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ELECTRICAL MEASUREMENTS AND THEIR INDUSTRIAL APPLICATIONS®

A NEW COMPARISON BRIDGE FOR THE RAPID TESTING OF COMPONENTS

Also

IN THIS ISSUE

● **THE TREND** toward complexity and more exacting specifications in electronic equipment has been accompanied by a tremendous increase in the quantities produced, and, as a result, more and more precise components — resistors, capacitors, and inductors — are being used. In general, it is necessary to measure these components before assembly, and this measurement, particularly for 1 per cent or 0.25 per cent components, is usually made on a "laboratory-type" bridge. As the number of components to be measured increases, the need grows for an accurate and simple, general-purpose bridge for production testing, and, to fill this need, the TYPE 1604-A Comparison Bridge, shown in Figure 1, has been developed.

In making the most precise bridge measurements, a substitution method is used. In one form of the general method, the bridge is "standardized" with a known standard impedance that has nearly the same value as the unknown to be measured. In this case, the bridge is used primarily to

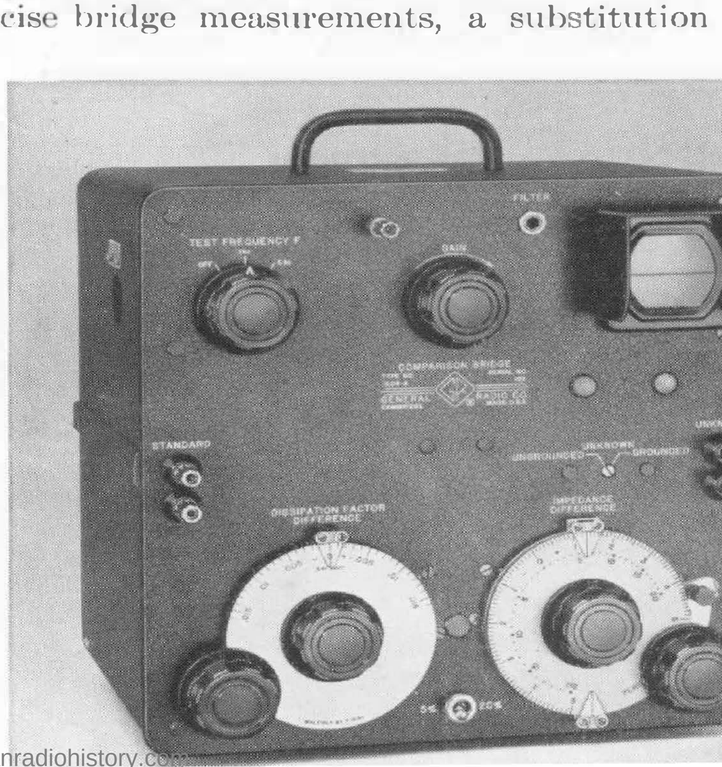


Figure 1. Panel view of the Type 1604-A Comparison Bridge.

measure the small difference between the standard and the unknown, and the effect of the bridge errors approaches zero as the difference between the standard and unknown approaches zero. The TYPE 1604-A Comparison Bridge is standardized in our calibrating laboratory at a 1000-ohm impedance level, and the true bridge zero is hand calibrated. At this point the bridge errors are effectively zero. By restricting the impedance difference range to ±5 per cent or ±20 per cent, bridge errors stay small and we obtain "laboratory accuracy" on a "production-type" bridge. This bridge is sufficiently accurate so that this standardization at 1000 ohms will hold good from a few ohms to a few megohms. However, the standardization can be checked at any time by simply interchanging the standard and unknown and noting that the bridge reading reverses.

The TYPE 1604-A Comparison Bridge is completely self-contained, consisting of a cathode-ray tube visual detector, bridge, and an oscillator which operates at 1 kc or 5 kc. It can be used to measure both impedance difference, ΔZ, and dissipation-factor difference, ΔD (or storage-factor difference, ΔQ), for resistors, capacitors, and inductors. By providing a ΔD or ΔQ balance as well as a ΔZ balance, a thorough check of components can be made. For example, if capacitors are being checked, not only will those that are outside capacitance limits be rejected, but also those with abnormal dissipation factors.

