# The GENERAL RADIO EXPERIMENTER

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ELECTRICAL COMMUNICATIONS TECHNIQUE AND ITS APPLICATIONS IN ALLIED FIELDS


## MEASUREMENT OF THE IMPEDANCE OF THE HUMAN BODY

> THE Horton Impedance Comparator described here was developed at the Electrical Engineering Department of the Massachusetts Institute of Technology and built by the General Radio Company. Although designed for use in medical diagnosis, it has a number of other applications in the physical sciences. It is already being used in physical chemistry to measure the impedance of solutions, where, by virtue of its four-terminal connection, it yields results which are independent of the impedance of the electrodes.

BY CHANGING merely the last two letters, the word physician becomes physicist. Actually, even this small change is unnecessary because the physician secures the greater part of his data regarding the condition of a patient through observations on various physical quantities. Among the many properties which may have diagnostic significance, those of an electrical character have not been generally considered. They have, however, received occasional attention since Galvani in 1791 first demonstrated that living matter exhibits electrical phenomena.

The first serious attempt to correlate the electrical properties of a human body with its pathological condition was made in 1881 by the French scientist, Vigoreaux. He reported that there was a relation between the electrical resistance of the body and the degree of thyroid activity. Measurements of d-c resistance were, however, difficult owing to polarization at the electrode surfaces and no practical use was made of Vigoreaux's findings. Following the introduction of alternating-current technique into electro-chemical measurements, Gildermeister, in Germany, repeated Vigoreaux's investigations, using alternating current. This avoided the difficulty of electro-polarization as such. It was found, however, that there was an appreciable reactance component in the

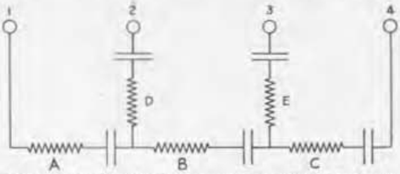



FIGURE 1. Equivalent network of the impedances joining four electrodes applied to the body. The electrodes are numbered *1*, *2*, *3*, and *4*. Path *B* is the impedance of the internal tissue between the inner electrodes *2* and *3*. Branches *D* and *E* are the surface tissue impedances under the inner pair of electrodes, while *A* and *C* are each the total impedance between one electrode of the outer pair and the junction of the impedances representing surface tissue and internal tissue under the corresponding inner electrode

measured impedance. This reactance has the sign of a capacitive reactance although it is probable that it is due to polarization within the tissues. Very recently Dr. Brazier, in England, has reported that there is a correlation between the resistance-reactance ratio and thyroid activity.

In an attempt to check Dr. Brazier's conclusions, an extensive investigation was carried out jointly by the Massachusetts Institute of Technology and the Massachusetts General Hospital.*† The first result of major importance was the discovery that there was a marked difference in behavior between internal and external tissues. The data on which these conclusions are based were obtained by applying four electrodes to the body. The current paths joining these four electrodes may be considered as made up of separate branches, some of which are composed wholly of external tissues and some wholly of internal tissues. By measuring with a bridge the impedance between each of the six possible terminal pairs, the impedance of these separate branches may be evaluated.

From studies made at different frequencies, it was evident that accurate observations of the reactance-resistance ratio could not be made for the external tissues at frequencies much higher than 10 kilocycles, nor for the internal tissues at frequencies much lower than this value. Consequently, 10 kilocycles was chosen as the most suitable frequency for subsequent investigations.

Data obtained by the bridge method indicated that the impedance of the internal tissues offered considerable promise as a diagnostic indicator. In order to simplify the measuring technique there has been developed a special form of alternating-current potentiometer by which the impedance of either internal or external tissues may be determined in a single measurement. This apparatus is designed to work only at 10 kilocycles and hence can be calibrated to read reactance in ohms directly.

The general arrangement of the potentiometer is shown schematically in

FIGURE 2. Panel view of the impedance comparator

* "The Electrical Impedance of the Human Body," J. W. Horton and A. C. VanRavenswaay, *Journal of the Franklin Institute*, Vol. 220, No. 5, November, 1935.

† "The Clinical Significance of Electrical Impedance Determination in Thyroid Disorders," Horton, Van Ravenswaay, Hertz and Thorn, *Endocrinology*, January, 1936, pp. 72-80.

