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NOTES ON POWER MEASUREMENT IN COMMUNICATION CIRCUITS*

By JOHN D. CRAWFORD

II

ANOTHER communication measurement problem makes its appearance when it is desired to determine experimentally how much power a given power source is capable of delivering to a specified load or sink. So long as the source itself is available for test, it is merely necessary to set up the equipment and make the measurements. If, however, the source is not available, some means must be found of simulating it. At least two methods for doing the job are available, and we propose to describe them. Both are perfectly general: the "source" may be a vacuum-tube oscillator or a microphone or an incoming transmission line; the "load" may be a loud-speaker or an attenuation network or an outgoing transmission line. There are only two restrictions: the "source" must supply a sinusoidal voltage, and the impedance of the "load" must not depend upon the current in it.

A generalized statement about networks called Thévenin's Theorem gives directly one of the methods for setting up a simulating source. We shall defer stating it until later because it will simplify matters to set up a specific hypothetical problem, follow through its solution, and with that as a basis, state the general law. Our discussion must be understood to be an attempt to show that Thévenin's Theorem is plausible without trying to prove it.

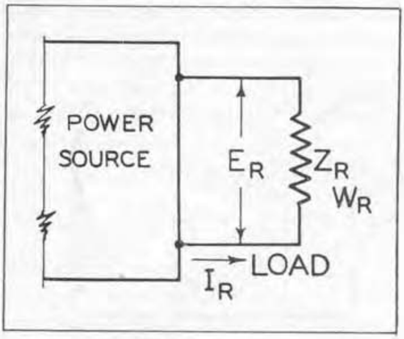

FIGURE 3

Consider, for example, the load circuit shown in Figure 3. Its impedance at a given frequency is Z_R; the voltage drop, current, and absorbed power which correspond to Z_R are, respectively, E_R, I_R, and W_R. Inasmuch as Z_R is assumed to be independent of

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* This is the second part of an article begun in the October issue of the *Experimenter*. Although complete in itself, this section depends upon the introduction preceding Part I.

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I_R, we can make the obvious statement that for any value of Z_R, W_R will depend only upon the magnitude of E_R (or of I_R, since E and I are linked by Ohm's Law).

Now suppose that we want to determine experimentally how much power the load will absorb at different frequencies from a given power source which is not available for the tests. What must we do in order to set up a simulating source? We have just seen that the only way a source can affect W_R is to change E_R. Therefore, all we need do to simulate the given source is to make sure that, no matter what value Z_R may assume (as a result of changing the test frequency, for example), E_R for the simulating source is the same as E_R for the source itself. In other words, no power measurements on the load could tell us which of two sources was supplying power if the terminal voltages (E_R) of each were the same.

Let us also assume that the source to be simulated is an alternator which delivers a constant voltage at its output terminals no matter what load is thrown upon it.* Because of a high-impedance line between the alternator and its load terminals, the voltage at the load terminals depends upon the size of the load. This condition is represented in Figure 4, where E is the voltage of the alternator, G, and Z_2 is the impedance of the line. E_R is therefore always less than E by E_2, the voltage drop in Z_2. In other words, W_R depends upon Z_2.

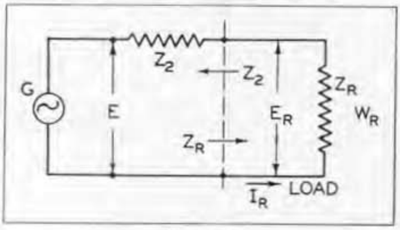

FIGURE 4

From what has gone before, Z_2 may be considered a part of a new load, Z'_R, having an impedance of $Z_2 + Z_R$. The power delivered to this new load will, as before, be fixed if the voltage drop across it is fixed. The generator, G, delivers constant voltage under all conditions of load, a fact which enables us to build a simulating source. Since the load cannot distinguish between one generator and another if the impressed voltages are the same, we can take any generator, maintain its terminal voltage equal to E by manual adjustment, and the power delivered to Z'_R will be the same for both the actual and the simulating sources. Furthermore, the voltage drop in Z_2 will be the same under both conditions, and the power delivered to Z_R will be the same as though it were connected, to the original source. Therefore, we have shown that any generator connected in series with an impedance equal to Z_2 will simulate this particular source, if the voltage at the generator terminals is maintained constant and equal to E.

