

## BRG's 25th Anniversary

The  
NOTEBOOK

BOONTON RADIO CORPORATION • BOONTON, NEW JERSEY

## Technical Contributions of the BRC Notebook

Discussed by Engineering Educator  
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As the Boonton Radio Corporation enters a new phase of its corporate existence, it is appropriate to pause and reflect — to view in retrospect the contributions of the BRC Notebook. We could just leaf through our file, stopping to read interesting articles, but in so doing, we might lose some basic messages. So we shall try to review the contributions of the Notebook as a whole, drawing liberally on its writings, without many quotations, yet with references to Notebook articles so that the curious reader may expand his horizon.

One of the primary requirements for a quality measurement is the combination of a fine instrument and skillful operator. Instrument companies try to achieve this combination when they sell an instrument, by supplying an instruction manual. But this is usually not enough. Users must repeatedly be urged towards a full understanding of the instrument they are using and so the BRC Notebook was born to distribute<sup>1</sup> to users and to as many other interested persons as possible, information of value on the theory and practice of radio frequency testing and measurement. In addition, as new techniques and applications were developed, they have been brought to the readers, together with material about new instruments.

It is easy to connect equipment together and get meter readings or balances, but to be certain these really mean something, the experimenter must

understand the circuit theory of his equipment. As an example of this, consider the measurement of radio receiver characteristics.<sup>2</sup> We plan to use a signal generator to feed the radio receiver. The signal generator has dials and meters which indicate the microvolt output, but we know that impedances must be right for these readings to be correct. But what is "right"? We look into the catalog<sup>3</sup> specifications of our signal generator, and under the heading "RF Output Voltage" we find "the maximum open-circuit voltage from the

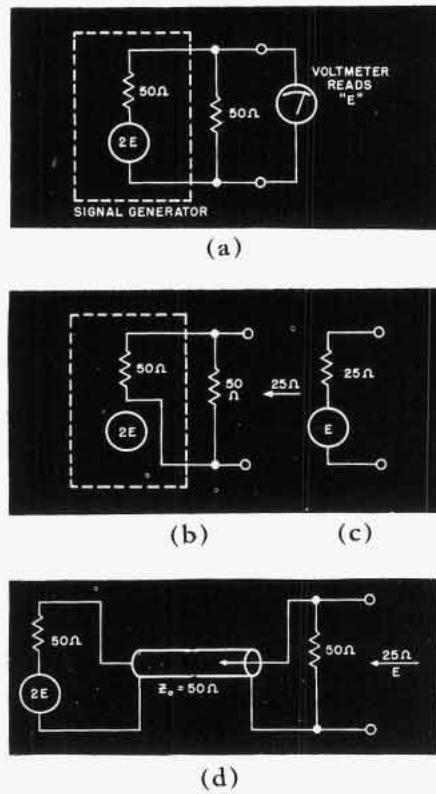


Figure 1. Thevenin's Theorem applied to signal generator use.

## To Our Many Friends:

As we pause at the end of the first quarter century of our operations as designer and manufacturer of electronic test equipment, we would first like to express our sincere thanks to our customers, our employees, our suppliers, and our business associates through whose help and cooperation we have been successful. As we look through our catalogs and back issues of The Notebook, we are pleased and proud of the contributions Boonton Radio has made to the electronic industry.

However, as fine as these contributions may be, we are not satisfied and we are starting the next quarter century with a very firm resolve and with plans to improve Boonton Radio's contribution to the electronic industry. We have embarked on a program to enlarge and improve our engineering department in order that we will be able to supply all of our customers with an ever expanding and ever improving line of instruments. We are planning to erect new plant facilities, which will be equipped with the most modern and up to date machinery and tools that we can procure.

I can assure you that we at Boonton Radio are going to give our very best efforts to doing an even better job in the next 25 years and we earnestly solicit the continued cooperation of our personnel, customers, and suppliers in reaching these ambitious goals.

G. A. Downsbaugh  
President

## YOU WILL FIND . . .

Technical Contributions of the BRC Notebook . . . . .	1
The Evolution of the BRC Q Meter . . . . .	7
Boonton Radio Corp. Merges with Hewlett-Packard Co. . . . .	10
New Plant Soon for BRC . . . . .	10
Looking Back 25 Years with BRC . . . . .	11

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BNC type RF output jack at the front panel is about 0.4 volt. With the standard output cable attached, the maximum calibrated output voltage at the cable terminals is 0.2 volt. When the RF monitor meter is set to the red calibration line and the standard output cable is attached, the RF output attenuator is direct reading in microvolts and continuously adjustable from 0.1 microvolt to 0.2 volt." Under the heading "RF Output Impedances" we find "the RF output impedance of the signal generator as seen looking in at the BNC type front panel connector is 50 ohms resistive. With the standard output cable attached, the RF output impedance as seen looking in at the output cable terminals is 25 ohms resistive."

Now if we know our circuit theory, this is all very clear, and is very logical. But if our knowledge of circuit theory is a knowledge of words rather than an understanding of ideas, we must do some studying, particularly of Thevenin's theorem and transmission line theory. Thevenin's theorem states that a two-terminal network can be replaced by an emf in series with an impedance. Thus in Fig. 1(a), the emf  $2E$  and the 50-ohm resistor inside the dotted rectangle represent a signal generator, as seen at the output jack. In this diagram, a resistor of value 50 ohms has been connected across the output jack, and a very high impedance voltmeter is shown measuring a voltage  $E$ , which is just half of the Thevenin emf of the signal generator because the two 50-ohm resistors form a 2:1 voltage divider. The impedance at the terminals, as seen by the voltmeter is 25 ohms, which is the value of the two resistances in parallel, as shown in Fig. 1(b). Consequently, when the signal generator and the 50-ohm load are considered as a unit, the Thevenin circuit at the terminals is as shown in Fig. 1(c). It is an emf  $E$  in series with a 25-ohm resistance. The open-circuit voltage is this emf, and is

equal to the reading on the signal generator dials.

Sometimes we use a length of coaxial cable to connect the signal generator to the receiver under test. The heart of the problem is that this length of cable can approach and exceed  $\frac{1}{4}$  wavelength, and consequently has voltage and impedance transforming properties which might nullify the calibration of the signal generator. To avoid this, we use a cable with a characteristic impedance equal to the impedance looking back into the output jack of the signal generator, and then we load this cable with a resistor of this same value. The circuit is as shown in Fig. 1(d). When the cable is terminated in 50 ohms (the value of  $Z_0$ ) the input to the cable seen by the signal generator is 50 ohms so as far as the signal generator is concerned, the situation is just like that in Fig. 1(a), and the voltage input to the cable is  $E$ . If the cable is lossless, the voltage at the 50-ohm load is also  $E$ . This is the emf of the equivalent Thevenin circuit of the whole combination viewed from the terminated end of the cable. This voltage is equal to the reading of the signal generator dials, as the specification stated. The impedance of the Thev-

enin circuit is 25 ohms, just as the specifications stated, because from the terminals we see 50 ohms in parallel with the cable, which in itself looks like 50 ohms as it is a 50-ohm cable terminated at the signal generator end with the 50-ohm Thevenin impedance of the signal generator itself.

To truly test a receiver, the receiver must be fed from an emf of a known number of microvolts in series with an impedance equal to the impedance of the antenna to be used with the receiver. The signal generator supplies the known emf and resistance. If this resistance is different from the antenna impedance, an extra series impedance, often called a dummy antenna, must be used.