Figure 3. Current is supplied independently by two identical transformers to one pair of electrodes on the patient and to a standard circuit including a fixed resistance and the primary winding of a mutual inductometer. These two currents are brought to identity with respect to both magnitude and phase by adding in series with the patient an impedance of such value that the loads on the two transformers are identical. This condition is indicated by equal voltage drops across the equal resistors $R_1$ and $R_2$ when the detector is switched to the dotted position. When this identity between the two currents has been established, the detector is switched so that it indicates the difference between the voltage set-up between the second pair of electrodes on the patient and a voltage composed of the resistance drop across the portion of the standard resistance and the induced voltage in the inductometer secondary. These last two components are adjusted until the differential voltage is zero. When this condition is established, the impedance of that portion of the patient which is common to the two current paths be-

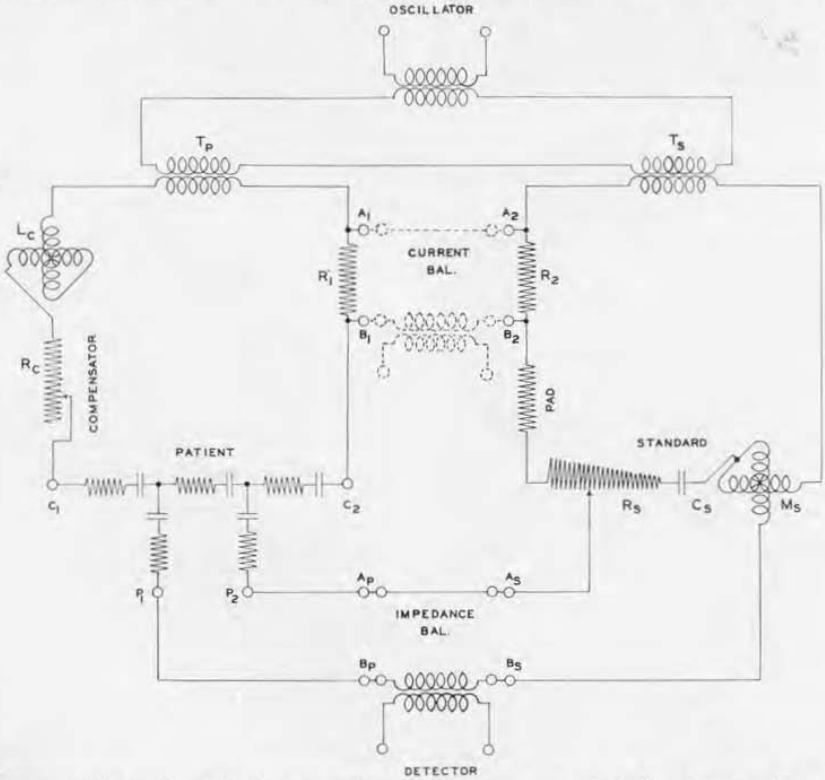



FIGURE 3. Schematic wiring diagram of the impedance comparator, including the network representing the patient. Since no current flows through electrodes $P_1$ and $P_2$ at balance, these act as potential terminals and measure the true internal impedance of the patient, corresponding to $B$ in Figure 1

FIGURE 4. For convenience the impedance comparator and its associated amplifier and power supply are mounted on a "tea wagon." The author is shown measuring the impedance of a patient. On the patient's right arm are one inner and one outer electrode. The other pair of electrodes are on the left arm

tween the two pairs of electrodes is known to have a resistance component equal to the included portion of the fixed resistance and a reactance component equal to the mutual reactance of the inductometer.

Using this device, to which the name "impedance comparator" has been given, extensive measurements have been made of a wide variety of pathological cases. Extensive measurements have been made also of the variations occurring in a single individual. The results may be generalized briefly as follows:

Every person in normal health has a value of $Q$ for the internal tissue which is characteristic of him as an individual. Any abnormal pathological condition will act to change this value, and changes of the order of 2 to 1 have been observed. For individuals in normal health $Q$ lies between 0.10 and 0.07. The pathological spread is from 0.02 to 0.14. In a single individual, $Q$ may vary as much as $\pm 10\%$ depending on the preceding history with respect to fatigue.

These studies have indicated that there are physiological differences between internal and external tissues as well as electrical differences, and it is believed that they should be measured separately in any study of the correlation between electrical impedance and pathological condition. For such measurements the comparator described above has been found to be both accurate and convenient.—J. W. HORTON

## A NOTE ON THE USE OF TYPE 508-A OSCILLATOR

USERS of the TYPE 508-A Oscillator may experience some difficulty in securing proper operation with the 45-type vacuum tubes currently available. The new tubes produce an appreciably greater amplitude of oscillation than do older types. Intermittent oscillation at 3 kc and 4 kc may occur owing to a charge accumulating on the grid condenser and resulting excessive negative bias. This can be remedied by using a lower grid leak resistance (30,000 ohms in place of 50,000 ohms), or by introducing a resistance of between 1000 and 5000 ohms in series with the grid, i.e., between the grid coil and the grid itself. The latter method is preferable since it improves the waveform.

