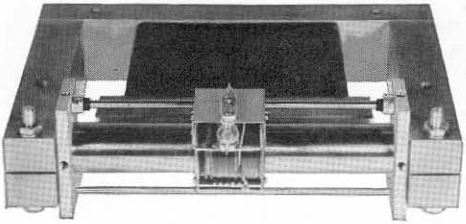


Figure 3. View of the magnetic structure and pen motor.

Pen Drive Circuit

The output of the detector is compared by emitter followers to a 1-volt dc reference obtained from the regulated 18-volt supply. An attenuator (gain switch) which changes the loop-gain according to the potentiometer used is located immediately after the emitter followers. A velocity-feedback signal (see below) is also injected at this point. The sum of the error voltage and the velocity feedback voltage is then amplified by a push-pull dc amplifier, which is drift compensated by means of negative feedback. Two power transistors are used to produce current through the drive coil or servo motor.

The servo motor consists of a center-tapped coil wound on a lightweight lucite form, which is positioned in the uniform magnetic field produced by a large Alnico permanent magnet. The magnetic structure and coil are shown in Figure 3. The interaction between the current in the coil and the field from the permanent magnet results in a force to move the coil in a direction to reduce the error voltage. When the coil is correctly positioned, the error voltage and the current in the coil become zero, and there is no further force on the coil. The coil will remain in this position as long as the input voltage remains constant because of the electrical restoring force produced on the coil for any slight movement about the correct null position. Full current flows through the coil for a displacement only a $\frac{1}{32}$ inch from the true null, resulting in a high degree of static accuracy. Because the pen and potentiometer wiper arm are located directly on the coil structure, there is no possibility of backlash, or dead zone, between movements of the servo motor and corresponding movements of the potentiometer and pen. Since the servo motor has a straight-line movement, the resulting recording is truly rectilinear.

Velocity Feedback

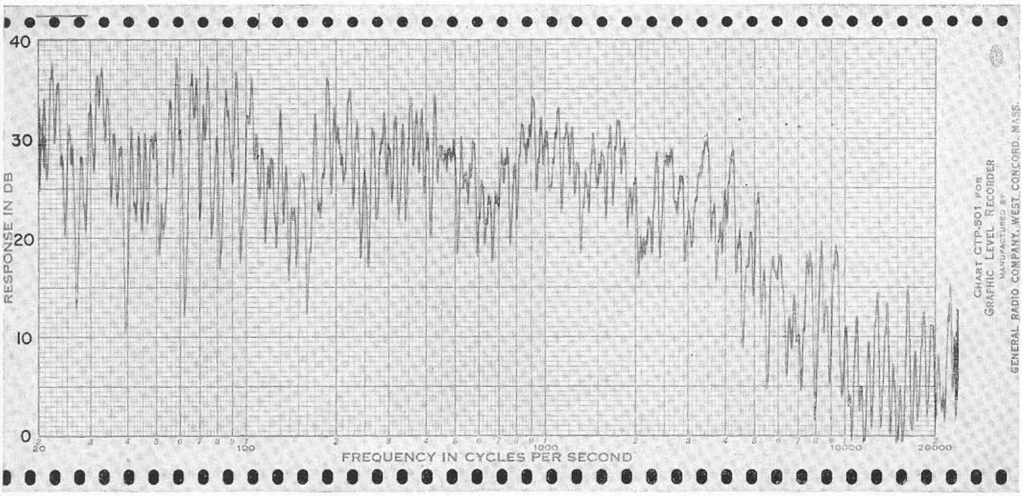
A second winding on the drive coil structure generates a voltage proportional to the coil velocity. This damping voltage is fed back around the drive coil through the dc amplifier to reduce the time constant of the drive-coil circuit. As a result, an adequate degree of stabilization can be obtained consistent with a reasonable bandwidth of the pen servo and the desired static accuracy. Slower writing speeds are obtained by increasing the amount of damping voltage. Since the output from the detector is limited, an increase in damping voltage results in a decrease in both the pen servo bandwidth and the maximum writing speed (saturation velocity of the pen). The slower writing speed positions are useful for filtering out rapid variations in the level of the input signal when it is desired to obtain an average value of these variations.

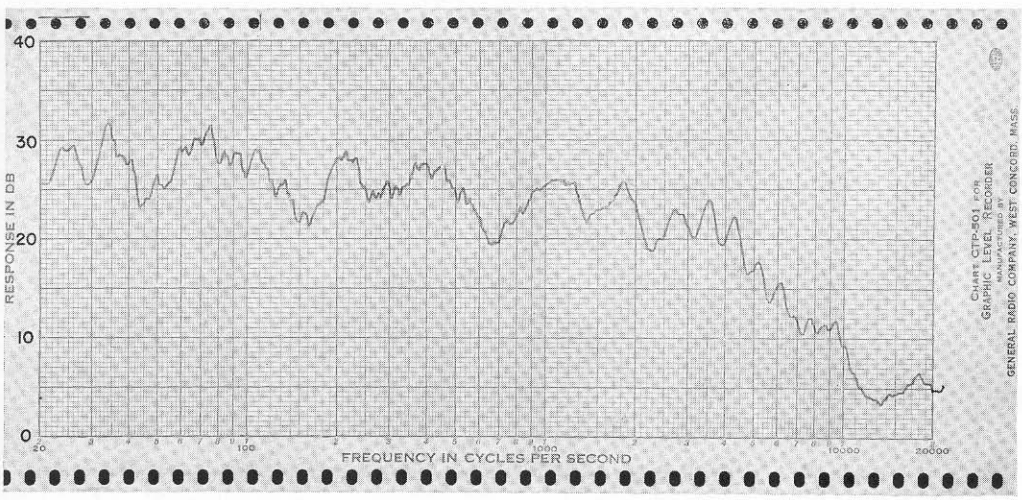
Figure 4 shows a plot of the frequency response of a public address system installed in a large auditorium as recorded with both maximum and minimum settings of the writing-speed control. The bandwidth of the pen servo is approximately 0-10 cps in the 20-inch per second writing speed position and decreases in approximately the same ratio as the writing speeds marked on the control. Because of the limitation in maximum velocity, the servo bandwidth is a function of amplitude. The writing speeds indicated on the control are only approximate and represent a coil velocity obtained when the dc amplifier is saturated. As such, they should be used only as an indication of the upper limit of the capabilities of the recorder to follow changes in the level of the input signal.

Logarithmic Potentiometers

The potentiometers have shaped winding forms and are tapped for the connection of padding resistors to obtain an accurate logarithmic function. Since the same size wire is used throughout the length of the potentiometer, a high degree of resolution is maintained for all positions of the slider. The rated accuracy of the potentiometers is 1% full scale, but that of the 20-db and 40-db potentiometers is usually better than 0.5% of full scale. Life tests on these potentiometers have indicated that, with periodic application of proper lubricants, a

Figure 4. Records of the frequency response of a public address system, taken with (*top*) maximum writing speed and (*below*) minimum writing speed.





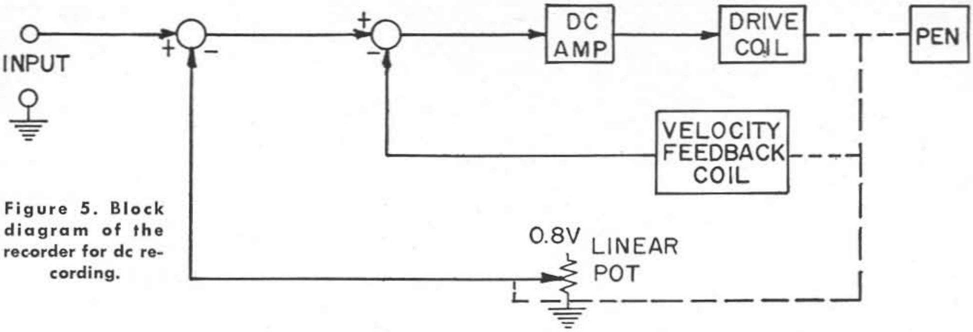


Figure 5. Block diagram of the recorder for dc recording.

life of many millions of cycles can be expected.

The potentiometers are positioned on the mounting shelf by means of two pins, which mate with corresponding holes in the shelf. Input connections to the potentiometer are made by means of a shielded cable which plugs into the top of the potentiometer case. Pins, located at the rear of the case, prevent the potentiometer from being seated unless the gain switch is in the correct position. This switch can be operated through the opening in the front of the instrument.

DC Recording

The Type 1521-A Graphic Level Recorder can be converted into a dc recorder with a 1-kilohm input impedance and an 0.8-volt full-scale sensitivity by use of the linear potentiometer (Type 1521-P4). Figure 5 is a block diagram of the recorder servo loop for dc recording. The necessary circuit changes are accomplished by means of the gain switch and one plug. Since the ac amplifier cannot be used for dc recording, the sensitivity of the recorder is considerably reduced. The input impedance is limited to 1 kilohm because of the collector leakage current of the input transistors. This impedance can be increased by a factor of 10 if the effects of leakage current are included in the zero adjustment of the recorder.

A zero adjustment is provided on the front of the linear potentiometer to allow the operator to set the zero position to any point on the chart paper. The servo bandwidth is not affected by the change to a dc recorder.

ACCESSORIES AVAILABLE

(See price list, page 12)

Potentiometers

The 40-db potentiometer is supplied, and the 20-db, 80-db, and linear potentiometers are available as accessories.

Motors

Accessory motors (50-cycle and 60-cycle) are available for slow-speed chart drive. These motors produce chart speeds of 2.5 to 75 inches/hour, a reduction by a factor of 60 from the speeds available with the standard motors.

Drive and Link Units

The 1521-P10 Drive Unit is designed to couple the recorder to all external oscillators or analyzers. Separate link units are required on the various external instruments for coupling the drive unit to the instrument dial shaft. By means of a cam-operated clutch, the recorder paper position and the oscillator or analyzer setting can be made completely independent of one another. Limit stop switches allow the operator to set the limit of travel of the drive unit. A slip clutch also is provided to protect the oscillator or analyzer.

The recorder can be used for time-base measurements without removal of the drive unit. To do this, the drive unit clutch is decoupled, and the limit switches are shorted out with a toggle switch behind the panel.

Link units are available for driving the dials of the following General Radio instruments: Type 1304-B Beat-Frequency Audio Generator, Type 760-B Sound Analyzer, and Type 1554-A Sound and Vibration Analyzer.

Charts

Four types of chart paper are available:

CTP-505 is supplied and is designed for recording level *vs.* time or for dc recording.

CTP-501 is designed for use with the Type 1304-B Beat-Frequency Audio Generator.

CTP-516 is designed for use with the Type 760-B Sound Analyzer.

CTP-554 is designed for use with the Type 1554-A Sound and Vibration Analyzer.

APPLICATIONS

Level *vs.* Time

The Type 1521-A Graphic Level Recorder can be used in conjunction with a Type 1551-B Sound-Level Meter to yield permanent records of sound level as a function of time. Rapid changes in the sound level can be filtered out, when desirable, through the use of one of the slow writing speeds.

Continuous recordings can be made for periods from 16 minutes to 8 hours with the standard motor or from 16

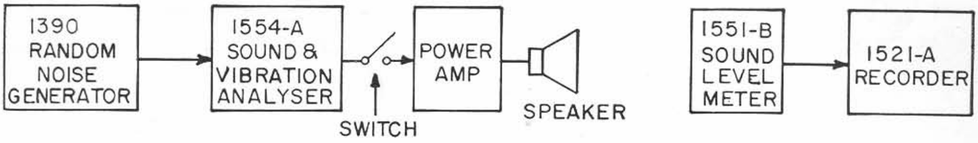


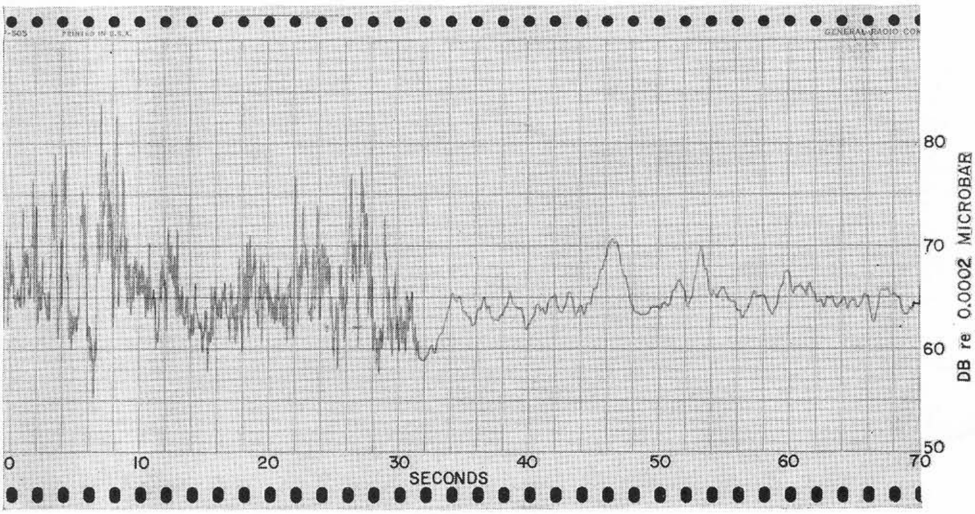
Figure 7. Block diagram of system for reverberation-time measurement with narrow-band noise source.

hours to 480 hours with the -P20 or -P21 Motors. The recorder can be calibrated to read in absolute sound pressure level with the sound-level meter attenuator switch in the CAL position. A typical plot of noise in a cafeteria with the recorder on both fast and slow writing speed positions is shown in Figure 6.

A second application as a time-base recorder is in the measurement of reverberation time. Reverberation time is defined as the time required for a sound level to decay 60 db. In this measurement a sound source in a room is abruptly shut off and the decay of the sound level is recorded. The 80-db potentiometer often is used for these measurements, but, since background noise often prevents reverberation recording over even a 60-db range, the 40-db potentiometer may be equally useful.

The nature of the sound source used for these measurements may have some influence on the accuracy of the results. The use of a fixed-frequency source can result in errors in the measurement owing to standing waves set up in the room. These errors can be avoided to some extent if the oscillator frequency is varied slightly or warbled. A better solution is the use of a noise source and a narrow band filter. Figure 7 shows a diagram of such a setup using the Type 1390-A Random Noise Generator and the Type 1554-A Sound and Vibration Analyzer to feed a power amplifier and loudspeaker. The sound level is picked up by a Type 1551-B Sound-Level Meter and applied to the recorder. A wider dynamic range can be obtained if a second analyzer is used following the Sound-Level Meter. The maximum writing speed and chart speed should be used when making reverberation measurements. Reverberation time as small as 0.5 second can be measured adequately with this recorder. A typical reverberation measurement made in an auditorium is shown in Figure 8.

Figure 6. Recording of noise level in a cafeteria with both fast and slow writing speeds and 40-db potentiometer.



Level vs. Frequency

The recorder can be used to plot directly frequency-response data of networks or systems in conjunction with the TYPE 1304-B Beat-Frequency Audio Generator. A TYPE 1521-P10 Drive Unit and TYPE 1521-P11 Link Unit are required to couple the generator to the recorder. Since the change in frequency of the generator with respect to dial rotation is logarithmic, chart-paper motion will correspond to a logarithmic frequency change. Chart Paper CTP-501 has the logarithmic frequency calibration printed along the time axis over the three decades from 20 cps to 20 kc. The amplitude control of the generator and the input attenuator of the recorder can be used to obtain the desired 0-db reference level. If the input to the network or system under test must be maintained at some specified value, the 0-db reference level can then be adjusted by means of the input attenuator and "CAL" control on the recorder, provided that the minimum input signal to the recorder is 1 millivolt or greater. The chart paper and oscillator can be adjusted to the desired starting frequency by disengagement of the clutch on the drive unit. Figure 9 shows the generator-recorder combination.

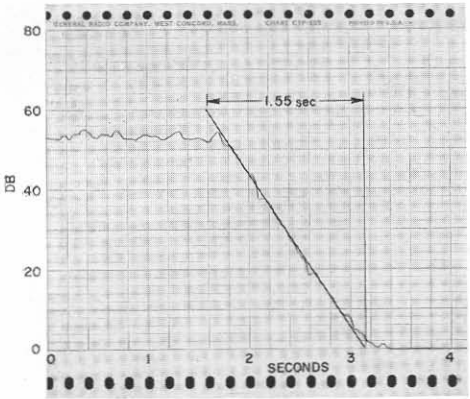


Figure 8. Record of sound decay in an auditorium. Reverberation time is 1.55 seconds.

This combination is ideal for measuring the frequency response of filters, attenuators, or other networks, as well as loudspeakers, microphones, or other transducers, and complete acoustic systems. A typical response of an adjustable notch filter is shown in Figure 10. The response of a condenser microphone mounted in an anechoic chamber is

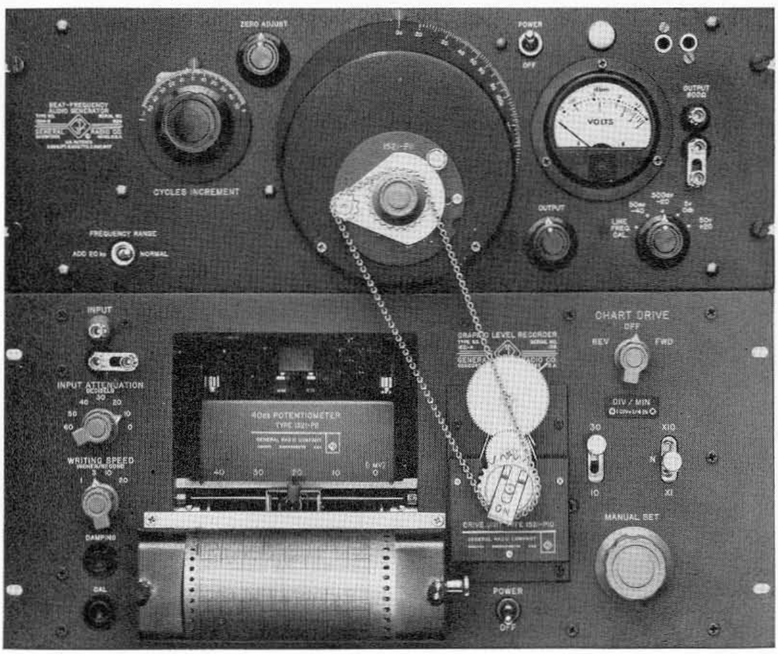


Figure 9. View of the Graphic Level Recorder coupled to drive the Beat-Frequency Audio Generator for automatic recordings of amplitude vs. frequency.

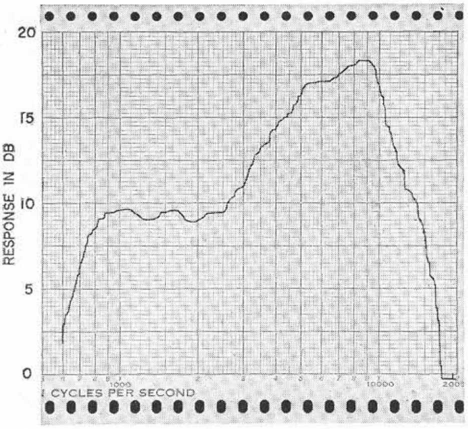


Figure 11. Recorded response, for frequencies above 600 cycles, of a condenser microphone in an anechoic chamber. Plot includes the characteristics of the source.

shown in Figure 11. The response of the public address system in an auditorium is shown in Figure 4.

The output voltage from the Type 1304-B Beat-Frequency Audio Generator is sufficiently constant with frequency (± .25 db) for most applications. In the calibration of a microphone where the sound source is a loudspeaker or where the device under test has a variable input impedance with frequency, it may be desirable to use a second Type 1521-A Graphic Level Recorder to maintain a constant sound pressure level or to vary the reference voltage to account for changes in the oscillator output voltage, as explained later.

Frequency Analysis

A frequency analysis of a sound spectrum or the output of an electrical device can be made with the recorder in conjunction with either the Type 760-B Sound Analyzer or the Type 1554-A Sound and Vibration Analyzer. Connection between the analyzer and the recorder is made by the appropriate link unit in the same manner as with the audio generator. The chart paper for use with the analyzer (CTP-516) has three calibrated ½-decade segments properly spaced so a 2½-decade analysis can be made without stopping the recorder. The change in range can be accomplished during the blank portion of the dial. The Type 1554-A Analyzer does not have a continuously rotatable dial, and so the dial must be returned manually to the low end before the next range is plotted. However, the dial ranges are in 1-decade intervals, so that only three resettings are required to cover the range from 25 cps to 25,000 cps.

Figure 10. Record of the transmission characteristic of an adjustable notch filter for four different frequency settings.

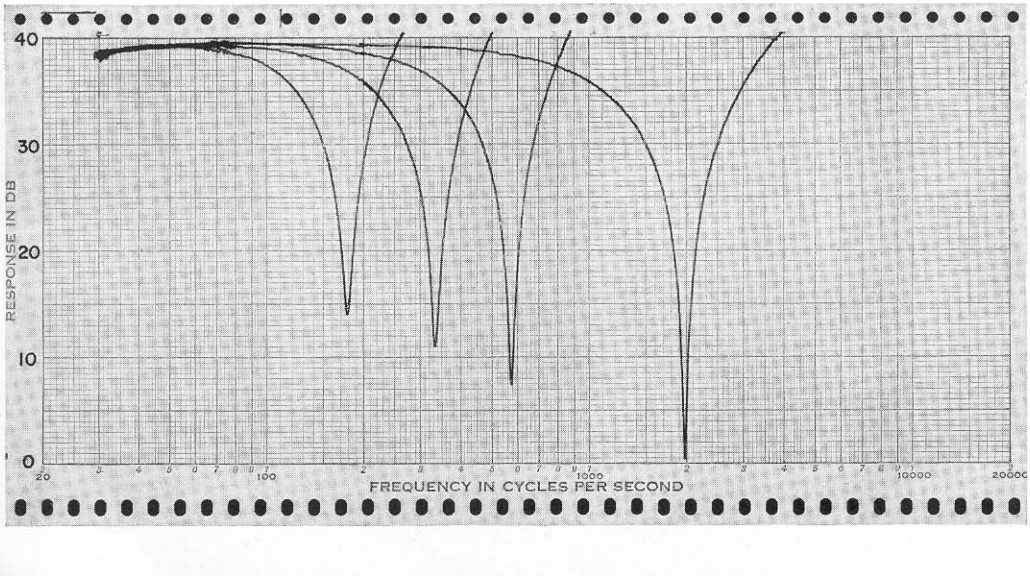
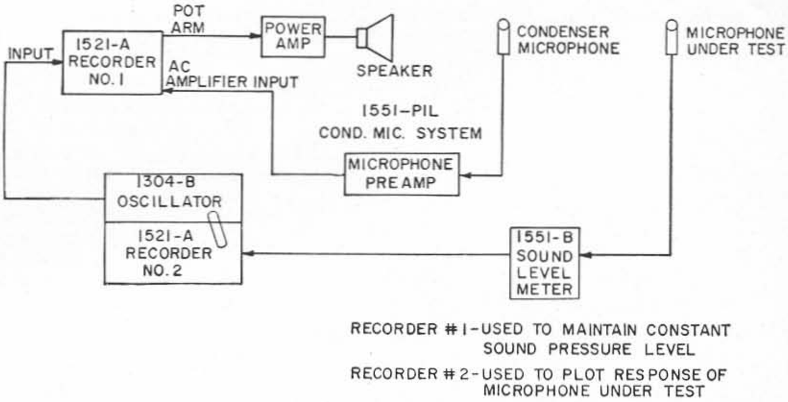


Figure 12. Block diagram showing how two recorders can be used to maintain constant sound pressure level for the measurement of microphone characteristics.



Miscellaneous

The TYPE 1521-A Graphic Level Recorder can be used to maintain constant sound pressure levels in a chamber when the frequency response of microphones is measured. The block diagram in Figure 12 shows the equipment required for this operation. The normal connection between the arm of the potentiometer and the input to the ac amplifier is opened by removal of a jumper on the rear of the etched circuit. The arm of the potentiometer is connected to the input of the power amplifier driving the loudspeaker, and the output of the condenser microphone pre-amplifier is connected into the ac amplifier in the recorder. The recorder will automatically position the potentiometer arm to maintain a constant output level from the condenser microphone. The range over which this correction can be made is the same as that of the potentiometer in the recorder. As long as the recorder is on scale, the sound pressure level will be maintained constant (assuming a flat response for the condenser microphone). The regulating recorder will plot the response of the loudspeaker system. A second TYPE 1521-A Recorder is necessary to plot the frequency of the microphone under test.

Small variations in the output level of an oscillator used for frequency response measurements can be corrected for by the use of an external reference which is a function of the oscillator output level and which can be generated by an external detector. This can be substituted for the internal fixed reference by the removal of a jumper on the back of the etched circuit.

Acknowledgments

The design of the TYPE 1521-A Recorder resulted from the combined efforts of a number of people. Particular credit should be given to James J. Faran, Martin Basch, P. K. McElroy, and George Neagle. D. B. Sinclair and Arnold Peterson supplied numerous suggestions and followed the development with considerable interest and enthusiasm.

— M. C. HOLTJE
M. J. FITZMORRIS

SPECIFICATIONS

Input Frequency Range: 20 cps to 200 kc, for level recording; servo bandwidth, dc to 10 cps.

Input Range: 0 to 40 db for level recording (20-db and 80-db potentiometers are also available); 0-0.8 volt (at 1000 ohms) full scale, for dc recording with zero input position adjustable over full scale.

Accuracy: Potentiometer balances within 0.5% of full scale.

Maximum Sensitivity: 1 millivolt at 0 db for level recording; 0.8 volt full scale for dc recording.

Maximum Input Voltage: 100 volts ac.

Input Impedance: 10,000 ohms for ac level recorder; 1000 ohms for dc recorder.

Paper Speeds: 2.5 inches per minute to 75 inches per minute. A slow-speed motor to provide speeds of 2.5 to 75 inches per hour is available.

Writing Speed: 1, 3, 10, or 20 inches per second (approximately), with overshoot less than 1 db.

Detector: Quasi-rms; within 0.25 db of rms for multiple sine waves, square waves, or noise.

Chart: 4-inch recording width on 5-inch paper.

Transistor Complement: 12-2N169A, 4-2N321, 2-2N301, 1-2N176.

Accessories Supplied: Spare fuses, power cord, 2 pens, 2-oz. bottle of ink, 40-db pot, 1 roll of CTP-505 paper, adaptor cable assembly for connection to Type 1551-B Sound-Level Meter.

Accessories Available: Potentiometers, charts, ink, slow-speed motors, and link units.

Power Supply: 105 to 125 (or 210 to 250) volts, 60 cycles, 35 watts. 50-cycle models are available.

Power input receptacle will accept either 2-wire (Type CAP-35) or 3-wire (Type CAP-15) power cord. Two-wire cord is supplied.

Dimensions: (Height) 9 x (width) 19½ x (depth) 14¼ inches, over-all. Available for bench or relay-rack mounting.

Net Weight: 50 pounds.

Type		*Code Word*	*Price*
1521-AR	Relay-Rack Model, for 60-cycle supply	AGENT	$995.00
1521-AM	Bench Model, for 60-cycle supply	ASTER	995.00
1521-ARQ1	Relay-Rack Model, for 50-cycle supply	AGENTRABID	995.00
1521-AMQ1	Bench Model, for 50-cycle supply	ASTERRABID	995.00

Patent No. 2,581,133.

POTENTIOMETERS FOR OTHER RANGES

1521-P1	20-db Potentiometer	FACET	$ 55.00
1521-P3	80-db Potentiometer	FELON	155.00
1521-P4	Linear Potentiometer, for dc recording	FAUNA	55.00

CHARTS

CTP-501	Calibrated 20 cps-20 kc, logarithmic, in 9 inches, repeating every 12 inches along time axis; for use with Type 1304-B Beat-Frequency Oscillator	LOGARCHART	$2.30*
CTP-505	Linear time base, 1 division = ¼ inch; for ac or dc records as a function of time	LINALCHART	2.30*
CTP-516	Calibrated 25-7500 cps in ½-decade segments, spaced for continuous rotation of analyzer knob; for use with Type 760-B Sound Analyzer	SOUNDCHART	2.30*
CTP-554	Calibrated 25-25,000 cps along time axis; for use with Type 1554-A Sound and Vibration Analyzer	ANNALCHART	2.30*

Charts are 5 inches wide and have 8 major divisions on a 4-inch vertical scale with 40 total divisions (80 on CTP-501). Roll length 100 feet. All may be used with any potentiometer.

INK (red)

1521-409	2-ounce bottle	INKAL	$0.85*
1521-409-2	16-ounce bottle	INKER	3.00*

*Subject to quantity discounts.

MOTORS FOR LOWER CHART SPEED

1521-P20	(60 cycles) for paper speeds of 2.5-75 inches/hour	PASTY	$52.50
1521-P22	(50 cycles) for paper speeds of 2.5-75 inches/hour	PERIL	52.50

DRIVE AND LINK UNITS FOR COUPLING TO OSCILLATOR AND ANALYZERS

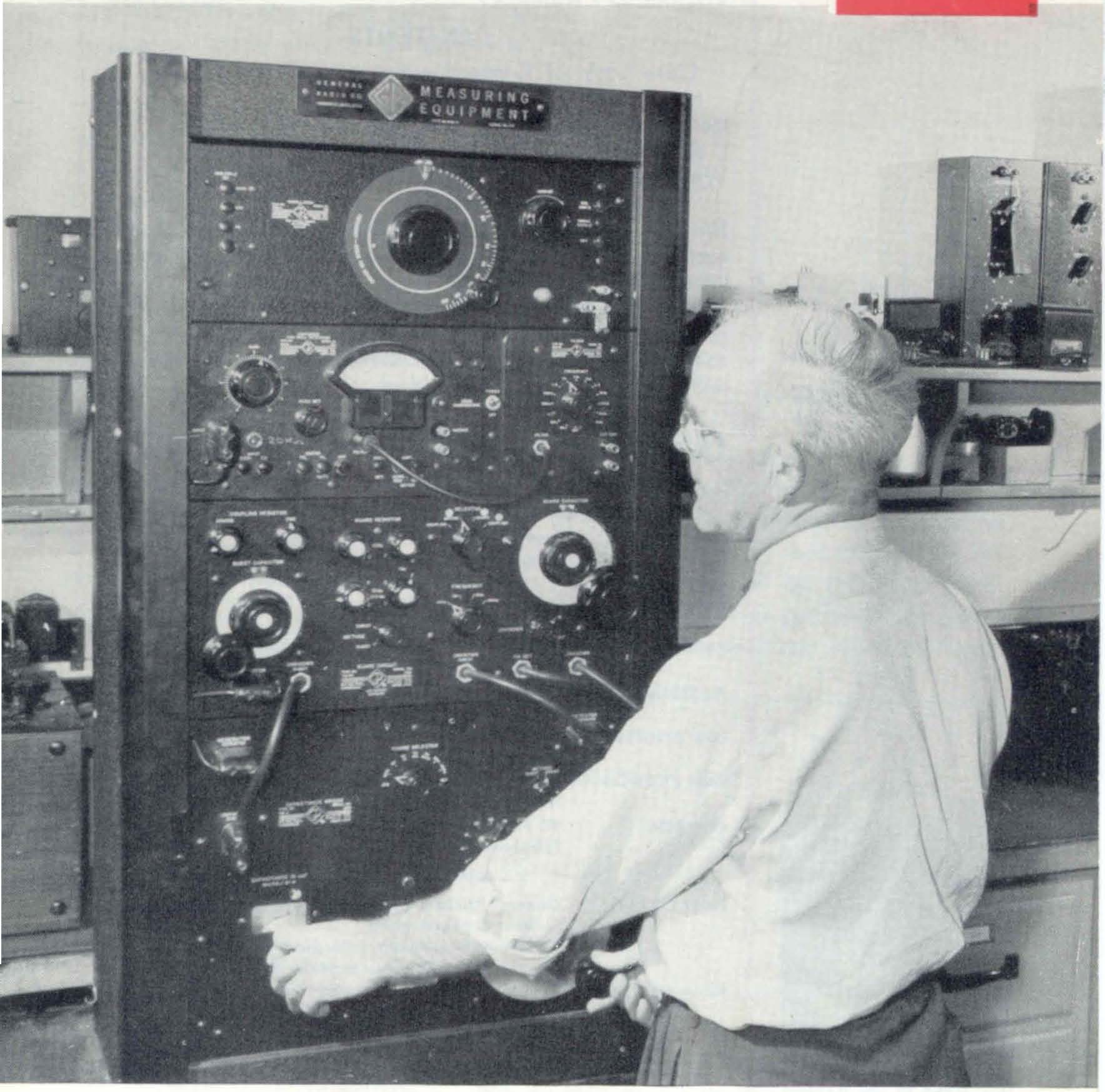
1521-P10	Drive Unit to operate all link units	PUPIL	$72.00
1521-P11	Link Unit for coupling to Type 1304-B or Type 1554-A	PRIOR	18.00
1521-P12	Link Unit for coupling to Type 760-B	PUPPY	18.00

General Radio Company

PRINTED IN U.S.A.

