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ELECTRICAL MEASUREMENTS AND THEIR INDUSTRIAL APPLICATIONS

NEW PRECISION CAPACITORS

TYPE 722-MD 1000 and 100 $\mu\mu$f — TYPE 722-ME 100 and 10 $\mu\mu$f

Also IN THIS ISSUE

Page

● **AS ATTESTED** by the popularity of the TYPE 722-D, a two-section precision capacitor represents a practical and economical means of obtaining two ranges of adjustable capacitance at less than the cost of two capacitors. By the use of a common case, frame, panel, and indicating means, a second section is obtained at only a moderate increase in cost over that of a single unit.

Two new General Radio precision capacitors of two-section construction are now available. These new models are intended for use in substitution methods of measurement and are calibrated in terms of capacitance differences rather than terminal capacitance. For convenience in use, the scales read directly the capacitance removed from the circuit.

The new TYPE 722-MD Precision Capacitor replaces the TYPE 722-M. This new model has the 0-1000 $\mu\mu$f ΔC range of the model it replaces but has, in addition, a 0-100 $\mu\mu$f ΔC range. The second model, TYPE 722-ME, has 0-100 $\mu\mu$f and 0-10 $\mu\mu$f sections. The 10-$\mu\mu$f section represents the first regular listing of this low, full-scale value. Such units have in the past been available only on special order.

Figure 1. Panel view of the Type 722-ME Precision Capacitor.

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Recently the industry requirement for accurate standards in low capacitance values has increased, largely because of the needs of manufacturers and users of ceramic-body capacitors. To meet such needs more effectively, the TYPE 722-ME is now manufactured for stock.

General Radio precision capacitors are accurate and stable standards of capacitance, carefully designed, and hand assembled and adjusted.

The entire assembly is mounted in a cast frame, which gives the unit rigidity. This frame, all spacers, the stator rods, and the rotor shaft are made of the best available alloys of aluminum, which combine the mechanical strength of brass with the weight of aluminum. The plates are also of aluminum, so that all parts have the same temperature coefficient of linear expansion.

A worm drive is used to obtain the desired high precision of setting. In order to avoid the slight eccentricity that occurs when a worm is mounted on a shaft, the shaft and the worm are one accurately machined piece. The dial end of this worm shaft runs in a self-aligning ball bearing, while the other end is supported by an adjustable spring mounting. Sealed, self-lubricating ball bearings, lightly stressed, are hand-fitted to both ends of the rotor shaft. Electrical connection to the rotor is made by means of a silver alloy brush bearing on a silver overlay drum to assure a positive electrical contact.

The preliminary assembly of the frame, shaft, and gears is motor driven to grind in the gears before final assembly.

SPECIFICATIONS

Capacitance Range:

Type	*Capacitance Range μμf*	*Direct-Reading Accuracy*		*Approximate Capacitance at Zero μμf*
722-MD	0 to 1050	±1 μμf	±0.1%	1140
	0 to 105	±0.2 μμf	±0.1%	135
722-ME	0 to 105	±0.2 μμf	±0.1%	145
	0 to 10.5	±0.05 μμf	±0.1%	35

Capacitance is indicated by the readings of the dial and drum, visible through a window in the panel.

Rotor Plate Shape: Semicircular for both models, to give a linear capacitance characteristic.

Over-all Usable Accuracy: The accuracies stated above can be attained in practice only if an acceptable standard technique is used by the operator to connect the capacitor into a measuring circuit. Otherwise, the usable accuracy at the capacitor terminals may be limited to approximately ±1 μμf. (See description in *General Radio Experimenter*, Vol. XXI, No. 12, May 1947, for a complete discussion of connection errors.)

Correction Chart: A correction chart is supplied giving corrections at multiples of 1, 10, or 100 μμf, depending on the total capacitance of the capacitor. Accuracies obtainable through the use of these charts are as follows:

Type	*Range, μμf*	*Accuracy after correction is applied* — *Total Capacitance*†	*Accuracy after correction is applied* — *Capacitance Differences*
722-MD	0 to 1050	±0.1% or ±0.4 μμf*	±0.1% or ±0.8 μμf*
	0 to 105	±0.1% or ±0.08 μμf*	±0.1% or ±0.16 μμf*
722-ME	0 to 105	±0.1% or ±0.08 μμf*	±0.1% or ±0.16 μμf*
	0 to 10.5	±0.1% or ±0.02 μμf*	±0.1% or ±0.04 μμf*

†From any zero *dial* setting. *Whichever is greater.

