THE General Radio EXPERIMENTER

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ELECTRICAL MEASUREMENTS AND THEIR INDUSTRIAL APPLICATIONS

INCREASED ACCURACY FOR THE PRECISION CONDENSER

Also

IN THIS ISSUE

● **LAST MONTH'S ARTICLE*** on connection errors in capacitance measurement suggests the need of a corollary article on the accuracy of calibration of the precision capacitor itself. The rating of $\pm 1\,\mu\mu$f for all settings, while corresponding to 0.1% for 1000 $\mu\mu$f, has imposed a serious handicap on its use at low-scale settings. A recent evaluation of the sources of error and a survey of calibration records indicate that it is possible to increase materially the guaranteed accuracy of the precision condenser at settings below full scale.

The best accuracy to which calibrations can be guaranteed is 0.1%, which allows for twice as much error as the known accuracy of our standards. Our capacitance standards are evaluated in terms of measurements by the National Bureau of Standards, which are certified to 0.05%. These standards are periodically intercompared, and we have found that our measurements check those of the Bureau to about 0.02%.

*R. F. Field, "Connection Errors in Capacitance Measurement," *Experimenter*, XXI, 12, May, 1947

Figure 1. Calibrating precision capacitors in the General Radio Standardizing Laboratory.

Such factors as temperature and aging can be expected to change the day-to-day capacitance slightly over the normal guarantee period of one year, so that 0.1% is a fair figure for the accuracy of commercial standards like the TYPE 722 Precision Condenser.

This tolerance of 0.1% corresponds to 1 $\mu\mu$f at a scale reading of 1000 $\mu\mu$f. The capacitance of the instrument is continuously adjustable from 1100 $\mu\mu$f to 100 $\mu\mu$f. On the TYPE 722-D Precision Condenser a low-capacitance section is also included, covering a 100-to-25 $\mu\mu$f range.

METHODS OF ASSEMBLY AND ADJUSTMENT

The rotor plates, spaced by suitable disc spacers, are clamped rigidly on a central shaft, which is mounted on ball bearings and is turned by means of a worm and gear. The stator plates with their spacers are mounted on two threaded rods which, at their ends, are supported by two steatite bars. The assembling of these plates is done in a jig in order to get all plates as nearly parallel as possible to each other and perpendicular to the axis about which the rotor turns. At each end of the stator stack there is a plate which can be moved axially in order to adjust the capacitance change per turn of the worm shaft to the scale value, such as 50 $\mu\mu$f for a 1000 $\mu\mu$f capacitor. One of these plates has its central portion removed in order to increase the capacitance per turn at the ends of the useful range, where this rate of change of capacitance naturally decreases. The other plate, while standard in shape, is faced by a rotor plate having nonradial slots extending from its edge in toward the center. Slight bending of the individual sectors will compensate for small irregularities in the rate of change of capacitance.

In the adjustment of such a capacitor, the solid adjusting plate is set to make the capacitance change for two turns of the worm shaft 100 ± 0.5 $\mu\mu$f or better over the range from 100 to 1100 $\mu\mu$f, subject to the limitation that the cumulative error is also less than ± 0.5 $\mu\mu$f. Frequently the adjusting plate must be set off from parallelism to accomplish this. The sectors of the slotted rotor plate are then bent slightly to decrease