Ease of operation has been stressed, so that measurements can be made rapidly. Two dials, conveniently located, are rotated to balance the bridge, or, for more rapid operation, the dials can be used to calibrate the cathode-ray tube, which then indicates the unbalance instantly. At balance, the dials indicate directly the D or Q difference and the impedance difference between the standard and unknown, expressed as a percentage of the standard impedance. Ordinarily, the bridge is used to check components from current production or purchase lots against a similar component independently measured and used as a standard. However, if a laboratory standard is used, rather than a sample component, the instrument becomes a precision laboratory comparison bridge.

This bridge can be used for the direct comparison of components over a very wide impedance range, from approximately 2Ω to 20 Meg Ω. The basic accuracy of the bridge is ±0.1 per cent, decreasing somewhat at the extremes of its impedance range. Two impedance-difference ranges are provided: one, 0 to ±5 per cent for accurate comparison of components close to each other in value; the other, 0 to ±20 per cent, of somewhat lesser accuracy, for checking to the common tolerances of ±10 per cent and ±20 per cent. The impedance-difference dial is shown in Figure 2.

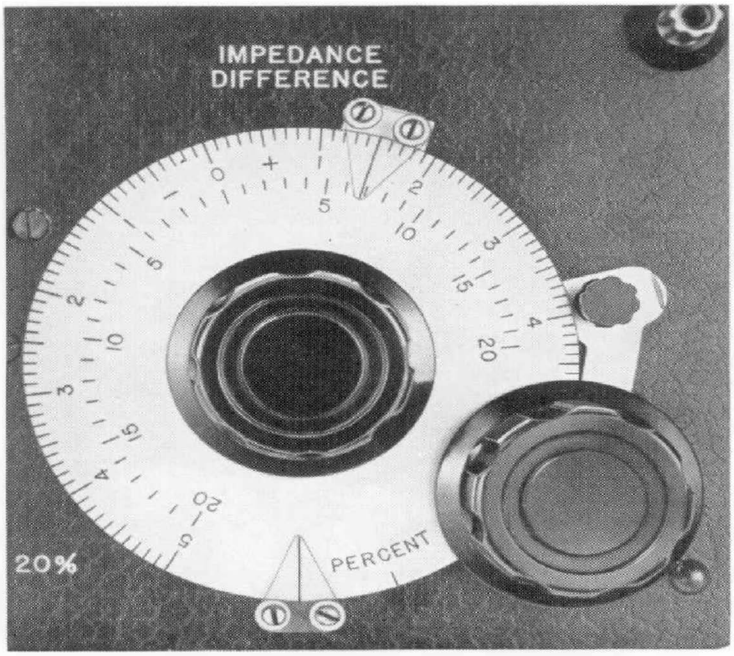


Figure 2. Close-up of the impedance-difference dial.

CIRCUIT

A simplified schematic diagram of the bridge is shown in Figure 3. A precision linear potentiometer in the ratio arms is used to provide a ±20 per cent impedance-difference range. This potentiometer is shunted to provide a ±5 per cent range for more precise comparisons. A differential capacitor across the ratio arms provides the dissipation-factor balance. The point at which the bridge is grounded can be switched, so that measurements can be made with the unknown either grounded or ungrounded.

The detector is a three-stage, high-gain, non-linear amplifier. The highly non-linear amplifier permits the bridge to be balanced without continual resetting of the gain control. Balance is indicated on a cathode-ray tube. The detector time constant has been made less than 100 microseconds, so that, for practical purposes, the error voltage appears instantly.

The oscillator is a conventional R-C phase-shift oscillator which is coupled to the bridge through a shielded bridge transformer and a cathode follower. The cathode follower eliminates any reaction of the bridge back on the oscillator, while the special transformer shielding prevents any unbalanced voltages from the oscillator from affecting the bridge balance. A differential capacitor is used to balance the capacitance from the transformer shield to the ends of the shielded winding.