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Worm Correction Calibration: Corrections for the slight residual eccentricities 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, μμf*	*Accuracy after correction is applied* — *Total Capacitance*	*Capacitance Differences*†
722-MD	0 to 1050	±0.1% or ±0.1 μμf*	±0.1% or ±0.2 μμf*
	0 to 105	±0.1% or ±0.02 μμf*	±0.1% or ±0.04 μμf*
722-ME	0 to 105	±0.1% or ±0.02 μμf*	±0.1% or ±0.04 μμf*
	0 to 10.5	±0.1% or ±0.005 μμf*	±0.1% or ±0.01 μμf*

†Differences from any zero *dial* setting. *Whichever is greater.

Maximum Voltage: All models, 1000 volts, peak.

Dielectric Supports: Bars of low-loss steatite support the stator assemblies, and conical polystyrene bushings insulate the terminals from the panel. Quartz bars, coated with silicone to prevent formation of a water film, can be supplied on special order. (See price list.)

Dielectric Losses: The figure of merit, *DC* (dissipation factor times capacitance), when measured at 1 kc, is approximately 0.04 μμf for steatite insulation and 0.003 μμf for quartz.

Residual Parameters: Effective series inductance is approximately 0.06 μh for all high-capacitance sections and 0.10 for low-capacitance sections. Effective series resistance at 1 Mc is approximately 0.02Ω for high-capacitance sections and 0.03Ω for low-capacitance sections. The series resistance varies as the square root of the frequency. Its effect is negligible below 100 kc.

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: Jack-top binding posts are provided. Standard ¾-inch spacing is used. The rotor terminal is connected to the panel and shield.

Mounting: The capacitor is mounted on an aluminum panel finished in black-crackle lacquer and enclosed in a shielded walnut cabinet. A wooden storage case with lock and carrying handle is supplied.

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

Weight: 10½ pounds; 19¾ pounds with carrying case.

Type		*Code Word*	*Price*
722-MD	**Precision Capacitor**	CYNIC	**$205.00**
722-ME	**Precision Capacitor**	COUPE	**205.00**
Worm-Correction Calibration for Types 722-MD and MDQ		WORMY	**70.00**
Worm-Correction Calibration for Types 722-ME and MEQ		WORMY	**90.00**

When ordering, use compound code word, CYNICWORMY, etc.

QUARTZ INSULATION

Any TYPE 722 Precision Capacitor can be obtained with quartz insulation.

Type		*Code Word*	*Price*
722-MDQ	**Type 722-MD with Quartz Insulators**	CYNICQUATZ	**$300.00**
722-MEQ	**Type 722-ME with Quartz Insulators**	COUPEQUATZ	**300.00**

PRECISION CAPACITORS—MADE TO MEASURE

Among the lumped circuit components available to the designer who is developing measuring or operating equipment, the variable capacitor occupies a unique position by virtue of its inherent characteristics and the ease with which they can be adapted and arranged to meet the circuit designer's requirements. While not perfect, it approaches perfection as a circuit element more closely than most other components, and its many advantages make it an acknowledged boon to the designer.

One of its most useful features is that it is variable continuously, rather than in steps. The only limitation to the precision of adjustment is the excellence of the mechanical drive that can be applied

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to it. Over the years direct drive has given way to spur gearing and later to worm gearing for drive purposes, and sleeve or cone bearings have been succeeded by ball bearings for the shafts. Successive refinements in design and manufacture of both the worm gearing and the ball bearings have continued to enhance the smoothness and precision of adjustment.

General Radio's precision variable capacitors have, during a life span of around 35 years, gone through the continuous development alluded to above until they now constitute an essential type of precise unit employed not only in the myriad expected applications in the electronics business but also in many unexpected ones. They are necessary, for instance, to the safe operation of aircraft, since they are used to provide highly accurate checks of the calibration of aircraft fuel gauges. It is the fuel for those last few miles that really counts the most and which the pilot must be sure is actually in the tanks.