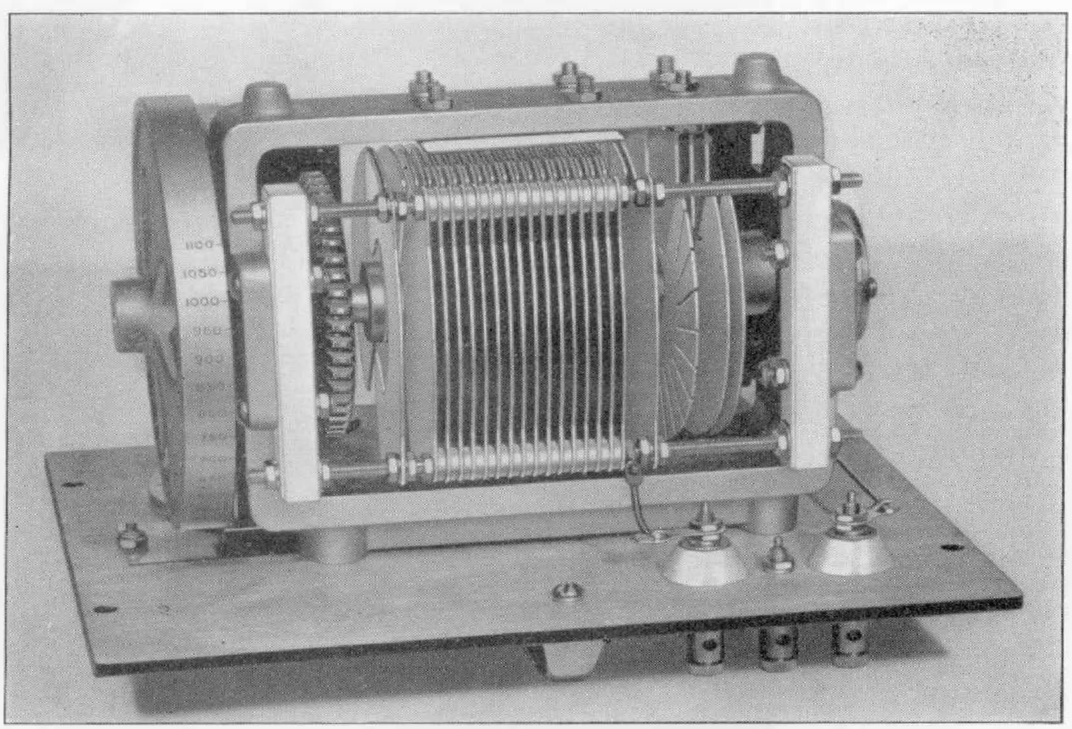


Figure 2. Interior view of a Type 722-D Precision Condenser. The slotted rotor plate for the LOW section can be seen near the right-hand end of the capacitor. The zero adjusting plate is mounted on the frame at the top.

Scale	μμf
100	−.7
200	−.5
300	−.5
400	−.1
500	+.4
600	+.7
700	+.7
800	+.8
900	+.7
1000	+.5
1100	.0

Figure 4. Correction data in this form are recorded on a card mounted on the panel of the capacitor.

the extreme variations which may occur at the ends of the range and sometimes in the center. A plot of capacitance change for every two turns of the worm shaft is shown in Figure 3.

The engraved drum and dial are mounted on their respective shafts in such positions, dictated by past experience, that the total capacitance is within a few micromicrofarads of their readings. The zero adjusting plate is then set so that the total capacitance is correctly indicated to ± 0.5 μμf. The capacitor is then baked in an oven overnight to reduce any strains set up by the adjusting process. If there are any changes greater than 0.25 μμf, the capacitor is readjusted and rebaked.

The numerical results of this last measurement of capacitance are recorded as the correction error in μμf in the form given in Figure 4. A plot of these corrections is shown in Figure 3. The maximum error of 0.75 μμf is equal to that allowed the testing laboratory, which in turn is three-fourths the catalog tolerance of ± 1 μμf. This particular capacitor, having the maximum allowable error, was chosen to illustrate the extremes which can occur.

ACCURACY OF CAPACITANCE READINGS

Since each complete worm turn changes the capacitance by 50 μμf, the intermediate multiples of 50 μμf will fall at the same worm positions as the 100-μμf multiples. Consequently, these points can be determined by direct interpolation to about the same accuracy as the