"To appreciate the logic leading to this choice let us consider the source of energy from which the combined system of the antenna and receiver is driven. Electromagnetic energy flowing in free space encounters a conductor and excites in it a voltage which acts in series with the antenna radiation resistance. Like the open-circuit electromotive force of a battery this voltage is available to us only in series with the internal impedance of the power source itself. The

TABLE I

Sweep Method	Advantages	Disadvantages
Mechanical Devices	High Q at all frequencies. High output possible (without buffer stage). Workable over wide range of output frequencies. Wide sweep range.	Microphonism causing frequency jitter. Non-linear sweep. Mechanical maintenance problems.
Reactance Tube	Good stability and accuracy. Non-microphonic. Linear sweep.	Limited to narrow sweep at low frequencies.
Saturable Reactor	Wide sweep range. Good stability and accuracy. Non-microphonic. Linear sweep.	Low Q at high frequencies. Susceptible to AC magnetic fields. Hysteresis effects.
Klystron Beat Method	Wide sweep range. Workable over wide range of output frequencies. Linear sweep. Non-microphonic.	Frequency jitter. Low output. Poor accuracy at low freqs.
Ferroelectric Capacitor	Non-microphonic. Linear sweep.	Excessive temperature Coeff. Low Q. Hysteresis effects.

Figure 2. Advantages and disadvantages of various means for frequency sweeping.

variation of this impedance with frequency may require a series-parallel combination of R, L, and C in the dummy antenna. Part or all of it may be contained in the signal generator output impedance."<sup>2</sup>

So far, we have treated the signal generator in terms of its equivalent Thevenin circuit, without much regard for the design of the equipment itself. From the user's point of view, this is wonderful if he can be sure of it! Just how Boonton Radio Corporation goes about making an instrument of which the user can be sure is an education in itself.

First there is electrical design. Take the matter of choosing a method of generating broad-band frequency deviations. All the known methods are studied and their advantages and disadvantages are determined and listed, as in Fig. 2. Then a method is chosen from this listing. For the type 240-A, the saturable reactor was selected.<sup>4</sup>

Then there is mechanical design, often overlooked by one steeped in circuitry. "From the moment the mechanical design of an instrument begins, a myriad of other considerations arise to confront what might otherwise seem a straightforward piece of electronic equipment. The mechanical designer must consider the electronic requirements of the development and project engineers, the functional and saleable appearance, weight and price insisted upon by Sales, and the mechanical urgencies of simple, rigid designs and drives using the proper materials. In addition the Shop must be allowed reasonable tolerances within the limitations of available processes and equipment. Assembly should have units adapted to smooth work flow, and Inspection (and the user!) needs easy accessible adjustments. Among many other factors are Purchasing's and Accounting's hopes that standard parts will be used, and Shipping's plea for enough unobstructed cabinet area to allow proper bracing in the packaging."<sup>5</sup>

The solution of an electro-mechanical design problem is shown in Fig. 3. This is the internal resonating capacitor which is "the heart of the Q Meter, and is an excellent example of the interdependence of mechanical and electrical design. Taking the 190-A Q unit as an example, the electronic requirements are low minimum capacitance, together with low and constant values of inductance and resistance all of which are

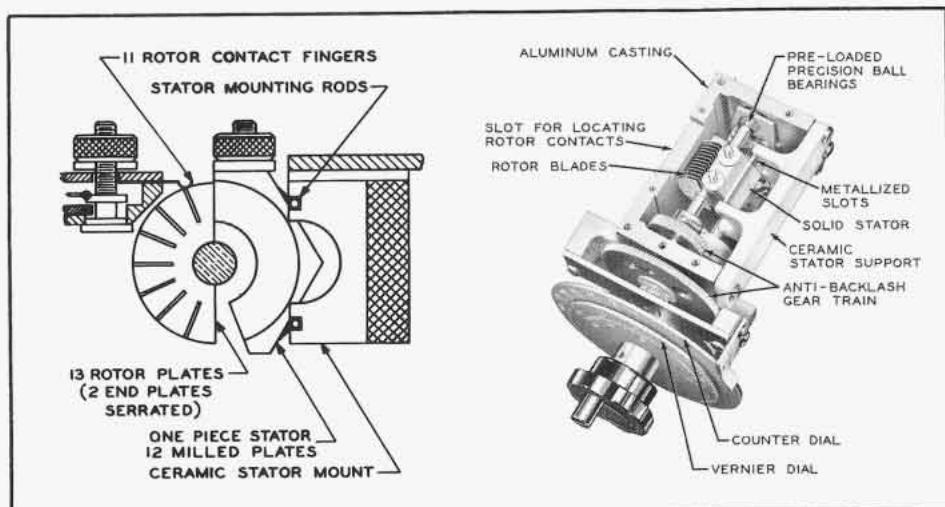


Figure 3. The 190-A capacitor solves the problem of rigidity, low capacitance, and constant inductance.

difficult to attain in conventional designs. Mechanically the design must be extremely rigid to assure constant and accurate re-setability. The massive structure ordinarily needed to attain the last-named end is in direct opposition to the minimum capacity requirement.

"The stator is mounted by means of two rods soldered into the metallized slots of a high quality ceramic support. Insofar as possible it floats in air dielectric. In addition, the rotor travel is restricted to less than 180°, with the included angle of the stator reduced by a proportionate amount to result in the largest possible angular gap between the two at the minimum setting. By these means the capacity at minimum was limited to the lowest value compatible with sufficient mechanical strength.

"Low and constant inductance between the stator plates is achieved by milling out a solid bar to leave only the outer shell and the plates, solidly connected with each other along their entire peripheries. A secondary result of this method is the 'built-in' shielding the shell provides from extraneous fields.

"The tandem edge wipers, contacting

all the rotor blades in parallel, serve to reduce the associated inductance and resistance to a very low and nearly constant value and are rhodium plated to provide good wearing qualities.

"Where other considerations do not enter, rigidity is attained in the complete unit by mounting all the parts on a rigid cast frame. All shafts are carried on preloaded ball bearings."<sup>5</sup>

Another electro-mechanical design is the attenuator system in the Type 245 RF voltage standard. As shown in Figs. 4 and 5, a disc resistor of very low value, 0.0024 ohm, is mounted across a tube, and two 50-ohm resistors are mounted as central conductors of a coaxial cable, one on each side of the disc. Study<sup>6,7,8</sup> of the circuit theory involved is again based largely on Thevenin's theorem, but the physical arrangement is what assures us that no leakage voltage gets into the output system.

In addition to this attenuator, the Type 245 voltage standard or Signal Generator Calibrator contains a transistorized diode voltmeter calibrated at 0.025, 0.05 and 0.1 volt, rf. This voltmeter is connected across the input of the attenuator, where the impedance is essentially 50 ohms, regardless of the output termination because the attenuation of the unit is so high (2500:1 for type 245-C or 25,000:1 for type 245-D) that the reflection of the output back into the input is negligible. Consequently, this unit can be used to check the output of a signal generator into a 50-ohm load at the three voltages mentioned above. It can also be used to

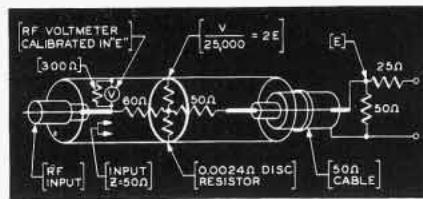


Figure 4. Schematic diagram of the RF attenuator and voltmeter in the Type 245.