What has given such versatility and wide application to the precision variable capacitor, such as the General Radio Type 722? It must be the many features which can be flexibly rearranged, in nature and in combination, to meet large numbers of vastly different requirements. Some of the features of precision variable capacitors which are subject to controlled modification by the designer will be discussed one by one. The first ones are exemplified often in capacitors which are available from catalog stock, whereas the later ones are usually observed only in special capacitors made to order to meet each customer's current desires.

1. Capacitance Range

This may be almost any figure within the limits of 1 $\mu\mu$f and 1000 $\mu\mu$f. The capacitance-rotation curve is essentially a straight line except at each end where fringing causes deviations. In stock models, linearity is maintained over slightly more than 150°. Capacitors are manufactured for catalog stock having straight capacitance sections spanning nominally 10, 100, and 1000 $\mu\mu$f (actually 10.5, 105, and 1050 $\mu\mu$f). Capacitors have been built with nominal capacitance span of 1 $\mu\mu$f linear (actually 1.05 $\mu\mu$f). If

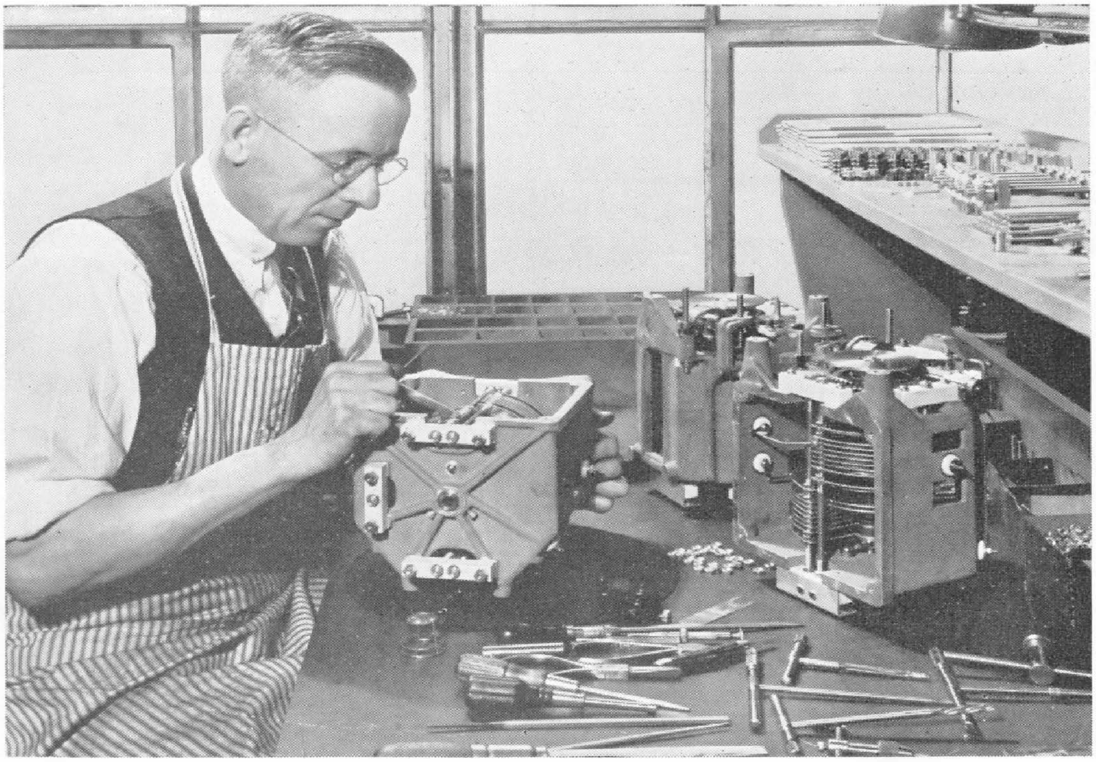

Figure 1. The accuracy and stability of a precision capacitor depend to a great degree upon the care and skill with which it is assembled and aligned. Here, a skilled machinist is assembling a group of capacitors for installation in heterodyne frequency meters.