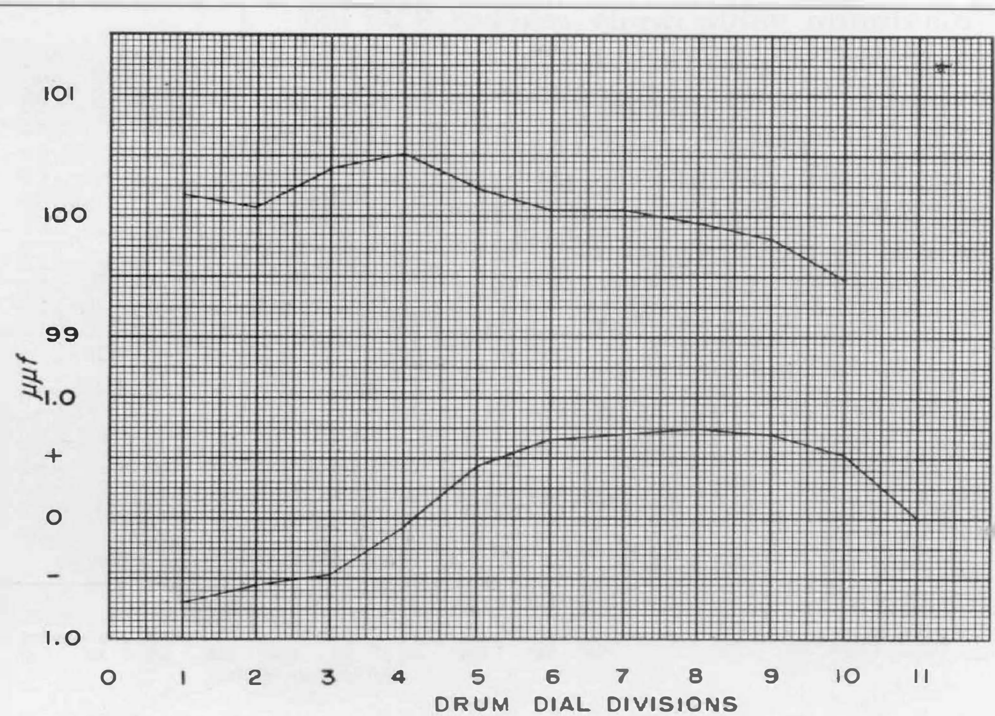


Figure 3. (Top curve) Actual change in capacitance per two worm turns for a Type 722 Precision Condenser. (Bottom curve) Cumulative error at nominal 100 μμf points. These data are recorded to the nearest tenth micromicrofarad, as shown in Figure 4, and are furnished with the capacitor for correcting the scale reading.

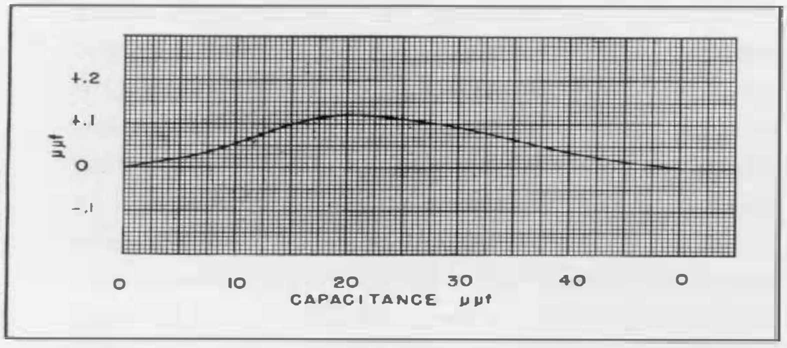


Figure 5. Worm correction for a typical Type 722 Precision Condenser.

100-μμf points. Capacitances at these points, when corrected, are accurate to ±0.1% or ±0.1 μμf, whichever is greater. Capacitance values other than multiples of 50 μμf obtained by interpolation between these corrected points cannot be as precisely determined, owing to the eccentricity of the worm.

Although the worm is cut directly on the worm shaft and considerable care is exercised in mounting the worm and gear both as to their bearings and the method of pressing the worm against the gear, a small degree of eccentricity remains. This appears as an approximately sinusoidal variation in capacitance about the average value. Its maximum value rarely reaches 0.25 μμf and controls are set up to see that this value is not exceeded. A typical worm correction curve is given in Figure 5. The particular point on the sinusoid at which the zero reading of the dial appears is entirely fortuitous. It just happens that in Figure 5 the entire correction is positive, thus giving the largest possible correction for this amount of eccentricity.