RANGE OF MEASUREMENT

The upper and lower limits of impedance measurement with this type of bridge are determined by three main factors: residual impedances, pickup from stray fields, and sensitivity.

At high impedances these limiting conditions are:

1. Parallel capacitance and resistance across the measuring terminals of the bridge.
2. Electrostatic pickup because of the high impedance level.
3. Decreased sensitivity because of the load of the detector on the bridge.

In the Type 1604-A Comparison Bridge, the input impedance of the detector is high, and sufficient sensitivity is provided so that detector loading does not limit performance. Thorough shielding within the bridge effectively eliminates errors from electrostatic pickup. However, in strong electrostatic fields, pickup external to the bridge is possible. Generally, this external pickup will be at 60~ and can easily be eliminated by inserting a filter, such as the Type 1231-P5 Adjustable Filter, at the filter jack on the panel. Parallel resistance across the measuring terminals is extremely high and is completely negligible. Shunt capacitance, however, does limit the high impedance range. When the unknown is grounded, the shunt capacitance, C_s, includes the capacitance of some shielding within the bridge and is approximately 40 $\mu\mu$f. With the unknown ungrounded, however, the shield capacitance is placed across the bridge ratio arms and C_s is less than 1$\mu\mu$f. Since the bridge measures the parallel com-

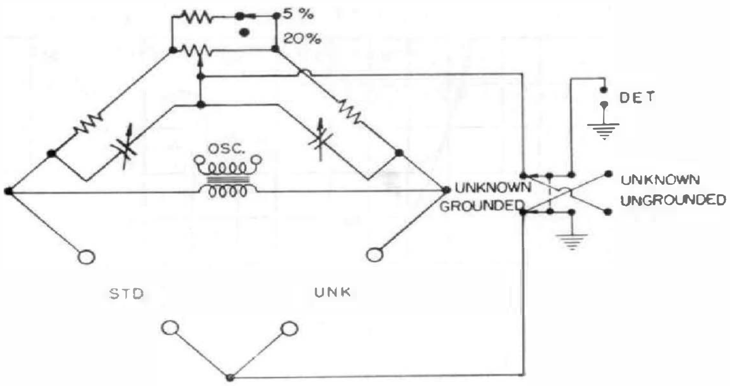


Figure 3. Elementary circuit of the bridge.

bination of the impedance to be measured and the stray capacitance across the measuring terminals, this extremely low value of shunt capacitance is necessary for high impedance measurements. An analysis of the bridge balance equations shows that the error at high impedance is:

For capacitance $1+\frac{C_s}{C_x}$ (See Figure 4.)
For inductance $1-\omega^2 L_x C_s$ (See Fig. 5.)
For resistance $1+\omega^2 {R_n}^2 {C_s}^2$ (See Fig. 6.)

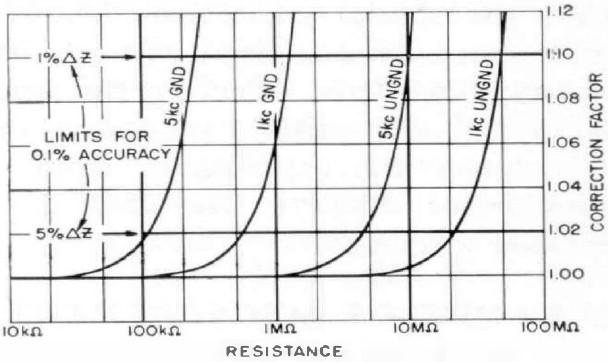
For a maximum error of 0.1 per cent on the 5 per cent range, these expressions must equal $1\pm.02$ since $(1\pm.02)\times 5$ per cent $= (5.0\pm0.1)$ per cent. This corresponds to a high impedance limit of 50 $\mu\mu$f, 500h, 20 Meg Ω at 1 kc.