— R. F. FIELD

# CARRIER ENVELOPE ANALYSIS WITH THE WAVE ANALYZER

FOUR years ago[1] this company announced a distortion factor meter which gave the root-mean-square distortion of a 400-cycle signal. This instrument, when used in conjunction with a modulation meter to rectify the r-f signal, gave corresponding results for the carrier envelope of a radio signal modulated at 400 cycles. A more recent instrument[2] combines these functions in a single unit.

Although distortion measurements at the standard test frequency of 400 cycles are adequate for all routine checks on broadcast transmitters, the larger stations, groups of stations and transmitter manufacturers often wish to make these measurements at other test frequencies or throughout the audio-frequency range. While instruments have been built to order for single test frequencies, the heterodyne-type wave analyzer[3] is the best answer to this need because it is not limited to a single-frequency fundamental.

There is still one missing link—the application of the audio-frequency heterodyne wave analyzer to a radio-frequency carrier envelope. This need has been taken care of to some extent by providing "ENVELOPE" terminals on the TYPE 732-A Distortion and Noise Meter, which makes the demodulated output of its linear rectifier accessible for further analysis. This, however, is a compromise because the distortion and noise meter is designed primarily for 400-cycle operation, and its characteristics are not entirely satisfactory when much higher modulation frequencies are used (above a 2000-cycle fundamental, for example).

A simple linear rectifier to plug into the TYPE 636-A Wave Analyzer is not difficult to construct. Figure 1 is a photograph of one used in the laboratories of the General Radio Company. The circuit is shown in Figure 2.

It will be noticed that the circuit is entirely conventional except for the choice of constants and the physical arrangement. The very high leak resistor is made possible by the fact that full-scale deflection on the wave analyzer is obtained with a current of only 0.01 microampere. This freedom in the choice of constants makes a

FIGURE 1. Photograph of the linear rectifier assembly

[1] W. N. Tuttle, "Direct Measurements of Harmonic Distortion," General Radio *Experimenter*, VI, 6, November, 1931.

[2] L. B. Arguimbau, "Monitoring of Broadcasting Stations," General Radio *Experimenter*, IX, 10, March, 1935.

[3] L. B. Arguimbau, "Wave Analysis," General Radio *Experimenter*, VIII, 12–13, June-July, 1933.

FIGURE 4. Showing the rectifier plugged into the input terminals of a TYPE 636-A Wave Analyzer

highly linear detector possible. The acorn type of tube was chosen primarily because its inter-electrode capacity from plate and grid to cathode is only 2.4 μμf, which permits the use of a small series condenser with consequent improvement of the audio-frequency characteristic. Incidentally, the effective carrier-frequency input impedance is increased.

Although not necessary, the meter shown in the circuit diagram is useful in measuring the magnitude of the radio-frequency input voltage.

The metallized 10-megohm resistor is mounted as a direct connection between two shielded compartments, the ends being in different compartments. No attempt has been made to measure the equivalent direct shunting capacity across this resistor, but it is less than 0.1 μμf and is probably very much smaller than this. This method of mounting is very important since a capacity as large as 1.0 μμf would begin to cause trouble at 10 kc.

The circuit as drawn is satisfactory at modulation frequencies up to 2000 cycles with almost perfect linear detection even when 100% modulation is exceeded. At modulation frequencies up to about 10 kilocycles it will work linearly, provided the modulation percentage is not allowed to approach 100%.

If the series resistor is replaced by a 1-megohm pad, as shown in Figure 3, the linearity will not suffer very much, and the unit may then be used at 10 kilocycles with 100% modulation. It turns out that, if the time constant of the CR combination is chosen in such a way that the net impedance presented to the tube at the modulation frequency is less than that presented to the rectified direct current, the extreme negative peaks of modulation will be somewhat clipped, generating distortion. — L. B. ARGUIMBAU

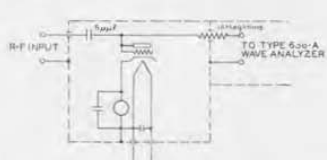



FIGURE 2. Circuit diagram of the linear rectifier

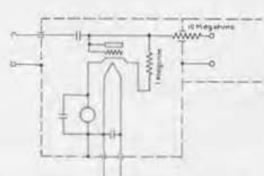


FIGURE 3. Alternative wiring diagram using a one-megohm pad

# VARIAC LIGHTING CONTROL IN THE LITTLE THEATER

Lighting control in the little theater presents a problem which taxes even the ingenuity of the amateur property man, who must reconcile limited funds and a need for flexibility with the necessary requirement of complying with the underwriters' rules.