THE GENERAL RADIO

EXPERIMENTER



VOLUME 33 No. 7 JULY, 1959

IN THIS ISSUE

THE GENERAL RADIO

EXPERIMENTER

Published Monthly by the General Radio Company

VOLUME 33 · NUMBER 7 **JULY, 1959**

CONTENTS

The General Radio EXPERIMENTER is mailed without charge each month to engineers, scientists, technicians, and others interested in electronic techniques in measurement. 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.

GENERAL RADIO COMPANY

West Concord, Massachusetts

Telephone: (Concord) *EMerson 9-4400;* (Boston) *CLearwater 9-8900*

NEW YORK:	**Broad Avenue at Linden, Ridgefield, New Jersey** *Telephone — N. Y., WOrth 4-2722* *N. J., WHitney 3-3140*
CHICAGO:	**6605 West North Avenue, Oak Park, Illinois** *Telephone — VIllage 8-9400*
PHILADELPHIA:	**1150 York Road, Abington, Pennsylvania** *Telephone — HAncock 4-7419*
WASHINGTON:	**8055 13th St., Silver Spring, Maryland** *Telephone — JUniper 5-1088*
LOS ANGELES:	**1000 North Seward St., Los Angeles 38, Calif.** *Telephone — HOllywood 9-6201*
SAN FRANCISCO:	**1186 Los Altos Ave., Los Altos, Calif.** *Telephone — WHitecliff 8-8233*
CANADA:	**99 Floral Parkway, Toronto 15, Ontario** *Telephone — CHerry 6-2171*

REPAIR SERVICES

EAST COAST:	**General Radio Co., Service Dept., 22 Baker Avenue, West Concord, Mass.** *Telephone — Concord, EMerson 9-4400* *Boston, CLearwater 9-8900*
NEW YORK:	**General Radio Co., Service Dept., Broad Ave. at Linden, Ridgefield, New Jersey** *Telephone — N. Y., WOrth 4-2722* *N. J., WHitney 3-3140*
MIDWEST:	**General Radio Co., Service Dept., 6605 West North Ave., Oak Park, Illinois** *Telephone — VIllage 8-9400*
WEST COAST:	**Western Instrument Co., 826 North Victory Boulevard, Burbank, Calif.** *Telephone — VIctoria 9-3013*
CANADA:	**Bayly Engineering, Ltd., First St., Ajax, Ontario** *Telephone — Toronto EMpire 2-3741*

COVER

This scene in the General Radio Standards Laboratory shows the Type 1610-A Capacitance Measuring Assembly in use for the measurement of 3-terminal capacitors.

A CLOSE LOOK AT CONNECTION ERRORS IN CAPACITANCE MEASUREMENTS

The growing interest in capacitance measurements both of higher accuracy and of smaller capacitance has led to a re-examination of some of the problems involved in the *precise* and *accurate* measurement of small capacitance. It has been evident for some time that errors and uncertainties of the order of a few tenths of a picofarad were present in most measurements of two-terminal capacitors.[1] Such errors are not very significant in the calibration of standard capacitors as long as the capacitance exceeds 100 pf and the desired accuracy is no greater than 0.1%. Any attempt however, to calibrate smaller capacitors to this accuracy, or to increase the accuracy of other calibrations, demands a consideration of the accuracy limitations imposed by the connection errors in the usual two-terminal measurements.

[1] The common capacitor is here characterized specifically as two-terminal because a three-terminal capacitor will be introduced and defined later.

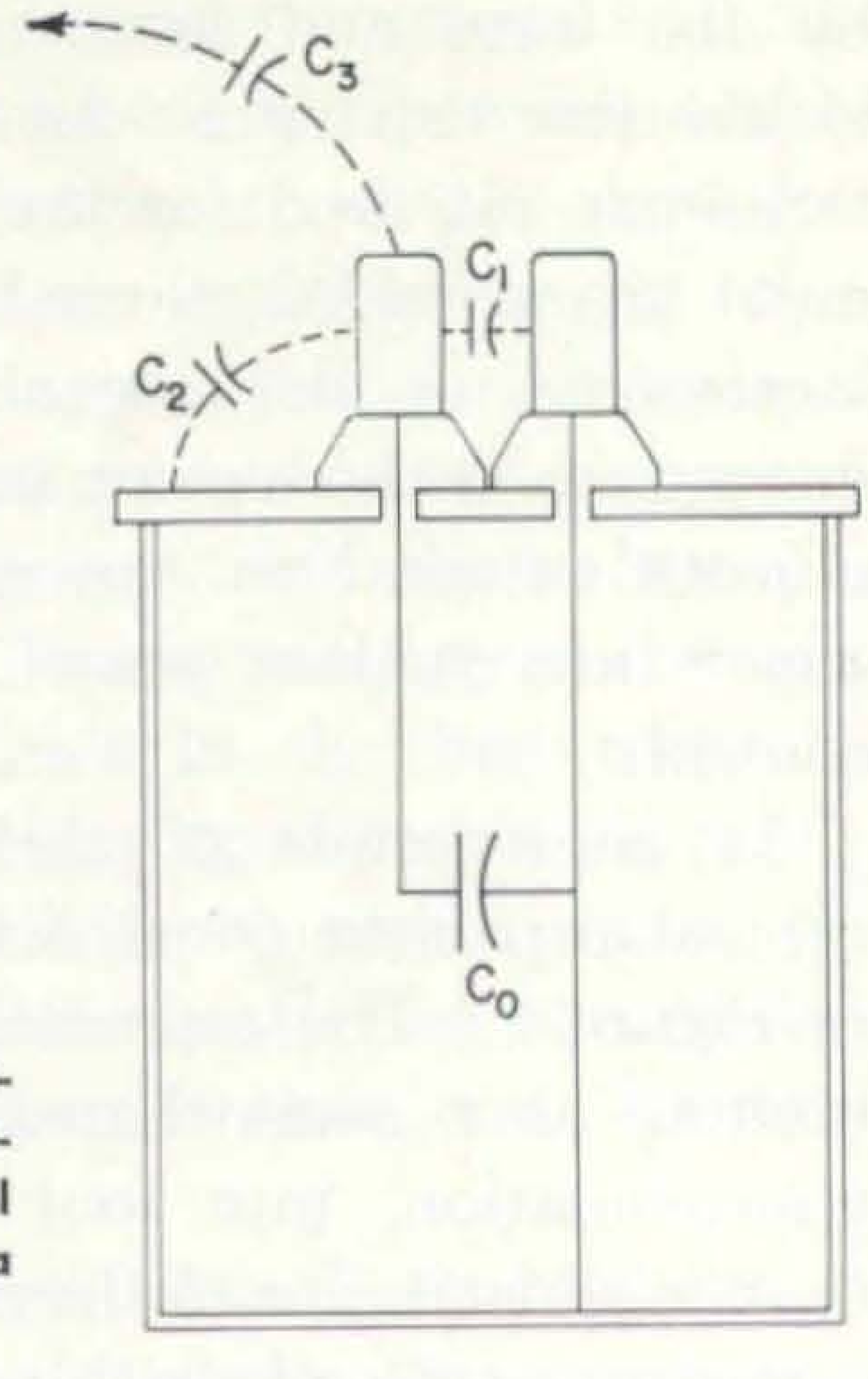
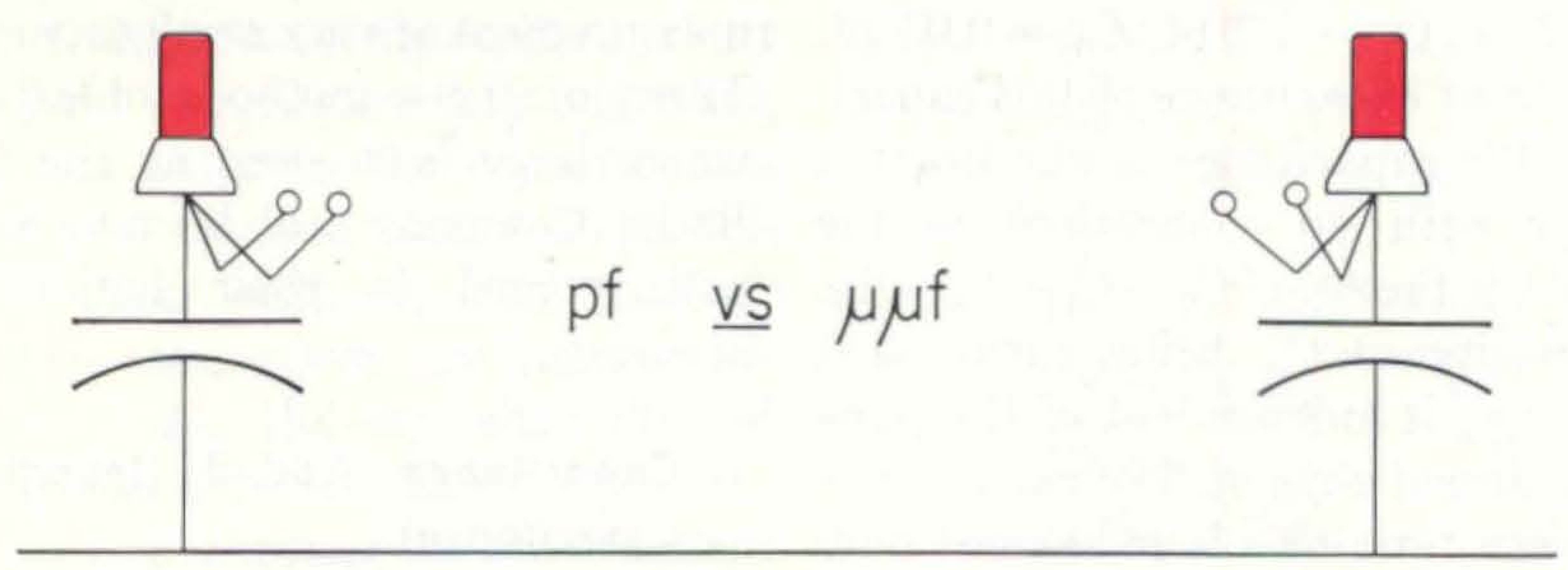


Figure 1. Schematic diagram showing the terminal capacitances of a capacitor.

The problems arise from the connections that must be made to a capacitor in order either to use or to measure its capacitance. The capacitance is, of course, determined by the geometrical configuration of the conductors (and by the dielectric material, which will here



As our capacitance measurements and standards move toward the millionth part of the millionth part of the millionth part of the farad (10^{-18} f), we have found increasing advantage in following the lead of the National Bureau of Standards and others in calling 10^{-12} farad a *picofarad* instead of a micromicrofarad. A privilege most prized by proponents of the picofarad is the right to write the abbreviated abbreviations 1 pf instead of 1 µµf for 10^{-12} farad and 1 µpf instead of 1 µµµf for 10^{-18} farad.

be assumed to have simple and constant characteristics). Only when one conductor completely surrounds the other is the capacitance simply defined by the form and nature of materials inside the capacitor. As soon as the terminals required for use or measurement are provided, these terminals add increments to the capacitance, which depend upon the nature and position of objects external to the capacitor and which are seldom easy to define or control.

As an example of this, consider a typical capacitor constructed as shown in Figure 1.[2] The capacitance has been broken, as a somewhat arbitrary first approximation, into four components: C_0, the capacitance of the multiple-plate capacitor and leads within the case; C_1, the capacitance between the external binding posts; C_2, the capacitance between the high terminal and the case, which is connected to the other terminal; C_3, the capacitance between the high terminal and all objects external to the capacitor and its terminals. Typical of the magnitudes of these components are the values $C_0 = 100$ pf, $C_1 = 0.2$ pf, $C_2 = 1.3$ pf, $C_3 = 0.03$ pf.

The "free" capacitance of this capacitor, i.e., the capacitance of the isolated capacitor with no connections to the terminals, is the sum,[3] $C_0 + C_1 + C_2 + C_3$. The capacitance C_0, being surrounded by the case, is independent of the position of external objects. The capacitance C_1 between terminals is influenced only by intrusions very close to or between the terminals. But C_3, and to a lesser extent C_2, can readily be affected by more distant environment of the capacitors, and variations of 0.01 pf or more can result from a slight change of position.

More radical changes in these external capacitances are produced by any connections made to the terminals. A wire connected to the high terminal, for example, obviously introduces new components of capacitance between the wire and the capacitor parts. It also, not so obviously, reduces the "free" capacitance by as much as 0.1 pf by changing the distribution of field around the terminals. There is a similar reaction of the capacitor on the connections, which makes the capacitance of the leads when connected to the capacitor differ from that of the leads alone. Indeed, the complexity of this mutual interaction is such that it is impractical to define the dividing line between capacitor and leads with a precision much better than ± 1 pf.

A consideration of these difficulties suggests several possible methods of measurement in which the errors and uncertainties can be reduced or eliminated in order to obtain accuracy in the measurement of very small capacitances. Three of these methods of calibration which have been used at the General Radio Company will be reviewed here with regard to their limitations in accuracy.

1. Capacitance Added (Insertion Capacitance).

Since the capacitance of the two-terminal capacitor depends upon the environment of the capacitor and upon the method of connection, an accurate calibration can be made only by defining with sufficient precision the geometry of both the environment and the connections. One practical method of achieving

[2] This is the structure used until recently in the General Radio TYPE 1401 Standard Air Capacitors.

[3] When the capacitor is isolated, C_3 is the capacitance to infinity. The similar capacitance from the low terminal to infinity is in series with C_3 in the "free" capacitance, but it can be neglected here because this capacitance to infinity is much larger than C_3 when the low terminal is connected to the capacitor case and is infinite when the low terminal is grounded, as it usually is in two-terminal measurements.

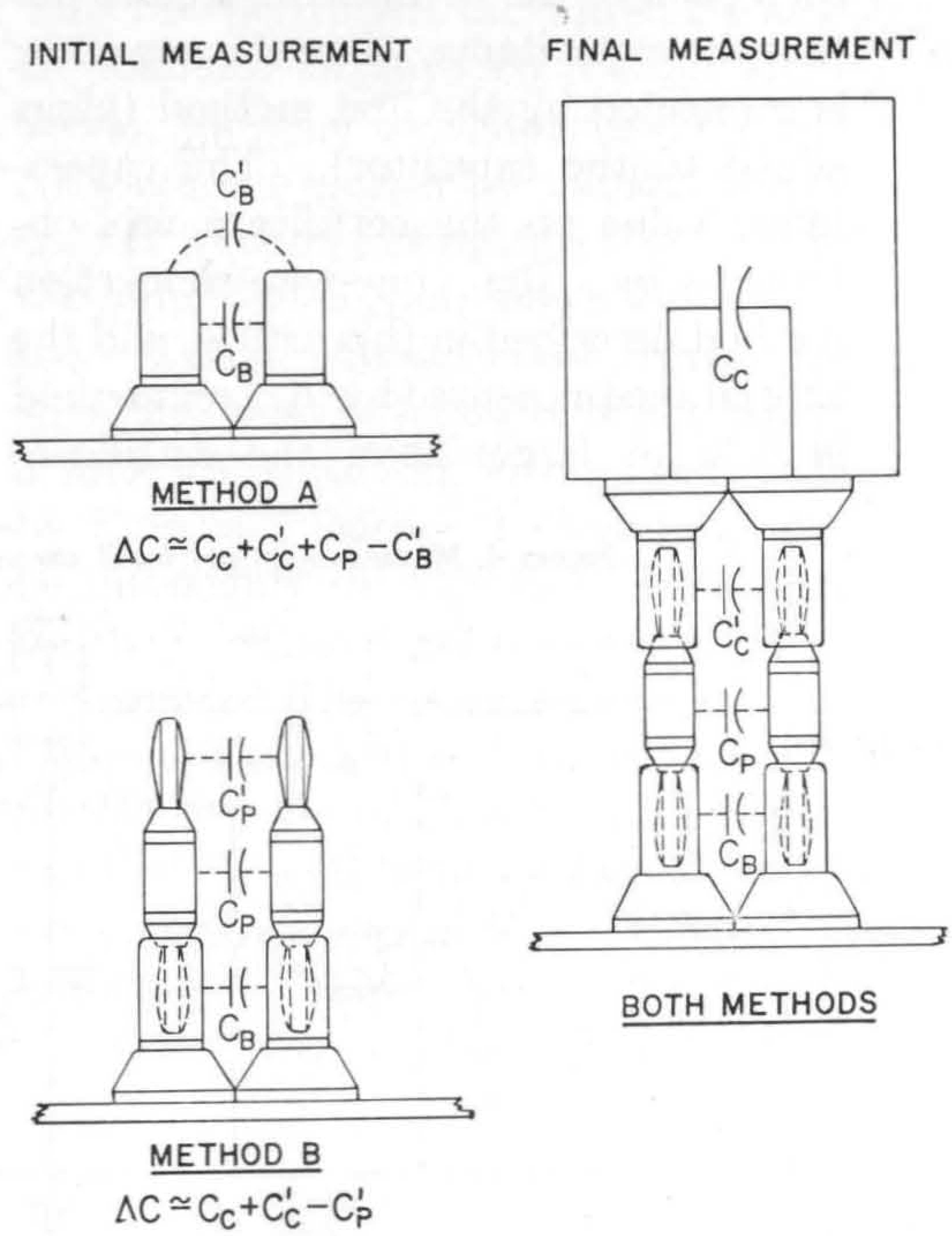
high accuracy is to calibrate in terms of the capacitance change at a pair of terminals when some change is made in the capacitor or its position. Two measurements are required to determine the capacitance change, and, hence, terminal conditions for both measurements must be either invariant or precisely specified. When the capacitor has variable capacitance, the shielded internal capacitance can be varied in an environment determined solely by the capacitor construction; while the external capacitances at the terminals, although dependent upon external connections and environment, can easily be held so constant during the capacitance change that they make no appreciable contribution to the difference. Such variable capacitors can be calibrated[4] in terms of the capacitance added or removed by rotation of the capacitor plates with essentially no limitation of accuracy by connection errors.

When the capacitor has a fixed capacitance, a calibration of high accuracy of the capacitance added requires that the capacitor be connected with specified leads to a specified set of terminals. For example, the General Radio TYPE 1409 Standard Capacitors are calibrated in terms of the capacitance they add when the banana plugs on the capacitor are plugged into General Radio TYPE 938 Binding Posts with ¾-inch spacing. When the connections are made with reasonable care, the reproducibility of measurement is better than 0.1 pf.

For greater accuracy the environment of the terminals must also be defined, for any change in terminal position or panel size (which results, for example, from the use of different bridges or of terminals on an external capacitor instead of the bridge terminals) can produce a change in the measured capacitance. The value assigned to the capacitor is the difference between two bridge measurements: the first with the bridge terminals open, and the second with the capacitor connected to the terminals. In the second measurement the capacitor case and bridge panel are usually effective in shielding the bridge terminals, so that this measurement is not very sensitive to changes outside the radius of a few inches. The capacitance of the open bridge terminals in the first measurement (and of any open terminals on the capacitor, such as those on top of the 1409 Capacitors) is affected to a greater extent by panel size and terminal position.

The General Radio TYPE 1401 Standard Air Capacitor is another example of a fixed capacitor calibrated in terms of the added or "insertion" capacitance. These capacitors are now being made, as shown in Figure 3, with banana-plug

Figure 2. Two methods for the measurement of capacitance added. The capacitances shown represent only major components in the complete expression of the self and mutual capacitances of the terminals.



[4]The General Radio TYPE 722-MD and TYPE 722-ME Precision Capacitors are calibrated in terms of capacitance removed.

terminals on the case, similar to those on the TYPE 1409 Capacitors. In previous production the TYPE 1401 Capacitors have had the jack-top TYPE 938 Binding Posts on their cases, and two double-ended banana plugs have been provided with each capacitor to connect it to another pair of similar binding posts. With these connectors two different methods of added-capacitance calibration can be made. In the first method, shown in Figure 2-A, the initial measurement is made with the bridge terminals open and the final measurement with the capacitor connected by means of the double-ended plugs. In the second method, shown in Figure 2-B, the initial measurement is made with the plugs in the bridge terminals and the final with the capacitor added to the plugs.

This choice of methods has in the past resulted in some confusion. The National Bureau of Standards has used the second method (plugs added to the bridge) in its calibrations of these capacitors, but the General Radio Company has given on its calibration certificates a correction of the certificate value to obtain the capacitance when the capacitor is connected by the first method (plugs added to the capacitor). The capacitance value on the certificate was obtained by the fine-wire-connection method described in this article, and the capacitance measured by the first method is 0.35 pf larger than the certificate

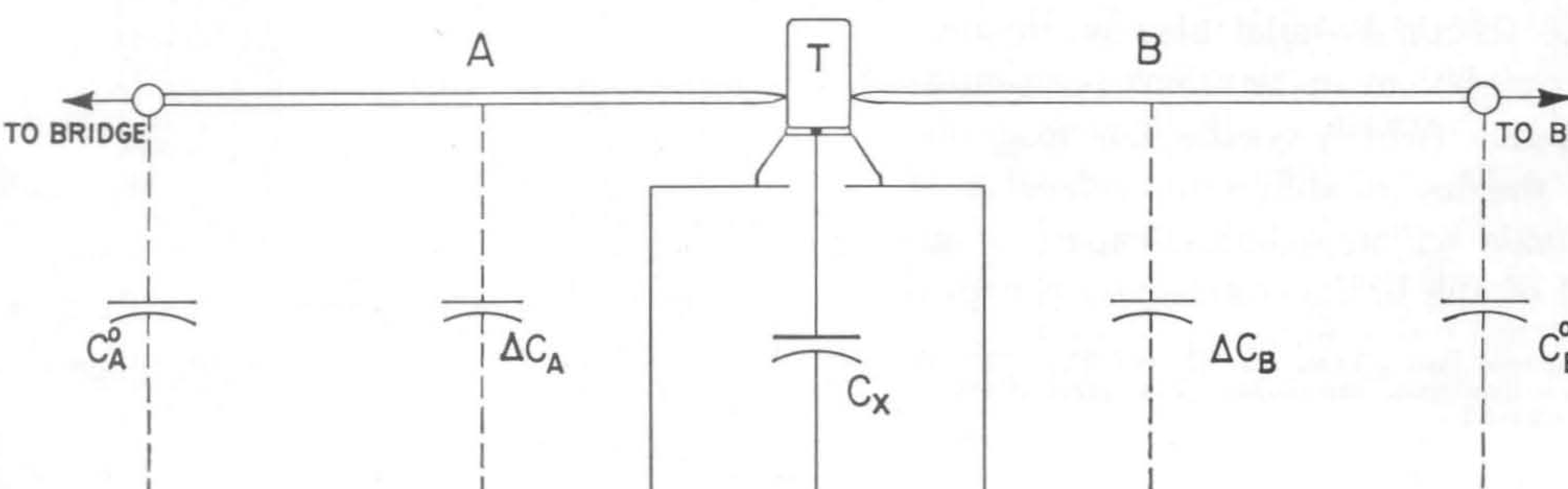
Figure 3. Type 1401 Fixed Air Capacitor as now supplied.

value. When the second method is used, the measured capacitance is 0.7 pf lower than that of the first method because the capacitance added to the bridge terminals by the plugs in the initial measurement $(C_p + C_p' - C_B')$ in Figure 2) is 0.7 pf. In neither method is the added capacitance the same as the "free" capacitance.[5] In the first method the added capacitance is greater than the "free" capacitance because of the capacitance, C_p, added by the plugs. In the second method the added capacitance is less than the "free" capacitance because the connection of the capacitor removes from the final measurement the capacitance, C_p', between the ends of the plugs that was included in the initial measurement.

To avoid both this choice between connection methods and also the limitations of the fine-wire-connection method,

[5]The value on the certificate, obtained by the fine-wire-connection method, also differs by about 0.2 pf from the "free" capacitance for reasons explained in this article.

Figure 4. Measurement of "free" capacitance by the Rosa and Dorsey method.



the 1401 Capacitors are now provided with only banana-plug terminals, and they are calibrated by both the National Bureau of Standards and General Radio Company, as the 1409 Capacitors are, in terms of the capacitance added when the capacitor is plugged directly into General Radio type binding posts.

2. "Free" Capacitance.

In the attempt to define a capacitance with high accuracy, an alternative to the method of specifying with sufficient precision the geometry of the connections is a method which eliminates all connections and defines the "free" capacitance of the capacitor with all disturbing connections and surroundings removed. In this method the difficulties of measuring the capacitance of a capacitor, isolated from its surroundings and without connections, are substituted for the difficulties of controlling the geometry of the connections and the environment.

It is possible to determine this "free" capacitance by evaluation of the disturbing effects of the connections and application of a correction for these effects to the measured capacitance. A method for doing this has been described by Rosa and Dorsey.[6] The effects of the connections can be eliminated from the measurement by the use of two sets of connecting leads which are not necessarily identical but which have no mutual interaction. As a simplified illustration of this method, consider the arrangement shown in Figure 4. The capacitor to be measured has a "free" capacitance C_x, which includes external components corresponding to C_1, C_2, C_3 in Figure 1. For simplicity only the high terminal, T, is shown in Figure 4, but the ground connection to the case and to one side of the capacitor shown in the figure can be made to a second, similar terminal on the capacitor. A first measurement is made with connecting wire A connected to the terminal and to the bridge and with wire B removed. The measured capacitance is $C_1 = C_A^\circ + C_B^\circ + \triangle C_A + C_X - \triangle C_X^A$. A similar measurement with wire B connected and A removed gives $C_2 = C_A^\circ + C_B^\circ + \triangle C_B + C_X - \triangle C_X^B$, where

$C_A^\circ + C_B^\circ$ is the measured capacitance of leads, bridge, etc., when both wires A and B are removed,

$\triangle C_A$ and $\triangle C_B$ are the increments added by wires A and B,

$\triangle C_X^A$ and $\triangle C_X^B$ are the changes in C_X resulting from the presence of A and of B.

With both wires A and B connected to the terminal the capacitance measured is $C_{12} = C_A^\circ + C_B^\circ + \triangle C_A + \triangle C_B + C_X - \triangle C_X^A - \triangle C_X^B$. These relations can be combined to show that $C_X = C_1 + C_2 - C_{12} - (C_A^\circ + C_B^\circ)$. The "free" capacitance C_X can thus be determined from four measured capacitances, C_1, C_2, C_{12}, and $C_A^\circ + C_B^\circ$.

In this derivation the wires A and B are assumed to have no mutual interaction, e.g., the capacitances $\triangle C_A$ and $\triangle C_X^A$ are not altered by the addition of wire B when C_{12} is being measured. In the simple connection shown in Figure 4 there is some mutual effect (which can with care be kept below 0.01 pf), but in a spherical capacitor such as that used by Rosa and Dorsey the two leads can be thoroughly shielded from each other by their locations on opposite sides of the sphere. The assumption that the calculated C_X is the "free" capacitance further requires that the initial measurement of $C_A^\circ + C_B^\circ$ be made with all measuring apparatus so far removed from the terminal T that it has no significant effect on the capacitance. In practice it

[6]E. B. Rosa and N. E. Dorsey, "A New Determination of the Ratio of the Electromagnetic to the Electrostatic Unit of Electricity," Bull. Bureau of Stand., Vol. 3, Nos. 3 and 4, 1907.

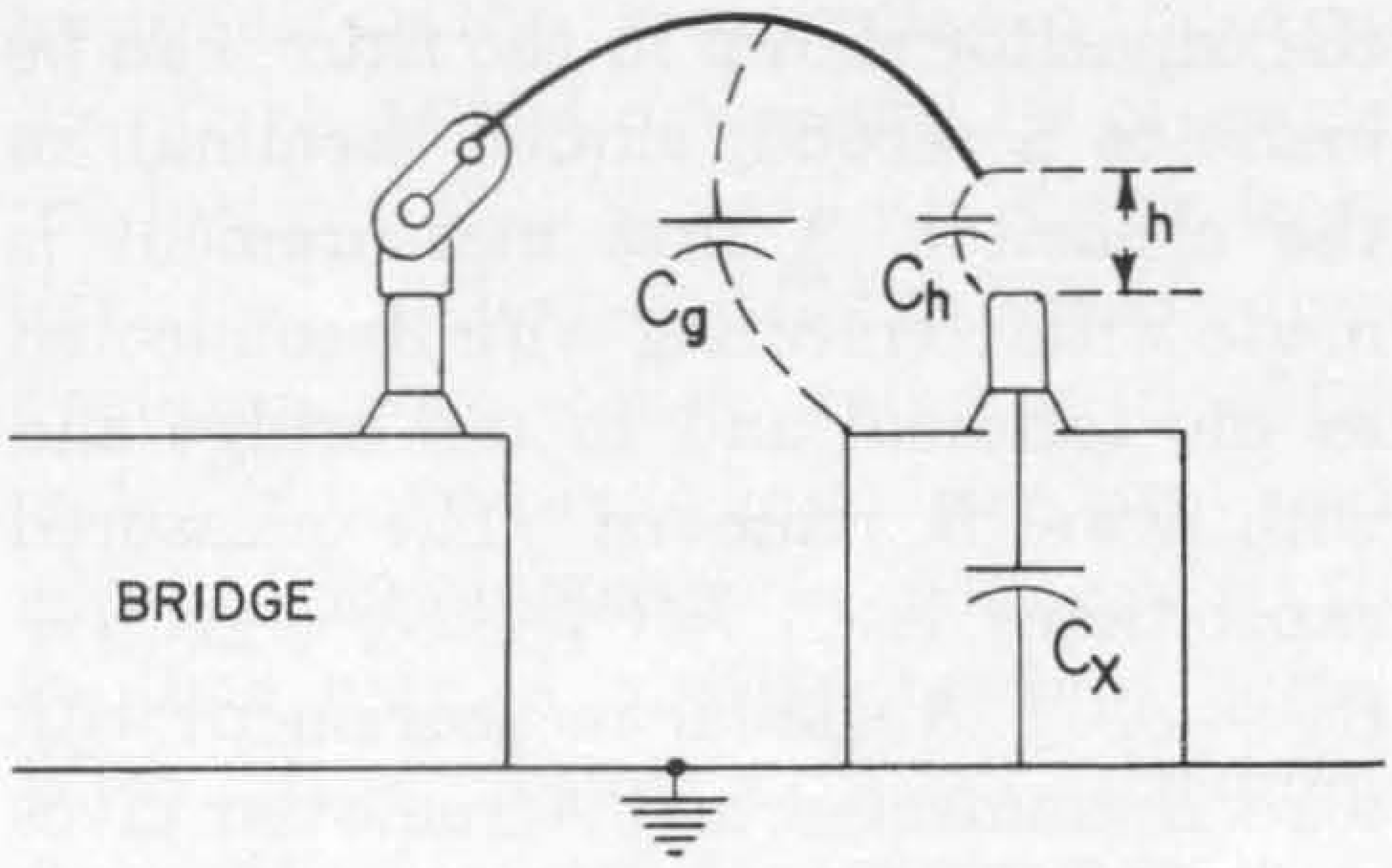


Figure 5. Diagram of connection method using a fine wire.

is difficult to approximate this condition to better than 0.01 pf unless, as in the Rosa and Dorsey capacitor of concentric spheres, one of the conductors surrounds and shields the other.

Another method which removes most, but not all, of the effects of the connections is the fine-wire-connection method described by R. F. Field.[7] In this method, as shown in Figure 5, the connection between the bridge and the high terminal of the unknown capacitor is made by a wire of small diameter pivoted near the bridge terminal so that its separation from the capacitor terminal can be varied. An initial measurement is made with the wire separated from the terminal by a distance h. With the assumption that the capacitance C_h between the wire and terminal is small compared to the unknown C_x, so that $C_hC_x/(C_h + C_x) \simeq C_h$, the measured capacitance is $C_1 = C_g^h + C_h$, where C_g^h is the capacitance between wire and ground when the separation is h. When the wire is moved in to touch the terminal, the capacitance C_h becomes infinite and the capacitance between wire and ground increases to C_g°. The measured capacitance now becomes $C_2 = C_g^\circ + C_x$. The unknown capacitance can thus be related to the measured values C_1 and C_2 by $\triangle C = C_2 - C_1 = C_x + (C_g^\circ - C_g^h - C_h)$. At some particular distance h, the capacitance C_h is equal to the change in C_g as the wire is moved, i.e., $C_h = C_g^\circ - C_g^h$, and the term in parentheses vanishes, leaving simply $C_x = C_2 - C_1$.

When the wire is curved and pivoted at the bridge end to approach the capacitor terminal from above in the manner described by Field, the change of $\triangle C$ with h is fairly linear, as shown in Figure 6 from Field's article. A plot of $\triangle C$ against h can then be extrapolated to $h = 0$, where $\triangle C = C_x$, and the value of h which corresponds to this $\triangle C$ was found by Field to be ¼ inch. The difference between the two capacitances measured with the wire touching the terminal and then ¼ inch above it should, therefore, be the value C_x of the unknown capacitor.

