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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.

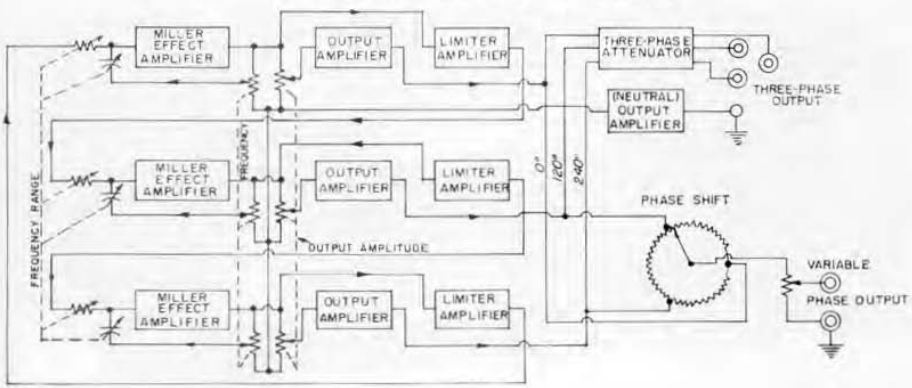
Oscillator build-up time, a phenomenon that usually goes unnoticed in oscillators operating at audio-frequencies and higher, can, at the frequencies in the range of the TYPE 1305-A, actually be measured in hours! For this reason, a rapid build-up switch is provided, to introduce a transient in excess 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.



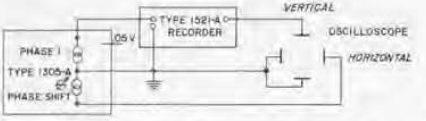


Figure 3. Arrangement of instruments for measuring closed- and open-loop phase gain characteristics.

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.

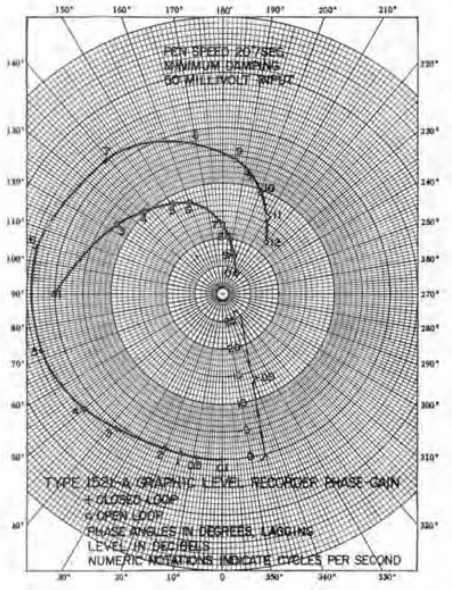
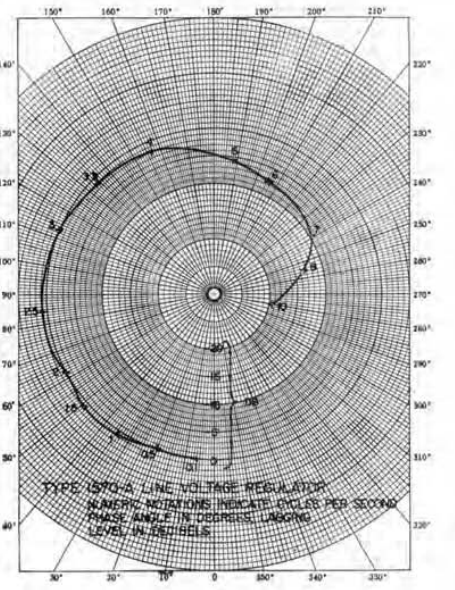


Figure 5. Closed-loop response of the Type 1570-A Automatic Voltage Regulator.



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: ±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 ±5%. Phase voltages are equal to each other within ±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, ±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, ±3°.

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

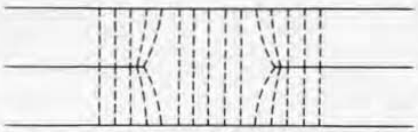


Figure 3. Sketch illustrating negative fringing.

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.

[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).

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.

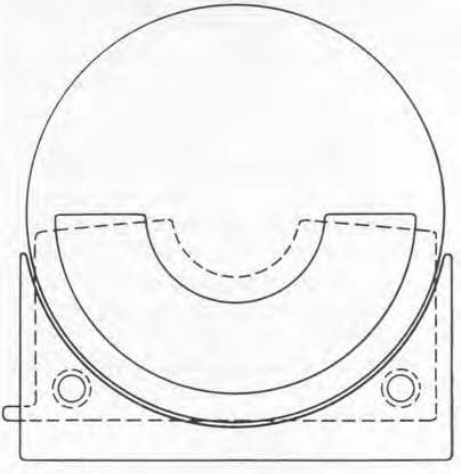
differ radically in design from the conventional rotor and stator structure of the TYPE 722-CB.

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.

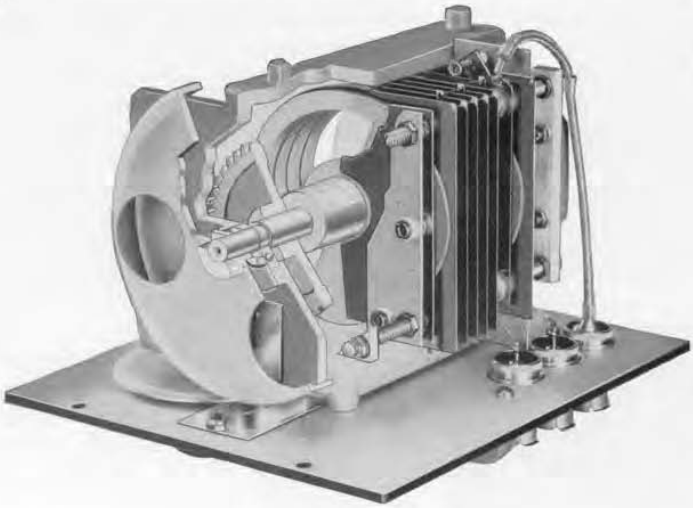


Figure 6. Interior view of the Type 722-CD Precision Capacitor.

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	±0.04 pf	0	75-100	90-110
	0.05 to 1.1	±0.008 pf		24-26	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	±0.02 pf	±0.04 pf
	0.05 to 1.1	±0.003 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	±0.1% or ±0.004 pf*	±0.1% or ±0.008 pf*
	0.05 to 1.1	±0.1% or ±0.001 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.

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