The *VARIAC* provides a convenient and efficient way of solving the problem. It provides a smooth variation of illumination and eliminates the waste of power which is inherent in resistive controls. In addition, the *VARIAC* can be used on any load up to its maximum capacity, while resistance dimmers are designed for a single load.

Figure 1 shows a lighting control unit built by East End Electric of Meadville, Pennsylvania, and used in the little theater at the College of

Figure 1. Photograph of the lighting-control panel

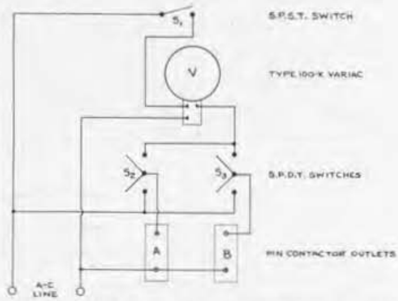



Figure 2. Wiring diagram showing connections for one *VARIAC*

William and Mary. It is entirely portable so that it can be moved from the theater to any part of the campus where it is needed. By the use of *VARIACS*, any size lamp load up to 2 kw can be dimmed from full intensity to black out.

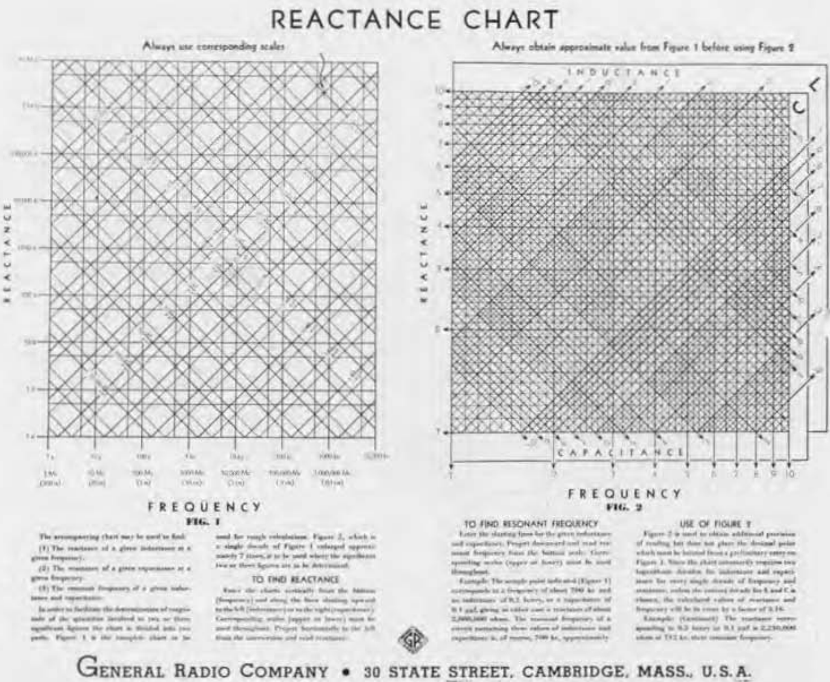
The board has a total load capacity of 33 kw and is supplied with a large stage cable that connects to the control board at the rear of the main safety switch at the base of the unit. All lighting equipment under control is plugged into the pin connector outlets on either side of the main switch.

Ten separate circuits are provided with controls arranged on the panel in two horizontal rows. The *VARIACS* are below the row of toggle flush switches (corresponding to $S_1$ in Figure 2), and below the *VARIACS* are the enclosed single-pole double-throw knife switches ($S_2$, $S_3$).

Figure 2 is a wiring diagram showing how each *VARIAC* is connected. Referring to Figure 2, if $S_2$ is in the upper position, outlet *A* is connected to the *VARIAC*, and its voltage may be varied from zero to full line voltage. The switch may then be thrown to the lower position, connecting outlet *A* directly to the line and leaving the *VARIAC* free for use on circuit *B* by means of the switch $S_3$.

This feature adds to the flexibility of the board, making it possible to control two separate scenes from the same *VARIAC* and to switch from one scene to the next without loss of time.

While the control board described here approaches the proportions of a professional installation, smaller amateur units can be built along the same lines, using smaller types of *VARIACS*.




We still have available a number of large reactance charts similar to that shown above. These charts are 19 x 24 inches and are suitable for mounting on the wall. Copies will be sent free to all who request them.

GENERAL RADIO COMPANY

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