the GENERAL RADIO Experimenter

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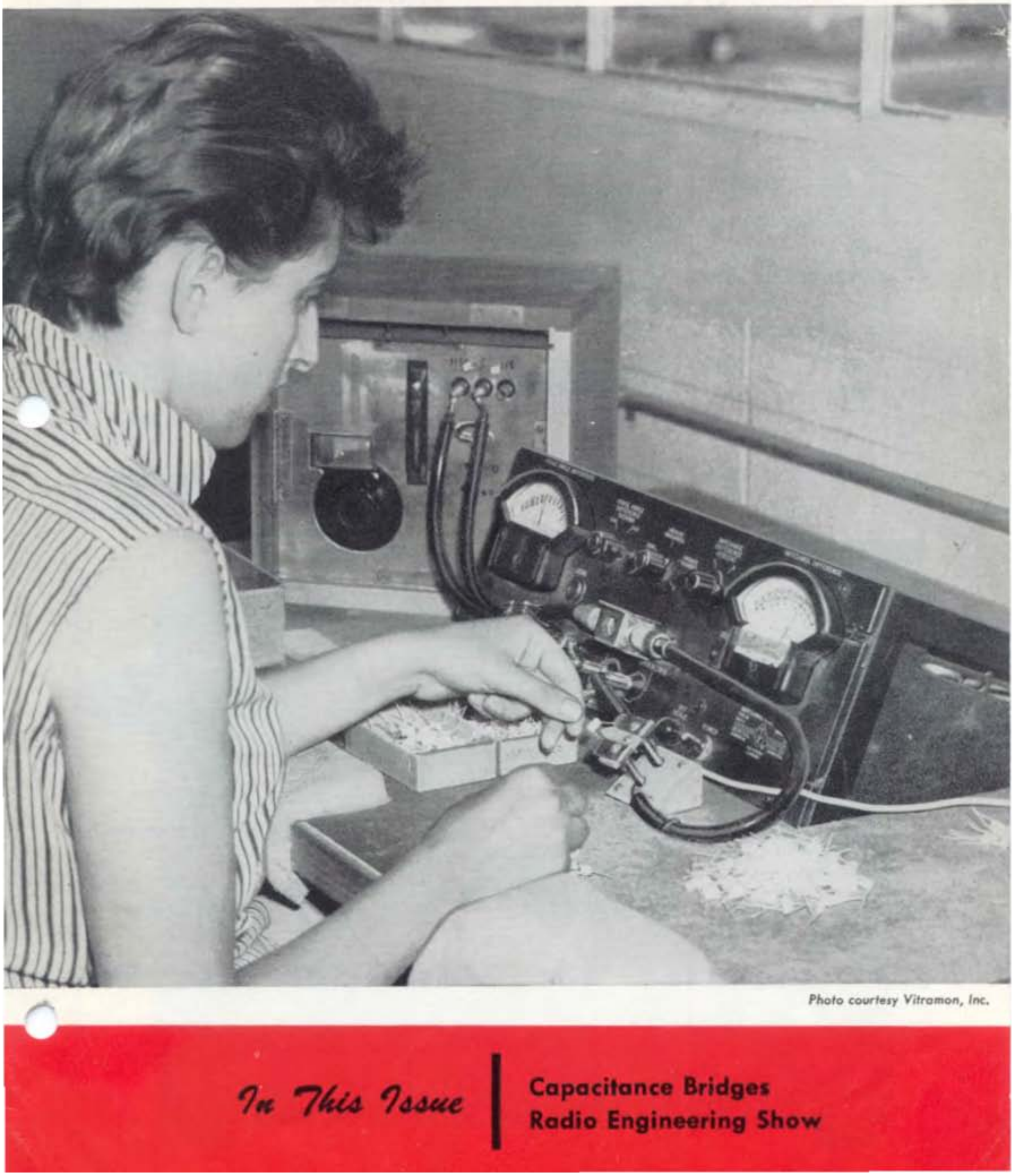

Photo courtesy Vitramon, Inc.

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Radio Engineering Show

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COVER

One of the earliest users of the Type 1605-A Impedance Comparator is Vitramon, Inc., of Bridgeport, Connecticut, manufacturers of ceramic capacitors. Vitramon uses Impedance Comparators for production testing, as shown in the photograph, and also for engineering tests to determine the effects of environmental factors such as temperature, humidity, immersion, and vibration.