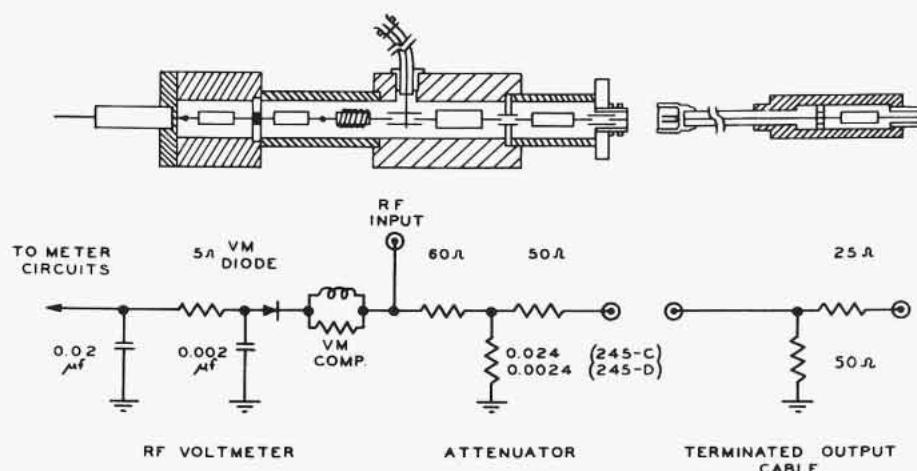


Figure 5. Cutaway view of the actual attenuator in the Type 245.

provide a standard low-level signal in the microvolt range by using the output of the attenuator when the input voltage is on one of the calibration marks. In addition, the input voltmeter is equipped with a demodulating system so it can be used to measure the percent amplitude modulation.

A good understanding of the nature and theory of the quantity to be measured is most important in the making of good measurements. In recent years, measurements of the sensitivity of noise-limited receivers has attracted considerable attention, and a body of knowledge and experimental techniques have grown up.<sup>9</sup> In order to make adequate measurements, one must understand the statistical nature of the noise. For example, a knowledge of the ratio of noise peaks to noise rms value is important so that the equipment can be operated with these peaks still in the linear region of the receiver. Without this information, completely incorrect results are possible. Moreover, results obtained by one type of measurement, while correct in themselves, may not be of much value in a situation not well simulated by the measurement. A thorough understanding of the theoretical basis of the measurement and the use to which the results are to be put is of highest importance.

This idea that the experimenter should understand has been a keynote in many of the theoretical Notebook articles. One "blind spot" of many engineers was tackled in the beginning with a study of the many faces of Q.<sup>10</sup> This quantity may be defined basically as the

ratio of the total energy stored in a resonant circuit to the average energy dissipated in the circuit per radian. Such a definition implies that the circuit is in resonance, for if it were not, the stored energy would not be constant. This means that the net reactance of the circuit is zero, and yet many engineers will define Q as X/R. Such a definition can be derived from the basic one only with three assumptions. These are (1) that the circuit is a series circuit; (2) that the X is either the inductive reactance or the capacitive reactance, but not the total; and (3) that the capacitance is lossless unless its losses are included in the R.

The theory of the Q Meter has been described in many places.<sup>10</sup> The circuit (Fig. 6a) is a series RLC circuit coupled to a source of radio frequency current by means of a very small resistance *r* (0.02 ohms in the type 260-A), with a high-impedance vacuum-tube voltmeter connected across the adjustable air capacitor. The inductance is in the coil to be measured. With the frequency and current values held constant, the capacitor setting is changed until the voltmeter indicates the resonant rise. The maximum voltage is  $\sqrt{1 + Q^2}$  times the voltage obtained by multiplying the coupling resistance by the input current. Consequently, with a known value of current, the voltmeter can be calibrated in terms of Q, and of course if Q is large, the voltage is proportional to Q.

Curiously enough, the mathematical treatment of the Q Meter circuit is most easily handled by converting it to

the equivalent parallel circuit shown in Fig. 6(b). This is done by applying Norton's theorem, which is the dual of Thevenin's theorem. The results are:

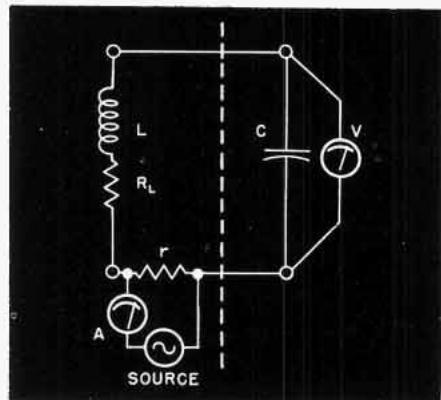
$$G = \frac{R}{R^2 + \omega^2 L^2} \quad A_1 = \frac{A_r}{R + j\omega L} \quad (2)$$

$$jB = \frac{-j\omega L}{R^2 + \omega^2 L^2} \quad Q = \frac{|IB|}{G} = \frac{\omega L}{R}$$

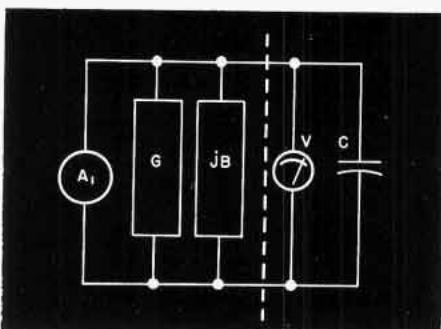
In this,  $A_1$  is a current source, giving the same current regardless of the load.

If we vary the capacitance in the circuit, maximum voltage across the capacitor occurs when the net susceptance is zero. Thus the value of the maximum voltage across the capacitor, is given by dividing the magnitude of  $A_1$  by  $G_L$ . When we do this, we get

$$V_e (\text{Max. Magnitude}) = A_r \sqrt{1 + Q^2} \quad (3)$$



(a)



(b)

Figure 6. The circuit of the Q Meter and an equivalent parallel circuit for analysis.

which is exactly what was obtained in the series circuit analysis.

The relative ease with which we obtained results by using the circuit of Fig. 6(b) leads us to explore the parallel circuit ideas further.<sup>11</sup> Suppose we consider the coil, which should be of high Q, as a "work coil". We adjust the Q Meter and record our readings as Q<sub>0</sub> and C<sub>0</sub>. Using the above ideas we get

$$G_0 = \omega C_0 / Q_0 \text{ and } B_0 = -\omega C_0. \quad (4)$$

Notice that these include all losses and energy storage in the system, including the vacuum-tube voltmeter!