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the capacitor desired is not to be direct reading, any reasonable capacitance span can be provided. If a direct-reading scale is desired, a capacitance span over the linear portion should be chosen which can make use of available worm drive ratios. The vernier dial span must be chosen with care, since it must repeat time after time, tracking the successive marks on the drum dial.

2. Dial Markings

While there is almost no limit to the particular legends which may appear on the main and vernier dials, there are usually employed only three kinds:

a. Direct capacitance
b. ΔC, in capacitance added
c. ΔC, in capacitance removed.

3. Worm Calibrations

Enhanced accuracy in use of the capacitor can be had by providing it with a worm calibration. No worm or worm wheel, in spite of precise machining, will come out absolutely concentric, even after the grinding-in period regularly employed in capacitor manufacture. Accordingly, there will be roughly sine-wave departures from linearity, of short period (one worm revolution) and of long period (one-half worm wheel revolution). These, of course, are superposed on any departures from linearity contributed by plate shape and by failure of the axis of rotor and stator plates to coincide exactly. Most of these unwanted variations are evaluated all at once for correction purposes in the worm correction data supplied when specifically requested.

4. Quartz Insulation

While binding posts are insulated by polystyrene in most instances, there is some steatite insulation in the capacitor.

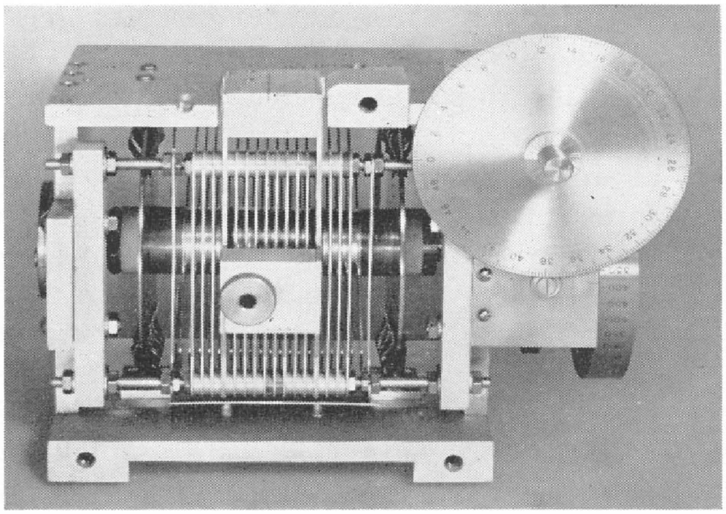

Figure 2. View of the capacitor used in the Type 821-A Twin-T Impedance Measuring Network. This capacitor is designed to have very low residual impedances.

For improved a-c dissipation factor and for improved d-c leakage resistance, silicone-treated fused-quartz insulators are available on special order. Fused quartz is in itself so expensive and so hard to machine that the fragile quartz insulation should be used only when really needed.

5. Double Scale Legends

For some purposes, such as bridge measurement, it is convenient to have two sets of scales on the main and vernier dials. Examples are:

a. Direct-reading capacitance in black characters and ΔC capacitance-removed in red.
b. ΔC capacitance-added in black and ΔC capacitance-removed in red.

6. Three-Terminal (Insulated-Rotor) Capacitors

In the usual construction, the rotor and shaft are common, and tied to the frame by a silver brush-drum takeoff short-circuiting the ball bearings. However, it is often desirable to have the rotor insulated from the frame. The reason might be that rotor and stator are

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both high in an oscillator circuit. Or it might be because the capacitor is to be used in a bridge or other measuring circuit with both sets of plates off ground, as for measurement of direct capacitance. It might be done to eliminate the variations of capacitance in the leads going to a remote capacitor, by using coaxial line to carry one of the two electrode leads, the shield going to the frame. The coaxial connection also inherently prevents electrostatic pickup.

Another particular advantage to be obtained from three-terminal construction is that the effects of stator-frame and rotor-frame capacitances and losses can be removed by proper circuit connections. This means that the zero capacitance of a three-terminal capacitor and the capacitance at the low end of the straight portion of the capacitance-rotation curve are both appreciably smaller (often as much as 25 $\mu\mu$f in typical TYPE 722's) than the corresponding values for a capacitor in two-terminal construction.