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THE TYPE P-582 CAPACITANCE BRIDGE

AN INSTRUMENT DESIGNED TO CALIBRATE CAPACITIVE FUEL-GAGE TESTERS

The full range of an airplane can only be achieved if the plane lands with a dry fuel tank. Any fuel left over has not only reduced the range by not being used, but it has also added to the weight of the plane during the entire trip. A margin of safety is, of course, necessary, but an accurate fuel gage can keep this margin from being unnecessarily large.

The fuel gage on a modern military aircraft measures the fuel quantity by measuring the capacitance of an element inserted into the fuel tank[1]. This element is, in effect, a capacitor whose capacitance changes as fuel is replaced by air. Periodic checks of the accuracy at full and empty gage readings are made by the substitution of a variable capacitor, such as the MD-1 (GR Type P-579) Field Variable Capacitance Tester,[2, 3] for the tank elements. The gage can be only as accurate as the test capacitor, which, although of high precision, should also be tested periodically, for an inaccuracy could result in a loss of life. Thus a bridge is necessary to test the tester which tests the fuel gage.

The GR Type P-582 Capacitance Bridge, shown in Figure 1, was developed to meet this need. Actually, original specifications (MIL-T-4778 (USAF)) called for a bridge of somewhat different design, but the Type P-582, which meets the essential requirements, is a smaller and lighter instrument, and yet provides greater range, higher accuracy, and has many convenience features.

After evaluation tests (including many environmental tests) the P-582 was given the militarily assigned commercial standard designation TEST SET, CAPACITANCE BRIDGE, TTU 24/E, PRECISION, THREE-TERMINAL, DEPOT.

1 "Temperature Compensated Aircraft Fuel Gage," R. J. Levine, ELECTRONICS, 27, 9, September, 1954, pp. 160-1.
2 "A Calibrator for Aircraft Fuel Gages," P. K. McElroy, *General Radio Experimenter*, September, 1955.
3 "Electronic Fuel Gage Tester," P. Bishop, ELECTRONIC INDUSTRIES, May, 1957, p. 75.

Figure 1. Panel view of the Type P-582 Capacitance Bridge.

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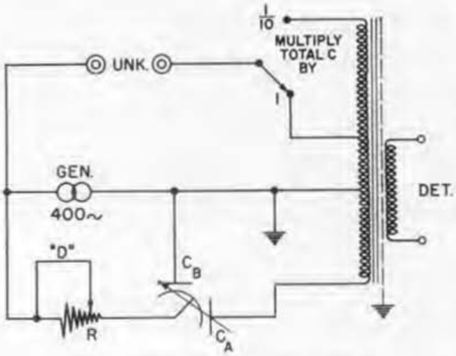

Figure 2. Basic bridge circuit.

This instrument is a self-contained bridge system which includes a 400-cycle oscillator and a sensitive null indicator. Since the fuel gage measures direct capacitance[1], a "transformer bridge"[4] was specified to make possible direct (three-terminal) capacitance measurements.[5] The basic bridge circuit is shown in Figure 2.

Capacitance from the unknown terminals to ground shunts either the oscillator or the tightly coupled transformer and has no effect unless it is very large (see specifications). In addition, the inductively coupled "ratio arms" of this type of bridge provide a ratio accuracy unattainable by other types of components. As a result, the accuracy of capacitance measurements depends almost entirely on the accuracy of the standard capacitor. The range is extended by changing the turns ratio of the transformer. The transformer is in the detector circuit which makes possible a constant voltage on the unknown capacitor as the range is changed, with no reduction in sensitivity. The transformer is potted inside of two, high-permeability shield cans to prevent stray fields from affecting the balance.

The important feature of this bridge is the T-network used in the "standard" side of the bridge. The direct impedance of this network balances out the direct impedance of the unknown at balance. The balance equations are:

$$C_X = C_A\ (M)$$

where M is a multiplier of 1 or 1/10 (as selected) and C_X is the series capacitance of the unknown.

$$D_X = \omega R\ (C_A + C_B)$$

The sum $(C_A + C_B)$ is kept constant, so that R is proportional to D_X and, therefore, is directly calibrated in dissipation factor. Other transformer-type capacitance bridges require a computation to obtain this quantity.