CORRECTION CHARTS

In the future, a table of corrections measured to the nearest tenth micromicrofarad will be supplied on the panel of each General Radio precision capacitor. These include not only the Type 722 series, but also bridges such as the Type 716-C Capacitance Bridge and the Type 821-A Twin-T, in which precision capacitors are used.

The rated accuracy of capacitance can be considerably increased if these correction data are used. The new specification for Type 722-D Precision Condenser (high section) will be ±0.4 μμf or 0.1%, whichever is the larger, for capacitances as indicated by the scale, and 0.5 μμf or 0.1% for capacitance differences, such as are used in substitution measurements.

The errors that make up the total are computed as follows:

Worm correction	0.25 μμf
Precision of correction	0.05 μμf
Standard tolerance	0.1 μμf
	0.4 μμf

The second item of 0.05 μμf arises from the fact that the correction is given to the nearest tenth micromicrofarad, which may differ by 0.05 μμf from the true value.

The third entry of 0.1 μμf is the stand-

Scale	0	10	20	30	40
100	-.70	-.68	-.57	-.49	-.63
150	-.65	-.57	-.41	-.33	-.48
200	-.54	-.51	-.38	-.33	-.51
250	-.57	-.52	-.40	-.32	-.43
300	-.46	-.36	-.18	-.07	-.16
350	-.21	-.16	-.01	+.10	-.05
400	-.07	+.01	+.17	+.32	+.22
450	+.24	+.35	+.52	+.61	+.50
500	+.44	+.48	+.59	+.69	+.54
550	+.52	+.59	+.73	+.85	+.69
600	+.66	+.73	+.83	+.92	+.76
650	+.67	+.71	+.83	+.91	+.76
700	+.70	+.73	+.87	+.95	+.77
750	+.72	+.78	+.90	+.99	+.81
800	+.75	+.78	+.88	+.95	+.80
850	+.75	+.82	+.93	+.97	+.79
900	+.70	+.73	+.84	+.92	+.73
950	+.65	+.66	+.76	+.80	+.61
1000	+.52	+.52	+.61	+.61	+.44
1050	+.32	+.28	+.33	+.35	+.11
1100	.00				

Figure 6. Worm correction data as furnished when a complete worm correction calibration is ordered.

ard laboratory tolerance. The accuracy of laboratory adjustment is three-fourths of the catalog specification. Hence with a 0.3-$\mu\mu$f laboratory error, the catalog value is 0.4 $\mu\mu$f.

For capacitance differences, one additional setting is involved, with its associated possible error of 0.05 $\mu\mu$f. To the nearest tenth, therefore, the accuracy can be specified as $\pm$0.5 $\mu\mu$f. At the 100-$\mu\mu$f divisions, and also at the 50-$\mu\mu$f divisions by linear interpolation, capacitance differences can be determined with an error of $\pm$0.2 $\mu\mu$f. For differences of less than 25 $\mu\mu$f the error decreases linearly from $\pm$0.5 $\mu\mu$f to $\pm$0.1 $\mu\mu$f.