From the foregoing discussion we may conclude that the presence of Z_2, the internal impedance for the given power source, is the reason why changes in the magnitude of Z_R affect the terminal voltage E_R. If Z_2 is equal to zero, E_R would be constant and equal to E, the open-circuit voltage of the source; but if Z_2 is not zero, then every decrease in the magnitude of Z_R causes E_R to be less than E by the voltage drop in $Z_2 = I_R Z_2$. Furthermore, any generator or any source behaves as though it had no internal impedance if its terminal voltage is maintained constant.

Suppose that G were not a constant-voltage generator, or, in other words,

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*An oscillator which could do exactly that would be a curiosity, having, as we shall point out later, a negligible "internal impedance."

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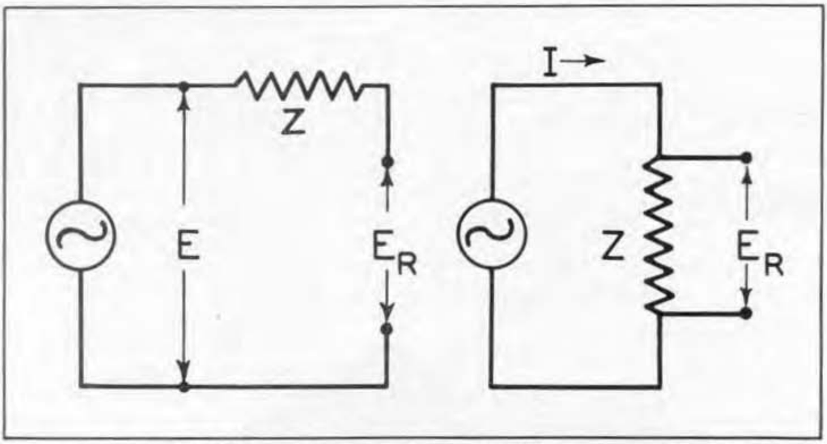

Figure 5. Two methods for simulating a power source when its open-circuit voltage $E = IZ$ and its internal impedance Z are known. Left: Constant-voltage method. Right: Constant-current method

suppose that its terminal voltage E depended upon the amount of current taken by the load. This would, of course, indicate that somewhere ahead of its output terminals there existed an appreciable impedance. To simulate this new source we would proceed exactly as before: maintain the simulating-generator voltage constant and equal to the open-circuit voltage of the source and connect in series with it an impedance equal to $Z_G + Z_2$, the sum of the internal impedance of G and the impedance of the intervening connecting wires.

It is now time to discard all of our labored attempts at a simple and orderly development to state the general law about which we spoke at the beginning of this section. It is a corollary of Thévenin's Theorem, a theorem that is capable of a formal proof with which we shall not concern ourselves here. Thévenin's Theorem permits us to state that *any* power source can be simulated (Figure 5) by a generator with a terminal voltage E connected in series with an impedance Z; E being equal to the no-load or open-circuit voltage of the source and Z being equal to the impedance of the source *as seen from its output terminals*. This can be verified experimentally for a simple source like the one we have been discussing by connecting an oscillator to a load of adjustable but known impedance and observing its terminal voltage as a function of delivered power or of load impedance or of current. Errors due to bad waveform and overloading in the oscillator must not be allowed to enter.

The diagram at the right in Figure 5 shows the second simulating method and although it does not follow directly from Thévenin's Theorem, it can be shown to be entirely consistent with it. In the second method, constant current is maintained through the parallel circuit formed by Z, the impedance of the simulating source, and the load impedance; the constant current being such as to make the no-load voltage drop across the simulating impedance equivalent to the no-load voltage of the power source. If we can show that for any value of Z_R the voltage E_R is the same for both the constant-current and the constant-voltage methods, the two are equivalent.