If noise caused by varying contact between balls and races is still too high in a critical application, a further improvement can be obtained through the use of rotor insulation, since it breaks the electrical paths through the main ball bearings.

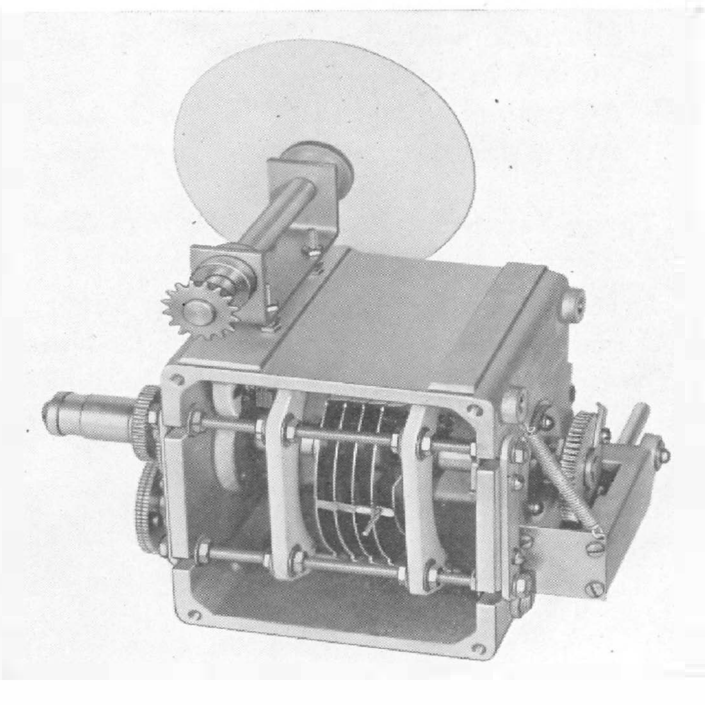

Figure 3. A special type of capacitor used in a precise heterodyne frequency meter. The cast aluminum frame provides both electrical shielding and mechanical stability.

7. Coaxial Connectors

For a large number of uses of three-terminal capacitors, replacement of the binding post terminals by coaxial connectors is indicated (see immediately above). While any type of standard coaxial connector can be supplied, use of our TYPE 874 Connectors is favored. Interconnections to other of our instruments (also using TYPE 874 Connectors) in measuring setups, for example, are easily made. Connections to almost any other type of coaxial system can readily be made with the adaptors available in the 874 line.

8. Shaped Plates

Curves other than the usual straight-line ones representing the relationship of capacitance to rotation can be had. While either rotor or stator plate can be shaped, it is usually the rotor that is so shaped for this purpose. 180° or 90° (approx.) stators are available for, respectively, 180° and 270° (approx.) rotations. Many types of curve can be produced, such as straight-line frequency of various frequency ratios, exponential frequency (giving a logarithmic dial distribution), or even arbitrary curves.

9. Residual Parameters

Nobody wants inductance and resistance in a capacitor but likewise no one seems to know how to eliminate them completely. The real problem is to reduce them as much as is practical. The residuals (L and R) in the TYPE 722-N Precision Capacitor (for use at radio

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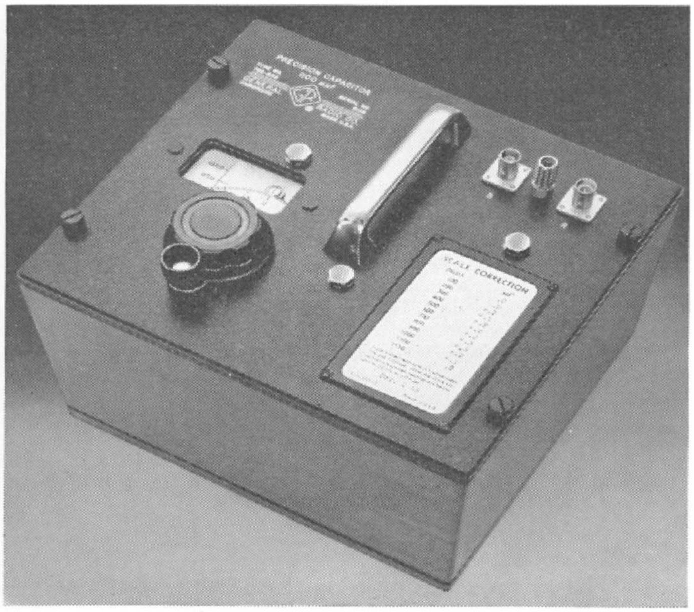