This method is simple and useful for calibrations where uncertainties less than 0.1 or 0.2 pf are not significant. It has in the past been used in the calibration of our Type 722-D Precision Capacitors, where the direct-reading accuracy limit is ±0.1% or ±0.2 pf,[8] and in the calibration of Type 1401 Standard Air Capacitors, with a limit of ± (0.1% + 0.1 pf). There are, however, several reasons why this method has connection errors which can be of the order of 0.1 pf. In the first place, even in the absence of other errors, the capacitance measured, C_x, is not the "free" capacitance (C_x^F), but the capacitance (C_x^w) in the presence of the connecting wire.[9] Even though the added capacitance to ground of the wire has been eliminated from the measurement, the wire still reduces the capacitance of the terminal

[7] R. F. Field, "Connection Errors in Capacitance Measurements," *General Radio Experimenter*, Vol. 12, No. 8, January, 1938, pp. 1-4; reprinted: Vol. 21, No. 11, April, 1947, pp. 1-4.

[8] Note that the catalog accuracy limit of ± 0.05 pf for the Type 722-ME Precision Capacitor refers to capacitance removed, that is, to a calibration with the capacitance varied but the connections unchanged.

[9] This was pointed out to us by Dr. F. R. Kotter of the National Bureau of Standards.

from its "free" value by disturbing the field around the terminal and, hence, the charge distribution on it. The fine-wire connector used by Field makes the measured capacitance of the TYPE 938 Binding Posts on TYPES 1401 and 722 Capacitors about 0.1 pf less than the "free" capacitance, i.e., $C_x^F = C_x^w + 0.1$ pf.

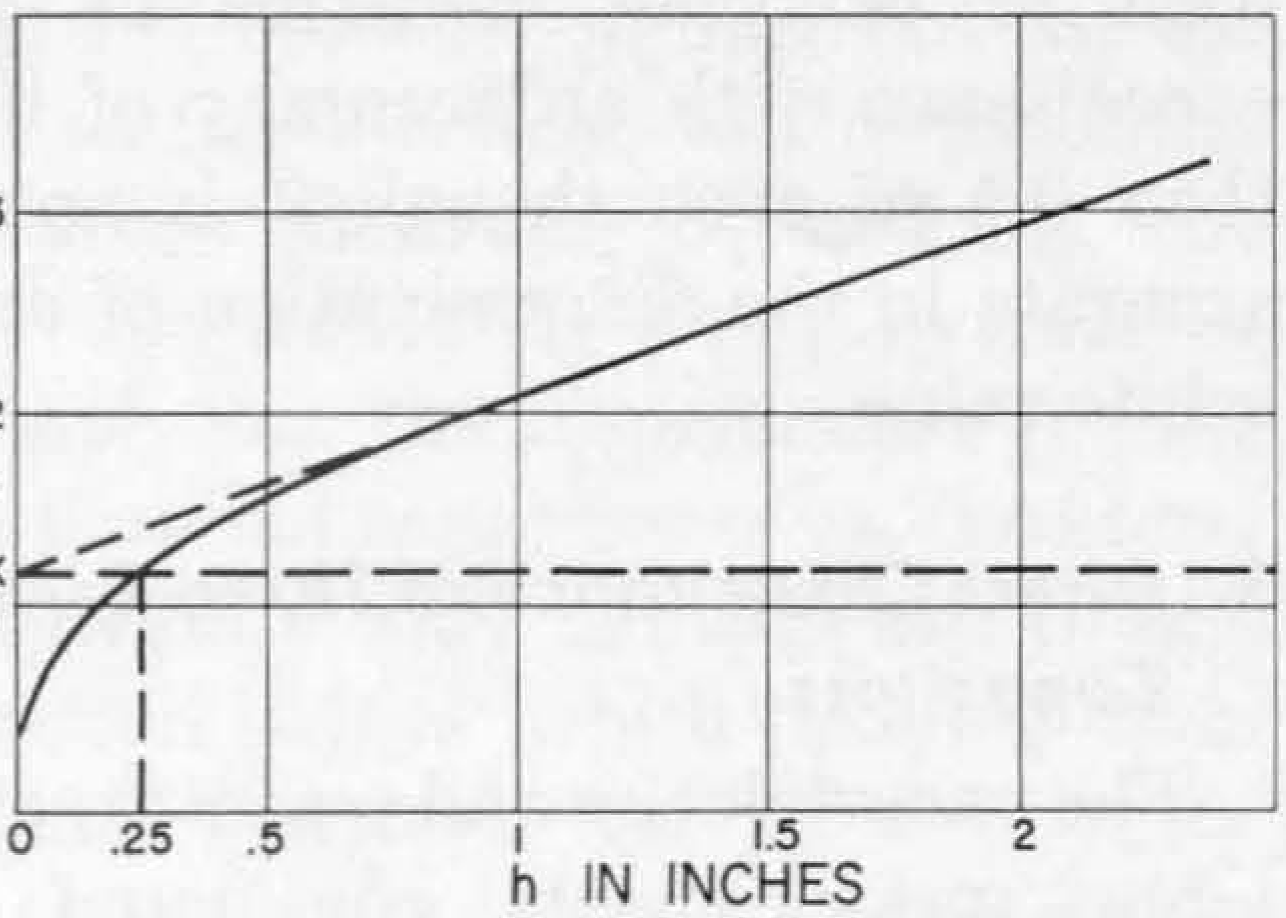


Figure 6. Determination of unknown capacitance C_x from ΔC measured with fine-wire connector. At $h = \frac{1}{4}$ inch $C_x = \Delta C$. (From Field paper[7])

A recent analysis of the component capacitances in the fine-wire method with a three-terminal capacitance bridge has revealed that even the capacitance C_x^w in the presence of the wire is hard to determine without errors of the order of 0.1 pf. The measurements were made on a capacitor which was externally identical to a TYPE 722-D Precision Capacitor but which had internal, guarded connections to the terminals to permit measurement of the "free" capacitance and the effects of the connector upon it.[10] To simulate the stray capacitances to external grounds in two-terminal measurements, the three-terminal measurements were made with a wire cage (30″ x 30″ x 30″) surrounding the capacitor and its connections and connected to the "ground" terminal of the capacitor.

The measured capacitances, C_x, C_g^h, $C_g^h + C_h$, and $\Delta C = C_x + C_g^\circ - (C_g^h + C_h)$, are plotted in Figure 7 as a function of the separation h between wire and terminal. For convenience, the capacitance level has been adjusted to make $C_x^F = 100$ pf. The upper curve shows the variation in C_x as the wire moves away from the terminal, with an increase of about 0.1 pf as the influence of the wire vanishes with increasing h. The next curve shows the results of the fine-wire method, with ΔC plotted as a function of h. The lower curves, with the level of the capacitance axis shifted, show the variations of the wire capacitances, C_g^h and $C_g^h + C_h$, with h.

The fine-wire method, when corrected for the effects of the wire on C_x, pre-

[10]These measurements were checked within ±0.01 pf by a measurement of "free" capacitance by the Rosa and Dorsey method.

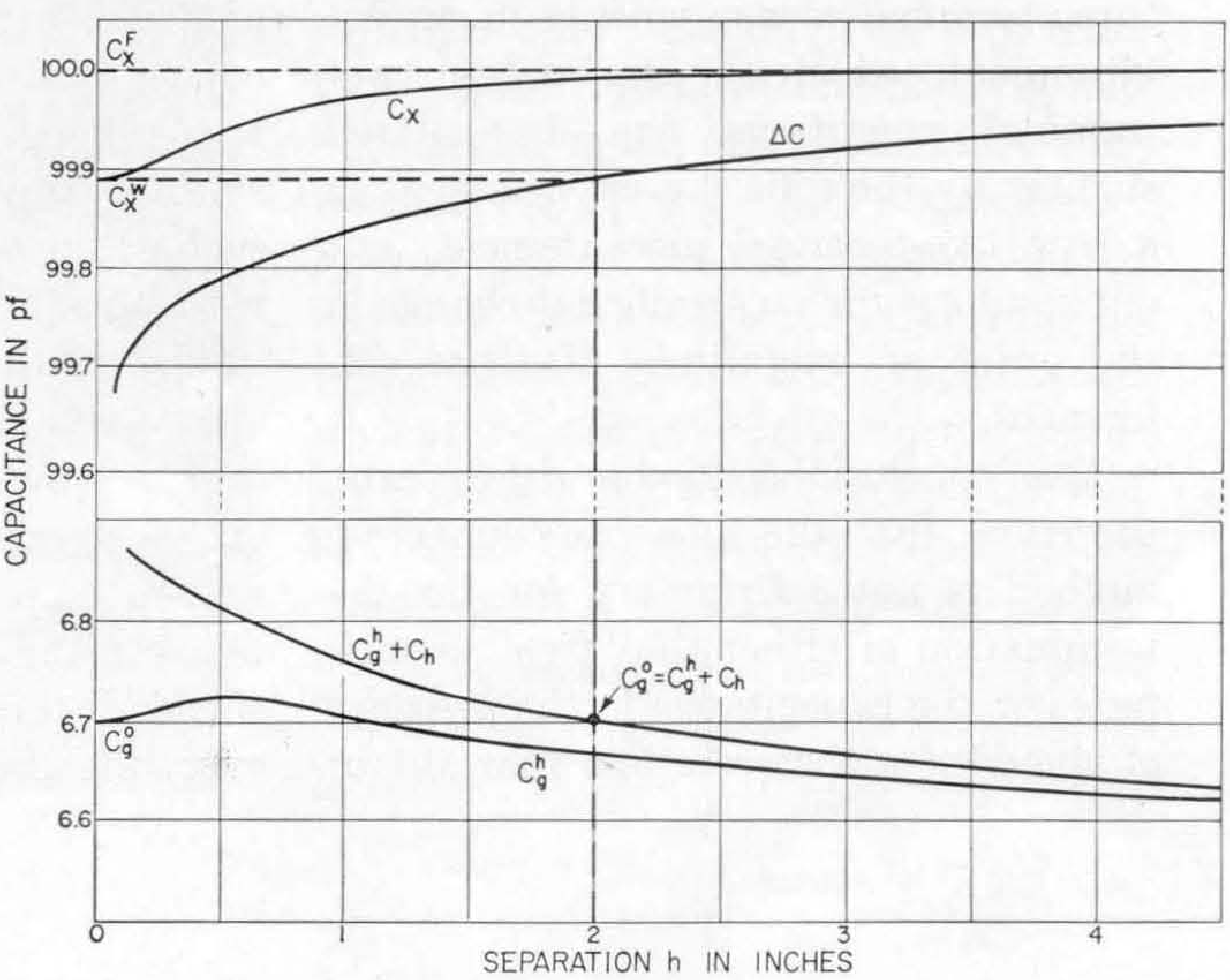


Figure 7. Variation of measured capacitances with fine-wire connector as a function of the separation *h*.

dicts that, at the distance which makes $C_g^h + C_h = C_g^\circ$, the capacitance difference $\triangle C$ will be equal to C_x^w. In Figure 7 this condition is shown to be satisfied at a distance $h = 2$ inches. Any attempt, however, to determine C_x^w here by extrapolation of the $\triangle C$ curve to $h = 0$ encounters difficulty because the curve is not very linear. Examination of the C_g^h, $C_g^h + C_h$, and C_x curves shows that C_h does, as expected, cause deviation from linearity at small h, that C_g^h is itself not linear for h less than about 2.5 inches, and that C_x is not constant with h, as assumed in the derivation of the method. In the region beyond 2.5 inches C_x is almost constant and C_g relatively linear, as desired, and it seems possible that a linear region beyond the range of the graph might extrapolate to C_x^w at $h = 0$.

The important point, however, is the obvious difficulty in determining C_x^w by this method without variations of 0.1 pf. Attention should also be directed to the difference between the $\triangle C$ value at the ¼-inch separation and the values of C_x^w and C_x^F. With the ¼-inch spacing, the fine-wire method would give under these conditions a capacitance 0.14 pf less than the capacitance C_x^w in the presence of the wire and 0.25 pf less than the "free" capacitance C_x^F. These results of three-terminal measurements in an environment which approximates two-terminal conditions can be altered slightly by the differing environment in a true two-terminal measurement, but our results show no significant change in the order of magnitude of these differences.

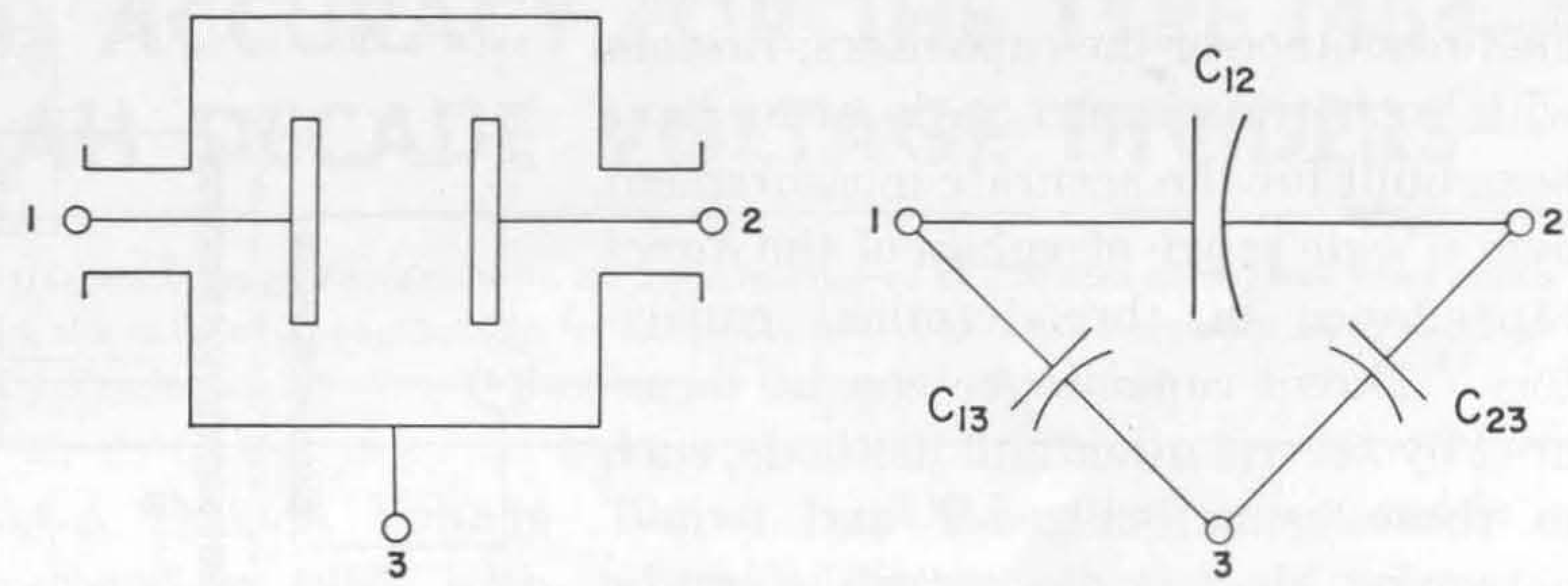
The conclusions to be drawn are, therefore, that the fine-wire-connection method is not satisfactory for the determination of either the "free" capacitance or the capacitance in the presence of the wire with errors less than 0.1 or 0.2 pf unless considerable care is taken in both making and correcting the measurements. As in the other methods of making connection to two-terminal capacitors, the results are reproducible with a precision of 0.01 or 0.02 pf if adequate care is taken to keep the geometry of the connections invariant. The fine-wire method can, therefore, be used to calibrate in terms of *added* capacitance with an accuracy of better than 0.1 pf even though it is not this accurate in the determination of an absolute value.

3. Direct Capacitance of Three-Terminal Capacitors.

The uncertainties and errors in capacitance measurements considered here have been the result of the variations in terminal capacitances produced by changes in the connections and in the environment. These problems associated with the capacitor terminals can be eliminated if the terminal capacitances can be separated from the capacitance to be defined and measured. One way of doing this is to introduce a third conductor as a shield or guard which completely surrounds all of at least one of the pair of conductors forming the capacitor to be measured except the area which produces the desired direct capacitance. The pair of conductors of the original capacitors and the added shield form a *three-terminal capacitor*, such as the one shown in Figure 8, along with its equivalent circuit.

The addition of the shield changes the capacitance that existed between 1 and 2 before the introduction of the shield by altering the field, and it also results in new capacitances, C_{13} and C_{23}, between the original conductors and the shield. If the shielding is complete, however, the capacitance C_{12} is now inde-

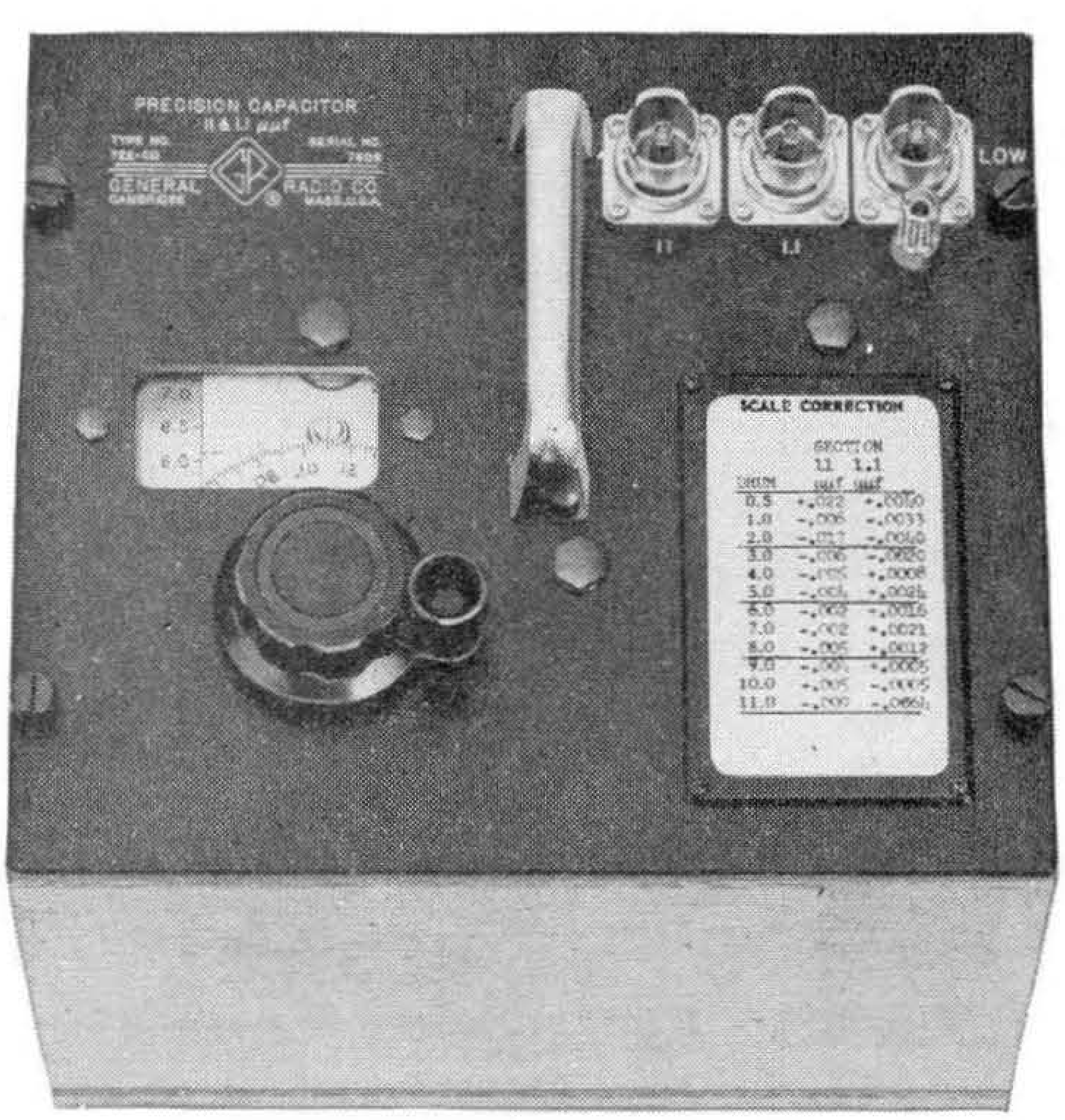
Figure 8. Diagram and schematic of 3-terminal capacitor.



pendent of the surroundings outside the shield and connections to the terminals 1 and 2 can affect only C_{13} and C_{23}. The direct capacitance C_{12} — usually referred to simply as the capacitance of the three-terminal capacitor — is, therefore, quite definite and not subject to the connection errors which trouble two-terminal capacitors.

Note, however, that if in this three-terminal capacitor one of the capacitor terminals, say 2, is connected to the shield, 3, the capacitor reverts to the usual *two-terminal capacitor*, with terminals 1 and 2. The capacitance C_{23} has thus been shorted; the capacitance C_{13} is now parallel with C_{12}, and the capacitor has the capacitance $C = C_{13} + C_{12}$. The capacitor is, thus, equivalent to that shown in Figure 1. Although C_{12} is still shielded from external influences, C_{13} is a function of connections and environment, and the total capacitance measured is subject to the variations described previously for such two-terminal capacitors.

Figure 9. View of the Type 722-CD Three-Terminal Precision Capacitor. Outer conductors of Type 874 Coaxial Connectors provide the shield. Inner conductors are the capacitor terminals.



The well-defined direct capacitance of the three-terminal capacitor is of practical use in a capacitance standard only if it can be measured with high accuracy and with reasonable ease. A bridge with transformer ratio arms is well-suited for just such measurements.[11] In the transformer bridge shown in Figure 10, the unknown and standard capacitors are driven by emf's of opposite phase and known ratio from a tapped transformer secondary winding, and the difference in the capacitor currents is measured by a detector. When the bridge is balanced for zero current through the detector, the currents through the direct capacitances C_{12} and C_s must be equal, and the balance relation is $C_{12}/C_s = n$. Any capacitance, such as C_{23}, across the detector has no effect at balance because there is no potential across it. Any capacitance, such as C_{13}, across the transformer winding will have negligible effect on the emf as long as the output impedance of the transformer is small compared to the

[11]The three-terminal capacitor and its measurement are well described by A. M. Thompson, "The Precise Measurement of Small Capacitances," I. R. E. Transactions on Instrumentation, Vols. 1-7, Nos. 3 and 4, Dec., 1958, pp. 245-253.

load reactance of the capacitors. Bridges with such transformer ratio arms have been built for the accurate measurement over a wide range of values of the direct capacitance of three-terminal capacitors.[12] Direct capacitance can be measured by several other null methods, such as those using bridged-T and twin-T networks. Most bridge networks can be adapted to the three-terminal measurement by the use of auxiliary bridge arms to balance the unwanted components,[13] but the double balance required is never convenient and it is difficult to obtain accuracy when the direct capacitance is very small compared to the other capacitances. In some bridges three-terminal measurements can also be made over a limited range by connecting the unwanted capacitances across low-impedance arms of the bridge and across the generator or detector where the shunting effect is negligible.[14]

In all these three-terminal measurement methods the connection errors in capacitance can be eliminated by having a complete external shield around at least one of the capacitor terminals. In Figure 10 the case of the capacitor and a shield lead from terminal 2 to the shielded detector complete the shielding around that terminal of the capacitor. A shielded lead to the other terminal is not usually required to eliminate connection capacitances but may be needed to prevent pickup from other sources. With such three-terminal measurements the measured direct capacitance should depend solely upon the construction of the capacitor and the accuracy of measurement should be limited only by the bridge or the reference standards used.

— John F. Hersh

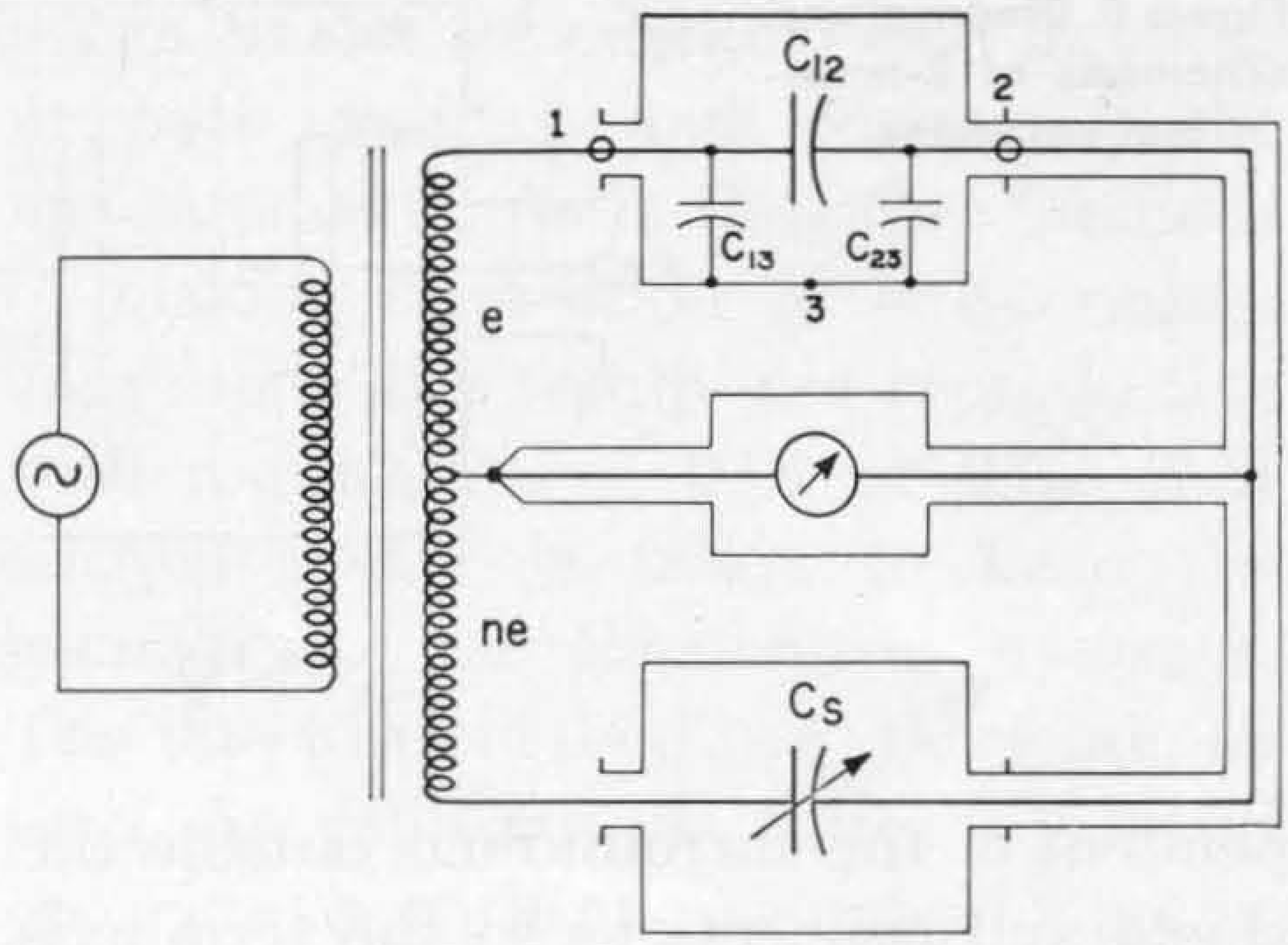


Figure 10. Schematic of transformer-ratio-arm bridge with 3-terminal capacitor connected for measurement.

[12]The Type 1613-A Capacitance Bridge is a transformer bridge covering the range from 5 to 11,000 pf.

[13]The Type 716-P4 Guard Circuit provides the components required to make three-terminal measurement with the Type 716-C Capacitance Bridge.

[14]Three-terminal measurements can be made with the Type 1650-A Impedance Bridge in this way.

Next month new 3-terminal capacitors, both fixed and variable, will be described. In a forthcoming issue Dr. Hersh will continue the discussion of accuracy considerations and calibration methods for capacitance.

VACATION CLOSING

During the weeks of July 27 and August 3, our Manufacturing Departments will be closed for vacation.

There will be business as usual in the Sales Engineering and Commercial Departments. Inquiries, including requests for technical and commercial information, will receive our usual prompt attention.

Our Service Department requests that, because of absences in the manufacturing and repair groups, shipments of equipment to be repaired be scheduled to reach us after the vacation period.

INCREASED ACCURACY FOR THE TYPE 1454-A AND -AH DECADE VOLTAGE DIVIDERS

A new model of the Decade Voltage Divider, with an input resistance of 100,000 ohms, has been made available. In addition, the accuracy specification for these dividers has been improved by a factor of 2.5. The factors affecting the accuracy are discussed in this article.

The Type 1454-A Decade Voltage Divider was introduced in 1955[1] with accuracy specifications of 0.1% in voltage ratio ±0.000001. The intent was to take advantage of the inherently good characteristics of the Type 510 Decade Resistors and to keep the voltage divider in the same price class by avoiding expensive adjustment to closer limits. Since the tolerance on the resistance decades is ±0.05%, it is evident that the worst combinations can produce an error in the voltage ratio of twice this value, or ±0.1%. The specification limits on the voltage divider were set accordingly.

It was recognized that the catalog limit of error was very seldom approached in actual service and most instruments would readily meet tighter tolerance specifications. A recent study has shown that only a few of the component resistors are critical and that proper selection of these during assembly would enable us to guarantee a considerably higher accuracy, 0.04%, for ratios above about 0.1 without appreciably increasing the price of the instrument.

The additive constant term of one part in a million in the expression for the error, however, was still the limiting factor at low settings. This could amount to 1% at a ratio of 0.0001. This error is caused by the contact resistance of the switches and is introduced in the manner shown in Figure 1. In the Kelvin-Varley circuit used in this divider, the resistors of the second decade parallel two adjacent resistors of the first decade, and so on. It will be seen that, in the present arrangement of four decades, the voltage drop of three switches in series appears in the output circuit. This causes a residual output voltage at the zero setting and an increased error at the lower outputs.

The cure for this second accuracy limitation was suggested by the fact that the switch contact resistance was found to be remarkably constant. The resistance may increase by a factor of two or three when the instrument is not in use but returns quickly close to its initial value after a few operations. The

[1] Ivan G. Easton, "An Accurate Voltage Divider for DC and Audio Frequencies," *General Radio Experimenter*, Vol. 30, pp. 1-5, August, 1955.

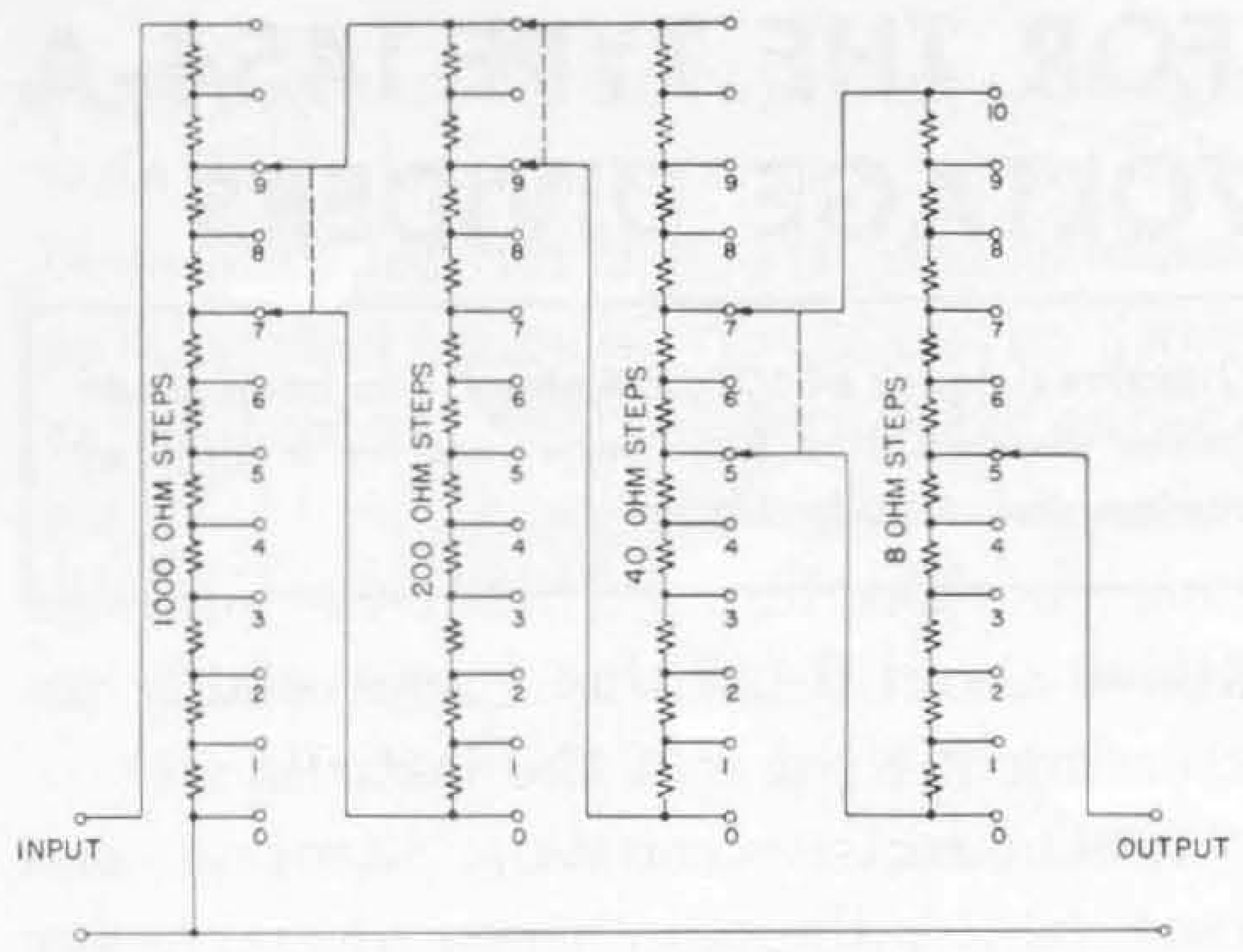


Figure 1. Schematic diagram of Type 1454 Decade Voltage Divider.

accuracy of the divider at low settings can be greatly improved if a bucking voltage equal to the average switch drop is introduced into the output loop.