Now place an unknown in parallel with the capacitance, readjust the Q Meter and record the readings as Q<sub>1</sub> and C<sub>1</sub>. Again we calculate

$$G_1 = \omega C_1 / Q_1 \text{ and } B_1 = -\omega C_1 \quad (5)$$

But G<sub>1</sub>, the new conductance is simply the sum of G<sub>0</sub> and the conductance G<sub>x</sub> of the unknown. Also, B<sub>1</sub> is the sum of B<sub>0</sub> and the susceptance B<sub>x</sub> of the unknown. So we can write

$$G_x = G_1 - G_0 = \omega \left( \frac{C_1}{Q_1} - \frac{C_0}{Q_0} \right) \quad (6)$$

and

$$B_x = B_1 - B_0 = \omega (C_0 - C_1). \quad (7)$$

From these we can get the equivalent parallel resistance and reactance of the unknown as simple reciprocals, thus

$$R_{Px} = \frac{1}{G_x} \text{ and } X_{Px} = \frac{-1}{B_x}. \quad (8)$$

If we want the equivalent series resistance and reactance we write

$$R_{Sx} = \frac{G_x}{G_x^2 + B_x^2} \quad (9)$$

and

$$X_{Sx} = \frac{-B_x}{G_x^2 + B_x^2}$$

The whole idea<sup>12</sup> that an unknown impedance or admittance can be looked on as either an R<sub>s</sub> and X<sub>s</sub> in series or as an R<sub>p</sub> and X<sub>p</sub> in parallel may be new to some readers. Actually no coil is really a series connection or a parallel

connection, but is a combination of both, with some capacitance thrown in for good measure.<sup>13</sup> The source of the series resistance is the wire of which the coil is wound and the sources of the parallel resistance are eddy currents in shields, core loss in magnetic materials, and dielectric loss in insulating materials (which is the easiest to reduce to the vanishing point). The parallel resistance in an actual coil becomes predominant if the frequency is carried high enough, so the Q of every coil will reach a maximum at some frequency, (where series and parallel losses are equal), and will decrease as the frequency is raised above this value. At any single frequency, however, we can consider the loss as being all in series resistance or as being all in shunt resistance. We cannot properly divide the loss between the two unless we know the behavior of the coil as a function of frequency.

Parallel equivalences are particularly valuable in many bridge circuits and circuits derived therefrom. One reason is that stray capacitances are most easily treated by such means. Another is that certain circuits just naturally give admittances rather than impedances. Consider the general impedance bridge in Fig. 7(a). The balance equation is

$$Z_1 Z_3 = Z_2 Z_4. \quad (10)$$

If we solve for 1/Z<sub>4</sub>, we get

$$\frac{1}{Z_4} = Y_4 = \frac{Z_2}{Z_1 Z_3} \quad (11)$$

If we use Z<sub>1</sub> and Z<sub>3</sub> as fixed components, the values of the components of Y<sub>4</sub>, which are G<sub>4</sub> and B<sub>4</sub>, can be found in terms of the series components of Z<sub>2</sub>. If we apply this idea to the Schering bridge circuit of Fig. 7(b), we have

$$G_4 + jB_4 = \frac{j\omega C_1}{R_3} \left( R_2 + \frac{1}{j\omega C_2} \right) \quad (12)$$

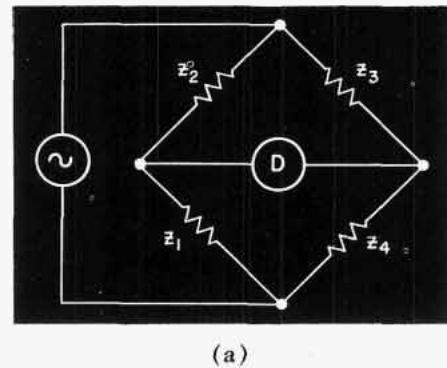
If B<sub>4</sub> is a capacitance, then we have

$$G_4 = \frac{C_1}{R_3 C_2} \text{ and } C_4 = C_1 \frac{R_2}{R_3} \quad (13)$$

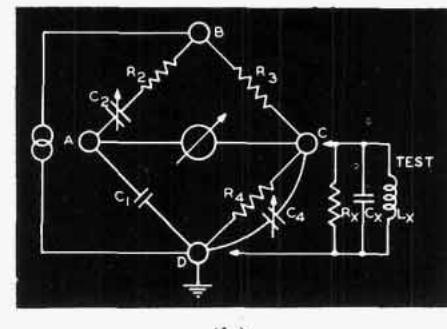
The RX Meter uses a modification of this circuit with a special balanced transformer so that the two sides of the

bridge can be supplied with equal voltages 180 degrees out of phase with each other, as is shown in Fig. 8. The result<sup>14</sup> of this is that the detector can be operated with one side grounded and with the other side coupled to the usual bridge detector points by a pair of small capacitors. The balance equations are identical with those for the bridge.

This circuit can be used in a manner similar to the way we used the Q Meter for parallel measurements. We balance the circuit with nothing connected



(a)



(b)

Figure 7. The basic impedance bridge circuit and the Schering bridge circuit.

across the "Test" terminals. Then we read the values of C<sub>2</sub> and C<sub>4</sub>. Let us call these C<sub>20</sub> and C<sub>40</sub>. We have balance equations as follows

$$G_{40} = \frac{C_1}{R_3 C_{20}}$$

$$\text{and } B_4 = \omega C_{40} = \omega C_1 \frac{R_2}{R_3}. \quad (14)$$

Now we connect an unknown admittance G<sub>x</sub> + jB<sub>x</sub> in parallel with the

elements already in arm 4, and we rebalance the circuit. The new readings of  $C_2$  and  $C_4$  we will call  $C_{21}$  and  $C_{41}$ . This time the balance equations become

$$G_{41} = \frac{C_1}{R_3 C_{21}} \quad (15)$$

$$\text{and } B_4 = \omega C_{41} + B_x = \omega C_1 R_2 / R_3 \quad (16)$$

The first of these is a new one, but the second simply indicates that the total  $B$  in arm 4 is still the same. Drawing on this fact, we can write

$$B_x = \omega(C_{40} - C_{41}). \quad (17)$$

Since the value  $G_{41}$  is the sum of  $G_{40}$  and  $G_x$ , we can write

$$G_x = G_{41} - G_{40} = \frac{C_1}{R_3} \left( \frac{1}{C_{21}} - \frac{1}{C_{20}} \right) \quad (18)$$

The value of  $G_x$  is determined by the values of  $C_2$  from two balances and the values of  $C_1$  and  $R_3$ . If these latter terms are known, the values of  $C_{20}$  can be marked as zero  $G$  and the scale of  $C_2$  can be calibrated in mhos of conductance. Alternately, the scale of  $C_2$  can be calibrated in terms of parallel resistance in ohms. Then the zero point of  $G$  becomes the infinity point of  $R_p$ . This is done in the RX Meter.

The value of  $B$  of the unknown involves only the value of angular frequency,  $\omega$ , and the values of two capacitor settings. The value  $C_{40}$  can be marked as zero, and the scale can be calibrated in capacitance values above and below this zero. Then the  $C_4$  dial reads the value of parallel capacitance which has a susceptance equal to the susceptance of the unknown. Thus the positive range of the  $C_p$  dial is the region of actual capacitance below the value of  $C_{40}$ . The negative range of the  $C_p$  dial indicates that the unknown is inductive.

The inductive range of the RX Meter can be extended to higher values of  $B$ , corresponding to lower values of  $L$ , by adding known capacitors in parallel with the unknown. Other methods of extending the range of measurements are also known,<sup>15</sup> and all of them depend on the experimenter's knowledge of the mathematics of electric circuits for their usefulness.