Figure 4. Panel view of a special Type 722 Precision Capacitor calibrated in direct capacitance. The coaxial terminals provide complete shielding for the leads.

frequencies) are about 2/5 of those of the large sections of other TYPE 722's. The small sections of dual capacitors have higher residuals. However, the residuals in the capacitor employed in the TYPE 821-A Twin-T are about 1/10 of those of the large sections of the usual TYPE 722, or about 1/4 of those of a TYPE 722-N. This capacitor construction, shown in Figure 2, is, although available, rather expensive, since it is not regularly made for separate sale.

10. Other Designs

Occasionally particular specialized features are desired. Designs of precision variable capacitors to accomplish these results are in existence.

Some have five-sided cast bathtub frames to secure more complete shielding and greater rigidity for extremely critical locations, such as frequency-measuring equipment.

Some are arranged for equal but opposite stators, having also equal and opposite rotors. These could be used in balanced circuits, such as balanced lines or a Colpitts oscillator. The disposition of the two rotors on opposite sides of the shaft is advantageous under conditions of shock or vibration.

11. Unmounted Models

Where precision variable capacitors are to be incorporated into a customer's equipment, they will be supplied unmounted or will be mounted to panels or cabinets supplied by him.

12. Special Mechanical Features

Many special or added mechanical features have been requested and supplied for the convenience of customers. A few of these are:

a. Extra length extensions from the worm shaft. These may be from one or from both ends of the shaft.

b. Clock spring loading for the worm drive instead of the usual type where a spring presses the worm into the throat of the worm wheel.

c. Special ball bearings designed to reduce still further the backlash (which can be detected only electrically with the capacitor in a sensitive electrical circuit).

d. Extra binding posts or other special types of external connections for particular customer applications.

One anomalous fact in connection with precision variable capacitors should be clearly understood by all who use them. This fact is a direct result of the state of the art of inductance and capacitance measurements as against resistance measurements. Resistance values can be given with certainty by the National Bureau of Standards to 20 parts in a million, or less, but certifications of capacitance values under the most favorable conditions are not so good by at least an order of magnitude.* Yet it is possible to measure and intercompare

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capacitors with existing bridge equipment many times closer than that.

There is then the somewhat unexpected situation in which internal consistency in capacitance readings can be obtained and repeated to several times the accuracy of the capacitance standards themselves. Worm correction charts are given to more than four significant figures, indicating the internal consistency which is obtainable. However, an overriding uncertainty of capacitance value of 0.05% to 0.1% must always be borne in mind and catalog specifications are so written.

—P. K. McElroy

*For a discussion of measurement procedure and the accuracy attainable, see NBS Circular 531, entitled "Extension and Dissemination of the Electrical and Magnetic Units by the National Bureau of Standards," obtainable from the Superintendent of Documents, U. S. Government Printing Office, Washington 25, D. C. Price 25 cents.

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To develop the type of product manufactured by the General Radio Company requires a large staff of engineers, each a specialist in one or more fields of engineering and science. One of the functions of this staff is to assist the customer in the selection of instruments in order that the correct equipment may be purchased with a minimum expenditure.

There has always been close contact between our engineering staff and our customers. The technical nature and the manifold uses of our product make the maintenance of this contact essential. For this reason, the General Radio Company maintains no sales agencies in the United States, but distributes its products directly to the user on a net-price basis. The Company maintains factory branch offices in several major cities of the United States which are staffed by skilled, factory-trained engineers.

Your correspondence is welcome, and may be directed to the main office at Cambridge or to the branch office nearest you. All inquiries receive individual and immediate attention.

Our terms, if you have an account with us, are net 30 days. If not, we will prepay shipping charges to any point in the continental United States, except Alaska, if payment accompanies the order. Otherwise shipment is C.O.D.

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