At low impedances the range is limited by

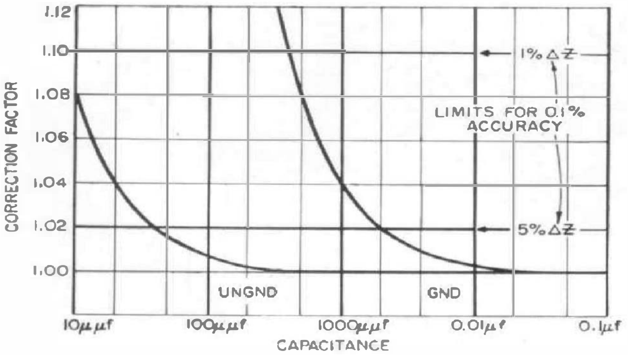
1. Series inductance and resistance in the standard and unknown bridge arms.
2. Electromagnetic pickup because of the high currents at low impedance.
3. Decreased sensitivity because of the load of the bridge on the oscillator.

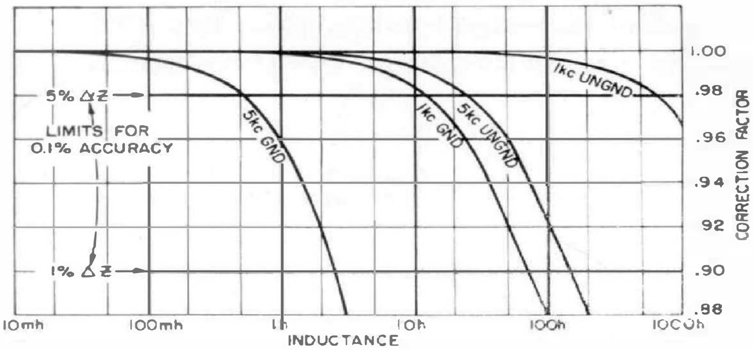
To maintain constant sensitivity, the voltage across the bridge must be held constant as the impedance level decreases. This requires supplying more power to the bridge. Since this power is limited, the low impedance range is limited. Sufficient sensitivity to balance the bridge to within 0.1 per cent can be maintained to an impedance level of about 2 ohms. At this low impedance level, large currents (about ½ ampere) flow through the bridge arms. The resultant electromagnetic pickup between bridge elements causes an error in the bridge balance. This error has been kept small by careful placement of leads. Series inductance and resistance has been kept small by using heavy bus-bar wiring in the bridge arms. The effect of this series impedance is further reduced by keeping the bridge wiring as symmetrical as practicable. The low impedance limit of the bridge is shown in Figures 7, 8, and 9. For a maximum error of 0.1 per cent on the 5 per cent range, the bridge may be used to 2 Ω, 0.5 mh, 30 μf at 1 kc.

The impedance difference and dissipation-factor-difference ranges are limited by the effect of cross-coupling terms in the bridge balance equations. As the impedance difference increases, it causes an error in the measured dissipation-factor difference. Similarly, as the dissipation-factor difference increases, it causes an error in the measured impedance difference. Because of these cross-



(Below) Figure 4, (below right) Figure 5, (right) Figure 6.





coupling terms, we have limited the dissipation-factor-difference range to ±0.02 where the maximum error in the impedance-difference measurement becomes 0.1 per cent. Instead of limiting the impedance-difference range to about 2 per cent, we have accepted a slightly larger error in the dissipation-factor-difference measurement.

USES

Because the bridge is calibrated in per-cent deviation, the job of sorting components to a given tolerance is greatly simplified. The high accuracy of the measurement, plus the fact that $\triangle D$ or $\triangle Q$ as well as $\triangle Z$ is measured, insures an accurate production check of components.