Imagine that both circuits are terminated in a load Z_R:

(a) for constant-voltage method,

$$E_R = I_R Z_R = \left(\frac{E}{Z+Z_R}\right) Z_R = \frac{EZ_R}{Z+Z_R};$$

(b) for constant-current method,

$$E_R = I\left(\frac{Z_R Z}{Z+Z_R}\right) = \frac{E}{Z}\left(\frac{Z_R Z}{Z+Z_R}\right) = \frac{EZ_R}{Z+Z_R}.$$

If the voltage of the source is non-sinusoidal or the impedance of the load is non-linear (i.e., a function of current), special care must be used in applying these simulating methods. The same care must be exercised when studying transient effects, since our discussion has been tacitly limited to the steady-state condition.

A NON-POLAR RELAY

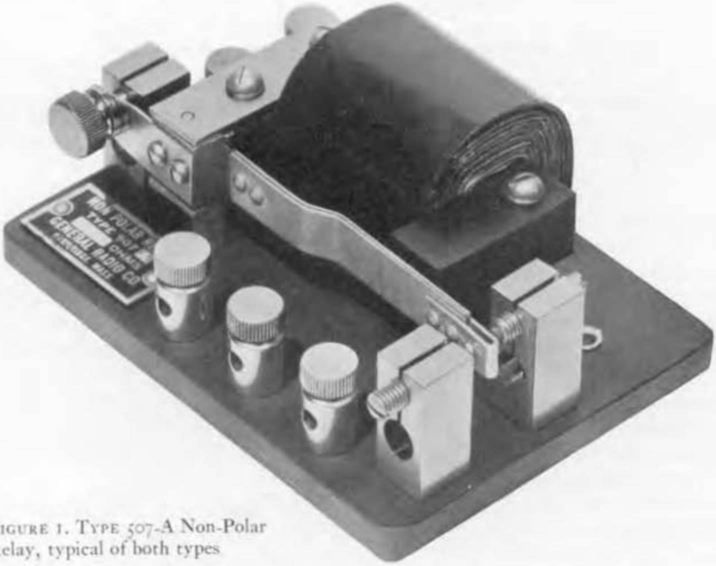

FIGURE 1. TYPE 507-A Non-Polar Relay, typical of both types

AS their names indicate, the new TYPE 507 Non-Polar Relays contain an armature that is not permanently magnetized. They do not, therefore, distinguish between the two directions of current as does the TYPE 481 Low-Current Relay.* Their principal use is in cases where contacts of low current-carrying capacity must control heavier currents, as in the TYPE 547-A Temperature-Control Box.

There are two of the new Non-Polar Relays, bearing the type numbers 507-A and 507-B, respectively. Their specifications are as follows, currents given corresponding to positive operation in either vertical or horizontal positions:

TYPE 507-A Non-Polar Relay. Current to close, 10 mla. Current to open, 6 mla. Resistance (±5%), 250 ohms. Code Word, NITRE. Price $12.00.

TYPE 507-B Non-Polar Relay. Current to close, 2 mla. Current to open, 1 mla. Resistance (±5%), 4000 ohms. Code Word, NOBLE. Price $15.00.

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*C. T. Burke, "A New Relay," *General Radio Experimenter*, III, February, 1929.

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TEMPERATURE CONTROL FOR PIEZO-ELECTRIC OSCILLATORS

QUARTZ plates for use as standards of frequency in piezo-electric oscillators must be kept under temperature control if constancy of frequency is to be expected. It is impossible to make a general statement about the frequency of such an oscillator as a function of the temperature of the plate, because the frequency-temperature coefficient varies considerably with the way the plate is cut. Even among plates of the same "cut" taken from the same mother crystal, the coefficients are not alike. It is, however, safe to say that the frequency variations per Centigrade degree will average about 30 parts in a million with a possibility of its being as great as 75 or 100 parts in a million. The necessity for temperature control where precision frequency standards are to be maintained is obvious.