The standard capacitor, which forms the differential unit consisting of C_A and C_B, is actually a 50-to-1100 $\mu\mu f$ variable air unit and a 1000-to-10,000 $\mu\mu f$ decade of silvered-mica capacitors. The sum $(C_A + C_B)$ is kept constant by the addition of an extra set of stator plates to a Type 722 Capacitor, and by differential switching of the mica units. On the ×1/10 range the lower limit is extended down by a factor of 1/10, so that the over-all range becomes 5$\mu\mu f$ to 11,000 $\mu\mu f$. The accuracy of the variable unit (with dial correction) is ± 0.4 $\mu\mu f$ or ± 0.1%, whichever is larger. In the ×1/10 position, this means a bridge accuracy of ± .04 $\mu\mu f$ or ± 0.1% over the range of 5 to 110 $\mu\mu f$. The range from 110 to 1100 $\mu\mu f$ can be covered in either of two ways: (1) with the variable air capacitor and a multiplier of ×1; or (2) by use of the mica decade and a multiplier of ×1/10. When only the air capacitor is used, the accuracy of measurement is 0.4 $\mu\mu f$ or 0.1%; with the mica decade, which has a 0.1% accuracy, the over-all accuracy is close to 0.1%, just as on the 1000-to-11,000 $\mu\mu f$ range.

[4] "Double Ratio A-C Bridges with Inductively Coupled Ratio Arms," A. A. Clark and P. B. Vandeclyn. *Proceedings of IEE*, 92, Part III, 1949, pp. 189-198.

[5] "Direct Capacitance and Its Measurement," R. F. Field, *General Radio Experimenter*, November, 1933.

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The percentage accuracy for capacitance measurement (with dial correction) is plotted against capacitance in Figure 3, which also shows the original specifications. The small jogs in the curve are the effect of the ± 0.4 $\mu\mu f$ specification of the variable capacitor and are of small consequence. The original specification called for a 1000 $\mu\mu f$ variable capacitor with an accuracy of ± 0.2 $\mu\mu f$ or ± 0.1%, which is unobtainable in present capacitors without a much more detailed correction chart than that called for by the specifications.

The dissipation-factor accuracy is ± 2% of reading ± 0.0002. The small losses of the mica decade are balanced out by resistive networks on the unknown side of the bridge which are switched as the decade is adjusted.

The 400-cycle oscillator is thermistor stabilized and uses a Wien bridge selective *R-C* network in a three-stage feedback circuit, which has such a high loop gain that the frequency is practically independent of tube parameter changes. The frequency-determining components are GR precision resistors and capacitors. A buffer cathode-follower amplifier is added to prevent external loading from affecting the frequency.

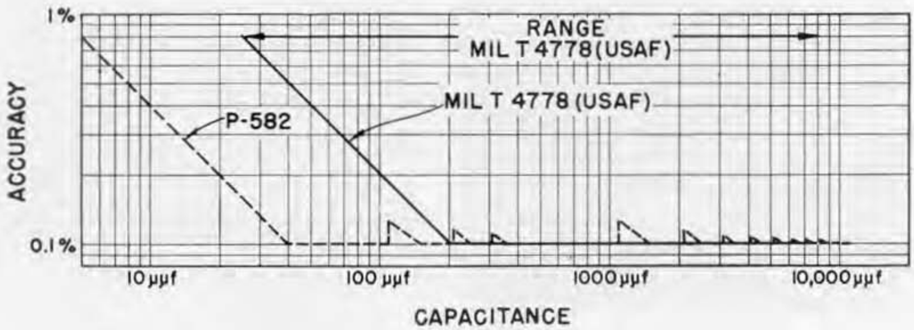
The detector circuit has several features that facilitate rapid and accurate balances. Two cascaded, selective, twin-T, feedback amplifiers provide high selectivity, and the sensitivity is more than adequate for a precise balance. The null indicator has a compressed response and uses a ruggedized meter. Two panel lights indicate the direction of capacitive unbalance when the meter is upscale. Thus it is not necessary to use a trial-and-error method of deciding which way to vary the standard capacitor when the unknown is first connected. This feature greatly reduces the time required to balance the bridge and usually makes gain-control adjustments unnecessary.

It should be noted that, although this bridge was designed for a particular purpose, it is also suitable for general capacitance measurements at 400 cycles. Its accuracy, range, portability, and self-contained nature make it a most useful instrument for precise, three-terminal measurements.

The author would like to acknowledge the contributions of the many people at General Radio whose ideas were incorporated in the instrument. The guiding hand behind the development was that of P. K. McElroy, whose aid in the design also assured compliance with the requirements of environmental tests. The ideas of I. G. Easton and R. A. Soderman were used in the circuitry, and the layout was largely the work of H. G. Stirling.

— Henry P. Hall

Figure 3. Plot of percentage accuracy versus capacitance measured.



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SPECIFICATIONS

Range: Capacitance: 5 μμf to .011 μf.
Dissipation Factor: 0 to .11.