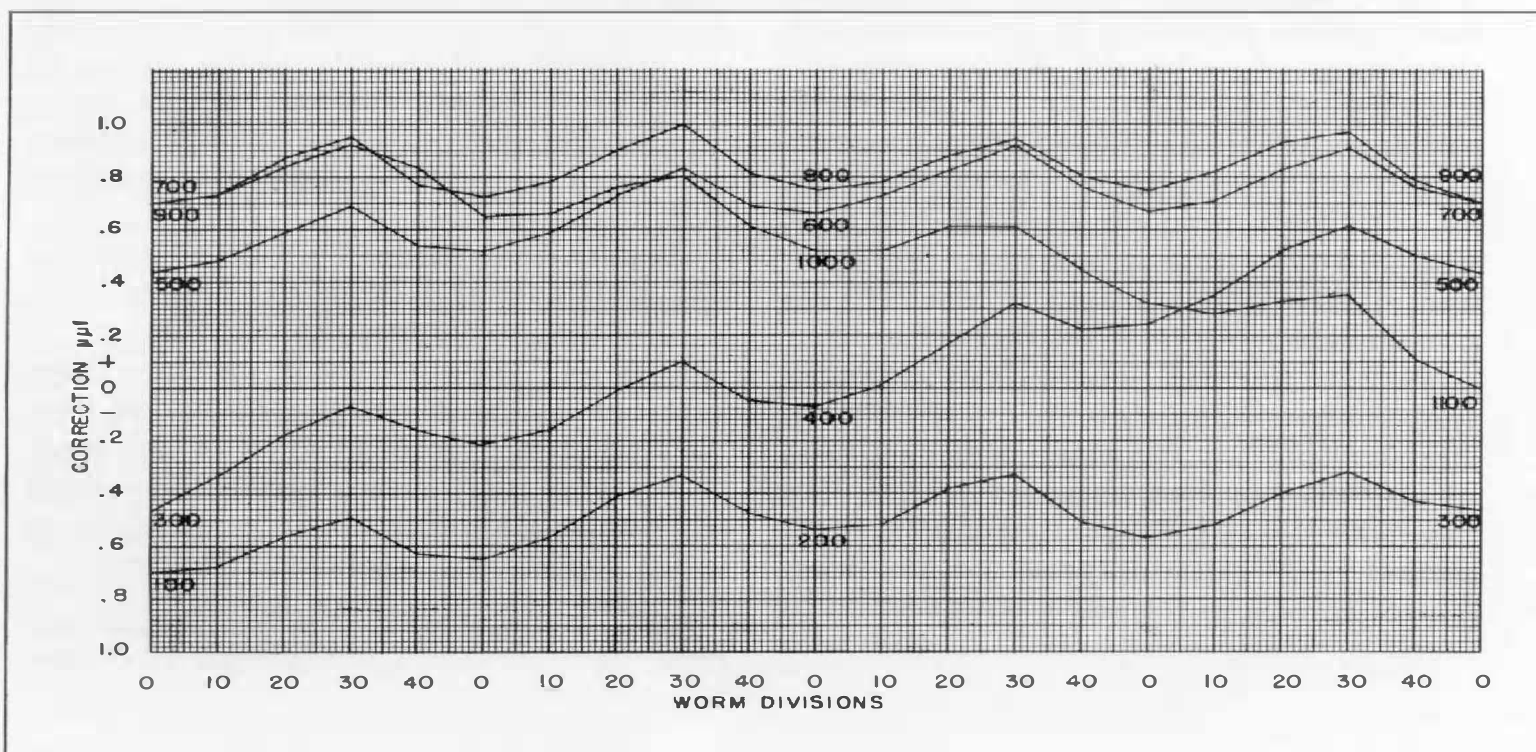
For the low section of the Type 722-D Precision Condenser (25 to 100 $\mu\mu$f), the correction is given to $\pm$0.01 $\mu\mu$f. As a general principle, fractional errors cannot be reduced in proportion to the size of the main quantity, and consequently the specification for this section is $\pm$0.1 $\mu\mu$f or 0.1% for both direct reading and differences. The slight increase of the direct-reading error to $\pm$0.1 $\mu\mu$f is caused by connection errors.

As mentioned earlier, the best accuracy to which capacitance can be guaranteed is 0.1%. Consequently, if the error as specified in micromicrofarads is less than 0.1%, the specification of 0.1% governs. If the correction data are not used, the accuracy of the capacitor is $\pm$1 $\mu\mu$f for direct-reading values and $\pm$ 2$\mu\mu$f for differences.