The contact-drop balancing arrangement is shown in Figure 2. A small resistor, *R*, is placed in series with the first decade at its low end and the low output terminal is connected to the high side of the resistor. The low output terminal thus differs in potential from the low input terminal by the voltage across the resistor, which is made equal to the switch contact drop. The voltage at the output terminals can be balanced to a negligible value by this arrangement. The balancing resistor is very small, about 5 milliohms, so that its presence is never noticed in ordinary use of the divider. When highest accuracy is needed at low ratios, the user must remember to keep the input and output circuits separate. The user must also remember to turn each switch back and forth several times whenever the instrument is first used. The tendency is to forget the first or second decade when these are left at the zero setting, but these contribute the most to the contact drop, since they carry more current, and must be restored to normal resistance if the compensation scheme is to be effective.

Although the selection and matching of the component resistors should insure meeting the new tolerances, a check to one part in 10^6 is made of each ratio of each decade in the final inspection of the instrument.

When maximum accuracy is required, temperature effects must be allowed for and the input voltage must be reduced considerably below that corresponding to the dissipation limit of the resistors. Since all resistors are of similar construction and have more or less equal temperature coefficients, the effects of ambient temperature variations are very small. The effects from self-heating are not balanced out, however. Referring to Figure 1, it will be seen that in the first decade between points 7 and 9, which are bridged by the second decade, only half of the input current is carried. The resistors between these points will have only one-quarter of the temperature rise of the others of the decade, causing an error in the output voltage. The temperature rise of the second and following decades is much smaller and can be neglected. The temperature effect is largest at the zero position of the first decade. It has been found that, to keep the self-heating error at this first position within the specification limits, the input to the Type 1454-A Decade Voltage Divider should be limited to 120 volts. The normal dissipation limit is

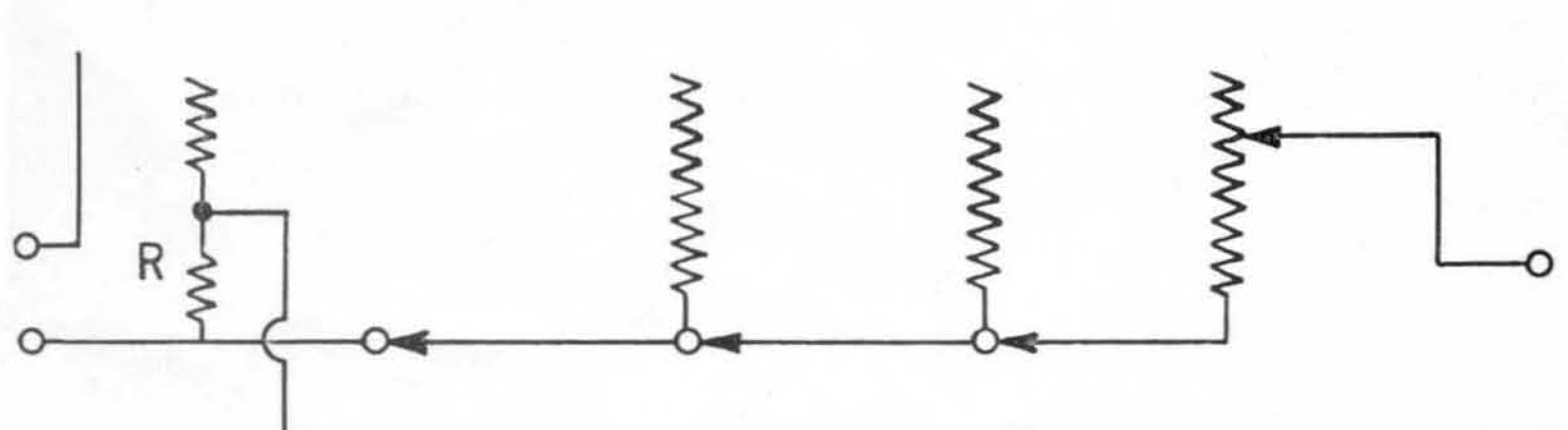


Figure 2. Arrangement for balancing the switch contact voltage drop.

230 volts. Neither limit applies to the high-resistance model, TYPE 1454-AH, which has one-tenth the dissipation at a given voltage.

— W. N. TUTTLE

SPECIFICATIONS

Voltage Ratio: .0001 to 1.0000 in steps of .0001.

Accuracy: ±0.04% of indicated ratio, for input voltages below 120. The voltage drop in switch contacts and wiring is balanced out so that full accuracy is maintained down to the lowest setting, 0.0001.

Linearity: ±0.02% of full-scale setting.

Frequency Characteristics: If the external capacitance placed across the output terminals of TYPE 1454-A is less than 50 $\mu\mu$f, the frequency error is less than 0.1% to 20 kc for any setting. For the TYPE 1454-AH, the frequency limit is 2 kc for the same capacitance.

Input Resistance: TYPE 1454-A, 10,000 ohms; TYPE 1454-AH, 100,000 ohms.

Output Resistance: Varies with output setting, depending primarily on the setting of the highest decade in use.

Maximum Input Voltage: 230 volts rms (or dc) for 40° C. rise of the resistors of the input decade. Input voltage should be limited to 120 for maximum accuracy. At maximum rated voltage the total error can approach ±0.1%.

Resistance Units: TYPE 510 Decade-Resistance Units.

Temperature Coefficient: Of the individual resistors, less than ±0.002% per degree. Since the voltage ratios are determined by resistors of similar construction, ambient temperature effects are very small.

Terminals: Jack top binding posts with standard ¾-inch spacing at input and output. A separate ground post is provided, so that the divider circuit can be used grounded or ungrounded, with the shield grounded.

Mounting: Aluminum panel and cabinet.

Dimensions: (Length) 15¾ x (width) 5¼ x (height) 5 inches, over-all.

Net Weight: 7¼ pounds.

Type		*Code Word*	*Price*
1454-A	**Decade Voltage Divider (10,000 ohms)..........**	ABACK	**$145.00**
1454-AH	**Decade Voltage Divider (100,000 ohms)........**	ABASH	**145.00**

WESCON 1959

Cow Palace, San Francisco -:- August 18-21

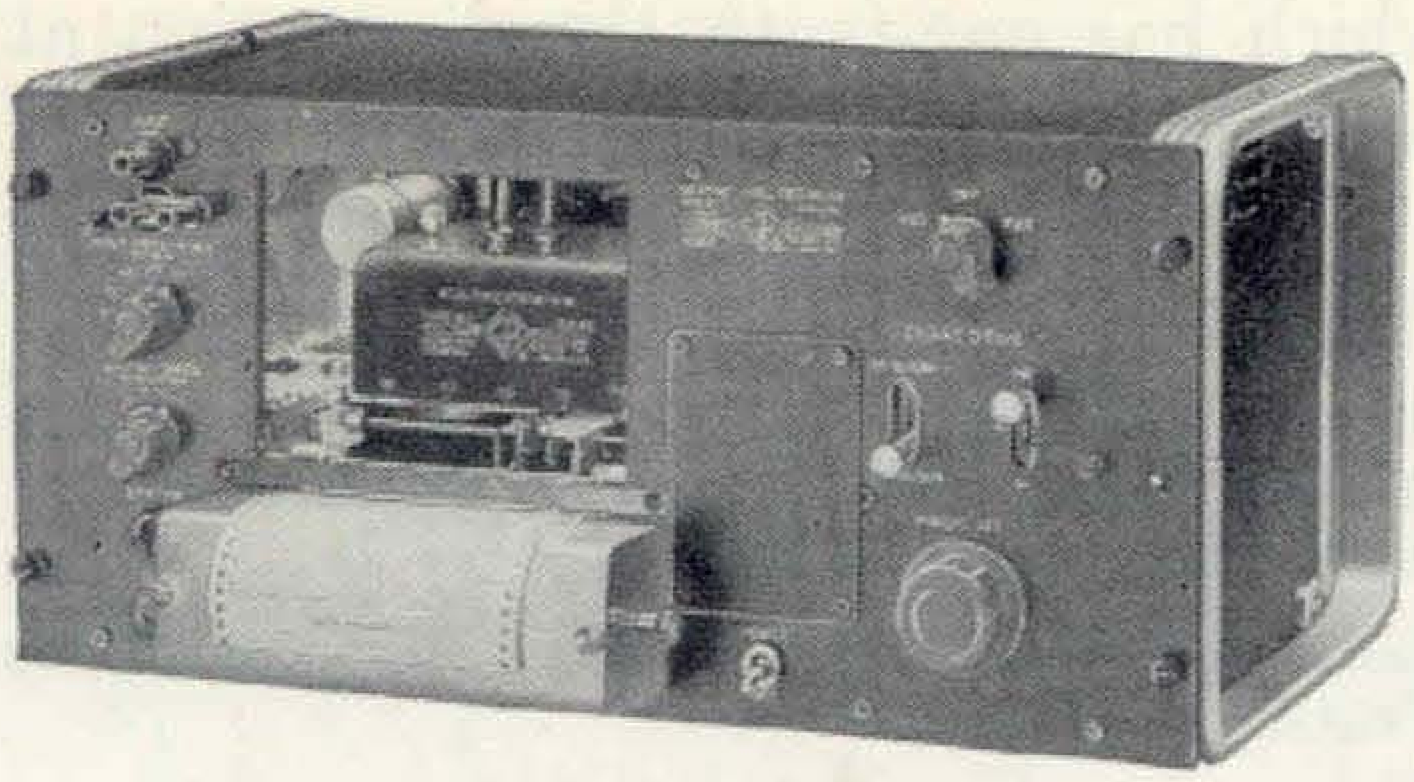
When you attend the Western Electronic Show and Convention, drop in at Booths 2015 and 2016 to see these new General Radio instruments:

TYPE 1650-A Impedance Bridge
TYPE 1521-A Graphic Level Recorder
TYPE 1305-A Low-Frequency Oscillator
TYPE 1632-A Inductance Bridge
TYPE 1554-A Sound and Vibration Analyzer

Each of these instruments has features of electrical and mechanical design that will interest you, performance specifications that will please you, and the same high quality of manufacture that you expect in General Radio products.

Type 1650-A Impedance Bridge

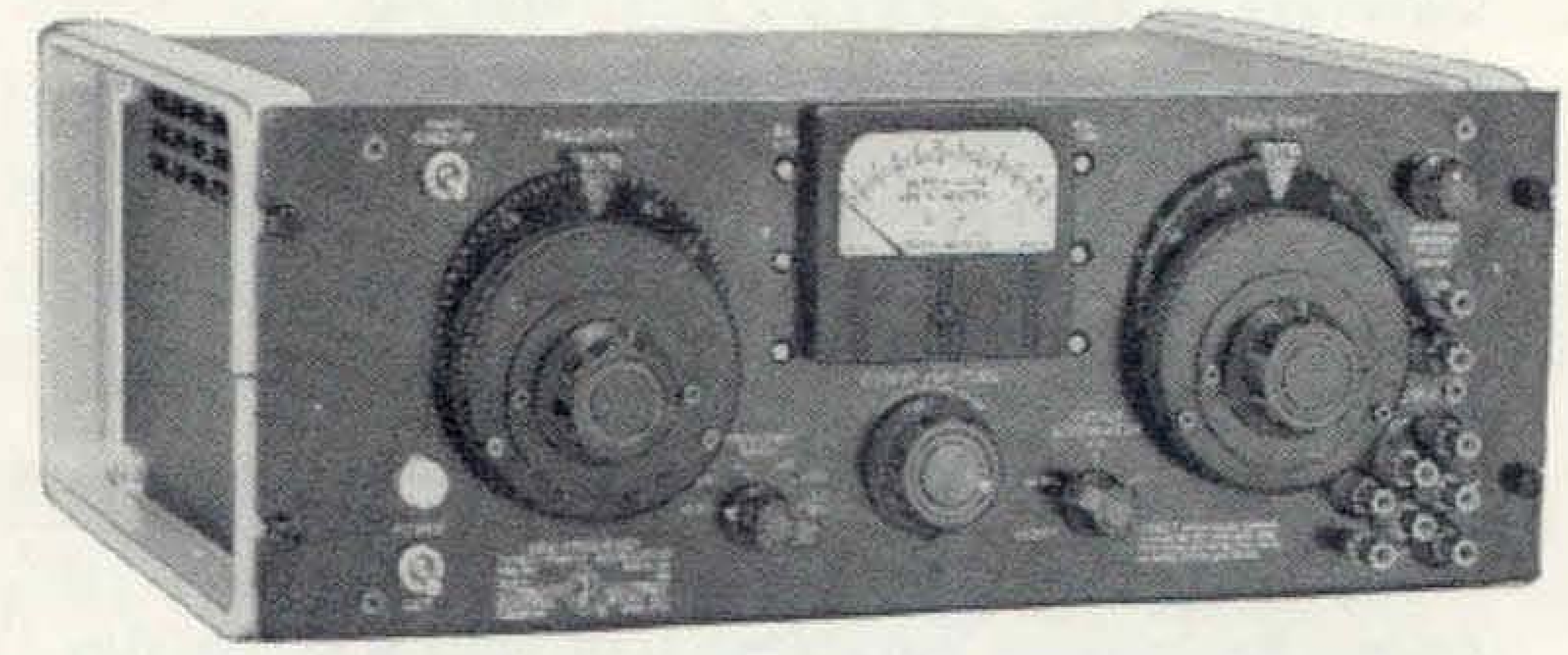
A wide-range, accurate, general-purpose bridge, measuring R, L and C. Completely new design with exclusive, patented *Orthonull* feature and self-contained, transistorized generator and detector. See *Experimenter* for March, 1959, for further details.



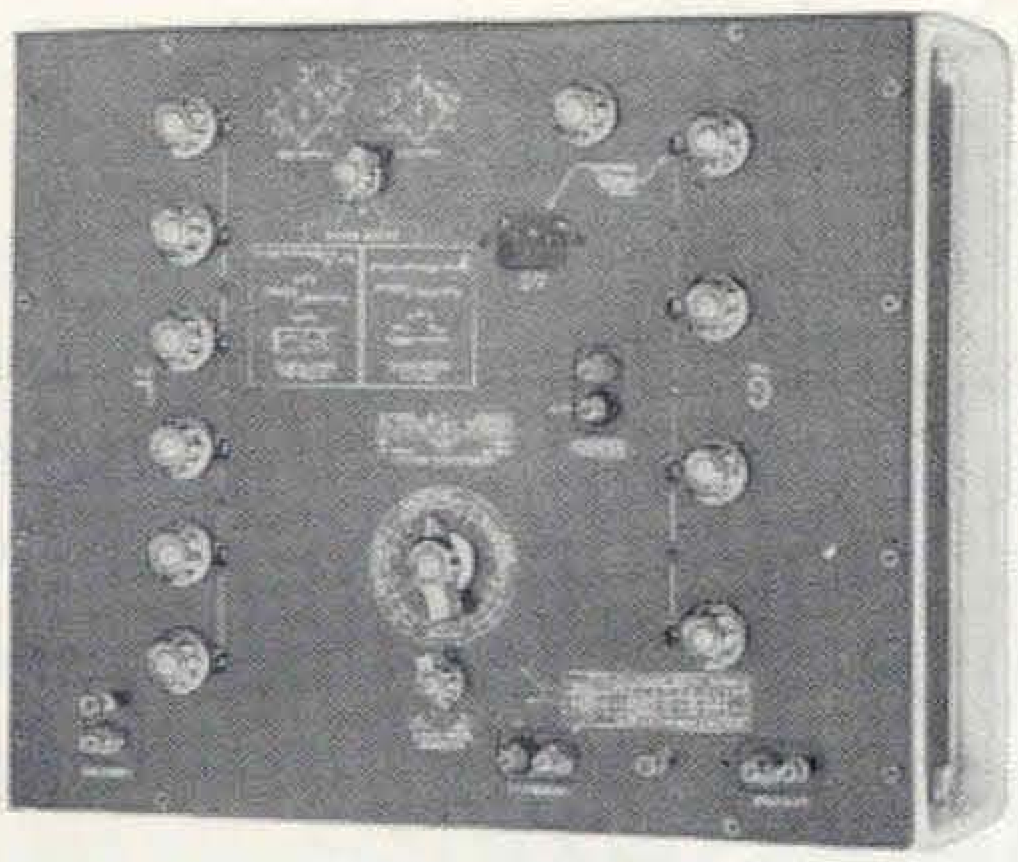
Type 1521-A Graphic Level Recorder

Fully described in last month's (June) *Experimenter*. High-sensitivity, single-channel recorder, which plots rms level of an ac signal as a function of either time or frequency. Simple to operate. Completely transistorized.

Type 1305-A Low-Frequency Oscillator



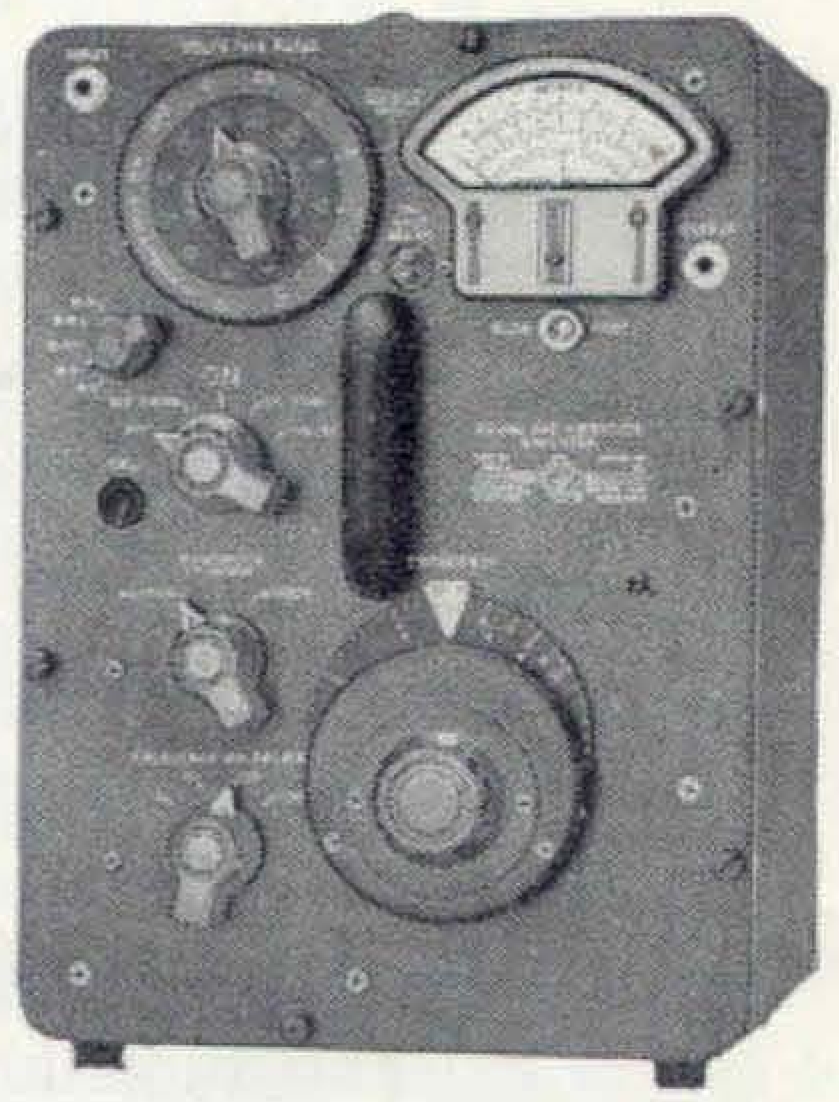
Sine-wave generator covering frequency range from 0.01 to 1000 cycles per second. Single phase, three-phase, and four-phase output, with single-phase output continuously variable in phase from 0 to 360°. Excellent stability, low distortion. To be described in a forthcoming issue of the *Experimenter*.



Type 1632-A Inductance Bridge

Wide-range inductance bridge for the precise measurement and standardization of two-terminal grounded inductors at audio frequencies. Range is 0.001 μh to 1111 h. Normal accuracy is 0.1%. Convenient to operate, has in-line read-out. Six-figure resolution gives high precision. To be described in a forthcoming issue of the *Experimenter*.

Type 1554-A Sound and Vibration Analyzer



Measures amplitude and frequency of the individual components of waveforms between 2.5 and 25,000 cycles per second. Has both 8% and one-third octave pass bands. Portable, battery powered, uses 6 tubes and 11 transistors. Can be used with sound-level meter, vibration meter, or microphone input for acoustic work, or directly as a general-purpose electric-wave analyzer. To be described in a forthcoming issue of the *Experimenter*.

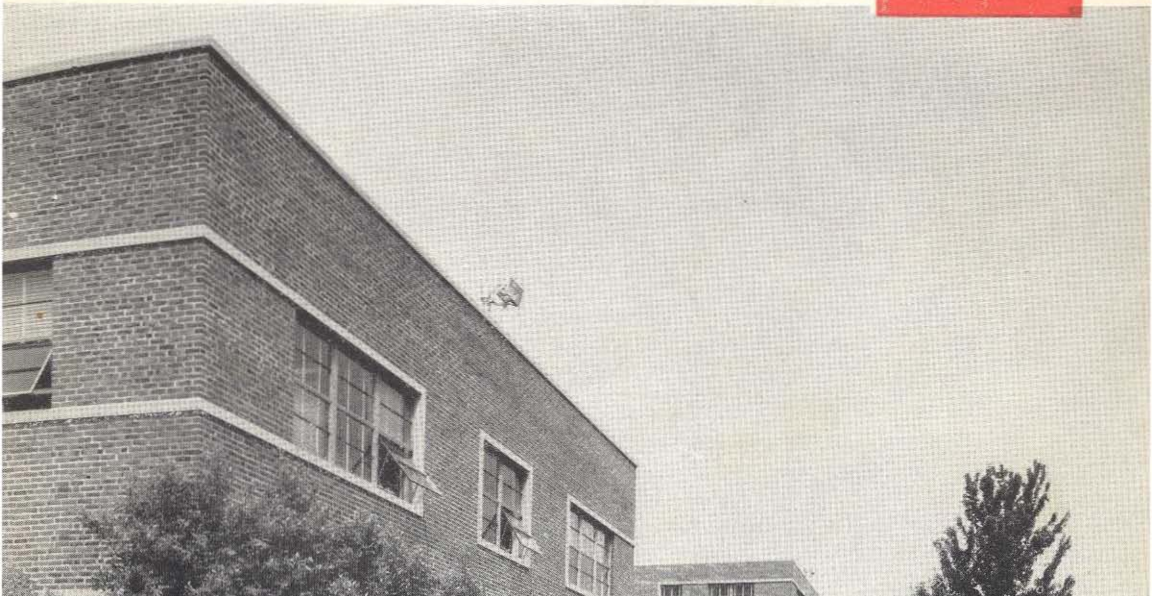
Other Instruments

Many other General Radio products will be on display, including Unit Instruments, Variac® autotransformers, and standards of capacitance and inductance.

General Radio Company

PRINTED IN U.S.A.

THE GENERAL RADIO
EXPERIMENTER



VOLUME 33 Nos. 8 & 9 AUGUST-SEPTEMBER, 1959

IN THIS ISSUE

THE GENERAL RADIO

EXPERIMENTER

Published Monthly by the General Radio Company

VOLUME 33 · NUMBERS 8 & 9 AUGUST-SEPTEMBER, 1959

CONTENTS

The General Radio EXPERIMENTER is mailed without charge each month to engineers, scientists, technicians, and others interested in electronic techniques in measurement. 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.

GENERAL RADIO COMPANY

West Concord, Massachusetts

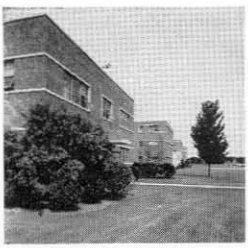
Telephone: (Concord) *EMerson 9-4400;* (Boston) *CLearwater 9-8900*

NEW YORK:	**Broad Avenue at Linden, Ridgefield, New Jersey** *Telephone — N. Y., WOrth 4-2722* *N. J., WHitney 3-3140*
CHICAGO:	**6605 West North Avenue, Oak Park, Illinois** *Telephone — VIllage 8-9400*
PHILADELPHIA:	**1150 York Road, Abington, Pennsylvania** *Telephone — HAncock 4-7419*
WASHINGTON:	**8055 13th St., Silver Spring, Maryland** *Telephone — JUniper 5-1088*
LOS ANGELES:	**1000 North Seward St., Los Angeles 38, Calif.** *Telephone — HOllywood 9-6201*
SAN FRANCISCO:	**1186 Los Altos Ave., Los Altos, Calif.** *Telephone — WHitecliff 8-8233*
CANADA:	**99 Floral Parkway, Toronto 15, Ontario** *Telephone — CHerry 6-2171*

REPAIR SERVICES

EAST COAST:	**General Radio Co., Service Dept., 22 Baker Avenue, West Concord, Mass.** *Telephone — Concord, EMerson 9-4400* *Boston, CLearwater 9-8900*
NEW YORK:	**General Radio Co., Service Dept., Broad Ave. at Linden, Ridgefield, New Jersey** *Telephone — N. Y., WOrth 4-2722* *N. J., WHitney 3-3140*
MIDWEST:	**General Radio Co., Service Dept., 6605 West North Ave., Oak Park, Illinois** *Telephone — VIllage 8-9400*
WEST COAST:	**Western Instrument Co., 826 North Victory Boulevard, Burbank, Calif.** *Telephone — VIctoria 9-3013*
CANADA:	**Bayly Engineering, Ltd., First St., Ajax, Ontario** *Telephone — Toronto EMpire 2-3741*

COVER



Set amid trees and broad lawns, General Radio's new plant in historic Concord presents a pleasing prospect to the visitor as he approaches the main entrance.

THE
TYPE 1305-A LOW-FREQUENCY OSCILLATOR

A UNIQUE INSTRUMENT FOR THE MEASUREMENT OF PHASE-GAIN CHARACTERISTICS IN THE RANGE OF 0.01 TO 1000 CYCLES PER SECOND

The TYPE 1305-A Low-Frequency Oscillator brings to the low-frequency field a convenient source of sinusoidal alternating voltage. Its unique circuitry provides a balanced, three-phase output and includes a continuously variable, calibrated, frequency-independent phase-shifter, for the measurement of phase shift up to, and beyond, 360 electrical degrees. An accessory, the TYPE 1305-P1 Four-Phase Adaptor, provides four output voltages of equal magnitude displaced 90°, also frequency-independent. Here, then, is the basis of a system for phase-gain measurement at low and power frequencies. It is particularly useful to those concerned with the performance of geophysical gear, servomechanisms, sonar networks, power-system analogues, and similar low-frequency equipment.

The TYPE 1305-A Oscillator is basically a phase-shift oscillator. Three identical resistance-capacitance networks are cascaded to produce a phase shift of 180° (60° per network) at the operating frequency.[1] For each decade range, fixed networks are provided. The *apparent* capacitance is varied by "Miller Effect"[2] amplifiers, as shown in the block diagram, Figure 2. This method of frequency variation has many distinct advantages:

A. The size of the polystyrene capacitors required for the lowest frequencies is reduced by an order of magnitude; an appreciable economy.

B. The frequency-varying elements are three, ganged, logarithmic potentiometers, of a convenient value, that yield a "constant-accuracy" calibration as they vary the Miller Effect gain, yet the *RC* networks behave as though capacitance were varied to yield a constant impedance at the oscillation frequency.

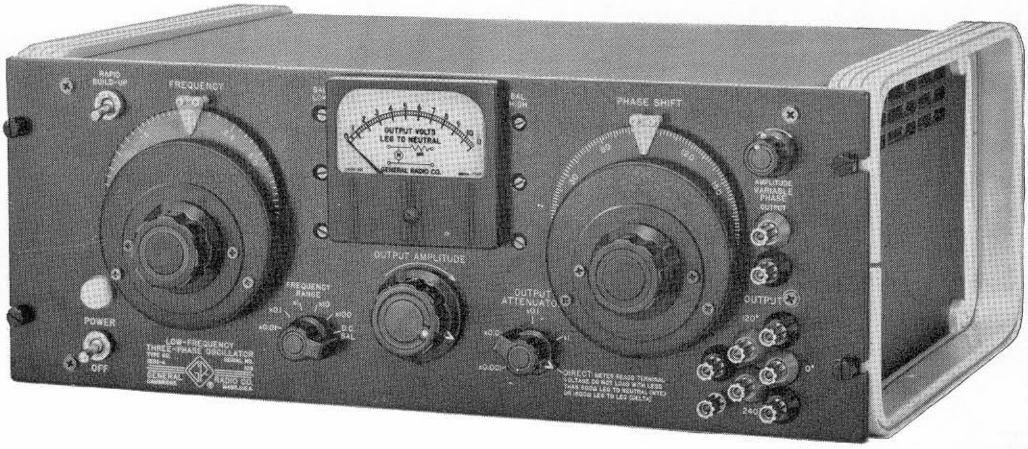
C. The three cascaded networks and amplifiers automatically result in a three-phase, wye configuration, which, in turn, introduces still further advantages:

1. The wye network connects to the oscillator power supply at the neutral (zero voltage) point. Hence oscillator

[1]Gilbert Smiley, "Ultra-Low-Frequency, Three-Phase Oscillator," *Proceedings of the IRE*, April, 1954.

[2]J. M. Miller, "Dependence of the Input Impedance of a Three-Electrode Vacuum Tube upon the Load in the Plate Circuit," *Bureau of Standards Scientific Paper*, 351.

Figure 1. Panel view of the Type 1305-A Low-Frequency Three-Phase Oscillator.



currents do *not* traverse the power supply.

2. The three-phase system makes possible the phase-shifter, previously mentioned. A continuously rotatable potentiometer is connected, at equally spaced points, to the three-phase output and is appropriately "padded" for constant output and linear phase-shift. The fixed, four-phase, Type 1305-P1 Adaptor is connected to the three-phase output through appropriate networks.

3. Output voltage indication is provided by a voltmeter supplied from a three-phase, full-wave rectifier across the oscillator output. The low ripple (−10%, +5% of rms voltage) permits accurate setting of output voltage at even the lowest frequency.

4. Another three-phase, full-wave rectifier, terminated in a reference diode, acts to reduce the oscillator loop gain when the reference voltage is exceeded. At this point the gain is "clipped," slightly, six times per cycle. Output is held constant within $\pm\frac{1}{2}$ db over the operating range with a minimum of distortion. This direct-acting limiter eliminates the intolerable time constant consequent upon the use of conventional automatic-gain-control circuitry at such low frequencies.

5. No phase shift exists at zero frequency (direct current), and the feedback loop is strongly degenerative (more than 18 db) against changes in vacuum tube or component parameters.

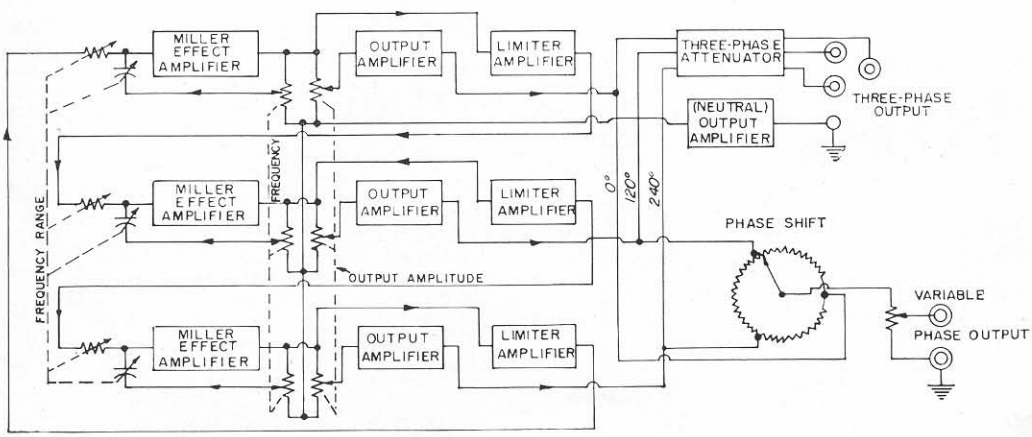
Oscillator build-up time, a phenomenon that usually goes unnoticed in oscillators operating at audio-frequencies and higher, can, at the frequencies in the range of the Type 1305-A, actually be measured in hours! For this reason, a rapid build-up switch is provided, to introduce a transient in excess of the limited amplitude. Within one cycle after the release of the switch, the oscillator achieves constant amplitude, so effective is the limiter action.