Accuracy: Capacitance: see Figure 3. Variable Capacitor: on ×1 Range, ± 0.4 μμf or ± 0.1%, whichever is greater; on ×1/10 Range, ± 0.04 μμf or ± 0.1%, whichever is greater. Decade Capacitor: ± 0.1% on both ranges.
Dissipation Factor: ± 2% of reading ± .0002.

Oscillator: Frequency: 400 cps ± 0.25%.
Output: 25 volts nominal.
Distortion: less than 0.5%.

Detector:
Sensitivity of amplifier alone: 10% scale deflection for 10 μvolts input.
Sensitivity of system: ×1 MULTIPLIER position — 10% deflection for .05 μμf ΔC.
×1/10 MULTIPLIER position—10% deflection for .005 μμf ΔC.
Selectivity of amplifier alone: down 56 db at 800 cps, down 64 db at 60 cps.
Selectivity of amplifier and bridge transformer: down 50 db at 800 cps, down 80 db at 60 cps.

Effect of Impedance to Third Terminal (Chassis): Impedance from the unshielded lead to chassis shunts the oscillator and, therefore, causes no bridge error. The output voltage is reduced approximately 50% by shunt impedance of 5 kΩ or 0.1 μf.
Impedance from the coaxial lead to chassis shunts the bridge transformer. On the ×1 MULTIPLIER position, there is negligible effect from a shunt of 1 kΩ or 0.1 μf. On the ×1/10 MULTIPLIER position, there is negligible effect from 10 kΩ or 0.01 μf.

Figure 4. View of Type P-582 Capacitance Bridge with cover in place.

Accessories Supplied: One power cord.

Tube Complement: 5-5751; 1-12AT7WA; 1-6X4WA.

Power Supply: 105 to 125 volts, 50-60 cycles.
30 watts input at 115-volt line.

Dimensions: (Length) 22½ in. x (height) 14 in. x (depth) 12¾ inches over-all, including cover.

Net Weight: 55 lbs.

Type		*Code Word*	*Price*
P-582	**Capacitance Bridge**	SUPER	**Price on request**

CAPACITANCE TEST BRIDGE

60/120-CYCLE MODEL NOW STANDARD ITEM

The special 60/120-cycle model[1] of the popular TYPE 1611-A Capacitance Test Bridge[2] has enjoyed such widespread acceptance that it now becomes the standard model and will be known as TYPE 1611-B. This bridge will measure capacitance and dissipation factor over wide ranges; at a frequency of 60 cps from the power line and at 120 cps from an external generator. Filters are provided in the null-detector circuit for both frequencies. Operation at other frequencies, up to 1000 cps, is also possible, if suitable external generators and filters are used.

120-Cycle Measurements

Capacitance measurements at 120 cps are used primarily for the measurement of polarized electrolytic capacitors. In the majority of applications of these capacitors, a 120-cycle ripple current is superimposed on the applied unidirectional voltage and, hence, it has become standard practice to test such capacitors at that frequency. The capacitance

[1] "Electrolytic Capacitor Testing at 120 Cycles," *General Radio Experimenter*, 28, 6, November, 1953, page 8.
I. G. Easton, "A 120-cycle Source for Electrolytic Capacitor Testing with the Capacitance Test Bridge," *General Radio Experimenter*, 31, 3, August, 1956, pp. 9-12.
[2] Ivan G. Easton, "A Wide-Range Capacitance Test Bridge," *General Radio Experimenter*, 23, 2, July, 1948, pp. 1-8.

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range of the bridge is 1 μf to 11,000 μf and the dissipation-factor range is 0 to 120% when the frequency of the test voltage is 120 cycles. The D dial is calibrated for 60-cycle measurements; at 120 cycles the correct value of dissipation factor is obtained by multiplying the dial readings by a factor of 2.

Measurements at 60 cps have many uses: In the laboratory and shop, for the testing of paper, mica, and other capacitors; in the electric-power industry, for the shop testing of insulators, particularly for the measurement of the dissipation factor of bushings and insulators, transformers, rotating machines, and cable; in the electronics industry it is used not only for measuring component capacitors, but also for measuring capacitance to ground of transformer windings, shields, and circuit elements.

The capacitance range for 60-cycle measurements is 0 to 11,000 μf; the dissipation-factor range is 0 to 60%. The extension of the capacitance range to zero is made possible by a unique compensating circuit[2], which eliminates the effect of stray capacitance at the bridge terminals. If, for practical purposes, we consider the lower limit of measurement to be one micromicrofarad, the bridge covers a capacitance range of 11 billion to one.