Transmission line parameters can be found from measurements made on the RX Meter.<sup>16</sup> Application of the circuit theory of transmission lines leads to measurement procedures which enable impedances at a distance from the ter-

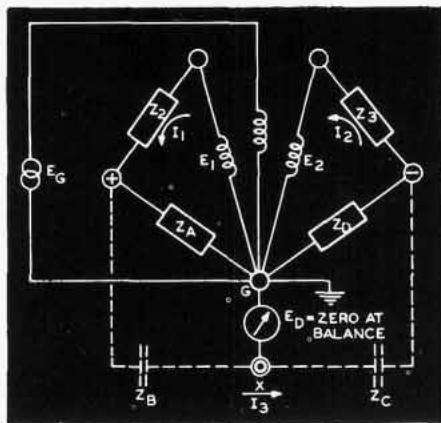


Figure 8. Basic circuit of the RX Meter.

minals of the RX Meter to be determined.<sup>17</sup>

In the area of transistor parameter measurements, circuit theory and measurement technique reach one of their finest meetings. From the circuit theory viewpoint, the problem is to find expressions for transfer parameters in terms of two-terminal impedances or admittances. From the measurement technique side, the problem is to measure the desired impedances or admittances with proper bias currents supplied to the transistor. The RX Meter is ideally suited for this, because it can carry fifty milliamperes direct current applied at the unknown terminals. With appropriate jigs to hold the transistor and supply adequate biasing, the measurements can be quickly made.<sup>18</sup>

The details on all of these things have been brought to the reader of the BRC Notebook. The presentations have been challenging and have encouraged many of us to delve into new theoretical points and experimental procedures. We, the readers of the Notebook are the richer for this, and we look forward to future issues of the Notebook with great expectations. Truly the well designed instrument and the skillful user produce remarkably useful results.

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#### THE AUTHOR

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# The Evolution of the BRC Q Meter

LAWRENCE O. COOK, Quality Control Engineer

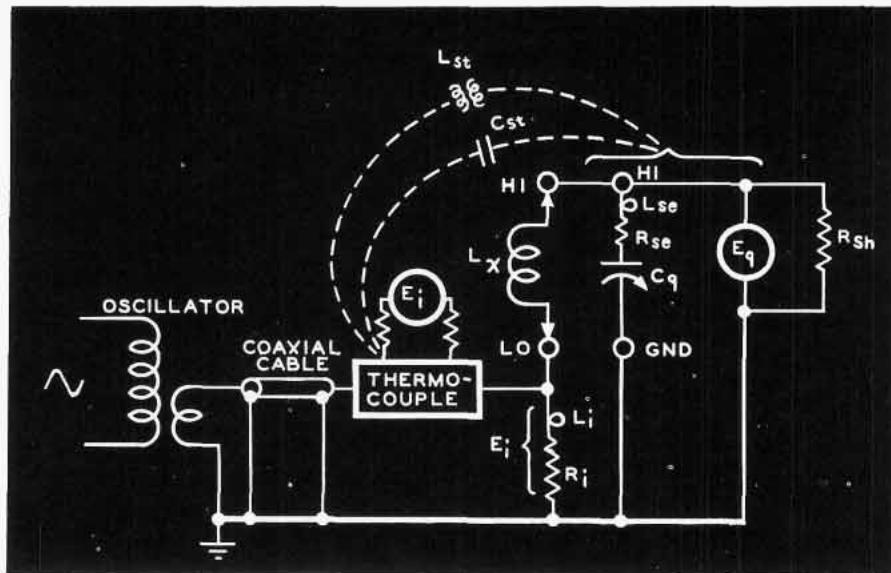
$Q$  is defined as  $2\pi$  times the ratio of energy stored to the energy dissipated per cycle.<sup>1,2</sup> In electronics, the concept of  $Q$  is commonly used to designate the ratio of series reactance to series resistance of a coil ( $Q = 2\pi fL/R$ ) or of a capacitor ( $Q = \frac{1}{2}\pi fCR$ ). While these and other relationships involving  $Q$  have been used in radio and electrical engineering for a great many years, the expression  $Q$  and its numerical value did not come into popular usage until early in the 1930's, during the time when the broadcast receiver industry was growing at a fast pace and a rapid means for measuring  $Q$  was sorely needed. Seeking to fulfill this need, the founders of Boonton Radio Corporation demonstrated the first  $Q$  Meter at the IRE Meeting in Rochester, N. Y. late in 1934.

## Fundamental Q Meter Circuit

The early model  $Q$  Meter employed the "voltage step-up" (also known as "resonance rise") method of  $Q$  measurement still used in current models. A simplified schematic of the fundamental circuit is shown in Figure 1. The  $Q$  of a resonant circuit, comprising a capacitor ( $C_q$ ) contained in the  $Q$  Meter and an external coil ( $L_x$ ), is measured by impressing a known voltage ( $E_i$ ) in series in the circuit and measuring the voltage ( $E_q$ ) across the capacitor when the circuit is resonated to the frequency of the impressed voltage.  $Q$  of the circuit is the ratio  $E_q/E_i$ . With  $E_i$  known, the voltmeter ( $E_q$ ) may be calibrated directly in  $Q$  and, because the circuit losses occur mostly in the coil, the  $Q$  indication obtained closely represents the  $Q$  of the coil. By inserting low impedances in series with the coil or high impedances in parallel with the capacitor, the constants of unknown circuits or components may be measured in terms of their effect on the original circuit  $Q$  and tuning capacitance.

## Basic Design Problems

Though the fundamental  $Q$  measurement method just described is extremely simple, the achievement of accurate results over a wide range of frequencies requires the solution of several basic



$R_q$  Q circuit injection resistor  
 (100-A and 160-A, 0.04 ohm;  
 260-A, 0.02 ohm)  
 $L_{st}$  Self inductance of  $R_i$   
 $E_i$  Injection voltage and meter for same  
 $C_{st}$  Stray capacitive coupling  
 $L_{se}$  Stray inductive coupling  
 $L_i$  Coil under test

$C_q$  Calibrated internal resonating capacitor  
 $L_{se}$  Q circuit residual inductance  
 (100-A, 0.08  $\mu$ H, 160-A  
 and 260-A, 0.015  $\mu$ H)  
 $R_{se}$  Q circuit residual series resistance  
 $R_{sh}$  Q circuit residual shunt resistance  
 $E_q$  Q vacuum tube voltmeter  
 $HI$  — LO External coil terminals  
 $HI$  — GND External capacitor terminals

Figure 1. Q Meter Fundamental Circuit — Including Residuals

problems.

1. The injection voltage system must be frequency insensitive.
2. Stray coupling occurring between the oscillator (including the injection system) and the  $Q$  measuring circuit must be reduced to a negligible value.
3. The  $Q$  measuring circuit residual inductance and series and shunt resistive losses must be minimized. Included are input circuit losses in the VTVM which measures the voltage across the resonating capacitor.
4. The oscillator waveform must be relatively free of harmonics.

These factors have been strenuously dealt with in  $Q$  Meter design and, over a period of many years, much progress has been made which benefits the user in terms of improved accuracy. Some of the results of this progress, in the LF and lower VHF range of frequencies, will be shown in the remaining paragraphs which trace the development of the  $Q$  Meter from the first model

marketed, the Type 100-A, to a model currently in production, the Type 260-A.

## Type 100-A Q Meter

The Type 100-A  $Q$  Meter was the first model to be sold (in early 1935) and is readily recognized because of its 45° panel slope.

A Type 45 tube operated in a tuned-grid oscillator circuit having tickler feedback. Turret selection of 7 calibrated frequency ranges provided a total range of 50 kc to 50 mc, the entire oscillator assembly being shielded to provide isolation from the  $Q$  measuring circuit.