The Type 1305-A is, by virtue of its rapid build-up time and constancy of output amplitude, a useful source of single-phase, three-phase, and two-or-four-phase signals over the range from 0.01 cycles to 1000 cycles. Outputs balanced to ground can be obtained from the four-phase output adaptor.

A most important use of the Type 1305-A Oscillator is the measurement of servo-system phase-gain characteristics. To illustrate this application, measurements have been made on two General Radio servo-operated devices, the Type 1521-A Graphic Level Recorder and the Type 1570-A Automatic Line Voltage Regulator, and the results have been plotted in the form of Nyquist diagrams.

Figure 4 shows the closed- and open-

Figure 2. Elementary block diagram of the oscillator.



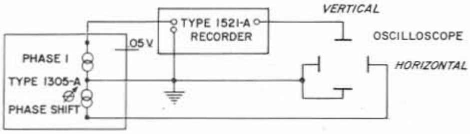


Figure 3. Arrangement of instruments for measuring closed- and open-loop phase gain characteristics.

loop phase-gain characteristics of the TYPE 1521-A Recorder as measured with the setup shown in Figure 3. The closed loop measurement, which is of greatest interest to the user, is extremely easy to make. The output of the recorder is taken across the dc input potentiometer, which is what the pen records. The oscillator phase-shifted output is applied to the horizontal deflection plates. For each frequency the peak-to-peak vertical deflection of the 'scope is a measure of the output voltage, and the phase shift is measured by adjusting the phase-shifted output to close the oval 'scope trace to a straight line. Measurements are started at a low enough frequency to insure a minimum phase shift (near zero degrees) and extended upward as far as needed.

Measurement of open-loop gain and phase characteristics is fundamental to the synthesis of stable phase-correcting networks. However, in a servo system with response to dc, this measurement can be much more difficult than the closed-loop measurement if the open-loop gain is high and there is dc drift. To obtain the open-loop response curve of Figure 4 required the combined efforts of two engineers, one correcting the drift with a potentiometer while the other observed the pattern on the oscilloscope.

Figure 5 shows the closed-loop response of the TYPE 1570-A Automatic Voltage Regulator as measured by similar techniques. The similarities of the two systems are certainly more marked than their differences!

Obviously, similar measurements can be made on other networks with equally informative results.

— GILBERT SMILEY

Figure 4. Closed-loop and open-loop phase gain characteristics of the Type 1521-A Graphic Level Recorder.

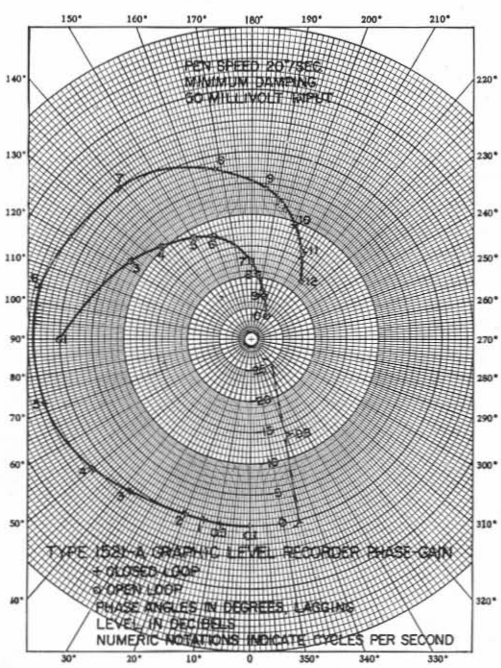
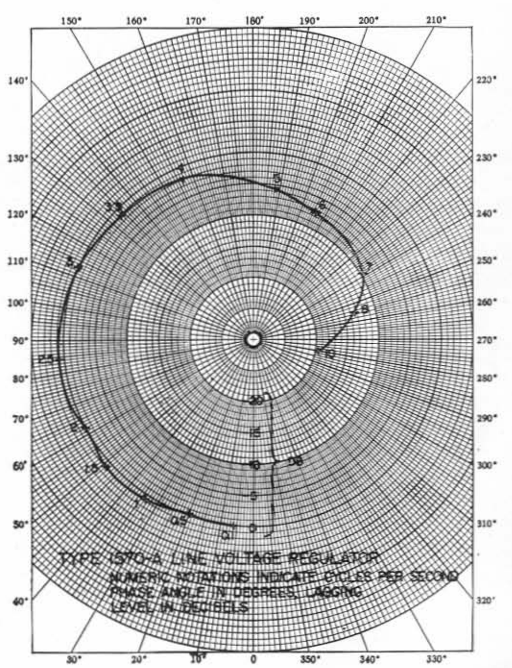


Figure 5. Closed-loop response of the Type 1570-A Automatic Voltage Regulator.



The development of the TYPE 1305-A Low-Frequency Oscillator was started some years ago by the writer, but brought to its final fruition through the work of James J. Faran, Jr. Thanks are due M. J. Fitzmorris and M. C. Holtje for their help in the measurement of the characteristics of the TYPE 1521-A Graphic Level Recorder and the TYPE 1570-A Automatic Voltage Regulator.

SPECIFICATIONS

Frequency Range: 0.01 to 1000 cycles in five ranges.

Frequency Control: The main frequency control dial is engraved from 1 to 10 cycles. A range switch multiplies the scale frequencies by 0.01, 0.1, 1, 10, and 100.

Frequency Calibration Accuracy: $\pm 2\%$.

Frequency Stability: Warm-up drift is less than 1% in the first ten minutes, less than 0.2% in the next hour.

Three-Phase Output: At least 10 volts rms, open circuit, line-to-neutral, behind 600 ohms in each phase, constant with frequency to $\pm 5\%$. Phase voltages are equal to each other within $\pm 2\%$.

The DIRECT position of the output attenuator switch provides 75 ohms per phase but must not be loaded with less than 600 ohms per phase, wye-connected, or 1800 ohms per phase, delta-connected. A neutral terminal is provided. Phase accuracy, $\pm 2°$.

Output power is 167 milliwatts per phase, maximum, into a 3-phase wye-connected load of 600 ohms per phase.

Four-Phase Output: At least 5 volts, rms, line-to-neutral, behind 600 ohms, from the 4-phase adaptor. Phase accuracy, $\pm 3°$.

Variable-Phase Output: Approximately 0.8 volt, rms, behind a maximum impedance of 15,000 ohms. Maximum error in total phase angle is $\pm 3°$. For phase angles of less than 10° the accuracy is $\pm 0.5°$. At any dial setting, small phase differences can be measured to an accuracy of $\pm 0.25°$.

Waveform: Total harmonic content is less than 2% for all output values and for all frequencies for any load except in the DIRECT position of OUTPUT ATTENUATOR switch. For the DIRECT position of the OUTPUT ATTENUATOR switch, total harmonic content is less than 2% for any wye-connected load of more than 600 Ω per leg or delta-connected load of more than 1800 Ω per phase. Line-frequency hum in the output is less than 10 millivolts.

Terminals: TYPE 938 Binding Posts. Neutral can be connected to the chassis, which can be grounded through a 3-wire power cord.

Mounting: Aluminum, 19-inch, relay-rack panel; aluminum cabinet. For table mounting (TYPE 1305-AM), aluminum end frames are supplied to fit ends of cabinet; for relay-rack mounting (TYPE 1305-AR), brackets for holding cabinet in rack are supplied. Relay-rack mounting is so arranged that panel and chassis can be removed from cabinet, leaving cabinet in rack, or cabinet can be removed from rear of rack, leaving panel attached to rack.

Power Supply: 105 to 125 (or 210 to 250) volts, 50 to 60 cycles. Total power consumption is 165 watts. Instrument will operate satisfactorily on power-supply frequencies up to 400 cycles.

Power input receptacle will accept either 2-wire (TYPE CAP-35) or 3-wire (TYPE CAP-15) power cord. Two-wire cord is supplied.

Tube Complement: Four each 6197; three each 6BH6, 5963; one each OB2, 12AX7, 6080; six 1N536 crystal diodes; eight 1N119 crystal diodes; one SV18 crystal diode.

Accessories Supplied: TYPE CAP-35 Power Cord, three TYPE 274-MB Double Plugs, spare fuses, Four-Phase Output Adaptor TYPE 1305-P1.

Dimensions: Panel, (width) 19 x (height) 7 inches; depth behind panel, 12 inches.

Net Weight: 35 pounds.

Type		*Code Word*	*Price*
1305-AM	**Low-Frequency Oscillator, Bench Model**	DEBUT	**$940.00**
1305-AR	**Low-Frequency Oscillator, Relay-Rack Model**	DONOR	**940.00**

YES, INDEED, WE'VE MOVED

We are still getting mail addressed to our former location in Cambridge. To help us give prompt attention to all inquiries, won't you please change our address in your records and ask your Purchasing Department to do the same?

Our new address: **General Radio Co.**
West Concord, Mass.

NEW THREE-TERMINAL CAPACITORS

To meet the growing need for standards suitable for use in three-terminal capacitance measurements, we are now making available both fixed and variable three-terminal capacitors. The fixed units, TYPE 1403 Standard Air Capacitors, are three-terminal versions of the two-terminal TYPE 1401, while the variable units are TYPE 722 Precision Capacitors. Both types are equipped with TYPE 874 Coaxial Connectors for complete shielding, and mating connectors are supplied.

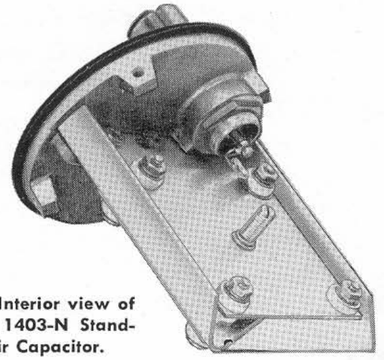


Figure 2. Interior view of the Type 1403-N Standard Air Capacitor.

FIXED CAPACITORS

This new series of fixed air capacitors is designed and calibrated for use in three-terminal measuring systems. These standards are available in powers of 10 from 0.01 pf to 1000 pf, supplementing the TYPE 1409 Standard Capacitors which are offered in the range from 1000 pf to 1 μf. Since the latter are arranged for either two-terminal or three-terminal use, the total range of GR fixed, three-terminal capacitance standards is now 0.01 pf to 1 μf, a total span of 100 million to 1.

The TYPES 1403-A, -D, and -G have nominal values of 1000, 100, and 10 pf respectively. The construction of these units is conventional — in fact, the capacitors are basically of the same design as the TYPE 1401 Standard Air Capacitors, consisting of interleaved stacks of aluminum plates. Each set of plates is insulated from the supporting casting and frame, and the coaxial terminals are provided so that completely shielded connections can be made.

Figure 1. View of the Type 1403-D Standard Air Capacitor.

For low capacitance values higher accuracy is possible with the three-terminal construction than with two-terminal types, since there is no connection uncertainty.[1] While in the two-terminal TYPE 1401 there is a progressively increasing uncertainty below 1000 pf, the inherent accuracy of any three-terminal capacitor such as the TYPE 1403 is independent of the capacitance value. (The reduced specification accuracy of the 0.01-pf unit reflects current limitation in measurement accuracy.)

At extremely low values of capacitance, the conventional plate construction becomes quite impractical. For these values (TYPES 1403-K, -N, -R) we have adopted an "aperture" type of

[1] John F. Hersh, "A Close Look at Connection Errors in Capacitance Measurement," *General Radio Experimenter*, 33, 7, July, 1959.

design similar in principle to those suggested by Moon,[2] Zickner,[3] and others. In this type of capacitor, the two electrodes are isolated from each other by a grounded plate between them. The shielding provided by this plate can easily be made sufficiently good to make the leakage between the active electrodes substantially zero. The capacitance between the electrodes is then determined solely by an aperture in the grounded plate, the magnitude of the capacitance being established by the area of the opening and the spacing between the active plates.

The effective area of the aperture is somewhat less than that determined by its diameter. This reduction of effective area can properly be described as "negative fringing" of the electric field, and the (negative) increment of capacitance which is contributed can be described as "negative edge capacitance." The situation is roughly illustrated in Figure 3 using the classical lines-of-force concept.

[2]Moon and Sparks, *NBS J. Research*, *41*, 497-507 (1948).
[3]G. Zickner, *Elek. Nachr.-Tech.*, 7, 443-448 (1930). *Z. angew Phys.*, 8, 187 (1956).

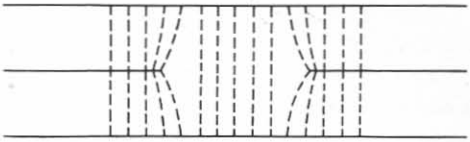


Figure 3. Sketch illustrating negative fringing.

Since there is no solid dielectric in the direct capacitance field, the losses in these capacitors are very low. The observed dissipation factor is 10 microradians or less (which is close to the limit of present measurement accuracy) and presumably arises from losses in air and at the interface between the air and the surface of the metal plates. The losses in the "edge capacitance," which in nearly all cases are noticeably higher than those in the direct capacitance, are in this design a part of the ground capacitance. Thus the desired direct capacitance is free of the losses which occur at the edges of metal plates from the increased field concentration at those edges.

SPECIFICATIONS

Terminals: TYPE 874 Coaxial Connectors for complete shielding of leads.

Accessories Supplied: Two TYPE 874-C58 Cable Connectors.

Calibration: A certificate of calibration is supplied with each unit.

Dimensions: ¾ (dia.) by 4¼ inches, over-all.

Net Weight: One pound.

Type	*Direct Capacitance*	*Adjustment Accuracy*	*Max. Volts*	*Dissipation Factor*	*Code Word*	*Price*
1403-A	1000 μμf	0.1%	700	10×10^{-6}	DABBY	**$60.00**
1403-D	100 μμf	0.1%	1500	10×10^{-6}	DAIRY	**55.00**
1403-G	10 μμf	0.1%	1500	10×10^{-6}	DASHY	**48.00**
1403-K	1.0 μμf	0.1%	1500	10×10^{-6}	DATUM	**45.00**
1403-N	0.1 μμf	0.1%	1500	10×10^{-6}	DAUNT	**45.00**
1403-R	0.01 μμf	0.3%	1500	10×10^{-6}	DAVIT	**45.00**

ADJUSTABLE CAPACITORS

Two new adjustable Precision Capacitors have been added to the well-established and widely accepted TYPE 722 series. A two-section unit, the TYPE 722-CD, has full-scale ranges of 11 pf and 1.1 pf; a single-section unit, TYPE

722-CC, has a full-scale range of 110 pf. These new models, together with the Type 722-CB (1100 pf) announced earlier,[4] provide a 1000-to-1 range of full-scale values now available for three-terminal capacitance measurements.

Externally the three capacitors are alike and, except for the coaxial terminals, similar to other units of the 722 line. Internally, however, the new models

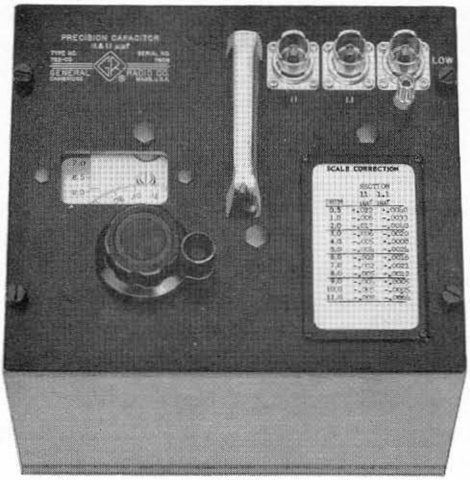


Figure 4. Panel view of the Type 722-CD Precision Capacitor.

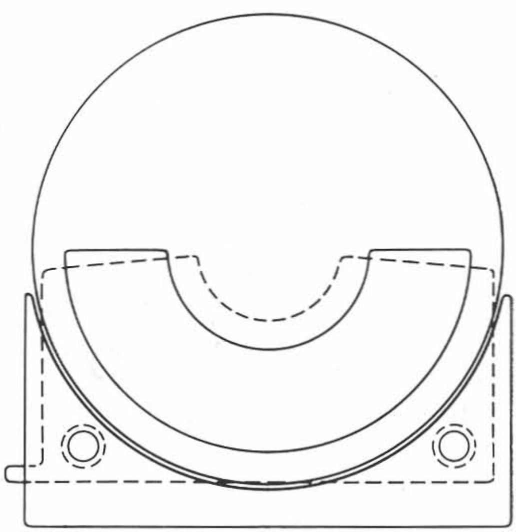
differ radically in design from the conventional rotor and stator structure of the Type 722-CB.

Two sets of stator plates, insulated from each other and from the supporting rods, are interleaved in a stack much after the manner of a fixed air capacitor. A ground plane interposed between plates shields the two sets of plates from each other, except for an annular aperture[3] in the ground plate, which provides the controlled direct capacitance between stator plates. The ground plane consists of two parts, one a fixed plate mounted to and connected to the same rods which support the stators, the other a circular rotor plate which rotates in the same plane as the fixed ground plate. The arrangement of the various plates is depicted in Figure 5.

The gap between the two portions of the ground plane is so small that the leakage capacitance through it is negligible compared to the desired direct capacitance. Furthermore, any leakage is constant with rotation.

When the annular aperture shown in Figure 5 is rotated into the stator stack, the direct capacitance varies linearly with the angle of rotation. Capacitors of this design possess inherently a high degree of linearity. The increment of capacitance per unit of angular rotation depends solely on the spacing between stator plates and the two radii of the annular aperture. The location of the rotor plates in the gap, the concentricity of the rotor shaft relative to the stator plates, and the dimensions of all plates are but some of the factors which are of first-order importance in conventional construction, but only of second-order importance in the aperture type of capacitor.

Figure 5. Sketch showing the arrangement of plates in the 3-terminal Variable Precision Capacitor.



[3] Loc. cit.

[4] Ivan G. Easton, "A Three-Terminal Precision Capacitor," *General Radio Experimenter*, 32, 17, October, 1958.

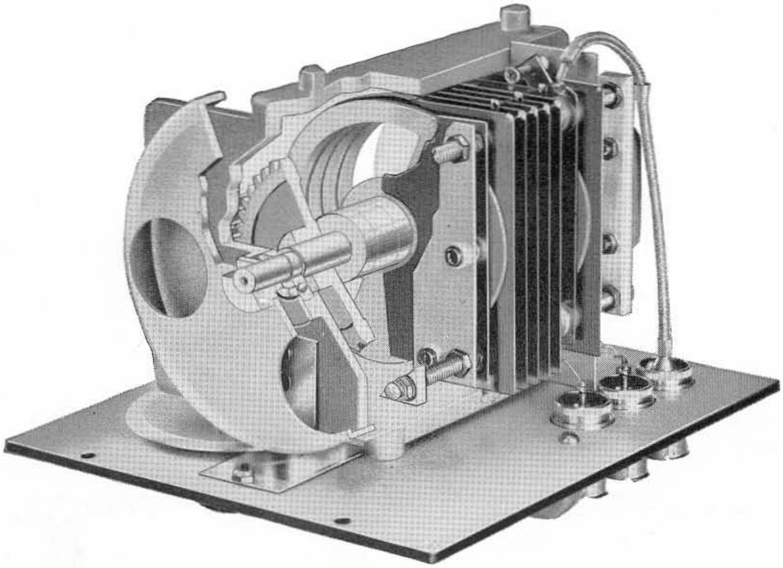


Figure 6. Interior view of the Type 722-CD Precision Capacitor.

For a given spacing between plates, the aperture-type capacitor can yield a maximum of only one-quarter as much capacitance in a given volume, even with zero thickness rotor plates, since alternate gaps are, in effect, in series rather than in parallel. A further reduction occurs because the aperture is of necessity smaller in area than a full rotor plate used in the conventional manner. As a result, the maximum available capacitance in a Type 722 frame is about 100 pf. Dielectric loss at the plate surfaces is minimized by the use of nickel-plated brass plates.

The terminal-to-ground capacitances of these new capacitors are drastically different in magnitude and variation from those usually encountered. In the previously announced Type 722-CB, for instance, the capacitance of stator to ground is about 20 pf and substantially independent of rotor setting. The capacitance of rotor to ground, of course, is a function of setting, varying (for example) from 33 pf to 37 pf. Whereas these values are small relative to the direct capacitance, in the Types 722-CC and -CD the terminal capacitances *are inherently larger* by a substantial factor than the direct capacitance. As the aperture is rotated out of the gap, the capacitance between plates is transferred to ground. Thus *both* terminal capacitances vary with setting. These capacitors, therefore, are not suitable for two-terminal use. Moreover, they can produce misleading results in three-terminal networks unless the effective impedances of the circuit from both rotor and stator to ground are low. Subject to this limitation these new capacitors should prove themselves useful in a wide variety of three-terminal measurement applications.

— Ivan G. Easton

The suggestion for, and preliminary design of, the aperture type capacitors was contributed by Dudley H. Chute. P. K. McElroy and the author collaborated with Mr. Chute in evolving the final designs.

SPECIFICATIONS

Capacitance Range

Type	*Capacitance Range, pf*	*Direct-Reading Accuracy*	*Approx. Cap. at Zero Scale Setting*	*Approximate Terminal-to-Ground Capacitances, pf* High	Low
722-CC	5 to 110	±0.2 pf	0	600-900	600-900
722-CD	0.5 to 11 0.05 to 1.1	±0.04 pf ±0.008 pf	0	75-100 24-26	90-110 90-120

Correction Chart: A correction chart is supplied giving corrections at multiples of 10, 1, or 0.1 pf, depending on the total capacitance of the capacitor. Accuracies obtainable through the use of these charts are as follows:

Type	*Range, pf*	*Accuracy after correction is applied* Total Capacitance	Capacitance Differences
722-CC	5 to 110	±0.1% or ±0.08 pf*	±0.16 pf
722-CD	0.5 to 11 0.05 to 1.1	±0.02 pf ±0.003 pf	±0.04 pf ±0.006 pf

*Whichever is greater.

Worm Correction Calibration: Corrections for the slight residual eccentricity of the worm drive can be supplied for all models at an extra charge indicated in the price list. Mounted charts are supplied, which give the corrections to at least one more figure than the guaranteed accuracies, which are stated below:

Type	*Range, pf*	*Accuracy after worm correction is applied* Total Capacitance	Capacitance Differences
722-CC	5 to 110	±0.1% or ±0.02 pf*	±0.1% or ±0.04 pf*
722-CD	0.5 to 11 0.05 to 1.1	±0.1% or ±0.004 pf* ±0.1% or ±0.001 pf*	±0.1% or ±0.008 pf* ±0.1% or ±0.002 pf*

*Whichever is greater.

Maximum Voltage: All models, 1000 volts, peak.

Temperature Coefficient of Capacitance: Approximately +0.002% per degree Centigrade, for small temperature changes.

Backlash: Less than one-half division, corresponding to 0.01% of full-scale value. If the desired setting is always approached in the direction of increasing scale reading, no error from this cause will result.

Terminals: Type 874 Coaxial Connectors.

Accessories Supplied: 2 Type 874-C58 Cable Connectors.

Mounting: The capacitor is mounted on an aluminum panel finished in crackle and enclosed in a shielded hardwood cabinet. A wooden storage case with carrying handle is supplied (weight 9¼ pounds).

Dimensions: Panel, 8 x 9⅛ inches; depth, 8⅛ inches.

Type		*Net Weight*	*Code Word*	*Price*
722-CC	**Precision Capacitor**	12¾ pounds	CHAOS	**$265.00**
722-CD	**Precision Capacitor**	10½ pounds	COFIN	**265.00**

WORM-CORRECTION CALIBRATION

Capacitor Type		*Code Word**	*Price*
722-CC	**Worm Correction**	WORMY	**$ 55.00**
722-CD	**Worm Correction**	WORMY	**165.00**

*When ordering capacitor with worm correction, use compound code word, CHAOSWORMY, COFINWORMY, etc.

BARD ELECTED CHAIRMAN OF THE IRE CHICAGO SECTION

Robert E. Bard, engineer at General Radio's Chicago district office, has been elected Chairman of the Chicago Section of the Institute of Radio Engineers for the year 1959-60. He was a member of the Executive Committee of the Boston Section and served on several committees in 1953-54, prior to his move to the Chicago area. Last year Mr. Bard was Vice-Chairman of the Chicago Section, and before this was Executive Editor of SCANFAX, the official publication of the IRE Chicago Section. Mr. Bard has also served as a member of the Executive Committee and Board of Directors of the National Electronics Conference since 1956. He is currently Chairman of the Exhibits Committee for the National Electronics Conference.

SURVEY OF RUSSIAN SCIENTIFIC LITERATURE AVAILABLE

The National Science Foundation has recently made available a detailed survey of Russian scientific literature, listing 76 Soviet journals now available in English.

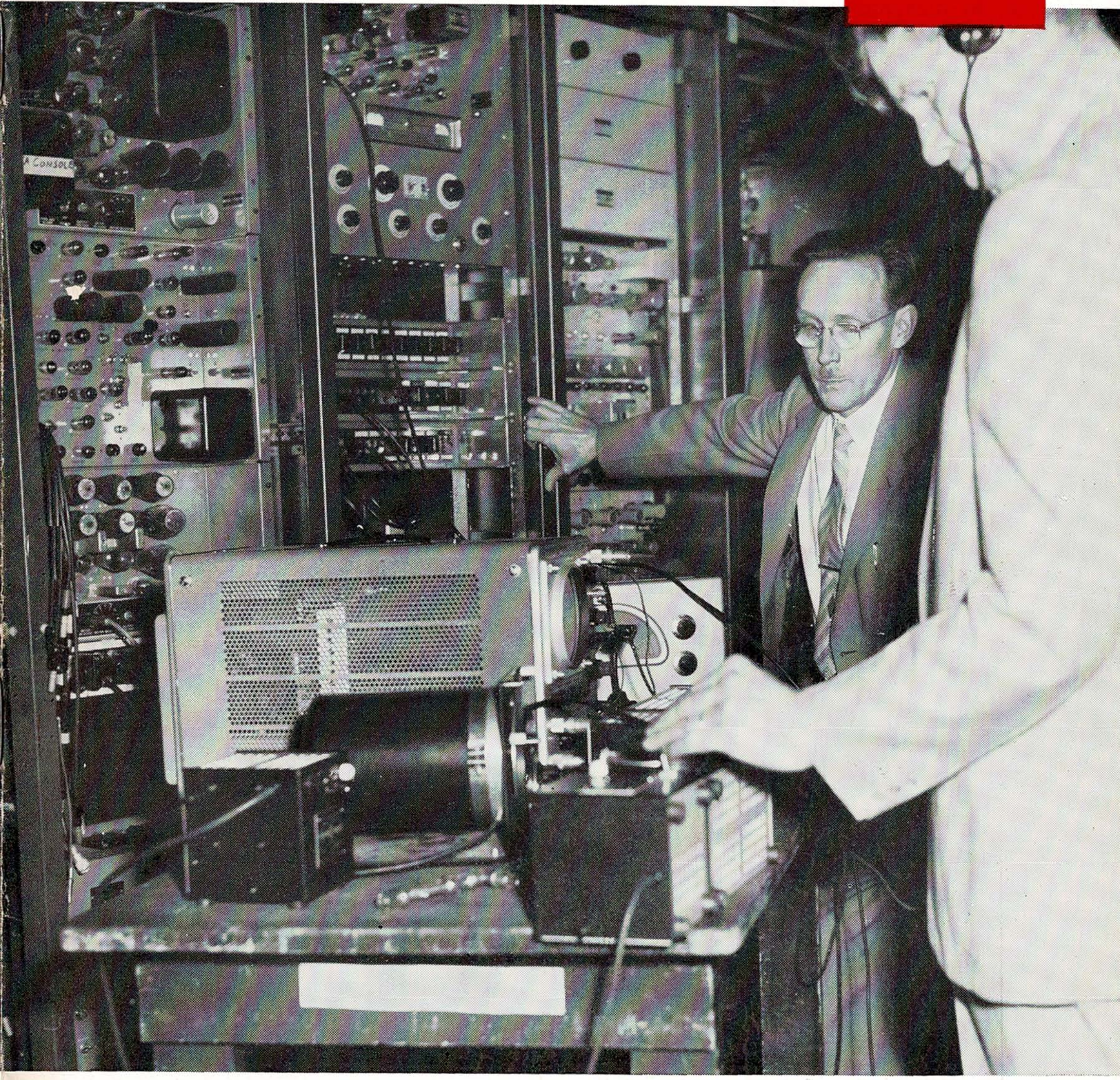
The survey reports on the sources of Soviet scientific literature, availability of such literature in the United States, and the current translation programs of professional and academic groups and government agencies. Current methods of providing comprehensive coverage of untranslated Russian material are also analyzed. Revised and expanded from an earlier edition, the survey was prepared by the Foundation's Office of Science Information Service.

Copies of the survey, entitled "Providing U. S. Scientists with Soviet Scientific Information," are available on request from the Office of Scientific Information Service, National Science Foundation, 1951 Constitution Avenue, NW, Washington 25, D. C.

PRINTED IN U.S.A.

THE GENERAL RADIO

EXPERIMENTER



VOLUME 33 No. 10 OCTOBER, 1959

IN THIS ISSUE

THE GENERAL RADIO

EXPERIMENTER

Published Monthly by the General Radio Company

VOLUME 33 • NUMBER 10 **OCTOBER, 1959**

CONTENTS

The General Radio EXPERIMENTER is mailed without charge each month to engineers, scientists, technicians, and others interested in electronic techniques in measurement. 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.

GENERAL RADIO COMPANY

West Concord, Massachusetts

Telephone: (Concord) *EMerson 9-4400;* (Boston) *CLearwater 9-8900*

NEW YORK: **Broad Avenue at Linden, Ridgefield, New Jersey**
Telephone — N. Y., WOrth 4-2722
N. J., WHitney 3-3140

CHICAGO: **6605 West North Avenue, Oak Park, Illinois**
Telephone — VIllage 8-9400

PHILADELPHIA: **1150 York Road, Abington, Pennsylvania**
Telephone — HAncock 4-7419

WASHINGTON: **8055 13th St., Silver Spring, Maryland**
Telephone — JUniper 5-1088

LOS ANGELES: **1000 North Seward St., Los Angeles 38, Calif.**
Telephone — HOllywood 9-6201

SAN FRANCISCO: **1186 Los Altos Ave., Los Altos, Calif.**
Telephone — WHitecliff 8-8233

CANADA: **99 Floral Parkway, Toronto 15, Ontario**
Telephone — CHerry 6-2171

REPAIR SERVICES

EAST COAST: **General Radio Co., Service Dept., 22 Baker Avenue, West Concord, Mass.**
Telephone — Concord, EMerson 9-4400
Boston, CLearwater 9-8900

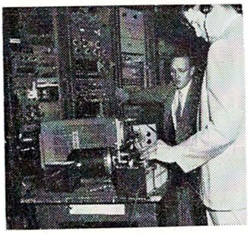
NEW YORK: **General Radio Co., Service Dept., Broad Ave. at Linden, Ridgefield, New Jersey**
Telephone — N. Y., WOrth 4-2722
N. J., WHitney 3-3140

MIDWEST: **General Radio Co., Service Dept., 6605 West North Ave., Oak Park, Illinois**
Telephone — VIllage 8-9400

WEST COAST: **Western Instrument Co., 826 North Victory Boulevard, Burbank, Calif.**
Telephone — VIctoria 9-3013

CANADA: **Bayly Engineering, Ltd., First St., Ajax, Ontario**
Telephone — Toronto EMpire 2-3741

COVER



General Radio engineers C. A. Cady and W. P. Buuck measuring frequencies in a radio and television station with the Type 1213 Time/Frequency Calibrator.

A TIME/FREQUENCY CALIBRATOR OF IMPROVED STABILITY

The Unit Time/Frequency Calibrator, Type 1213,[1, 2] is a unique instrument. Seldom have seven electronic tubes done so much in so small a package and at so low a cost. In less than ⅓ cubic foot it provides all the functions of a secondary standard.

The circuitry and the design of this compact little instrument have received a continuing attention, both in our own laboratories and among our customers, with the result that its performance has been periodically improved as new methods and components became available. The latest design, Type 1213-D, embodies a new quartz crystal and its associated oscillator circuit, together with an improved 10-1 Mc multivibrator. With these improvements, the short-time stability of the output frequencies is increased by a whole order of magnitude and is now better than 1 part in 10^7.

The new circuit and design features are described in this article; the balance of the instrument is identical with that described in reference 2.

[1]Robert B. Richmond, "The Unit Crystal Oscillator," *General Radio Experimenter*, February, 1952.