Other Frequencies

Measurements at other frequencies up to 1000 cycles can be made with this bridge, over a range of 1 μf to 11,000 μf. Both external generator and external filters must be used. The dissipation-factor range is 0 to f%, where f is operating frequency in cycles per second. Dissipation-factor dial readings are multiplied by $\frac{f}{60}$ to obtain the true dissipation factor, expressed in per cent.

Accessory Equipment

For 120-cycle measurements, the recommended external generator is the Type 1214-AS2 Unit Oscillator. For higher frequencies the Type 1210-B Unit R-C Oscillator is satisfactory, or for fixed-frequency measurements at 1000 cycles, the Type 1214-A Unit Oscillator. Polarizing voltage can be furnished by any convenient d-c power supply. For voltages up to 300 volts, the Type 1204-B Unit Variable Power Supply is recommended.

SPECIFICATIONS

Capacitance Range: 0 to 11,000 μf at 60 cycles. 1 μf to 11,000 μf at 120 cycles or other external frequency.

Dissipation-Factor Range: 0 to 60% at 60 cycles. Range proportional to frequency. (0 to 120% at 120 cycles.) Dial readings must be multiplied by the ratio $\frac{f}{60}$ for frequencies other than 60 cycles.

Accuracy: Capacitance, ±1%. Dissipation factor, ±(2% of dial reading +0.05% x $\frac{f}{60}$ dissipation factor).

Detector Filter: Tuned to 60 or 120 cycles, selected by switch. Jack provided for use of an external filter for other frequencies.

External Generator: Required for frequencies other than 60 cycles. Type 1214-AS2 Oscilla-

Figure 1. Panel view of Type 1611-B Capacitance Test Bridge.

tor listed below is recommended for 120-cycle measurements.

Polarizing Voltage: Terminals are provided for connecting an external d-c polarizing voltage. The maximum voltage that should be impressed is 500 volts.

One of the terminals is grounded so that any a-c operated power supply with grounded output can be used. The terminal capacitances of the power supply do not affect the bridge circuit.

Power Supply Voltage: 105 to 125 (or 210 to 250) volts, 60 cycles.

Power Input: 15 watts.

Accessories Supplied: TYPE CAP-35 Power Cord and spare fuses.

Mounting: Portable carrying case of luggage-type construction. Case is completely shielded to insure freedom from electrostatic pickup.

Tube Complement: One each 6X5-GT/G, 6SJ7, and 6U5.

Net Weight: 30½ pounds.

Dimensions: (Width) 14½ x (depth) 16 x (height) 10 inches, over-all, including cover and handles.

Type		*Code Word*	*Price*
1611-B	Capacitance Test Bridge	FAVOR	$570.00
1214-AS2	Unit Oscillator (including power supply)	ABBOT	100.00

IRE—1958 RADIO ENGINEERING SHOW

New York Coliseum, March 24-27

Experimenter readers who attend the 1958 Radio Engineering Show are cordially invited to visit the General Radio display in Booths 3302 to 3310. These booths are on the third floor of the Coliseum, which is devoted almost completely to electronic instruments and test equipment.

Several new instruments will be on display, among them:

Slotted Line for Dielectric Measurements — A new model of the popular General Radio slotted line, developed particularly for measurements of dielectric constant and dissipation factor of solid insulating materials. Operating at frequencies between 200 and 5000 megacycles, this line will measure dielectric constants between 1 and 10 with an accuracy of approximately $\pm 2\%$, and dissipation factors between 0.0001 and 0.1 with an accuracy of $\pm$ (5% + 0.0001).

Transfer Function Meter — A new VHF-UHF instrument for the direct measurement of forward and reverse transfer functions of transistors, vacuum tubes, and networks.

Capacitance Bridge — A transformer bridge, which measures direct (3-terminal) capacitance over a range of 5 $\mu\mu f$ to 0.011 μf at 400 cycles. This bridge is fully described elsewhere in this issue of the *Experimenter*.

6-Gang Variac® Autotransformer — Six TYPE W50 Variac® Autotransformers on a single shaft, rated at 34½ KVA.

Other Important Displays include Pulse Equipment, Laboratory Standards, Voltage Regulators, Electrometer, Impedance Bridges, General Radio Parts and Connectors, and a complete line of the well-known General Radio Unit Instruments.

Plan to Visit the GR Booths. You'll find it worth your while. Our engineers will be on hand to greet you and to discuss your measurement problems.

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