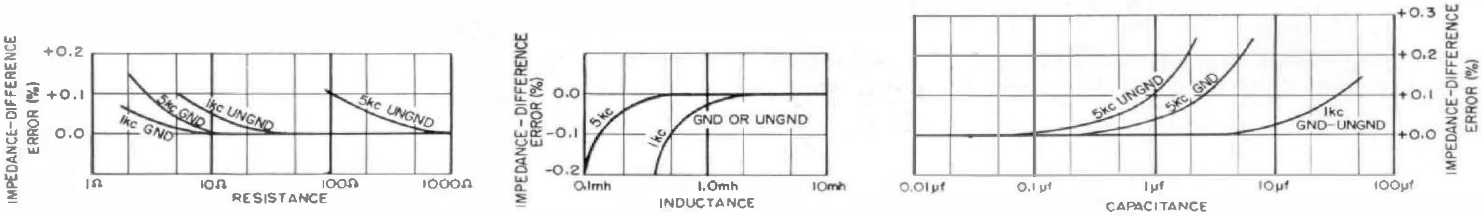
The Type 1604-A Comparison Bridge can be used in either of two ways. First, an unknown can be compared against a suitable standard by rotation of the balance dials of the bridge until the cathode-ray tube indicator shows a balance. The difference between the standard and unknown is then read from these dials directly. Second, the cathode-ray tube can be calibrated at the desired sorting tolerance and used to give an instantaneous "go, no-go" indication. The first method provides better accuracy, while the second permits really high-speed sorting.

For production testing, the standard need not be a precision laboratory standard, but can be a component, similar to those being checked, which has been independently measured. A standard precisely at the desired value is not necessary, since an offset zero is provided within the bridge. Thus if ±2 per cent resistors are being sorted and the available standard is off ±1.3 per cent, the bridge zero can be offset exactly 1.3 per cent and the resistors checked as if a perfect standard were available.

To select or to check matched pairs of components, no standard is necessary. The pair are simply connected to the standard and unknown terminals, the difference between the components being indicated directly by the bridge.

The Type 1604-A Comparison Bridge is ideal for measuring center-tapped windings to be sure that the tap is correctly centered. Similarly, two windings on the same core can be compared for unity turns ratio. In these cases the measurement is made with identical currents through the two windings.

An example of a production problem at the General Radio Company shows the type of application for which the Type 1604-A Comparison Bridge has realized large economies in test time. A large air-core inductor, accurate to 0.25 per cent, is used in the frequency-discriminator section of one of our frequency monitors. Variations in wire from spool to spool, winding tension, and other variables make it impossible to hold the inductance to a 0.25 per cent tolerance by simply counting turns as the coil is wound. As a result, these coils are wound with a few per cent more inductance than necessary and then "peeled down." The coils were formerly measured on a Type 667 Inductance Bridge to within 0.1 per cent, turns removed, and the measurement repeated. This process would then be repeated as many times as necessary to bring the coil within limits. The operation was



(Left) Figure 7, (center) Figure 8, (right) Figure 9.

time-consuming with a precision laboratory bridge. The job has now been speeded up considerably by a direct comparison with a standard coil. The coil to be adjusted is placed on a turntable which makes contact to one end of the winding. This contact is brought through a slip ring to the grounded unknown terminal on the TYPE 1604-A Comparison Bridge. The other end of the winding is connected directly to the bridge. The bridge instantly indicates that the coil is outside limits. Turns are now removed while the coil is still connected to the bridge. As each turn is removed, the cathode-ray tube instantly indicates the approach to balance. When the balance condition is reached, the wire from the coil is cut and soldered to its terminal. In this way the coils are easily and quickly made identical within 0.1 per cent.

The comparison bridge has also proved very helpful in the measurement of very small capacitors. In this application the bridge is not used to compare two small capacitors, but actually measures one capacitor directly. We had several lots of 1, 2, and 3 $\mu\mu$f condensers to be checked. These were quickly checked by placing 100 $\mu\mu$f capacitors at the standard and unknown terminals of the bridge and setting the offset zero so that the bridge indicates zero. By placing the small capacitors to be measured in parallel with the 100 $\mu\mu$f capacitor at the unknown terminals, the small capacitor can be measured by re-balancing the bridge. The ±5 per cent ΔZ scale now reads ±5 per cent of 100 $\mu\mu$f or ±5 $\mu\mu$f full scale. Each division of the scale (see Figure 2) represents 0.1 $\mu\mu$f. By suitable choice of the shunting capacitor, the full-scale reading can be made any value. At ±1 $\mu\mu$f or less, full scale, stray capacitances become very important and must be considered if accurate measurements are to be made.