COMPLETE WORM CORRECTION

For those who need the greatest possible accuracy, a complete worm correction extending over the entire range of the capacitor is available. The chart takes the form shown in Figure 6. The data given are for the same capacitor as was referred to in Figures 3 and 4. Its worm correction has the maximum allowable value of 0.25 $\mu\mu$f, so that the maximum correction is almost 1 $\mu\mu$f. Since the corrections are given to 0.01 $\mu\mu$f, direct-reading capacitances can be easily corrected to $\pm$0.1 $\mu\mu$f or $\pm$0.1% and differences to $\pm$0.2 $\mu\mu$f or $\pm$0.1%. These data are plotted in Figure 7.

Figure 7. Complete correction curve as plotted from the data of Figure 6.



When a large number of observations must be reduced, it is sometimes easier to read the correction from a graph than from a chart.

SUMMARY

Tabulated below are the accuracy ratings of the several General Radio precision capacitors mentioned in this article.

	Direct Reading		After Correction		
Type No.	*Capacitance*	*Capacitance Differences*	*100 $\mu\mu f$ (and 50 $\mu\mu f$) Multiples*	*Interpolated Points*	*Differences*
722-D High Section	$\pm 1\ \mu\mu f$	$\pm 2\ \mu\mu f$	$\pm 0.1\ \mu\mu f$	$\pm 0.4\ \mu\mu f$	$0.5\ \mu\mu f$*
722-D Low Section	$\pm 0.2\ \mu\mu f$	$\pm 0.4\ \mu\mu f$		$\pm 0.1\ \mu\mu f$	$0.1\ \mu\mu f$
722-N	$\pm 1\ \mu\mu f$	$\pm 2\ \mu\mu f$	$\pm 0.1\ \mu\mu f$	$\pm 0.4\ \mu\mu f$	$\pm 0.5\ \mu\mu f$*
722-M		$\pm 1\ \mu\mu f$	$\pm 0.1\ \mu\mu f$		$\pm 0.4\ \mu\mu f$*
716-C	$\pm 2\ \mu\mu f \times$ Multiplier	$\pm 2\ \mu\mu f$			$\pm 0.5\ \mu\mu f$*
821-A		$\pm(0.1\% + 2\ \mu\mu f)$			$\pm(0.1\% + 0.5\ \mu\mu f)$*

*For capacitances less than 25 $\mu\mu f$, the error decreases linearly to $\pm 0.1\ \mu\mu f$.

— R. F. Field

TWO YEARS OF RECONVERSION

The road of reconversion for American industry has proved to be far less smooth than most of us hoped. Unforeseen obstacles have been frequent, particularly shortages of materials and parts, necessitating the use of circuitous detours, and, as with any road so heavily traveled, traffic jams were inevitable. One by one, however, the travelers are arriving at their goal—full peacetime production.

We at General Radio had expected that our own reconversion would be simpler than most. Since the nature of our production had changed little during the war except for the quantities required, we were able to avoid the problem of complete retooling that had to be faced by many companies. At the same time it was not possible to foresee to the necessary degree the stringent shortages of material and rapidly rising prices of parts and labor. These factors have necessarily slowed the process of getting redesigns and new designs into production.

Just two years ago*, we listed some of the new General Radio products that peacetime conditions would bring. A review of the succeeding twenty-three numbers of the *Experimenter* shows that we have not fallen far short of our goal. Seventeen new instruments have been announced, as well as three redesigns of older types. A complete list follows.

*"Development Engineering at the General Radio Company," *Experimenter*, XX, 1, June, 1945.