The oscillator output current, controlled by adjustment of the dc plate voltage, was fed through a coaxial cable to a thermocouple and then through a 0.04-ohm "voltage injection resistor". This resistor, a closely shielded resistance strip, provided a low value of self inductance so that the voltage drop developed across the resistor was rela-

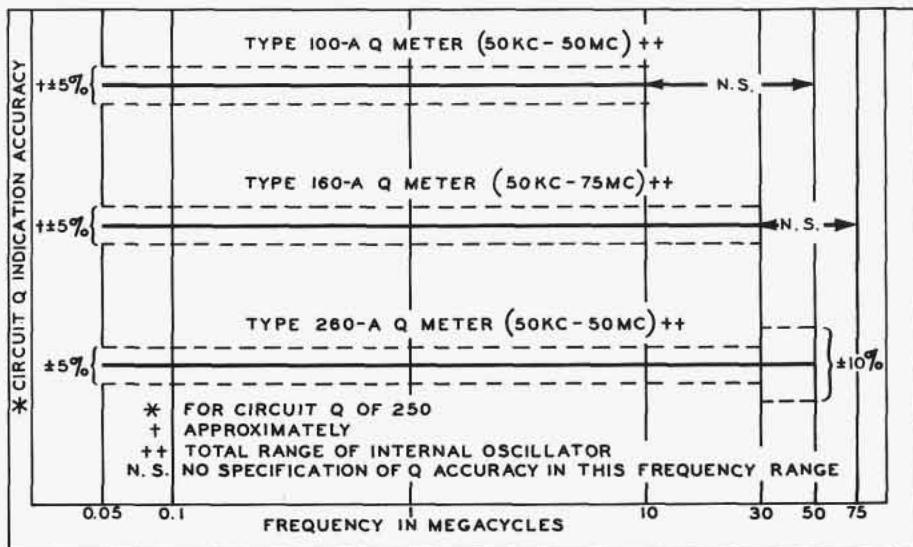


Figure 2. Specification of Circuit Q Indication Accuracy vs Frequency

tively independent of frequency. The thermocouple operated a 3-inch dc meter which was calibrated at two Q range settings in terms of the voltage developed across the resistor at dc and at low frequencies.

The Q measuring circuit included a single-section, receiver-type capacitor having aluminum plates which provided a calibrated capacitance range of 37 to 460  $\mu\text{f}$ . Impregnated mica insulation was employed in the capacitor for low loss purposes, each mica insulator being tested under conditions of 90% relative humidity. The vernier capacitor was in a separate frame and employed similar insulation.

External terminals for connection of the coils and capacitors to be tested were of the commercial, nickel-plated type mounted on impregnated mica insulators.

The Q voltmeter circuit employed a triode tube operating as a form of "plate rectifier" with provision for zero balance of the cathode current meter. The Type 2A6 tubes were individually selected in the operating circuit for high input resistance at rf, normal input capacitance, low direct grid current, and normal rectified dc output versus ac signal voltage. The 3-inch meter was calibrated in two ranges of circuit Q (0 to 250 and 0 to 500) in addition to signal volts. The VTVM grid return resistor (100 megohms at dc) was of a design chosen for high effective resistance at rf.

The Q Meter power supply was of the unregulated type commonly used at

that time.

Performance of this instrument, for the Q measurement of inductors and capacitors, was generally satisfactory at frequencies up to 10 mc, as shown in Figure 2. For increasing frequencies (i.e., above 10 mc) the accuracy gradually worsened because of the effects of injection resistor inductance, stray coupling between the thermocouple system and the Q measuring circuit, and Q measuring circuit residual inductance and residual resistance.

#### Type 160-A Q Meter

Increased use of higher frequencies

in the communications field created a need for improved Q Meter accuracy at these higher frequencies. To meet this need, a new model, the Type 160-A Q Meter, was developed and introduced in 1939, superseding the Type 100-A. In addition to greatly improved accuracy, this model had a 15° panel slope and a considerably different appearance.

The oscillator was essentially the same as used in the Type 100-A instrument except that an eighth frequency range (50 to 75 mc) was added. Mechanical reliability of the shielding was also improved.

The injection system provided a completely shielded thermocouple with the injection resistor being included in the same shielded assembly. Stray coupling to the Q measuring circuit was thus greatly reduced. Additional division lines on the "Multiply Q By" meter scale plate provided a wider (20 to 625) range of circuit Q measurements and improved accuracy.

The Q measuring circuit resonating capacitor, calibrated range 30 to 460  $\mu\text{f}$ , was of a design especially developed to provide low residual inductance and resistance for this purpose. Main and vernier capacitor sections were included in a single frame to avoid the inductance of a connecting lead. The main rotor and stator were split into two equal sections, the rotor being "center fed"; i.e., to provide a shortened current path, the rotor was grounded by fingers contacting a disk located on the shaft midway between the two sections. Rotor and stator plates fabricated of copper

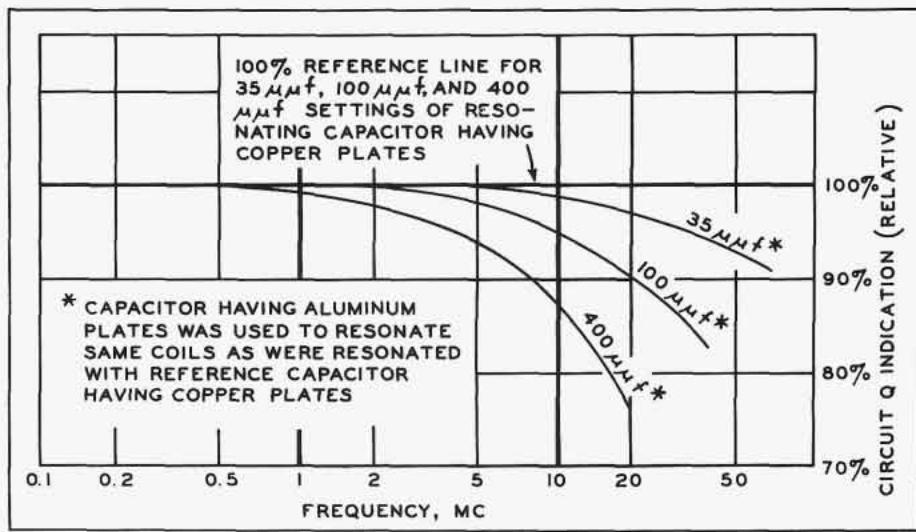


Figure 3. Circuit Q Indication of Q Meter vs Resonating Capacitor Plate Material

provided lowered rf resistance as compared to the aluminum material formerly used. (See Figure 3.) The stator insulators of this capacitor were at first of impregnated mica, but a subsequent design modification substituted pyrex glass balls for improved electrical reliability.

External terminals (Figure 1) were of gold-plated copper to provide high conductivity. To permit shortened internal leads the panel slope was changed from 45° to 15° and the external terminals were mounted integrally with the capacitor. The residual inductance of this unit, measured at the COIL terminals, was 0.015  $\mu$ h, a considerable reduction from the Type 100-A inductance of 0.08  $\mu$ h.

For improved readability, a 4-inch meter was used in the Q-VTVM. The meter was critically damped to eliminate the pointer over-swing found in the Type 100-A. The power supply was of the conventional unregulated type.

While the Type 160-A instrument achieved a wide usage in the electronic field and offered greatly improved accuracy at the higher frequencies over its predecessor the Type 100-A (Figure 2), its accuracy at frequencies above 30 mc was limited and the thermocouple factor of safety was low.

#### Type 260-A Q Meter

Progress in the electronic and instrument art indicated that a revised Q Meter of refined design and improved accuracy was needed. To meet this need, the Type 260-A Q Meter, superseding the Type 160-A, was developed in 1953 and is still being produced. This model is similar in shape and size to the Type 160-A but is recognizable by its recessed dials.