The comparison bridge is ideal for checking ganged potentiometers that must track each other within a given tolerance. A point-by-point measurement of a pair of non-linear potentiometers on a laboratory bridge can be very time-consuming and costly. By calibrating the cathode-ray tube at the desired tolerance and connecting the potentiometers to be checked to the standard and unknown terminals of the bridge, the potentiometers can be checked in a second or two by simply rotating them through their range while watching the cathode-ray tube. Failure to track within the specified limits at any point is instantly indicated.

Similarly, ganged condensers for oscillators or filters can be checked in a small fraction of the time required by a point-by-point measurement. Furthermore, the condensers are not checked at a few discrete points but continuously over their whole range.

These are but a few of the possible applications for which the TYPE 1604-A Comparison Bridge can be used, but they serve to illustrate its versatility. It combines ease of operation with sufficient accuracy for component testing in nearly all production jobs.

— M. C. HOLTJE

SPECIFICATIONS

Deviation Range: For impedance, ±5% and ±20%, selected by a panel switch. For dissipation factor, ±.015 at 1 kc, ±.075 at 5 kc.

Impedance Range and Accuracy: Impedances between 2 Ω and 20 MΩ can be compared. For the 5% deviation range the basic accuracy is ±0.1%, but at extreme values of impedance the accuracy is somewhat poorer. The range for resistors, capacitors, and inductors for which the ±0.1% accuracy applies is given in the table:

	R	C	L
1 kc	2 Ω – 20 MΩ	30 μf – 50 μμf	500 μh – 250 h
5 kc	4 Ω – 2 MΩ	2 μf – 50 μμf	200 μh – 10 h

These ranges apply when comparing components whose dissipation factor differences do not exceed .02. On the 20% deviation range the accuracy is 0.5% over the same impedance ranges.

Dissipation Factor Accuracy: The accuracy of measurement of differences of dissipation factor at 1 kc is ±(.0005+2% of the impedance difference), and at 5 kc, ±(.0025+2% of the impedance difference).

Frequency: Frequencies of 1 kc and 5 kc are provided, selected by panel switch. The frequency is within ±3% of the nominal value.

Grounding: Two ground positions are provided, one of which grounds the junction of the standard and unknown impedances. With this connection the total impedances between the high terminals and ground are compared. In the other connection the junction of the ratio arms of the bridge is grounded, leaving both terminals of the standard and unknown ungrounded. With this connection the direct impedance between terminals of a component is measured, and terminal impedances to ground, within certain limits, will not affect the bridge balance.

Voltage Applied to Unknown: Approximately one volt, for impedances above 500Ω. For lower values of impedance the voltage is decreased, corresponding to a source impedance of the order of 100 Ω.

Zero Adjustment: An adjustable index mark is provided with locking means so that the zero can be offset to correspond to the deviation of the standard component from the desired nominal value.

Accessories Supplied: Line-Connector cord.

Accessories Required: For general purpose, use adjustable calibrated standards such as the TYPE 1432 Decade Resistors, TYPE 219 Decade Capacitors, and TYPE 1490 Decade Inductors. Fixed standards such as the TYPE 509 Standard Capacitors, TYPE 1481 Inductors, and TYPE 500 Resistors may also be used whenever appropriate values are available.

For production tests, the standard is often a component of the type to be tested, that has been measured independently or otherwise selected.

Mounting: Welded aluminum cabinet.

Dimensions: (Width) 12 inches, (height) 14¼ inches, (depth) 10 inches.

Net Weight: 22½ pounds.

Type		*Code Word*	*Price*
1604-A	**Comparison Bridge**	FATTY	**$335.00**

Licensed under patents of the Radio Corporation of America.