Frequency Measuring Instruments

TYPE 720-A Heterodyne Frequency Meter July–August, 1945
TYPE 816-A Vacuum-Tube Precision Fork September, 1945
TYPE 1140-A U-H-F Wavemeter........ October, 1945
TYPE 1176-A Frequency Meter......... February, 1946
TYPE 1181-A Frequency Deviation Monitor November, 1946
TYPE 1175-A Frequency Monitor........ February, 1947
TYPE 724-B Precision Wavemeter....... March, 1947

Impedance Measuring Equipment

TYPE 1614-A Capacitance Bridge....... February, 1946
TYPE 1631-A Inductance Bridge........ February, 1946
TYPE 716-C Capacitance Bridge......... April, 1947
TYPE 1231-A Amplifier and Null Detector. March, 1946

Meters

TYPE 1800-A Vacuum-Tube Voltmeter..... September, 1946
TYPE 1802-A Crystal Galvanometer...... October, 1946
TYPE 1861-A Megohmmeter............ November-December, 1946

Miscellaneous

TYPE V-5 Variac..............May, 1946
TYPE V-10 Variac.......July-August, 1946
TYPE 1530-A Microflash.....October, 1945
TYPE 762-B Vibration Analyzer......... November-December, 1945
TYPE 1931-A Modulation Monitor....... November, 1946
TYPE 1261-A Power Supply............ March, 1946
TYPE 1260-A Variac Rectifier.......... March, 1946

Other new instruments are about to go into production and others are now under development. These will first be announced in these pages.

NEW PRICE SCHEDULE

Included in the last mailing of the *Experimenter* was a new price list, which became effective on June 9, 1947. This price list supersedes all previous price lists, which should be destroyed to avoid confusion or error in ordering. In accordance with long-established policy, all prices shown in our price schedules are net, f.o.b. the factory in Cambridge, Massachusetts. If you can use additional copies of the list, we shall be glad to supply them.

The costs of manufacturing in our industry, and most others for that matter, have risen greatly since the war. We have always tried to maintain a fixed price schedule, but it has been impossible to do this during the past two years. Although the costs of manufacturing, that is, the prices of raw materials, components, wages and salaries, still continue to climb, we feel that the time is here to attempt to stabilize prices again. During the recent era of rapidly rising costs, the custom of quoting prices effective as of the date of shipment became quite general. We have always been opposed to this open price system and we still have sufficient confidence in the stability of the nation's economy to guarantee all formally quoted prices for six months. Although no change in prices is indicated in the near future, there are so many factors beyond our control that currently it does not seem practical to quote firm prices for periods longer than six months. Any customer who has placed an order where the delivery is over six months has the option of cancelling that order if any price increase is made on it.

We are glad to say at this time that the delivery situation is continually improving. Although many items are now available from stock, the delivery time required for some others is a great deal longer than we like to see it. Each month shows a general improvement in deliveries, and we look forward to the time when we can resume deliveries of almost everything from stock.

MISCELLANY

HONORS—Conferred upon Harold B. Richmond, Chairman of the Board of the General Radio Company, the honorary degree of Doctor of Engineering, at the 128th Commencement of Norwich University, for his pioneer radio service, his work on guided missiles in World War II, and his interest in engineering education. A graduate of the Massachusetts Institute of Technology, Class of 1914, Mr. Richmond has served for eleven years as a member of the Corporation of M.I.T. and is trustee of Northeastern and Norwich Universities. He has been President of the Radio Manufacturers' Association, and was recently elected Board Chairman of the Scientific Apparatus Makers of America. Joining the General Radio organization in 1919, he became Secretary in 1921, Assistant Treasurer in 1924, Treasurer in 1926, and Chairman of the Board in 1944. Mr. Richmond is a Fellow of the Institute of Radio Engineers and of the American Institute of Electrical Engineers.

TECHNICAL PAPERS — "U-H-F Measurements," by William R. Thurston of the development engineering staff, before local I.R.E. sections, at Ottawa, April 3; Toronto, April 7; London, April 8; and Montreal, April 9.

"A Very-High-Frequency Bridge for Impedance Measurements at Frequencies Between 20 and 140 Megacycles," by Robert A. Soderman of the development engineering staff, at the New England Radio Engineering Meeting, Cambridge, May 17.

VISITORS to our plant and laboratories — D. Putnam, Marconi Instruments, Ltd., St. Albans, England; C. M. Benham, Managing Director, Painton and Company, Northampton, England; A. Bergqvist and Major K. B. Genberg, Swedish Army Ordnance Department, Stockholm.

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