An oscillator of complete redesign employs a modern tube and modern components. The circuit is designed for low harmonic content. Output current control is in the low wattage screen grid circuit. Turret selection of eight calibrated frequency ranges provides a total coverage of 50 kc to 50 mc.

The thermocouple and "Multiply Q By" meter circuit have been redesigned for a lower thermocouple operating temperature and consequent greater safety factor. Thorough shielding is employed and a 4-inch meter with mirror scale provides greater accuracy of setting the injection voltage.

The injection voltage resistor is a 0.02-ohm annular type providing es-

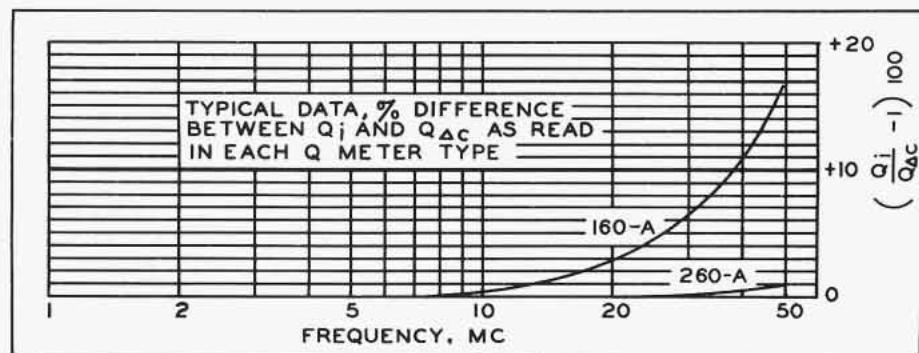


Figure 4. Q Indicated ( $Q_i$ ) vs Q by Delta-C ( $Q_{\Delta C}$ ) Method

sentially noninductive performance at frequencies as high as 50 mc, a welcome change from the inductive voltage rise experienced with the shielded resistance strip type of resistor used in Q Meters Type 100-A and Type 160-A. Figure 4 plots the error in the Type 160-A largely attributable to this cause. The error in the 260-A is negligible. The lowered resistance value of 0.02 ohms in the Type 260-A versus 0.04 ohms in the Types 100-A and 160-A (this resistor being in series with the Q measuring circuit) raises the measured circuit Q by as much as 15% at the higher frequencies<sup>3</sup>. Thus the circuit Q and the coil Q are brought into closer agreement.

The resonating capacitor (calibrated for a range of 30 to 460  $\mu\mu$ f) is of the same design as was employed in the

later 160-A's except that the external terminals are supported on a teflon insulator for improved uniformity, strength, and reliability. The direct reading capacitance scale is supplemented by a direct reading inductance scale for use at specified frequencies.

In addition to the usual main Q scale (40 to 250), the Q indicating meter provides a low Q scale (10 to 60) and a  $\Delta Q$  scale (0 to 50). These direct reading scales, when used in conjunction with the "Multiply Q By" meter (range X1.0 to X2.5) provide a circuit Q measurement range of 10 to 625. Each meter employs a mirror scale for the elimination of parallax error.

The power supply voltages are regulated by a voltage stabilizing transformer and "glow tubes", thus provid-

ITEM	100-A Q METER	260-A Q METER
Oscillator Harmonic Content	High at some frequencies, causing Q indication error.	Low at all frequencies, negligible Q error.
Oscillator Output Thermocouple (A) Overload factor (B) Shielding	(A) Small, susceptible to burnout. (B) Poor, causing Q indication error.	(A) Large, burnout rare. (B) Good, negligible Q indication error.
Injection Voltage Resistor	Inductance causes Q indication error at higher frequencies.	Inductive effect negligible; lowered resistance value improves circuit Q.
Resonating Capacitor (Q Measuring Circuit)	Receiver type with aluminum plates, vernier separate, external COIL and COND terminals separately mounted, impregnated mica insulation.	Specially designed, silver plated copper plates, rotor current center-fed, vernier in same frame, external COIL and CAP terminals integrally mounted, teflon and pyrex insulation, residual inductance and resistance greatly reduced.
Circuit Q Measurement Range	10-500	10-625; includes low Q Range and $\Delta Q$ range for better accuracy.
Meters	3 inch	4 inch, mirror scale.
Power Supply	Unregulated	Regulated; meter indications stabilized against line voltage fluctuations.

Figure 5. Highlights of Q Meter Design Differences

ing stability of meter indications in the presence of power line voltage fluctuations.

Figure 5 offers a quick review of the design highlights which contribute to the improved performance of the Type 260-A Q Meter. Note that the Q indication accuracy specification now extends upward to include the full frequency range of 50 kc to 50 mc (Figure 2).

#### Accessory Inductors

The Type 103-A Inductor has long been available as a "work coil" for use in Q Meter measurement of capacitors and other components. The more recently introduced Types 513-A and 518-A Q Standards provide a ready means for the user to check the accuracy

of his Q Meter, thus assuring instrument accuracy at the time of Q measurement.

#### Conclusion

Twenty-five years of electronic engineering effort has brought forth many advancements in the electronic field. We believe that Q Meter design has kept pace in terms of improved accuracy of measurement, improved reliability, and improved stability of operation.

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## Boonton Radio Corp. Merges With Hewlett-Packard Co.

Boonton Radio Corporation recently became the newest member of the Hewlett-Packard Co. family of Palo Alto, California as a wholly-owned subsidiary and joined other companies operating under similar status including: F. L. Moseley Co., Pasadena, California, makers of strip chart and X-Y recorders; Palo Alto Engineering Co. of Palo Alto, manufacturers of transformers, potentiometers, and other components; and Dymec, Inc. of Palo Alto, now a division of H-P, manufacturers of precision electronic measuring equipment and systems.

Announcing the arrangement between the two companies, Dr. George A. Downsborough, President of BRC, emphasized that BRC would continue to operate as a separate company with no changes in either management or personnel contemplated. He stated that plans for a new plant, which were underway prior to the merger, would be accelerated. These remarks were echoed by Messrs. Hewlett and Packard who visited BRC to personally welcome BRC into the H-P fold.

BRC is looking forward to expanding its line and development activities through the use of H-P development of components and close liaison with their development activities.

From a humble beginning in 1939, the Hewlett-Packard Co. has grown to be one of the largest manufacturers of electronic test equipment in the world. The company produces more than 300 different instrument types, including oscillators, voltmeters, signal generators, waveform analyzers, microwave and waveguide test instruments, and oscilloscopes. These products are sold to more than 3000 business organizations throughout the world, with the government, through its various agencies, constituting one of the largest single users of H-P equipment.

In addition to its expansion in this country, Hewlett-Packard has established subsidiaries in Germany and Switzerland. The Stuttgart, Germany plant is due to begin production of H-P instruments for the Continental market early next year. This plant will be the manufacturing outlet of the company's wholly-owned Swiss sales organization which was set up last January.

Boonton Radio Corporation is proud to be a member of the progressive Hewlett-Packard family and is looking forward to expanding with a fast growing industry.

## NEW PLANT SOON FOR BRC

The purchase, in December of 1958, of a 70-acre tract in Rockaway Township, a few miles Northwest of the present plant, was the first step towards a long-range expansion program in effect at BRC. The tract is located less than a mile from the recently completed interchange on the newly-aligned Route 80 interchange, and is easily accessible to BRC's 150 employees who mostly reside in the area. Ample room is available on the new site for enlarged plant construction and recreation facilities.