[2]R. W. Frank, F. D. Lewis, "The Type 1213-C Unit Time/Frequency Calibrator," *General Radio Experimenter*, June 1956.

BASIC CIRCUIT SYSTEM AND ITS FEATURES

Figure 2 is a block diagram of the redesigned instrument. The circuits consist of a 5-Mc oscillator and frequency doubler, which can be set against WWV by use of a radio receiver or against a local standard. Three multivibrators are used to produce the standard frequencies of 1 Mc, 100 kc, and 10 kc, which are available at a cathode follower for time calibration. The four standard frequencies also generate harmonic spectra which can then be fed to external systems for calibration or mixed with externally generated signals to produce a beat note within the instrument for the calibration of externally produced rf signals. Thus, the instrument can be used to:

1. Calibrate the time axis of oscilloscopes.
2. Calibrate receivers in frequency.
3. Control the timing of external systems.
4. Calibrate oscillators by either Lissajous figures or zero-beat techniques at any frequency from 10 kc to at least 1000 Mc.

Figure 1. Panel view of the Type 1213-D Unit Time/Frequency Calibrator with Type 1203-B Unit Power Supply.

5. Calibrate (and monitor the calibration of) high-frequency oscillators on any frequency to a high degree of accuracy. In this application a standard signal generator is first calibrated by the standard frequencies and then used to permit precise offset of the harmonic series.

The performance of this instrument hinges, as with any frequency standard, upon the short-term frequency stability of the oscillator. In most crystal oscillators the chief factor affecting the stability is temperature. To minimize frequency changes caused by temperature, two methods are available. One is the use of a temperature-controlled oven, the other the use of a crystal with an adequately low temperature coefficient of frequency.

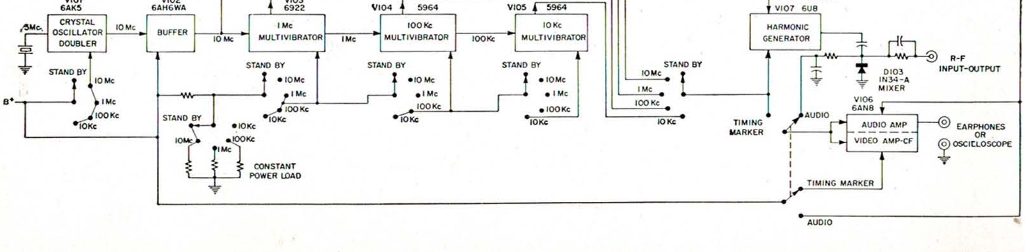
The conventional method is to control the temperature of the crystal. Unless elaborate ovens are used, however, the temperature of the crystal will cycle, resulting in cyclic variations of frequency. If cost or size is important, small ovens, usually with bimetallic thermostats, must be used. Temperature cycling is of the order of ±1°C, with resulting periodic frequency variations of as much as 1 ppm. The cycling effect is particularly undesirable when the unit is to be used as a transfer oscillator with reference to WWV, because the rate of variation can be as great as 1 ppm per minute.

The second method requires that the crystal have a low temperature coefficient of frequency over the entire contemplated range of operating temperature. Because there is no temperature cycling, there will be no rapid changes in frequency. After thermal equilibrium has been reached, the temperature of the crystal can be made quite stable over short periods of time. This short-term stability can be increased by the addition of thermal inertia to the crystal unit. Stabilities of a few parts in 10^8 per minute are possible with a temperature coefficient of 1 in 10^7/°C for the crystal.

Another design objective is the reduction of warm-up drift. This can be met if the crystal is kept at ambient temperature or if the crystal temperature rise is kept very low. The high component density of modern vacuum-tube instruments makes this difficult without the use of forced air cooling, and forced air cooling materially adds to size, noise, weight, and cost. The use of transistors would reduce the temperature rise, but at present their higher cost will not permit their use in low-priced instruments. As a consequence, the crystal should have a very low temperature coefficient, not only over its operating range, but in its warm-up range as well.

The crystal for the Type 1213-D Unit Time/Frequency Calibrator was designed for an operating range of 20-60°C. After thermal equilibrium has been reached, the crystal temperature is approximately 20°C higher than the ambient. This determines an operating ambient range for the instrument of 0°C to 40°C. Figure 4 shows the frequency-versus-temperature characteristics of the crystal. The solid line shows the ideal design characteristics. The

Figure 2. Block diagram of the calibrator.



dotted lines show the upper and lower extremes due to manufacturing tolerances. The temperature coefficient is small at temperatures down to 0°C, which fulfills the requirements for low warm-up drift from the lowest ambient temperature for which the instrument is operative. An additional requirement is that the crystal activity should be constant over the entire temperature range. This combination of requirements makes the manufacture of the crystal unit quite difficult; in fact, in some instances dips in activity near 0°C cannot be avoided. The activity is essentially constant above 5°C. This means that, if the instrument is turned on at 0°C ambient, the oscillator may not start until the crystal has warmed up to over 5°C. This will require about 5 to 10 minutes of warm-up time. Thermal equilibrium will be reached in about 1 hour. Thermal insulation around the crystal unit was added to eliminate rapid changes in crystal temperature caused by drafts. This improved the minute-to-minute stability by about one order of magnitude.

It has been pointed out above that the temperature rise at the crystal is about 20°C owing to the power dissipated within the instrument. In the switching provided for the several functions of the instrument, loads are substituted for circuits not active, so that the total power input to the instrument remains constant.

The plate supply of the oscillator is regulated to reduce the effect of ±10% line-voltage variations to an equivalent frequency shift of less than 5 x 10^{-8} when the inexpensive Type 1203-B Unit Power Supply is used.

With the newly designed oscillator and crystal, the over-all stability of the unit is better than 10 ppm for six months, and when this accuracy is adequate, no calibration against a precise standard is necessary. If higher accuracy is needed, the crystal can be calibrated against standard-frequency radio transmission (WWV), or another frequency standard of adequate accuracy, immediately before its use. With this transfer method, frequency measurements and calibration to about 2 x 10^{-7} are practical.

CIRCUITS

Oscillator and Buffer

A 5-Mc crystal controls the frequency of a triode oscillator formed by the screen grid, control grid, and cathode of a pentode. A panel control for frequency is calibrated in ppm incremental frequency change. When unknown frequencies near zero beat are being measured, it is convenient to deviate the

Figure 3. Elementary schematic of the crystal oscillator.

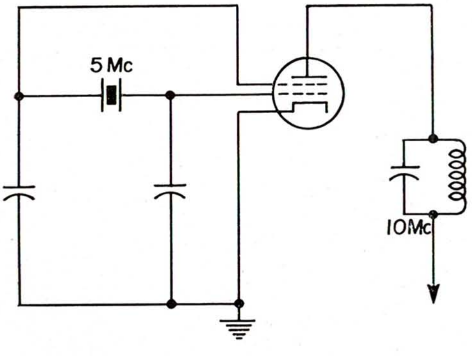
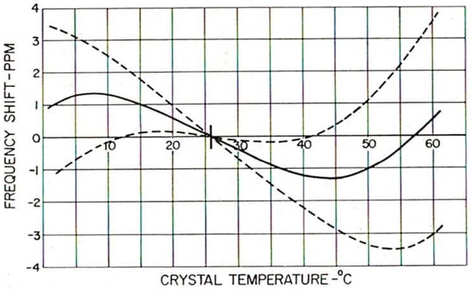


Figure 4. Frequency-vs-temperature characteristics of the crystals, showing tolerance limits.



crystal oscillator frequency slightly without disturbing its basic frequency setting. For this purpose, a "touch-button" is provided on the front panel. Touching this button with the hand decreases the oscillator frequency slightly and permits a sense determination of the beat note. The plate circuit of the oscillator stage is tuned to 10 Mc and drives a buffer-limiter. The buffer provides constant output voltage even if the oscillator output changes due to changes in crystal activity. The buffer output is adjustable by means of a screen-grid voltage control to permit precise setting of the synchronizing voltage for the 10:1 frequency-dividing multivibrator.

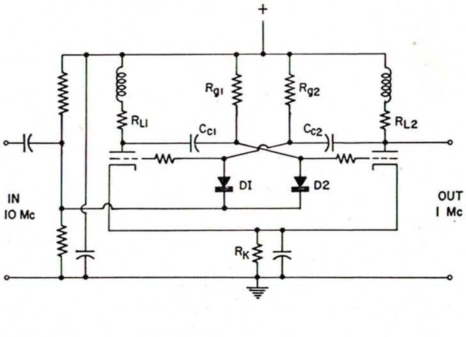
Frequency-Dividing Multivibrator

The 10-Mc buffer drives either an output circuit (in the 10-Mc switch position) or the 1-Mc multivibrator. The multivibrator design originated for the Type 1213-C has been improved for the D model. The original tube has been replaced by a new frame-grid type, and the circuit has been completely redesigned to permit the maximum possible tube aging before a failure of the multivibrator by miscounting occurs.

The multivibrator circuit is shown in Figure 5. In the June 1956 issue of the *Experimenter*, the design of frequency-dividing multivibrators for maximum stability against tube and component aging was discussed, including the general problem of proper circuit design for optimum stability at lower frequencies. Additional factors not previously considered are important in the higher frequency divider circuits, where the high values of plate load resistors necessary for "hard-bottoming" cannot be used, because recovery time would be too great. Let us consider a typical multivibrator designed to divide some higher frequency down to 1 Mc. This multivibrator must have a free-running frequency near 1 Mc, and, if the circuit is symmetrical, the plate voltage of the "off" side must recover to nearly the plate supply voltage (say four time constants) in one-half microsecond. A realistic value for the distributed capacitance at a multivibrator plate consisting of the plate capacitance, the load capacitance, and the grid capacitance referred to the plate is about 40 pf. With this value of capacitance, the maximum load resistor determined by the recovery time constant will be 4000 ohms.

With a load resistor of this magnitude, the classical circuit is very sensitive to changes in the tube cathode emission. For example, let us assume that the tube in the circuit of Figure 5 is a high performance triode with an initial $\bar{r}_p$ of 3000 ohms. The total resistance of the tube plus the plate load will be 7000 ohms, and a 10% change in current (and hence the drop across the plate load resistor) will be occasioned if the tube $\bar{r}_p$ rises to 3700 ohms (23%). This will certainly cause failure of even an optimally adjusted multivibrator. In the new multivibrator design of Figure 5, the characteristics of the vacuum tube are stabilized by negative feedback. The large value of cathode resistance, R_k, causes the $\bar{r}_p$ variations to be swamped by the

Figure 5. Elementary schematic of the 10-1 Mc multivibrator.



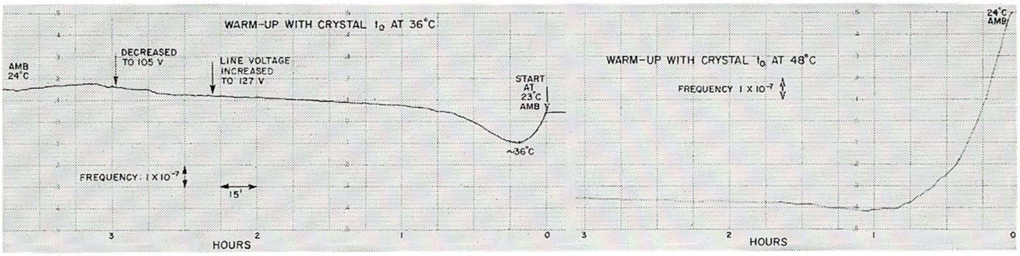


Figure 6. Warm-up characteristics of the instrument with two different crystals, one having its zero-temperature-coefficient point at 36°C, the other at 48°C. Note that time in hours runs from right to left.

feedback, and the tube drives its plate load resistor as a stabilized current source. Instead of $\bar{r}_p$ as a variational quantity, therefore, we have $\bar{r}_p$ plus R_k $(1+\mu)$, and both R_k and μ are relatively stable with aging. This condition is valid as long as the tube remains in the negative grid region.

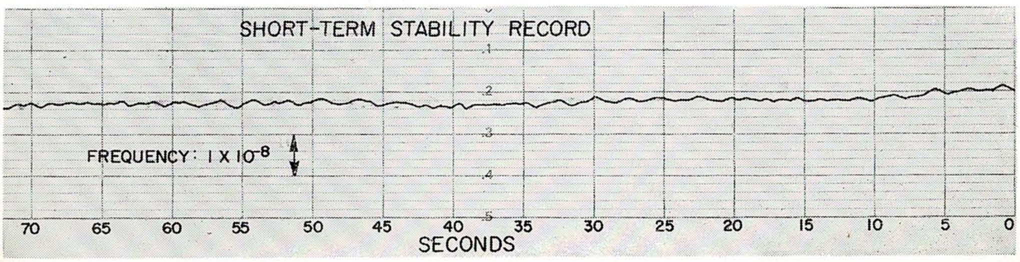
The diodes in the grid circuit, D-1, D-2, are returned to a source impedance low with respect to the grid timing resistors, and thus they hold the grid in the negative region. With this connection the 1-Mc multivibrator can be stabilized to less than a 5% frequency shift with a doubling (100% change) of $\bar{r}_p$. Plate current stabilization feedback, however, exacts a price. The performance of a new tube has been reduced to that of an aged tube in order to obtain reliability. This general circuit technique can be applied to all sorts of pulse circuits in which the end value of plate current is of importance, but in oscillatory circuits such as the free-running multivibrator, the loop gain may often be insufficient to permit self-oscillation. In fact, a trigger or transient may have to be supplied before the circuit will operate at all. Such a characteristic can be a distinct advantage in frequency-dividing multivibrators because, before the tube has aged sufficiently to cause a multivibrator division error, the circuit will simply not operate at all.

APPLICATIONS

When the Time/Frequency Calibrator is used as an independent standard, its over-all accuracy is about 10 parts per million. When standardized against WWV radio transmissions or other known standard, accuracies comparable with that of the reference standard can be attained, that is, a few parts in 10^7. When the instrument is calibrated before each measurement, the accuracy is determined by the short-term stability of the crystal oscillator, the effects of switching, and external connections. The total error from these sources will be less than 2×10^{-7}.

With this instrument, oscillators and receivers can be calibrated at 10-Mc intervals up to at least 1000 Mc, at 1-Mc intervals up to 500 Mc, at 100-kc inter-

Figure 7. Short-term stability record of the crystal oscillator. Total change in one minute is less than 6 parts in 10^9.



vals up to 100 Mc, and at 10-kc intervals up to 10-Mc.

If the frequency to be measured is not a multiple of a standard harmonic, a double transfer system can be used. A beat note of the unknown frequency and the nearest standard harmonic is obtained and then compared against a calibrated variable low-frequency oscillator. An accuracy of a few parts in 10^7 is possible up to 100 Mc. This method has been described in detail elsewhere.[3]

— R. W. Frank
H. P. Stratemeyer

[3]C. A. Cady, W. P. Buuck, "Frequency Measurements in the Broadcast Field," *Technical Publication B-10*, General Radio Company. (Copies available on request.)

SPECIFICATIONS

Output Frequencies: 10 Mc, 1 Mc, 100 kc, 10 kc.

Output Amplitudes: 10 Mc: 5 v peak-to-peak; 30 v peak-to-peak at lower output frequencies from pulse amplifier; rf harmonics usable to 1000 Mc from 10-Mc output, to 500 Mc from 1-Mc output, to 100 Mc from 100-kc output, and to 10 Mc from 10-kc output.

Output Impedance: Video cathode-follower, 300 ohms; rf output obtained from crystal-diode harmonic generator.

Frequency Stability:

1. *Temperature*

a. Warm-up Characteristics:
For ambient temperatures of 25°C, or over, the warm-up drift will not exceed -2×10^{-7}/°C. With ambient 0—10°C crystal may not operate until instrument attains operating temperature. Minimum operating ambient 0°C.

b. Operating Characteristics:
In ambient range 20-40°C, the oscillator drift is between -1×10^{-7}/°C and $+2 \times 10^{-7}$/°C.

2. *Line Voltage Effects*
Momentary line voltage changes of ±10% affect frequency by less than 5×10^{-8}. Changing line voltage will affect frequency per temperature specification above. (±10% line will change temperature ±4°C.)

3. *Switching and Loading Effects*
The combined effects of switching and loading due to external connections are less than 1×10^{-7}.

Sensitivity: Usable beat notes can be produced with 50 millivolts signal input to mixer over the harmonic ranges specified above under "Output amplitudes."

Tubes: One each 6AK6, 6AH6WA, 6922, 6AN8, 6U8; two 5964.

Power Required: 6.3 v ac, 3 amp; 300 v dc, 60 ma. Type 1203-B Unit Power Supply is recommended.

Accessories Supplied: Type 1213-P1 Differentiator, Type 874 Coaxial Connector, and multipoint connector.

Mounting: Aluminum panel and sides finished in gray; aluminum cover finished in clear lacquer. Relay rack panel (Type 480-P4U3) is available for mounting both calibrator and power supply.

Dimensions: Width 10½, height 5¾, depth 7 in., over-all.

Weight: 4 lb., 10 oz.

Type		*Code Word*	*Price*
1213-D	**Unit Time/Frequency Calibrator***	REBEL	**$310.00**
1203-B	**Unit Power Supply**	ALIVE	**40.00**

*U. S. Patent 2,548,457; licensed under patents of the American Telephone and Telegraph Co., of Radio Corporation of America, and of G. W. Pierce (pertaining to piezo electric crystals and associated circuits).

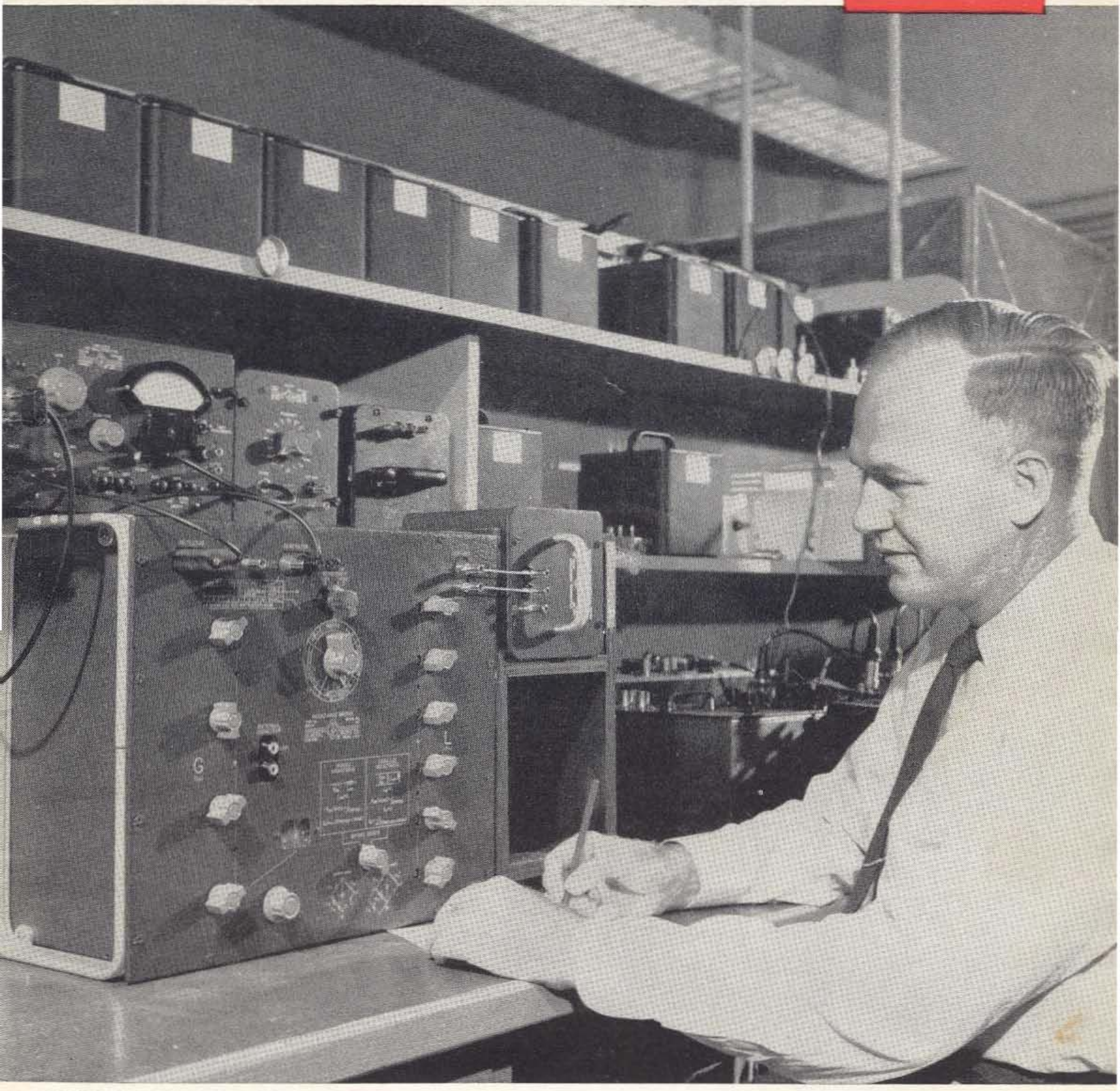
SEE THEM AT THE SHOWS

Many of the new General Radio instruments that you have been reading about in the *Experimenter* will be displayed at technical meetings this fall.

Place	*Date*	*Meeting*	*GR Booth Number*
Chicago	**Oct. 12-14**	**National Electronics Conference**	**177, 178, 179**
Atlanta	**Nov. 9-11**	**4th Instrumentation Conference**	**C6**
Boston	**Nov. 17-19**	**Northeast Electronics Research and Engineering Meeting**	**9, 10**

THE GENERAL RADIO

EXPERIMENTER



VOLUME 33 No. 11 NOVEMBER, 1959

IN THIS ISSUE

THE GENERAL RADIO

EXPERIMENTER

Published Monthly by the General Radio Company

VOLUME 33 · NUMBER 11 **NOVEMBER, 1959**

CONTENTS

The General Radio EXPERIMENTER is mailed without charge each month to engineers, scientists, technicians, and others interested in electronic techniques in measurement. 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.

GENERAL RADIO COMPANY

West Concord, Massachusetts

Telephone: (Concord) *EMerson 9-4400;* (Boston) *CLearwater 9-8900*

NEW YORK: **Broad Avenue at Linden, Ridgefield, New Jersey**
Telephone — N. Y., WOrth 4-2722
N. J., WHitney 3-3140

CHICAGO: **6605 West North Avenue, Oak Park, Illinois**
Telephone — VIllage 8-9400

PHILADELPHIA: **1150 York Road, Abington, Pennsylvania**
Telephone — HAncock 4-7419

WASHINGTON: **8055 13th St., Silver Spring, Maryland**
Telephone — JUniper 5-1088

LOS ANGELES: **1000 North Seward St., Los Angeles 38, Calif.**
Telephone — HOllywood 9-6201

SAN FRANCISCO: **1186 Los Altos Ave., Los Altos, Calif.**
Telephone — WHitecliff 8-8233

CANADA: **99 Floral Parkway, Toronto 15, Ontario**
Telephone — CHerry 6-2171

REPAIR SERVICES

EAST COAST: **General Radio Co., Service Dept., 22 Baker Avenue, West Concord, Mass.**
Telephone — Concord, EMerson 9-4400
Boston, CLearwater 9-8900

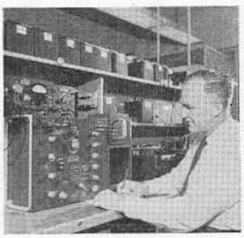
NEW YORK: **General Radio Co., Service Dept., Broad Ave. at Linden, Ridgefield, New Jersey**
Telephone — N. Y., WOrth 4-2722
N. J., WHitney 3-3140

MIDWEST: **General Radio Co., Service Dept., 6605 West North Ave., Oak Park, Illinois**
Telephone — VIllage 8-9400

WEST COAST: **Western Instrument Co., 826 North Victory Boulevard, Burbank, Calif.**
Telephone — VIctoria 9-3013

CANADA: **Bayly Engineering, Ltd., First St., Ajax, Ontario**
Telephone — Toronto EMpire 2-3741

COVER



John F. Hersh, author of the article describing the new precision inductance bridge, is shown operating the bridge in the General Radio standards laboratory.

A BRIDGE FOR THE PRECISE MEASUREMENT OF INDUCTANCE

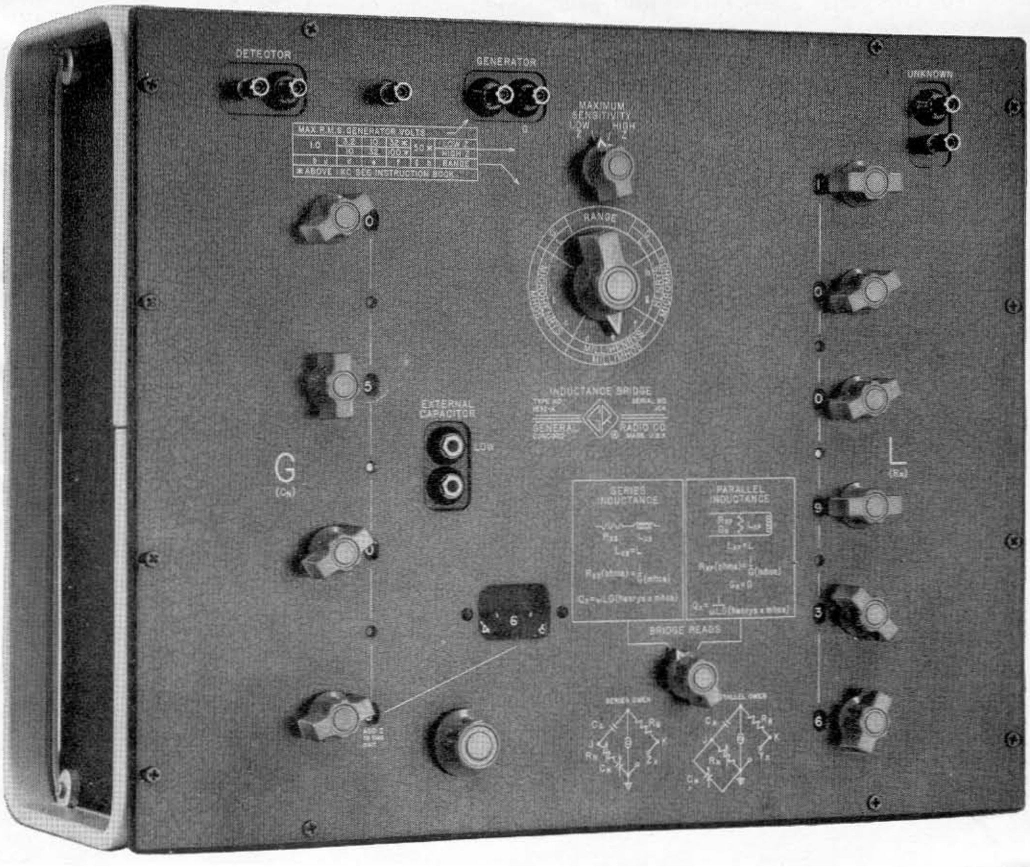
TYPE 1632-A INDUCTANCE BRIDGE

The instrument manufacturer who makes resistors, capacitors, and inductors of high accuracy and low residual impedance has both the need and the opportunity to build the impedance bridges required for high-accuracy measurements of these components. The General Radio Company has for many years been building, and continually improving in accuracy and stability, the Type 510 Decade-Resistance Units[1] which are used in the Type 1432 Decade Resistors. The materials and winding methods used in these units produce not only the excellent stability and low temperature coefficient required for a significant accuracy of ±0.05%, but also the small residual reactances which permit use of the resistors over a wide frequency range. Fixed standards of capacitance have also undergone a continuous process of improvement, and the current silvered-mica Type 1409 Standard Capacitors[2] are accurate to ±0.05%, with a long-term stability of better than 0.01%.

[1]Ivan G. Easton, "The New Type 1432 Decade Resistors," *General Radio Experimenter*, June, 1951, Vol. XXVI, No. 1.

[2]Ivan G. Easton and P. K. McElroy, "New Silvered-Mica Standard Capacitors," *General Radio Experimenter*, July, 1957, Vol. 32, No. 2.

Figure 1. Panel view of the Type 1632-A Inductance Bridge.



Another recent addition to the General Radio line of precision components is a series of highly accurate and stable standard inductors.[3] The TYPE 1482 Standard Inductors, being toroidally wound on ceramic cores and shielded from external thermal, mechanical, atmospheric, and electrical disturbances, have the high stability and reliability[4] that make possible their calibration with the closest tolerance ($\pm 0.03\%$) that the National Bureau of Standards will place on its certification of absolute inductance. For General Radio to certify the inductance of these inductors with the same accuracy limit of $\pm 0.03\%$, the inductors must be intercompared with a set of NBS-calibrated inductors with a precision of higher order than the tolerance. This need for the measurement of inductance over the 100-μh to 10-h range of the TYPE 1482 Standard Inductors with a resolution and precision of 0.003% or better led to the construction for our standardizing laboratory of a new inductance bridge, which made use of our wide range of precision resistors and standard capacitors to measure the inductors. With improvements that make it more convenient to use and more generally useful, this new, wide-range, high-precision bridge is now being produced as the TYPE 1632-A Inductance Bridge.

For inductance standardization as well as for general inductance measurement, this bridge approaches the ideal, not only in inductance range and accuracy, but also in speed and convenience of operation. Two important features are digital in-line readout and the inclusion of operational data and circuit schematic on the panel.

[3]Horatio W. Lamson, "A New Series of Standard Inductors," *General Radio Experimenter*, November, 1952, Vol. XXVII, No. 6.

[4]Horatio W. Lamson, "Standard Inductors, a Stability Record," *General Radio Experimenter*, May, 1957, Vol. 31, No. 12.

An Owen Bridge

This bridge uses the Owen bridge circuit in which the inductance balance is made with precision decades of resistance, thus achieving a high degree of resolution and a high accuracy at moderate cost. The other bridge circuits commonly used for inductance measurement, the Maxwell and the Hay, require variable capacitors for the inductance balance, and capacitors of the desired range and accuracy are very expensive. In the Owen bridge shown in Figure 2, the fixed arms consist of the standard capacitor C_A and the resistor R_B. The unknown Z_X is balanced by the decade resistor R_N and decade capacitor C_N, and at balance the unknown is related to the standards by the equations:

$$L_X = (C_A \, R_B) \, R_N \qquad (1)$$

$$G_X = \frac{1}{C_A \, R_B} \, C_N \qquad (2)$$

The decades can be switched to either a series or a parallel connection, so that the bridge can be made direct reading in either series or parallel components of the unknown inductor. When the resistance and capacitance decades are connected in series, the equivalent series inductance, L_{XS}, and series conductance, G_{XS}, of the unknown Z_X are proportional to R_N and to C_N; when the standards are connected in parallel, R_N and C_N determine the equivalent parallel inductance, L_{XP}, and parallel conductance, G_{XP}. The equivalent resistance in either configuration is the reciprocal of the conductance, $R_X = 1/G_X$. Over a wide range of Q, the unknown can be measured in terms of whichever components are most convenient. Even when the Q is very high or very low, a balance for one of the equivalents can usually be obtained. When the Q is very low, the series components can usually be measured; when the Q is very high, the parallel components can be measured.

The variable standard resistance R_N consists of six TYPE 510 Decade Resistance Units in 10-kilohm to 0.1-ohm steps, with a calibration accuracy of ±0.05% in all except the two lower decades. Since the measured inductance is proportional to this resistance, these six decades give the bridge a resolution of inductance up to six significant figures. The range of inductance covered by these six decades can be changed readily by a change in the $C_A R_B$ product which relates L_X to R_N. Through an eight-position range switch a choice can be made among three C_A capacitors and six R_B resistors to cover a range of full-scale inductance from 1,111 henrys to 111 microhenrys. The minimum inductance indication is, thus, seven decades below 111 microhenrys or 0.0001 microhenry.

The accuracy of the inductance indication is, of course, limited by the accuracy and stability of all of the components entering into Equation (1). The resistance R_B is made up of the same stable and accurate wire-wound resistors as are used in the decades of R_N, and the residual inductance or capacitance is compensated. Equally stable silvered-mica standard capacitor units are used for C_A. These components make possible a direct-reading bridge accuracy of 0.1% over wide ranges of inductance, Q, and frequency.

Full use can be made of the potential resolution and accuracy in inductance reading only if the resistive component of the unknown can be balanced both with comparable precision and without appreciable interaction between balances as a result of residual impedances. In the Owen bridge such resistance balance requires a variable capacitor of wide range having low losses and both loss and capacitance independent of frequency. The TYPE 1632-A Inductance Bridge is possible only because General Radio now produces high-quality polystyrene capacitors,[5] used in the TYPE 1419-A Decade Capacitor, which have stable and constant capacitance and low dissipation factor, even at the frequencies below 100 c which are often used in inductance measurements. C_N consists of four decades of these polystyrene capacitors, in 0.1- to 0.0001-μf steps, followed by a continuously variable 130-pf* air capacitor. These decades are calibrated to an accuracy of ±1%; better accuracy in the measurement of G is rarely needed and is usually prohibited by errors caused by bridge residuals. When a capacitance greater then 1 μf is required to balance a very high conductance, an external capacitor can be connected at panel jacks to parallel the C_N decades.