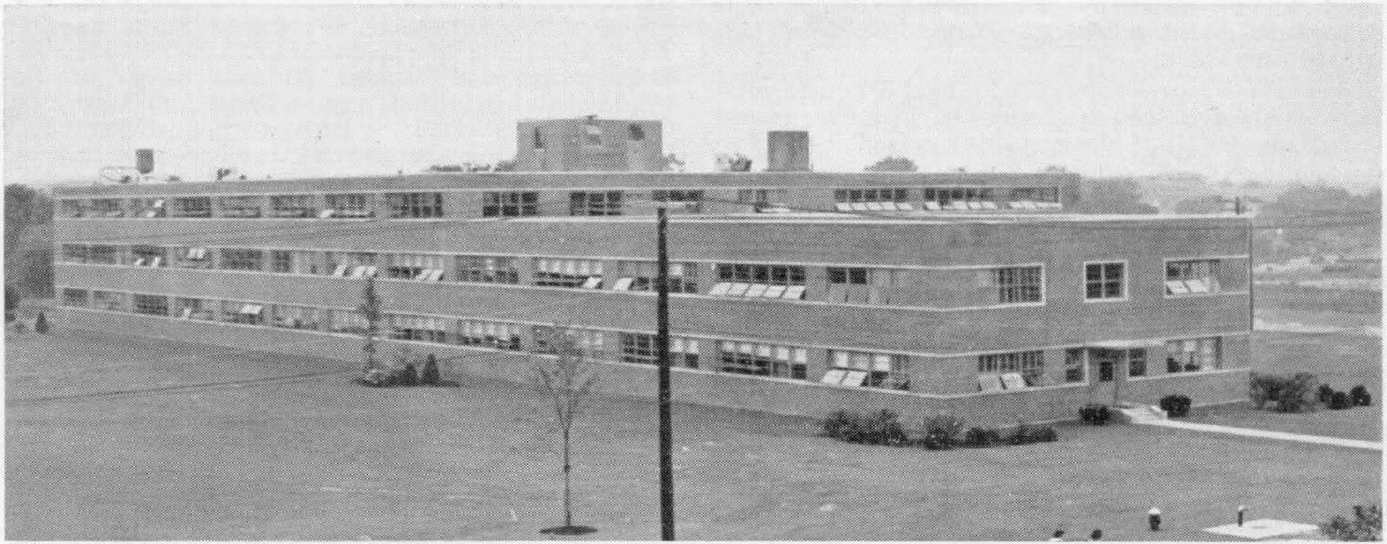
NEW BRANCH PLANT

Recognizing that the demands of another emergency could not be met by the then-available facilities, the General Radio Company, in 1948, began to explore the possibilities for expansion. Any further major expansion was, for many reasons, all but impossible at the present location in Cambridge. After a careful search, accompanied by an analysis of the residence locations of its employees, availability of suitable local manpower pools, accessibility, including nearness to highway and railway facilities, a building site was chosen in a country district in West Concord, Massachusetts, some eighteen miles west of Cambridge. About eighty acres of land were purchased to allow for adequate open space around any buildings that might eventually be constructed.

The Korean trouble brought the need sooner than could have been expected. In the late spring of 1950 the rearmament program began in earnest, and General Radio was called upon to make its contribution of precision test equipment and components at a rate far beyond the capacity of its plant. In fact, the ascending curve of new defense orders matched closely the curve caused by the rearmament program beginning in 1940.

Plans for construction on the new site were drawn up immediately, but before construction could be started a certification of the necessity of this new facility was required. This was issued by the National Production Authority upon the request of the Department of Defense, and building was started in July, 1951. The first production operations began in April, 1952.

This modern, fireproof plant has seventy-two thousand square feet of floor space and is devoted to manufacturing, with auxiliary shipping, receiving, and stockroom facilities.



Courtesy Boston Edison Co.

View of the new General Radio branch plant at West Concord, Mass.

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