More recently, BRC has engaged an Architectural firm to draw up plans for the new building. These plans should be completed in the near future and plans are that ground will be broken early in 1960.

The new building will be a modern, single-story structure providing at least 50,000 square feet of space, or more than double the area of the present plant. The Engineering, Production, and Administration Departments are being laid out with ample room allowed for future expansion. The plant will be fully equipped with the most modern machinery and tools obtainable. Facilities are expected to include air conditioning and a cafeteria.

Details on the new plant will be the topic of a future Notebook article which will be published as soon as the building plans are firm.



An aerial view of BRC's new plant site.

## Looking Back 25 Years With BRC

Boonton Radio Corporation was established in 1934, but the scene was set before that time, just after the end of the First World War. Many of the concepts that made wireless communication possible were discovered before the War, but it was during the War that new ideas were evolved and that considerable practical experience was gained in the use of these new ideas. When the War was ended, the public was beginning to appreciate the usefulness of transmitting intelligence over distances without wire and was taking a keen interest in its development.

Manufacturers, recognizing this intense interest, began devoting time and money to the development of improved radios and radio devices. They found it necessary to obtain component parts which were new to most of them, and for which they were sadly lacking in testing methods.

These were the conditions under which the Boonton Hard Rubber Company in Boonton, New Jersey established a group for dealing with the new problems. The staff of the newly formed group, including at first just one physicist, produced coil forms and other radio components using insulating material. Later, additional technical people were employed, and the work of general engineering consultation was undertaken. This type of work naturally led to an understanding of basic test equipment requirements.

Late in 1934, Mr. William D. Loughlin, who had been President of Radio Frequency Laboratories and who was one of the industry's pioneers, together with several associates, purchased one of the buildings which had been used by the Boonton Hard Rubber Company for its radio activities, and formed the Boonton Radio Corporation. The new company concentrated its engineering skill toward the development of new measuring equipment sorely needed by the radio industry at that time. For example, there was at that time a specific need for a quick and accurate method for measuring Q. Q measurements were being made indirectly by means of bridges which measured the effective reactance and resistance concerned. These measurements were too often subject to error because of the involved techniques



*Larry Cook, with BRC since 1935, is shown with a preproduction model of BRC's first Q Meter and the current Type 260-A Q Meter.*

required, and were time consuming.

It was this Q measuring problem, in fact, which led to the development of the first Q Meter. Manufacturers were confronted with the costly annoyance of producing coils that would meet all of the requirements when tested at their own plant, only to be rejected because they did not pass inspection at their customers plant. A need for approved standards was evident and this was among the first assignments of the BRC engineers.

### First Q Meter Introduced

In November of 1934, Boonton Radio Corporation presented at the Institute of Radio Engineers' Fall meeting in Rochester, New York, a model of the Company's first Q Meter. This instrument covered the frequency range of 50 kc to 50 mc and was known as the Type 100-A. With this instrument, Q measurements were made simple and rapid. It was also capable of many other valuable laboratory measurements on basic components and circuits. The Q Meter was immediately accepted as a standard by the radio industry and research laboratories. Over the years improved models (the Types 160-A and 260-A) of Q Meters in this frequency range have been introduced.

In 1941, a high frequency model (30

to 200 mc) of the Q Meter, known as the Type 170-A, was introduced. This instrument was followed by the QX Checker (Type 110-A), similar to the Q Meter but designed specifically for rapid production testing of components with laboratory accuracy. This instrument was very easy to operate and could be handled by unskilled personnel.

Today, a faster, more versatile instrument, the Q Comparator Type 265-A has replaced the QX Checker and the low frequency Q Meter (Type 260-A) and high frequency Q Meter (Type 190-A) are in very broad use.

### FM and HF Test Equipment

Just before the Second World War, BRC began development work on a frequency-modulated signal generator to meet the demand for test equipment for the new fm communication equipment. A model of this generator was first presented in 1940 at the Institute of Radio Engineers' meeting in Boston. Several models of these FM Signal Generators, developed by BRC, were used during the war by military and commercial customers.

During the Second World War, BRC provided large quantities of the standard commercial equipment, which had been previously designed for its commercial customers, to the Military Services for use in the War effort. In fulfilling its patriotic duty, the Company prepared a microwave pulse modulated rf signal generator for manufacture. A large number of these instruments were produced for the Military Services for use in testing radar systems. This Signal Generator is still used by the Military.

At the end of the War the FM Signal Generator was redesigned to permit coverage of a wider frequency range, to include AM as well as fm, and to obtain deviations in frequency which did not vary with carrier frequency. This instrument had very low leakage and a wide selection of accurately calibrated output voltages. It soon became the standard in its field.

### Aircraft Navigation Test Equipment

In the 1940's, the aircraft transportation field was developing more accurate methods of navigation and better methods of landing in bad weather. A system for solving these problems was approved by the Civil Aeronautic Administration and put into use both commercially and by the military services. During the development phases of this

Aircraft Navigation and Landing System, BRC was asked to develop test equipment of unusual accuracy for testing several of the receivers involved. A signal generator for navigation equipment was produced in 1947, to be followed a short time later by an equipment for testing receivers used in landing aircraft. A more advanced model of the "Glide Path" testing equipment for the landing of aircraft was produced in 1952.

### The Productive 1950's

In the last decade, the Company's efforts have been directed toward the development of other self-contained, broad-band, flexible instruments. The RX Meter, introduced in 1953, measures parallel resistance and parallel reactance of two-terminal networks over the LF and VHF ranges. This instrument has contributed to the development of the diffusion-based transistor, which in turn is playing a large part in America's missile and satellite program. More recently, the instrument has ventured from the world of missiles and electronics to become one of the medical world's latest weapons against disease. The University of Pennsylvania School of Medicine put the instrument

to work measuring the electrical properties of human and animal tissue.

In addition to the RX Meter, the 1950's brought about the redesign of both the low-frequency and high-frequency Q Meters, increasing the usefulness and accuracy of these instruments, and the development of a Film Gauge for measuring film thicknesses.

In the last 2 years, BRC has offered three new instruments to the electronic industry, all of which were announced at the 1959 IRE Show in New York. These instruments include a Q Comparator designed to give instantaneous and simultaneous readout of Q, inductance, and capacitance on a cathode-ray tube, for production testing of components; a Signal Generator Calibrator which provides accurately calibrated RF output voltages for testing signal generators and receivers and measures percent AM; and a new Signal Generator which provides improved frequency stability over a wide range.

### Expansion of Personnel and Facilities

As the BRC instrument line increased, naturally the plant had to be enlarged and the number of employees increased. The original RFL building

has been lost in a series of major additions, the last of which was completed about eight years ago. The plant now has about 23,000 square feet of working area and houses all of the Company's operations. Company personnel has grown from as few as six persons to a payroll which now includes more than one hundred and fifty employees.

During the past year, the Company has taken two major steps which figure to play an important part in future expansion. The first was the purchase of a 70-acre plant site on which a new plant will be erected in the very near future, and the second was joining forces with the Hewlett-Packard Company to become a wholly-owned subsidiary of that firm.

### Quality Key to Success

Over the years, BRC has built electronic tools which have come to be recognized throughout the world for their superior quality. We attribute this success to the fact that our instruments receive expert care from the drafting boards to the final test department, and to our policy of building only those instruments which have been pioneered in our own laboratories.

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