[5] "New Decade Capacitors with Polystyrene Dielectric," *General Radio Experimenter*, July, 1956, Vol. 31, No. 2.
*pf = picofarad = μμf.

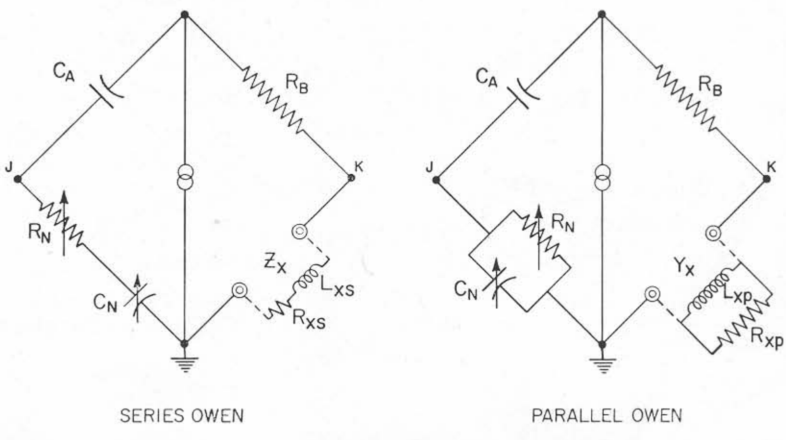
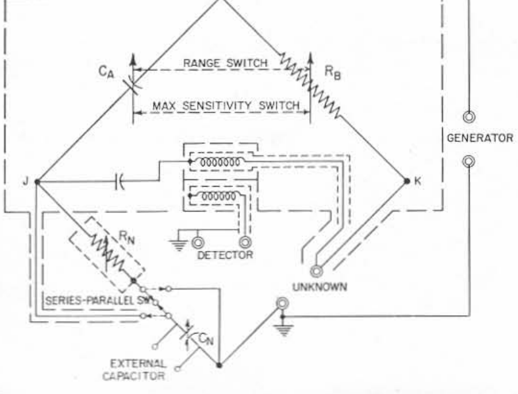


Figure 2. Elementary schematic of the Owen bridge circuits used in the Type 1632-A Inductance Bridge.

With Low Residuals

The simple, independent balance conditions, which constitute one of the advantages of the Owen bridge, can be obtained in practice only if the bridge arms are free of residual impedances. In the TYPE 1632-A Inductance Bridge many of the possible residuals are minimized by the use of capacitors with very small residual resistance and of resistors with very small residual inductance and capacitance. Other residuals are reduced or controlled by the careful internal shielding shown in Figure 3.

The most troublesome residuals are capacitances across the unknown arm and across the standards, R_N and C_N, when they are in series. These capacitances are minimized by the shield enclosing the C_A and R_B arms of the bridge. By extension of this shield into the base of the UNKNOWN terminals, the capacitance added across the unknown by the bridge is reduced to the 1-pf capacitance between the external terminals. In the "standard" arm another shield encloses the resistance decade R_N to reduce the capacitance across the series combination of R_N and C_N to the negligible value of less than a picofarad. The capacitance of this shield to ground appears across C_N and is included in the calibration of the conductance decades. This shield capacitance limits in minimum C_N to 200 pf, and results in the "ADD 2" that appears on the instrument panel below the window of the fourth G dial.



Further special shielding within the transformer used between bridge and detector permits the detector to be grounded without additional contribution to the bridge residuals. The intershield capacitances of the transformer, however, add some 100 pf to the C_A arm of the bridge, which can be included in the calibration of C_A. Since the total C_A is only 1000 pf in the lowest or a range of the bridge, the lower stability and higher loss of the transformer capacitance limit somewhat the accuracy of this range. An accuracy of the order of $\pm 1\%$ can be realized on the a range, and this reduced accuracy is indicated by a red a for this multiplier position. Since the primary use of this a range is the measurement of the very low inductance of leads and of shorted terminals, the reduction in accuracy here is not detrimental.

With this control and reduction of residual impedances, the 0.1% inductance accuracy of the bridge can be maintained over wide ranges of inductance, Q, and frequency. The ranges of measurement are so wide, however, that additional errors arise from the remaining very small residuals at the extremes of the ranges. When the Q of the unknown is very low, these residuals, including the small dissipation factors of the capacitors used as C_A and C_N, can increase the inductance error by $\pm .05\%/Q_X$. At the frequencies of 10 kc and higher, the error is also increased by the small, uncompensated reactances of the R_B arm, particularly when R_B has its extreme values of 1 ohm and 100,000 ohms at the very low and high ends of the range.

Figure 3. Bridge schematic showing the internal shielding to minimize residual-impedance errors.

Easy to Use

The TYPE 1632-A Inductance Bridge is designed not only to make measurements of high resolution and accuracy, but to make such measurements with maximum ease and rapidity. For this purpose the dials of the decades indicating L and G are arranged to show only the pertinent digit of each decade, and these digits are placed for convenient vertical, in-line, digital readout of the six significant figures. The eight-position range switch both indicates the units of L and G and automatically places the decimal point in the line of digits. Operation is further simplified, particularly for the occasional user, by the presentation on the panel of the bridge circuits and balance equations, as well as a table of the limits of maximum input voltage. The bridge can be balanced easily and rapidly to its full resolution because in an Owen bridge with such small residuals the L and G balances are independent and there is no trouble with a sliding balance and false nulls.

Neither generator nor detector is built into this bridge, because the versatility required in them to match that of the bridge can best be built into external units. Adequate generator range and power for most bridge uses can be provided by the TYPE 1304-B Beat-Frequency Audio Generator or by the combination of the TYPE 1210-C Unit R-C Oscillator and the TYPE 1206-B Unit Amplifier. Since these generators are designed for operation into loads of the order of 600 ohms and the bridge input impedance on the lower four ranges is of the order of 1 to 100 ohms, a matching transformer (TYPE 1632-P1) with turns ratios of 1:20 and 1:5 is supplied to raise the bridge input impedance to match the generator output. In order to keep its magnetic field away from the bridge and the inductor being measured, this transformer is designed to be plugged into the generator instead of being built into the bridge.

A detector of high sensitivity and low noise is required to make use of the full six-figure resolution of this bridge. The requirements can be met by the TYPE 1231-B Amplifier and the Null Detector with the TYPE 1231-P5 Adjustable Filter, followed by a null indicator with additional gain, such as a pair of headphones, an oscilloscope, a millivoltmeter, or another TYPE 1231-B Null Detector. For measurements requiring only the direct-reading accuracy of $\pm 0.1\%$, a single TYPE 1231-B with filter is usually adequate. The maximum available sensitivity, particularly at low frequencies, has been realized by making the detector transformer impedance as high as possible and by locating the transformer to satisfy best the condition that the bridge is most sensitive when the detector is connected at the junctions of arms having equal impedances. As another aid to sensitivity, a MAXIMUM SENSITIVITY switch has been provided to permit on some ranges a choice of the magnitude of the C_A and R_B arms to satisfy best this condition. On the middle (d, e, f) ranges, this switch changes both R_B and C_A by a factor of ten without changing their product, $C_A R_B$, and thus does not alter the multiplying factor of the bridge which has been set with the range switch.

For Most Inductance Measurements

The TYPE 1632-A Inductance Bridge is designed for the precise measurement of either the series or parallel components or two-terminal, grounded inductors at audio frequencies. Full-scale ranges of inductance extend from 1,111 henrys to 111.1 microhenrys. Six-figure resolution and high sensitivity make this bridge particularly suitable for standardization measurements of high accuracy, since standard inductors, such as the TYPE 1482, can be intercompared to better than 5 parts in a million. Its direct-reading inductance accuracy of $\pm 0.1\%$, the ease of balance, and in-line readout make it convenient to use. Although designed primarily for use at frequencies of 1000 c and lower, it can be used, with some decrease in accuracy, to at least 10 kc.

The bridge is well suited for the measurement of inductors with ferromagnetic cores, since its sensitivity makes a balance possible with only a small voltage applied to the inductor, and measurements can thus be made in the region of initial permeability. Measurements of inductors with nonlinear characteristics are further facilitated because in this bridge the voltage across the unknown inductor will not change appreciably when the L and G controls are varied to balance the bridge. The bridge is not suitable for the measurement of incremental inductance at high ac or dc excitation, because the dissipation in the precision resistors in the bridge must be limited to the order of one watt. The maximum voltage which can be safely applied to the bridge varies from 1 to 100 volts, depending upon the range being used, and these limits are indicated in a table engraved on the bridge panel. The bridge can be used for incremental inductance measurements at levels within these limits, when the desired direct current is supplied to either the generator terminals of the bridge or directly to the unknown. The capacitor C_A blocks the direct current from the R_N standards, and a capacitor connected in series with the internal detector transformer prevents any flow through that path. Use can also be made of the range and resolution of the bridge in making measurements of mutual inductance and of magnetic core materials.

—JOHN F. HERSH

Acknowledgments

Work on a similar Owen bridge was begun some years ago by R. F. Field. Much of the development of the present TYPE 1632-A Bridge is the result of the work of Horatio W. Lamson and of many others of the Engineering Department. After Mr. Lamson's retirement in 1958, the bridge was completed by Ivan G. Easton and John F. Hersh.

SPECIFICATIONS

Range: Range selection is by an eight-position switch, which indicates units and range, and locates the decimal point in the in-line balancing decades.

Full-scale ranges from 111 microhenrys to 1111 henrys for inductance; from 111 micromhos to 1111 mhos for conductance.

Minimum inductance indication is 0.0001 microhenry, which makes possible balances to a precision of 0.1% for inductance as low as 0.1 microhenry.

Inductance Balance: Six, precision decade resistors are used for the inductance balance. Maximum resistance is 100,000 ohms, in 0.1 ohm steps.

Conductance Balance: Four decades of low-loss polystyrene capacitor plus one variable air capacitor. Maximum capacitance is 1.111 μf, minimum capacitance is 200 $\mu\mu$f.

Sensitivity Switch: An additional control is provided which changes the value of R_B by a factor of 10 without altering the range.

Frequency: Designed primarily for precise and accurate measurements at 1 kc and lower. Usable to at least 10 kc with some decrease in accuracy, see below.

Inductance Accuracy: Basic direct-reading inductance accuracy is $\pm 0.1\%$.

Because of the extremely wide range of the bridge arms, the full accuracy cannot be realized at the extreme of inductance, Q, or frequency.

The direct-reading accuracy is reduced to $\pm 1\%$ on the lowest (a) range, which is provided for the measurement of the very low inductance and high conductance of leads and terminals.

When the Q_X of unknown inductor is low, the accuracy is reduced by an error of

$$(+0.05 \pm Q_B)\%/Q_X.$$

The R_B resistors, switched in decade steps from 1Ω to 100kΩ, are compensated to have the small phase angles (expressed as Q_B at 1kc) given in the table.

R_B	1 Ω	10 Ω	100 Ω	1 kΩ	10 kΩ	100 kΩ
Q_B at 1 kc	±.03%	±.005%	±.002%	±.002%	±.02%	±0.1%

For frequencies above 1 kc and for the extreme R_B values, the accuracy is reduced by residuals to $0.1 \times 10^{-8} f^2 \%$ when $R_B = 1\Omega$ and to $4 \times 10^{-8} f^2 \%$ when $R_B = 100\text{k}\Omega$.

The capacitance across the unknown terminals is approximately 1pf.

Two nearly equal inductance values can be intercompared to a precision of one part in 10^5 or better.

Conductance Accuracy: The capacitor C_N is adjusted to within $\pm 1\% + 2$ pf.

Errors in conductance arising from residual phase angles of the bridge arms depend upon frequency and Q_X. Such errors are best defined in terms of the dissipation factor of the unknown (reciprocal of Q_X). The error in dissipation factor is less than ±0.001 at 1 kc, for R_N values less than 10,000 ohms. At higher frequencies the error increases directly with frequency, with R_N, and with R_B. The error can be kept at the ±0.001 level by reducing the product $R_B R_N$ inversely with frequency. The maximum value of inductance that can be measured with a given accuracy for conductance (or Q) is thus inversely proportional to frequency.

Circuit: The capacitance decade for resistance balance can be connected in series or in parallel with R_N. Thus the equivalent series or equivalent parallel inductance of the unknown inductor can be measured. For the series connection the maximum value of Q is proportional to frequency, with a maximum value of 60 at 100 cps. For the parallel connection the maximum value of Q is inversely proportional to frequency and R_N. Maximum value at 100 cps and R_N = 100,000 ohms is 80. By selection of the R_N value, either series or parallel measurements can be made in most practical cases.

Applied Voltage: Maximum safe applied voltage ranges from 1 volt on the lower inductance ranges to 100 volts on the higher ranges. Values are engraved on the panel.

Accessories Supplied: Two TYPE 274-NL Shielded Patch Cords supplied for connection to generator and detector; TYPE 1632-P1 Transformer, having step-down voltage ratios of 1:22 and 1:5, to match the low bridge input impedance on the *a*, *b*, *c*, *d* ranges to generators requiring a 600 Ω load.

Accessories Required: Generator and detector.

Mounting: Aluminum cabinet and dress panel, crackle finish. Can also be rack mounted.

Dimensions: Panel, 19 x 15¾ inches; over-all depth, 9⅜ inches.

Net Weight: 40 pounds.

Type		*Code Word*	*Price*
1632-A	**Inductance Bridge**	BARGE	**$875.00**

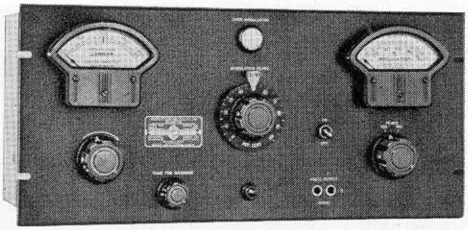
HAVE PROTECTION — WILL TRAVEL

General Radio instruments are hardy world travelers. During 1958, for instance, not one instrument per 2000 shipped was reported as damaged in transit to the customer. Considering that most of the material shipped is laboratory test equipment, and that many instruments go halfway around the world by trucks, ships, planes, and trains, there must be a story behind such a record.

First off, the instruments themselves are no softies. Often they are built to stern military specifications and most instruments — military or not — pass a shake test here at GR to prove their ruggedness. Panels and shafts, chassis bracing, knobs, connectors — all are designed not to "get by" but to take years of use, along with some inevitable abuse.

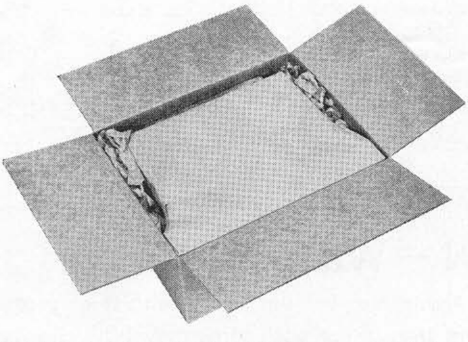
But rugged or not, we can expect that, at the very least, some stevedore in Bazra may not fully appreciate the nature of the cargo he is handling. And as the box is jounced from hold to hold, a hard battle goes on inside—a battle anticipated and planned for weeks before at GR's Shipping Department.

Realizing that ocean shipments are liable to be the most — ah — adventuresome, we pull out all stops when preparing an instrument for such a journey. First, a protective shield — either a wooden cover or a heavy cardboard cover with wooden spacers — is placed

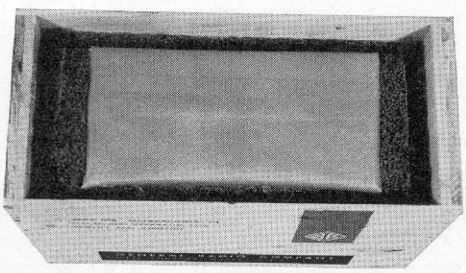


(1) The instrument, a Type 1931-B A-M Monitor.

(2) Paper and wood-reinforced cardboard protect panel.



(3) Wrapped and placed in heavy cardboard carton. Accessories, instruction book have been added.



(4) Waterproof bag is placed around carton and evacuated. Then into rugged wooden shipping case, with rubberized fiber pads.

An instrument is readied for a long sea voyage.

over the front panel of the instrument to safeguard the knobs, meters, binding posts, etc. Then the instrument, along with a cushion of heavy kraft paper, is placed in its cardboard stock carton.

The stock carton is then slipped into a close-fitting bag made of a plastic-laminated heavy waterproof paper known as Polykraft. The air is removed from inside the bag, so that it hugs the carton like an undersized bathing suit. This evacuated bag, after heat-sealing, offers protection against moisture, fumes, fungus, etc.

Next, the instrument in a box in a bag is nestled into its wooden packing case, with two-inch-thick rubberized fiber pads inserted as shock absorbers on all six surfaces. The wooden crate is finally steel-strapped and marked with appropriate shipping instructions. These may include, at the request of the customer, a bright green band, a red diamond, a blue crescent, or other unique marks to help the consignee spot his shipment at the place of unloading.

The multilayered protection described above is not usually necessary for air shipments. Also, such elaborate crating would add measurably to the customer's shipping expense by air, whereas with ocean shipment weight is a less critical

(5) Top pads have been added, lid secured, box strapped, and labeled.

cost factor. Thus, for air and most domestic shipments, instruments are usually sent in their stock cartons. Our extremely low damage rate indicates that, no matter what the destination or the transportation, our packaging will see it there safely.

— F. T. VAN VEEN

DELAY-LINE OSCILLATOR

A Novel Circuit for a 1 to 20-Mc Single-Range Oscillator

A novel use for a variable delay line is illustrated in the schematic diagram of Figure 1. The circuit utilizes the delay line as the feed-back element of a triode oscillator. The delay line may be thought of as a phase-shift network having 180° phase shift at a frequency corresponding to twice the delay time and its odd harmonics.

A simpler physical picture of the circuit operation is obtained from a time-domain description. Let us assume that the triode is suddenly biased to cutoff by a negative voltage step at its grid. A positive voltage step will occur at the plate. This positive step travels down the delay line and is coupled back to the grid by the coupling capacitor, turning the triode on. A negative voltage step then occurs at the plate, which travels down the delay line, cutting the triode off, and the process repeats.

With a large value of coupling capacitor, the grid and plate voltage waveforms are essentially rectangular, and the amplitudes are fairly constant over the entire range owing to the on-off nature of the oscillations. With a small value of coupling capacitor, the oscillations are more nearly sinusoidal and smaller in amplitude.

The circuit shown, utilizing a General Radio TYPE 314-S86 Variable Delay Line[1] (0 to 0.5-μsec), oscillates readily up to about 30 Mc. The grid voltage waveforms at frequencies of 1, 5, and 20 Mc are shown in Figure 3. The upper end of the frequency range is quite crowded because of the hyperbolic relationship between the frequency of oscillation and the shaft rotation of the linear delay line ($f = \frac{1}{2T}$). Up to about 20 Mc, however, operation is quite smooth and uniform. The lower end of the frequency range is limited by the maximum delay of the line (1 Mc for

[1]F. D. Lewis, R. M. Frazier, "A New Type of Variable Delay Line," *General Radio Experimenter*, Vol. 31, No. 5, October, 1956.

Figure 1. Schematic of the delay-line oscillator.

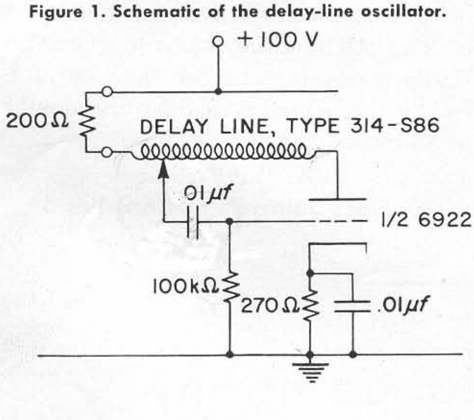
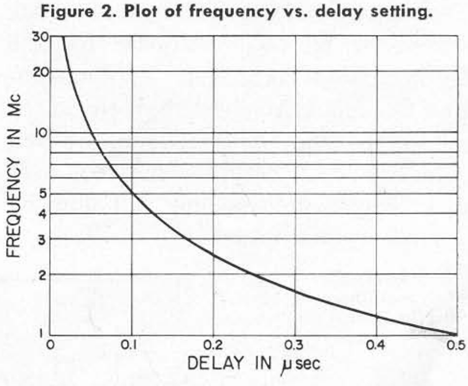


Figure 2. Plot of frequency vs. delay setting.



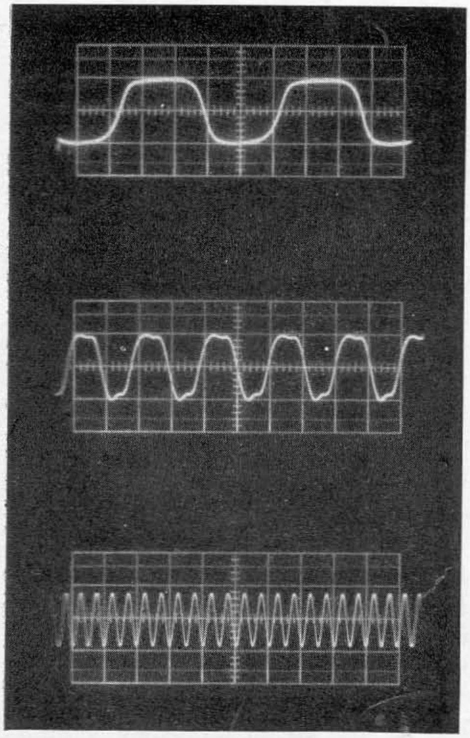


Figure 3. Grid-voltage waveforms.

(a) 1 Mc. Vertical scale, 2 volts/cm. Horizontal scale, 0.2 μ sec/cm.

(b) 5 Mc. Vertical scale, 2 volts/cm. Horizontal scale, 0.1 μ sec/cm.

(c) 20 Mc. Vertical scale, 2 volts/cm. Horizontal scale, 0.1 μ sec/cm.

(Tektronix Type 543 Oscilloscope)

the Type 314-S86). Since the frequency of oscillation depends primarily upon the delay line and is relatively independent of the tube characteristics, it is quite stable at any particular setting of the line.

— H. T. McAleer

NEW REPRESENTATIVE FOR BELGIUM AND LUXEMBURG

In the past the needs of our customers in Belgium and Luxemburg have been served by our representative for the Netherlands, Technische Verkoopkantoor Groenpol, Amsterdam, Holland.

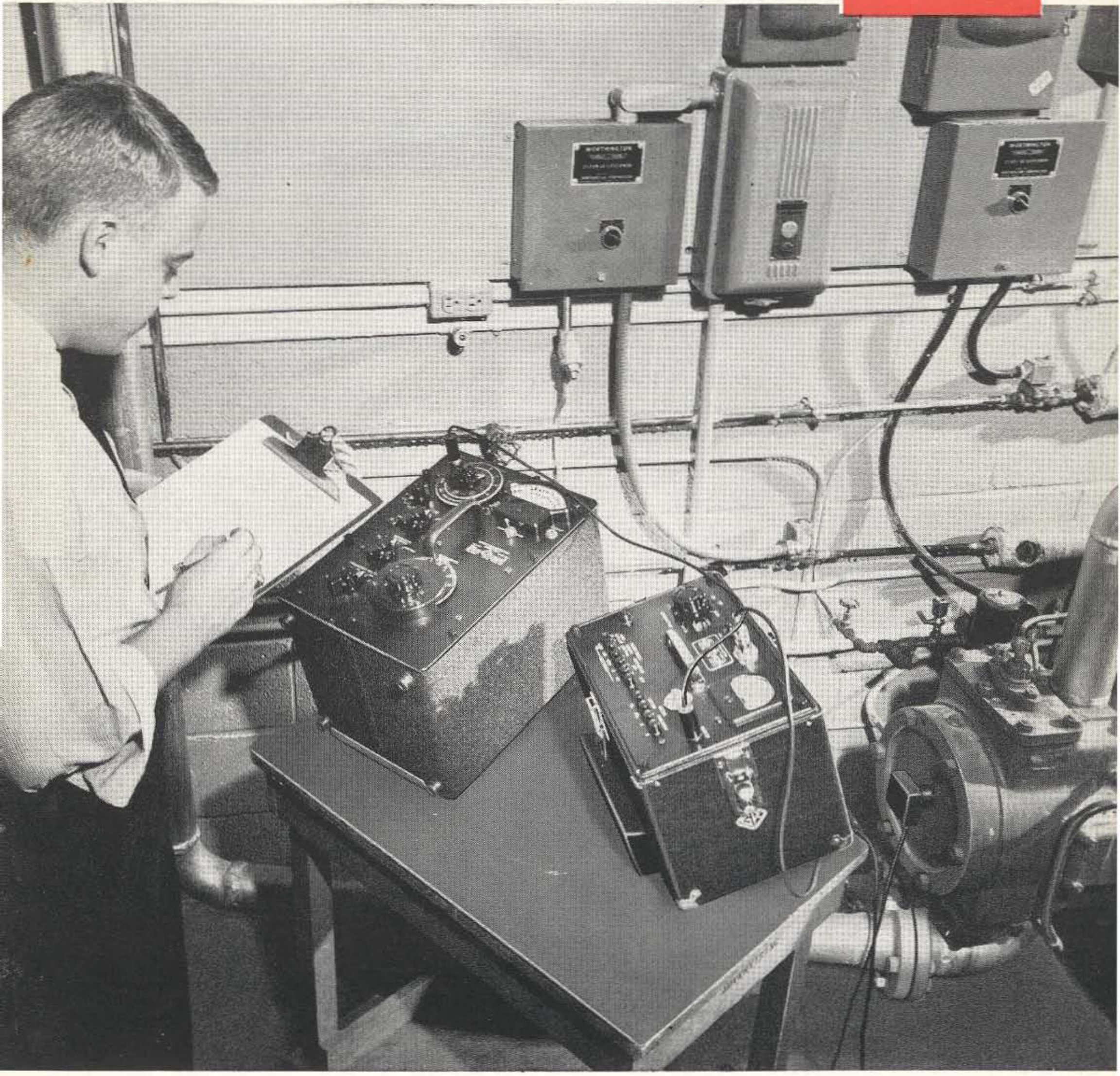
Effective September 1, 1959, the Belgium firm, S. A. Multitechnic, took over these responsibilities and will now be serving directly our customers and prospective customers in Belgium and Luxemburg. All inquiries concerning General Radio products, whether they be of a technical or a commercial nature, should be addressed to:

S. A. Multitechnic
30, Place Saintctelette, Bruxelles 8

PRINTED IN U.S.A.

THE GENERAL RADIO

EXPERIMENTER



VOLUME 33 No. 12 DECEMBER, 1959

IN THIS ISSUE

Sound and Vibration Analyzer

50-ohm Signal Generator Termination

THE GENERAL RADIO

EXPERIMENTER

Published Monthly by the General Radio Company

VOLUME 33 • NUMBER 12 **DECEMBER, 1959**

CONTENTS

The General Radio EXPERIMENTER is mailed without charge each month to engineers, scientists, technicians, and others interested in electronic techniques in measurement. 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.

GENERAL RADIO COMPANY

West Concord, Massachusetts

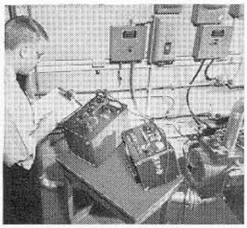
Telephone: (Concord) *EMerson 9-4400;* (Boston) *CLearwater 9-8900*

NEW YORK:	**Broad Avenue at Linden, Ridgefield, New Jersey** *Telephone — N. Y., WOrth 4-2722* *N. J., WHitney 3-3140*
CHICAGO:	**6605 West North Avenue, Oak Park, Illinois** *Telephone — VIllage 8-9400*
PHILADELPHIA:	**1150 York Road, Abington, Pennsylvania** *Telephone — HAncock 4-7419*
WASHINGTON:	**8055 13th St., Silver Spring, Maryland** *Telephone — JUniper 5-1088*
LOS ANGELES:	**1000 North Seward St., Los Angeles 38, Calif.** *Telephone — HOllywood 9-6201*
SAN FRANCISCO:	**1186 Los Altos Ave., Los Altos, Calif.** *Telephone — WHitecliff 8-8233*
CANADA:	**99 Floral Parkway, Toronto 15, Ontario** *Telephone — CHerry 6-2171*

REPAIR SERVICES

EAST COAST:	**General Radio Co., Service Dept., 22 Baker Avenue, West Concord, Mass.** *Telephone — Concord, EMerson 9-4400* *Boston, CLearwater 9-8900*
NEW YORK:	**General Radio Co., Service Dept., Broad Ave. at Linden, Ridgefield, New Jersey** *Telephone — N. Y., WOrth 4-2722* *N. J., WHitney 3-3140*
MIDWEST:	**General Radio Co., Service Dept., 6605 West North Ave., Oak Park, Illinois** *Telephone — VIllage 8-9400*
WEST COAST:	**Western Instrument Co., 826 North Victory Boulevard, Burbank, Calif.** *Telephone — VIctoria 9-3013*
CANADA:	**Bayly Engineering, Ltd., First St., Ajax, Ontario** *Telephone — Toronto EMpire 2-3741*

COVER



The Type 1554-A Sound and Vibration Analyzer with the Type 761-A Vibration Meter, as set up for the measurements on an air compressor (see Figure 4, page 5).

A NEW ANALYZER FOR SOUND AND VIBRATION

The TYPE 1554-A Sound and Vibration Analyzer (Figure 1) is a new instrument designed to supersede both the TYPE 760-B Sound Analyzer and the TYPE 762-B Vibration Analyzer. Its tuning range (2.5 to 25,000 cycles per second) is wider than those of the two earlier analyzers together. It provides for the first time a continuously tunable one-third-octave pass-band as well as a narrow band (8%). Among its other features are an "all-pass" mode of operation for measurement of the level of the entire input signal, greatly increased attenuation far from the center of the analysis band, and 10-to-1 span on the main frequency dial.

This new analyzer is battery powered and portable and is, therefore, convenient for analysis of sound and vibration "in the field." In the laboratory, in conjunction with the TYPE 1521-A Graphic Level Recorder, it provides continuous records of level versus frequency.

Several types of analyzers are used for the analysis of sound and vibration spectra. The constant-bandwidth heterodyne type, exemplified by the General Radio TYPE 736-A, is very useful where a high degree of selectivity is required, i.e., where the frequency separation of adjacent components is very small. The constant-percentage-bandwidth type, of which the General Radio TYPE 760 is an example, has a bandwidth which increases in proportion to its center frequency.

The analysis of sounds with broad-

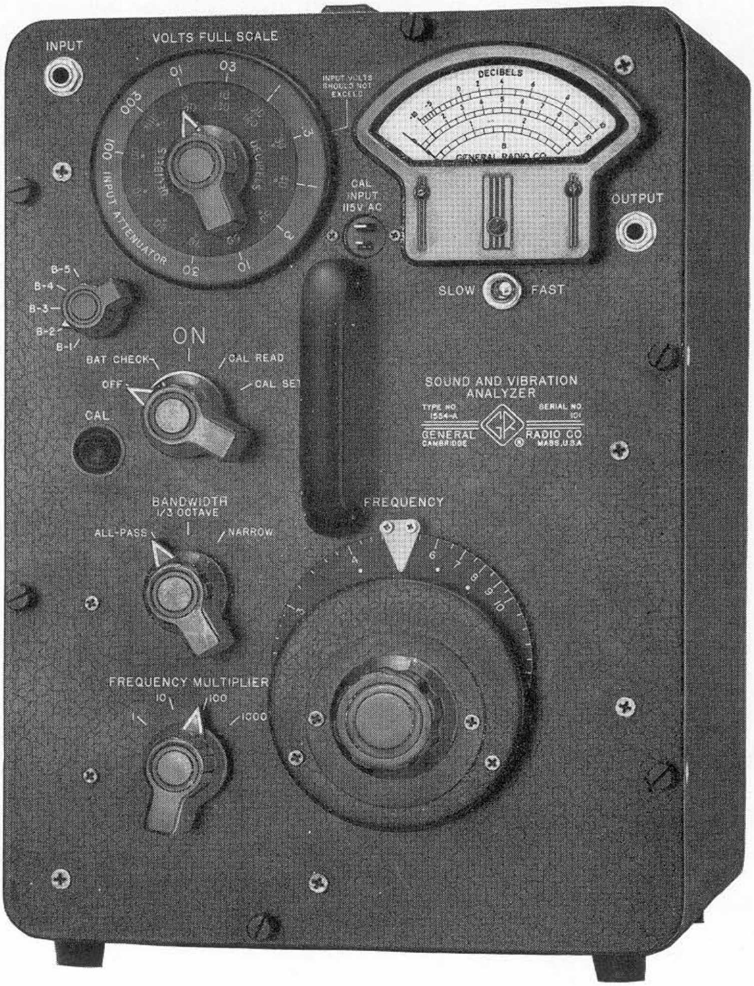


Figure 1. Panel View of the Type 1554-A Sound and Vibration Analyzer.

band or continuous spectra requires the measurement of bands of noise, rather than of discrete components, and for this purpose octave-band analyzers, like the General Radio TYPE 1550-A, are used. This type of analysis provides data for the calculation of speech interference level and hearing-damage risk.

A later development, and one of ever-increasing popularity, is measurement with a one-third-octave bandwidth, which gives more detailed spectrum data than the octave band, but which is still not as time-consuming as a very-narrow-band measurement. Many standard measurement procedures and some military specifications now call for one-third-octave analysis. It was to provide equipment for such measurements that the TYPE 1554-A Sound and Vibration Analyzer was designed. To achieve maximum usefulness, the frequency range was extended to include those low frequencies of interest in most vibration measurements, and the narrow filter characteristic was added for the identification and measurement of single-frequency spectrum components.

A WIDE VARIETY OF USES

The TYPE 1554-A Sound and Vibration Analyzer has been designed for analysis of the output voltages from the TYPE 1551-B Sound-Level Meter and the TYPE 761-A Vibration Meter, but also has many other uses in acoustical and electrical wave analysis.

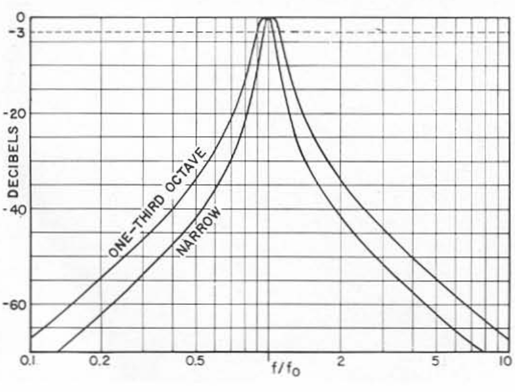


Figure 2. Response characteristics of the analyzer.

1. Measurement of Noise and Vibration.

Figures 3 and 4 show sound and vibration spectra as measured with the analyzer. These measurements were occasioned by the presence in a group of offices of an intense low-frequency noise, which was easily traced to an air compressor some distance away. The measured spectra were plotted on Codex No. 31.462 graph paper, which is especially arranged for one-third-octave frequency analysis. Dots on the main frequency dial of the TYPE 1554-A allow one to advance it easily from one preferred one-third-octave center frequency to the next. The strong 40-cycle peak shown in the noise spectrum of Figure 3 was evidently the annoying component. A simple calculation demonstrated a resonance in the offices at this frequency. The vibration measurements were made on the pump structure and indicated that no important vibration at the offending frequency was present. The pulsations of air at the compressor intake proved to be the source of the noise. Corrective measures were taken, and the resulting sound spectrum is shown in Figure 5.

Because the measurement extended to frequencies below 20 cycles, the TYPE 761-A Vibration Meter was used for both sound and vibration measurements. For sound measurements, the vibration pickup was replaced by a microphone of the type used on the TYPE 1551-B Sound-Level Meter, and the selector switch on the vibration meter was set to ACCELERATION.

2. Electric Wave Analysis.

Outside the field of purely acoustical measurements, the TYPE 1554-A Sound and Vibration Analyzer has considerable

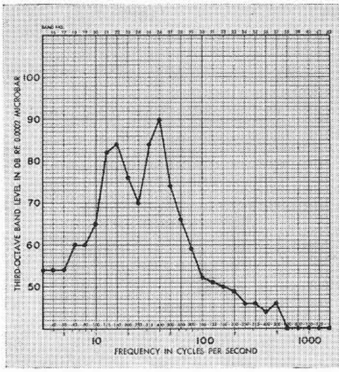


Figure 3. Sound spectrum of noise in office.

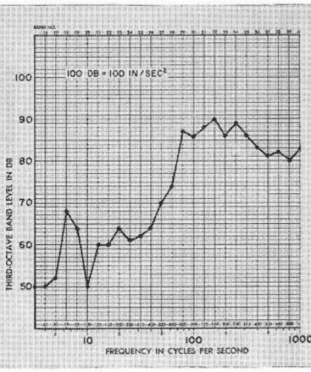


Figure 4. Vibration spectrum at pump.

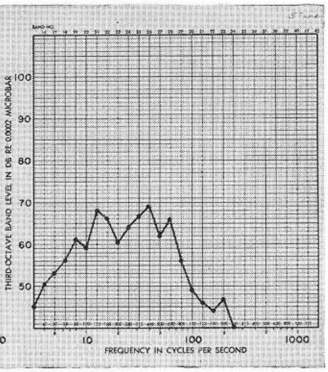


Figure 5. Sound spectrum of office noise after corrections.

usefulness as an electric wave analyzer, especially for the determination of the spectrum of electrical noise signals. A particularly difficult problem has been the accurate measurement of the low-frequency spectrum of the output of the General Radio TYPE 1390 Random Noise Generator. Previously, with a narrow-band analyzer, it has been necessary to use exceedingly long averaging times to produce reliable data. The measurement can be made more easily with the one-third-octave bandwidth, which permits a shorter averaging time, but is still sufficiently selective to yield reliable data. A graph of the one-third-octave spectrum level as a function of frequency for the TYPE 1390-B is shown in Figure 6. Note that, because the bandwidth of the analyzer is proportional to the frequency to which it is tuned, "white" noise appears to slope upwards with increasing frequency at 3 db per octave.

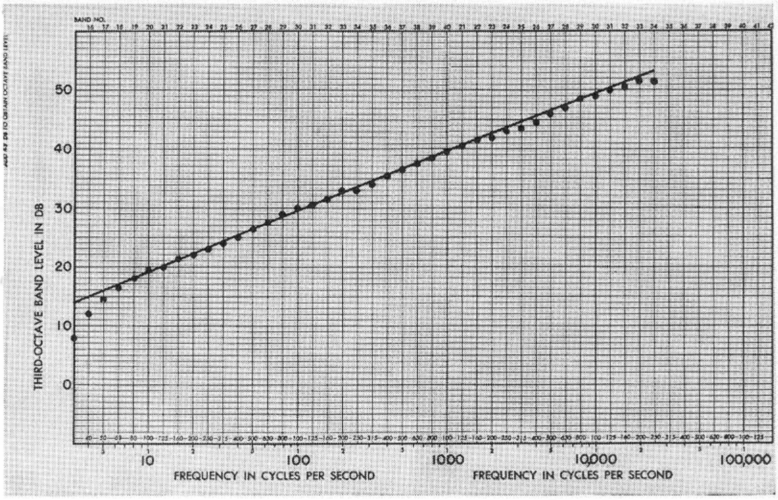


Figure 6. Spectrum level of the Type 1390-B Random-Noise Generator as measured with the one-third-octave bandwidth.

3. Use with Graphic Level Recorder.

There are many advantages to using the TYPE 1521-A Graphic Level Recorder to record automatically the output of the sound and vibration analyzer. Data are acquired with much less concentration and strain on the part of the operator; they are acquired more rapidly; and are in the form of continuous curves rather than as data taken at discrete points such as the one-third-octave band center frequencies. Figure 7 is a photograph of the TYPE 1554-A Sound and Vibration Analyzer coupled to the TYPE 1521-A Graphic Level Recorder.

Special chart paper, Type CTP-554, for the recorder has a frequency scale which matches the dial of the analyzer. Because the lower limit of the frequency range of the recorder is 20 cycles per second, this chart paper covers only the top three dial spans of the Type 1554-A, from 25 to 25,000 cycles per second. Within this frequency range, the combination of the analyzer and recorder can be used for the frequency analysis of sounds, vibration, or electrical signals.

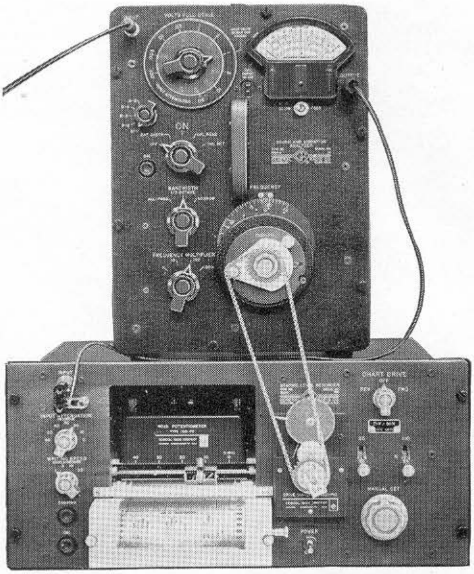


Figure 7. View of the analyzer with dial drive coupled to the Type 1521-A Graphic Level Recorder.

An example of this use is the measurement of the response of a loudspeaker in a room inadequately treated for good listening properties. When such a measurement is made with a sine-wave signal, the response fluctuates over a wide range of level, depending strongly upon the position of the receiving microphone. The results of two such measurements made with the Type 1304-B Beat-Frequency Oscillator chain-driven by the recorder are shown in Figure 8. It would be difficult to average a number of such curves or to draw a relatively smooth average curve on either graph. It has been customary in acoustic measurements of such systems to use a warble tone (a sine-wave signal frequency-modulated over a relatively wide range at a low frequency) to average, in effect,

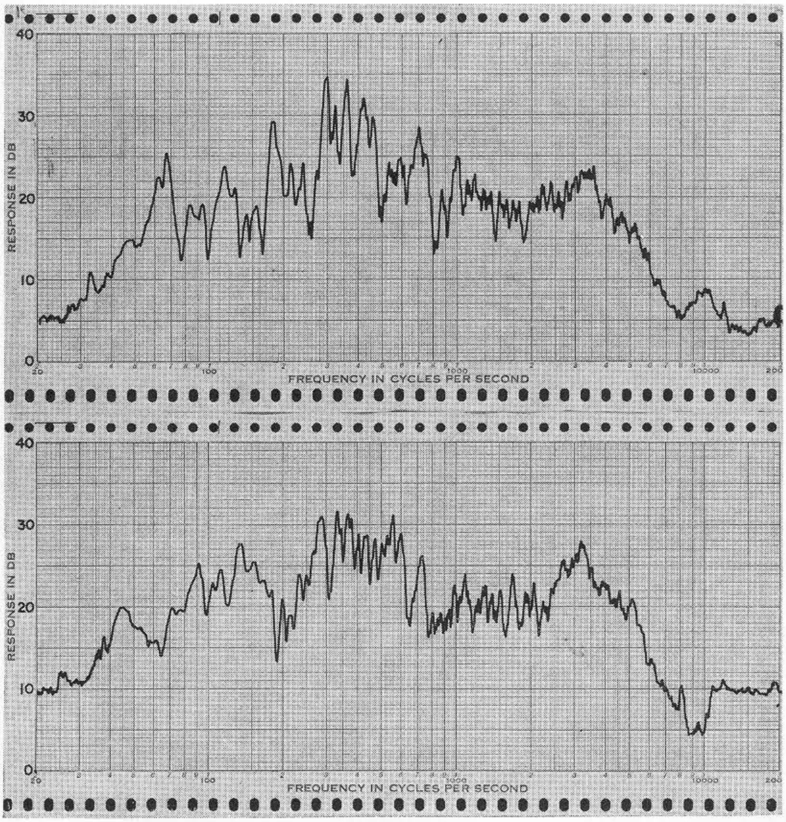


Figure 8. Two typical loudspeaker characteristics as measured with a sine-wave signal from the Type 1304-B Beat-Frequency Audio Generator and recorded automatically on the Type 1521-A Graphic Level Recorder.

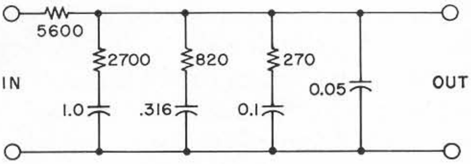


Figure 9. Schematic of pink noise filter.

over a range of frequencies and thereby produce a smoother response curve. From such a curve, gross tendencies away from ideal performance can be easily detected and corrective measures designed. A more modern technique uses random noise. It is convenient to correct first for the 3-db-per-octave slope of white noise as viewed through a constant-percentage-bandwidth filter. A filter having a slope of —3 db per octave from 20 to 20,000 cycles per second is shown in Figure 9. White noise which has been converted by such a filter from constant energy per cycle to constant energy per octave has been called "pink" noise.[1] The spectra of the white noise output of the Type 1390-A Random Noise Generator and the pink noise output of the filter as measured with the one-third-octave bandwidth are shown in Figure 10.

This pink noise was applied to the loudspeaker in the same location and the response was recorded after passing through the one-third-octave filter of the Type 1554-A. Figure 11 is a block

[1] C. G. Mayo and D. G. Beadle, "Equipment for Acoustic Measurements (Part 4)," *Electronic Engineering*, Vol. 23, pp. 462-465, December, 1951.

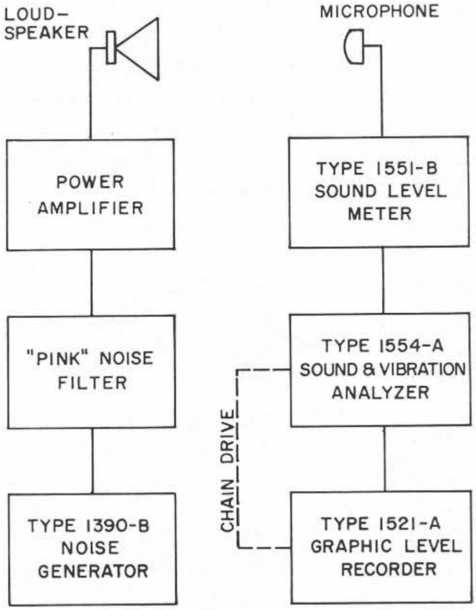


Figure 11. Block diagram of the system used for the loudspeaker measurements.

Figure 10. (*Upper curve*) White noise output of the Type 1390-B Random-Noise Generator as measured by the one-third-octave bandwidth and (*lower curve*) pink noise output of the filter. Curves were plotted automatically on the Type 1521-A Graphic-Level Recorder, coupled to the Type 1554-A Sound and Vibration Analyzer.

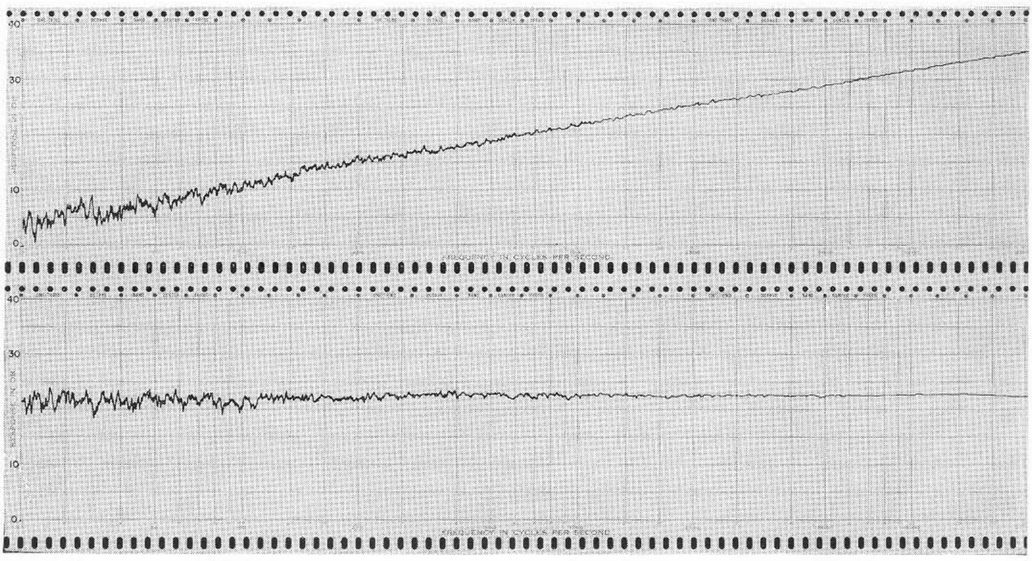


diagram of the measurement system. The response is shown in Figure 12, and the improvement over the curves of Figure 8 is evident. The response measured with the narrow filter of the Type 1554-A is shown at the bottom. Here a little more of the fine structure of the curve is apparent.

On these curves the fluctuation steadily decreases as the center frequency increases because the pass band of the filter is steadily increasing. This will be a characteristic of all such recordings of noise signals made with the Type 1554-A or any other constant-percentage-bandwidth analyzer.

The analyzer used with a random noise generator constitutes a generator of one-third-octave bands of noise, which are desirable for many types of acoustical measurements. The superiority of one-third-octave bands of noise over warble tones for measurements of sound decay time has been pointed out in a recent article.[2] An example of this use of the Type 1554-A Sound and Vibration Analyzer was the measurement of the reverberation time of a large auditorium reported in a recent issue of the *Experimenter*.[3] The block diagram and the recorder chart (Figures 7 and 8 of that article, respectively) show the measurement setup and the resulting decay curve.

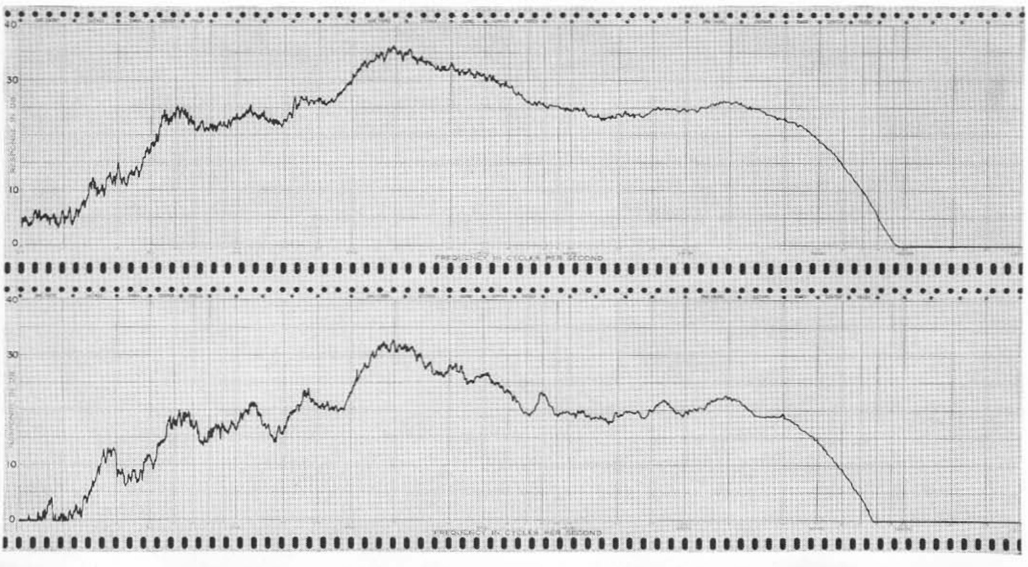
DESCRIPTION OF THE TYPE 1554-A SOUND AND VIBRATION ANALYZER

Figure 13 is a block diagram of the Type 1554-A Sound and Vibration Analyzer. The four main blocks are the preamplifier, the two tuning units, and the meter-and-output amplifier. There are two attenuators operated by coaxial controls. The large outer dial controls the input attenuator, which is used to adjust the gain of the preamplifier to suit the input signal; the knob controls the main attenuator, which is used during the analysis of a signal. The main attenuator is in three separate sections, located at the inputs of the tuning units and of the meter-and-output circuit. Consecutive 10-db steps of attenuation are inserted in the different sections in such a way as to yield the greatest possible dynamic range and protection against overloading.

[2] C. G. Balachandran, "Random Sound Field in Reverberation Chambers," *The Journal of the Acoustical Society of America*, Vol. 31, pp. 1319-1321, October, 1959.

[3] M. C. Holtje and M. J. Fitzmorris, "A Graphic Level Recorder With High Sensitivity and Wide Ranges," *General Radio Experimenter*, June, 1959.

Figure 12. Loudspeaker response as measured with pink noise and *(top)* one-third-octave bandwidth on the analyzer and *(bottom)* narrow bandwidth.



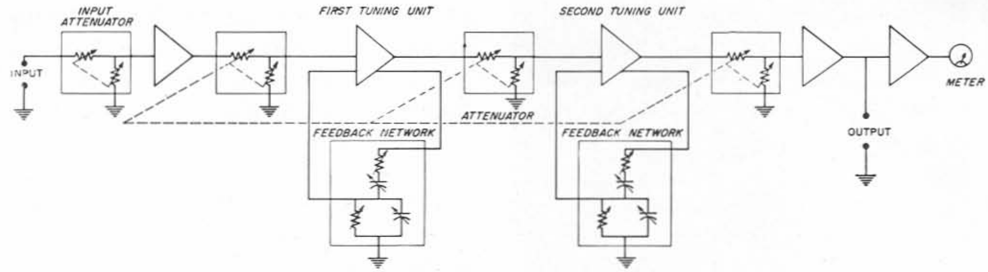


Figure 13. Block diagram of the analyzer.

A simplified schematic diagram of one of the tuning units is shown in Figure 14. The circuit is basically a two-stage tube-and-transistor amplifier. There is negative feedback from the collector circuit of Q-1 to the filament of V-1, which stabilizes the gain of the amplifier and the operating points of V-1 and Q-2. There are two possible paths for positive feedback. One of these is the so-called Wien bridge network, which produces a maximum feedback at one frequency and gives the tuning unit its selective characteristic. The other is a resistive voltage divider, which gives the tuning unit its flat frequency or all-pass characteristic. When either positive feedback network is used, there is always an excess of negative feedback for stability of gain.

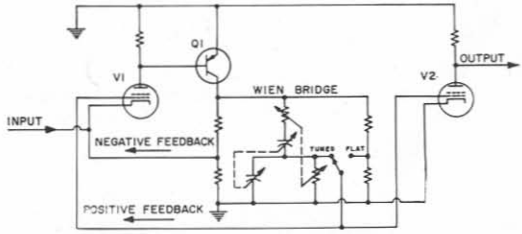
The one-third-octave response was synthesized by choice of the Q and the frequency separation of two tuning units in cascade. The resultant response is flat topped, as shown in Figure 2. When the BANDWIDTH switch is in the NARROW position, the two circuits are tuned to the same frequency, producing the narrow peak shown also in Figure 2. The resulting bandwidth is 8%, approximately one-tenth octave.

CALIBRATION

For measurements made in conjunction with the TYPE 1551-B Sound-Level Meter, the sound and vibration analyzer can be calibrated to be direct reading in sound-pressure level. The method for doing so can best be explained by reference to Figure 15, a photograph of the attenuator controls. The large outer dial marked INPUT ATTENUATOR is set according to the amplitude of the input signal so that the appropriate number is adjacent to the INPUT VOLTS SHOULD NOT EXCEED marker. The main attenuator knob is usually turned fully clockwise (as it is in Figure 15) during calibration. The signal from the sound-level meter is connected to the input of the analyzer and, with the analyzer BANDWIDTH switch set at ALL-PASS, the reading of the analyzer meter can be made the same (in decibels) by adjustment of the CAL thumb control, while at the same time the movable DECIBELS dial under the attenuator knob can be moved so that the same number is below the pointer of the knob as is shown at the window of the attenuator on the sound-level meter.

Both the sound-level meter and the analyzer then read the same over-all level, and the analyzer is thenceforth direct reading in one-third-octave sound-

Figure 14. Elementary schematics of the tuning unit used in the analyzer.



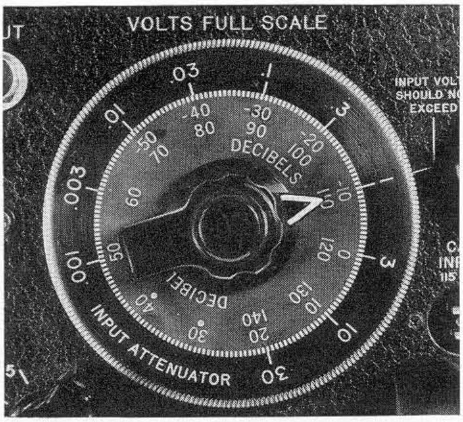


Figure 15. View of the attenuator dial.

pressure level (the sum of the meter reading on the decibel scale and the indication of the attenuator knob against the DECIBELS dial).

A similar system can be used with the TYPE 761-A Vibration Meter to make the analyzer's meter scale direct reading in amplitude. The analyzer also can be operated directly from a microphone, if the component levels are sufficiently high (see specifications), and the TYPE 1552-B Sound-Level Calibrator can be used for calibration.

If the analyzer is to be used for electrical signal analysis, it can be internally calibrated by use of a 115-volt ac line to be direct reading in voltage at the input jack.

ACKNOWLEDGMENT

As is often the case, the author has received much assistance in the development of this instrument from many colleagues. It is a particular pleasure, however, to single out A. P. G. Peterson for his helpful and inspiring direction and H. C. Jensen for aid in the mechanical design.

— J. J. FARAN

SPECIFICATIONS

Frequency Range: From 2.5 to 25,000 cycles in four ranges. The FREQUENCY dial is calibrated from 2.5 to 25 cycles; the FREQUENCY MULTIPLIER switch has four positions, 1, 10, 100, and 1000.

Frequency Calibration Accuracy: $\pm 2\%$ of the frequency dial settings.

Input Voltage Range: 100 microvolts to 30 volts for useful indication. Most sensitive range is 1 millivolt full scale.

Frequency Response: "NARROW": Maximum response is flat ± 2 db over the entire tuning range. "ONE-THIRD OCTAVE": Maximum response is flat ± 4 db over the entire tuning range. With respect to the "ALL-PASS" response, the effective bandwidth for noise is one-third octave ± 2 db. "ALL-PASS": Flat from 2.5 cycles to 25 kilocycles ± 2 db.

Bandwidth: "NARROW": (See plot) Response is down 3 db at $\pm 4\%$ of selected frequency. At one-half and twice selected frequency, response is down more than 40 db. "ONE-THIRD OCTAVE": (See plot) Bandwidth is 1.26:1 at the 3 db points. At one-half and twice the selected frequency, the response is down more than 30 db.

Input Impedance: 100 kilohms, unbalanced. Low input terminal grounded to case.

Meter: Three ranges, -10 to $+10$ decibels, 0 to 3 volts, and 0 to 10 volts.

Attenuator: Adjustable in 10-db steps.

Direct Use with Microphone:

Microphone Type	Component Levels Must Exceed
759-P25*	50 db re 0.0002 microbar
1551-P1L	50 db re 0.0002 microbar
1551-P1H	65 db re 0.0002 microbar

Output: Jack on front panel provides approximately 1 volt, open circuit, when meter indicates full scale. Output impedance, 5 kilohms.

Tubes: Four CK512AX and two CK526AX.

Transistors: Six 2N169A, two 2N521A, and seven 2N324.

Batteries: Four 1.5 volt (Eveready No. 935 Size C or equivalent) and two 67.5-volt (Eveready No. 467 or equivalent). Batteries are supplied with instrument. Life of batteries approximately 100 hours. A BATTERY CHECK position on the OFF-ON switch connects the panel meter to indicate when the batteries are satisfactory or need to be replaced.

Accessories Supplied: Shielded cable-and-plug assembly for connection to sound-level meter. Plugs to fit input and output jacks. Cable-and-plug assembly for calibration using 115-volt line. Pouch for accessories. Airplane-luggage-type carrying case.

Dimensions: $10\frac{5}{8} + 15\frac{3}{8} + 11\frac{1}{2}$ inches, over-all.

Weight: $31\frac{1}{2}$ pounds without accessories or carrying case; $39\frac{3}{4}$ pounds with accessories and carrying case.

*TYPE 1550-P1 Adaptor Plug required (see below).

Type		*Code Word*	*Price*
1554-A	**Sound and Vibration Analyzer**	DRAMA	**$1060.00**
	Set of Replacement Batteries	DRAMAADBAT	**7.80**
1550-P1	**Adaptor Plug**	MATOR	**4.00**

INCREASED BIAS CURRENT RATING ON TYPE 1607-A TRANSFER-FUNCTION AND IMMITTANCE BRIDGE

The maximum permissible continuous d-c bias current rating of the Type 1607-A Transfer-Function and Immittance Bridge has been increased from 100 ma to 250 ma. The new rating applies to both old and new instruments, since no change has been made in the instruments, but a re-examination of the temperature rises involved has shown the original rating to be too conservative.

In measurements on transistors with this instrument, in some cases difficulty has been encountered as a result of low-frequency oscillations arising in the circuit consisting of the external power supply and bias filters in combination with the transistor. This difficulty shows up as an inability to balance the instrument to a complete null. (The omission of the Type 1607-P500 Damper Unit may also produce a similar effect, but the resulting oscillation is then at a high frequency.) The presence of this low-frequency oscillation can be detected by means of an oscilloscope and cured by a rearrangement of the power supplies or by the addition of appropriate by-pass capacitors and loading resistors.

A 50-OHM TERMINATION FOR THE TYPE 805-C STANDARD-SIGNAL GENERATOR

To facilitate measurements on 50-ohm devices, a new 50-ohm termination, Type 805-P2, is now available for use with the Type 805-C Standard-Signal Generator. This generator has an open-circuit output impedance of 75 ohms, and the termination unit normally supplied with the generator gives output impedances of 37.5, 7.5, and 0.75 ohms. The output voltmeter reads output

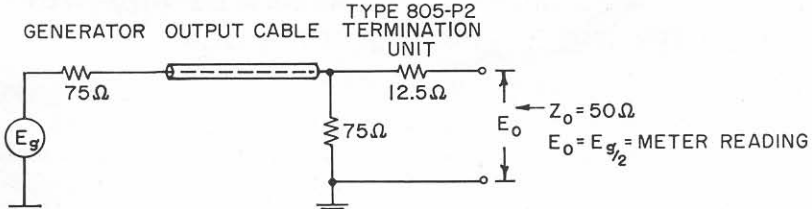


Figure 1

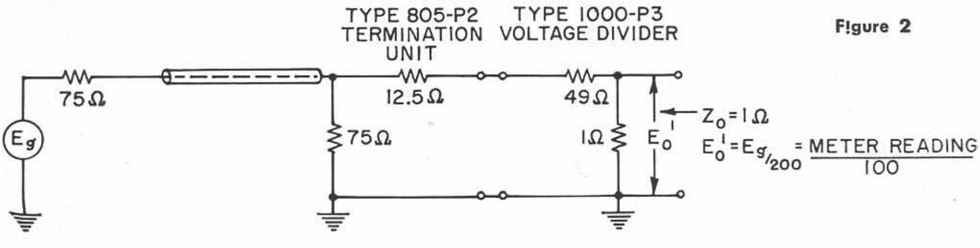
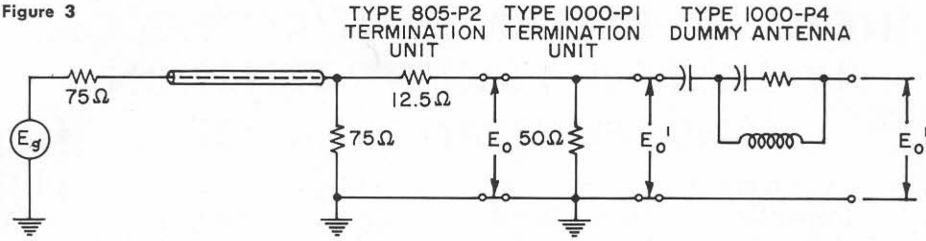


Figure 2

Figure 3



voltage directly for the 37.5-ohm termination; for the two lower impedances, the voltmeter reading is divided by 10 and 100, respectively. The TYPE 805-P1 Termination Unit supplied with the generator also includes a dummy antenna.

The TYPE 805-P2 50-ohm Termination Unit is shown schematically in Figure 1. It will be seen that the no-load voltage is still indicated correctly by the panel meter. With a 50-ohm load, the load voltage is one-half the meter reading.

Figures 2 and 3, respectively, show the 50-ohm termination unit as used with the standard TYPE 1000-P Signal Generator accessories, the TYPE 1000-P3 Voltage Divider, and the TYPE 1000-P4 Dummy Antenna.

The maximum output voltage with either termination is 2 volts. With the termination removed, the maximum open-circuit output voltage is 4 volts.

Type		*Code Word*	*Price*
805-P2	**50-ohm Termination Unit**	ALTER	**$25.00**
1000-P3	**100:1 Voltage Divider**	ARMOR	**17.50**
1000-P1	**50-ohm Termination**	ALOUD	**25.00**
1000-P4	**Dummy Antenna**	ARROW	**15.00**

SALON INTERNATIONAL DE PIÈCES DÉTACHÉS, TUBES, ÉLECTRONIQUES, ACCESSORIES, APPAREILS DE MESURES POUR LES INDUSTRIES ÉLECTRONIQUES

This international exhibit will be held at the Parc des Expositions, Porte de Versailles, Paris, February 19th through 23rd, 1960.

General Radio will participate again as in 1958 and will show a group of modern electronic instruments for laboratory and production. Engineers from our representatives in France, ETS. RADIOPHON, will be in attendance to greet our overseas friends and to discuss their measurement problems.

General Radio Company

PRINTED IN U.S.A.