On the question of temperature-control methods there are different points of view taken by two groups. One says: standardize on a definite operating temperature, maintain it as closely as possible, and specify the operating frequency of the quartz plate at that temperature. The other group says: standardize on a nominal operating temperature *near* which the temperature is to be maintained, and rely upon making adjustments in the frequency of the plate by changes in its temperature. Control equipment to meet the specifications of both groups should reduce variations in temperature to the same minimum, but the second group requires, in addition, a thermo-regulator that can be readily adjusted to any value in the neighborhood of the standard temperature.

The General Radio Company holds that with plates for frequency standards,* the temperature should be kept constant and all adjustments of frequency made by the use of an adjustable air-gap in the plate holder or by changes in the circuit constants of the oscillator itself. This attitude has much to recommend it from the point of view of both the manufacturer and the user of high-precision quartz plates, for it simplifies the problem of constructing suitable temperature-control boxes and makes for interchangeability of one plate with another. It has an important bearing upon the cost of adjusting quartz plates, since the extra time and labor involved in calibrating one plate at 51.7 degrees and the next at 48.3 degrees (for example) is considerable. The General Radio Company has established 50.0 degrees Centigrade as its operating temperature for standard quartz plates, a value which is in accord with those established by other American laboratories, civil and military. This temperature is high enough to make possible the operation of temperature-control equipment in the tropics without heat absorbers (refrigeration).

When it became apparent two years ago that quartz plates of high precision would be in demand, the General Radio Company investigated the temperature-control equipment that was already on the market with a view to adapting it to meet the following requirements: (*a*) ability to maintain the temperature to within one- or two-tenths of a Centigrade degree over a fairly wide variation in room temperature; (*b*) absence of circulating air and

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* As distinguished from their use as controls in oscillators where a maximum power output is one of the first considerations. All General Radio quartz plates are intended for use only in low-powered oscillators.

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oil baths; (*c*) compactness; and (*d*) ease with which modifications for electrical connections could be made.

It may be of interest to note that the range of permissible variations in room temperature is a most important feature of any temperature-control unit. Yet, strangely enough, it is one of the specifications that is often overlooked. A box which would control the temperature to within one degree when the room-temperature variations were limited to two degrees might show an entirely different characteristic if the room temperature were allowed to change with the weather.

No commercial unit that met all of the requirements being available, a development program was begun which has extended over an entire year, ending with the design of the TYPE 547-A and the TYPE 547-B Temperature-Control Boxes shown in Figures 1 and 2. They are of the same construction, differing only in the type of thermo-regulators employed.

Both boxes are encased in walnut cabinets within which are arranged (in order): a balsa wood insulating layer, the heaters, an aluminum distributing layer, an asbestos pressboard attenuation layer, and a second casing of aluminum which forms the temperature-controlled chamber. The inner space is 4 inches by 4 inches by 3⅝ inches deep, and in it are two sets of terminal blocks into which two TYPE 376 Quartz Plates may be plugged. A switch on the front of the bakelite panel allows a selection to be made. The heaters are placed on all six faces of the outer aluminum casing, the aluminum tending to equalize the temperature over the surfaces and reduce the temperature gradient inside the controlled chamber. Heater current is supplied from any 110-volt main, either alternating- or direct-current.

Of special interest to those desiring temperature-control for use with General Radio piezo-electric oscillators is the fact that the TYPE 547 Temperature-Control Boxes are intended to be mounted on top of them. The cabinet size is the same as that of the TYPE 275 Piezo-Electric Oscillator and a special

FIGURE 1. TYPE 547-A Temperature-Control Box

connecting bar is available for linking the two units. A slight modification in the Type 375 Station Piezo-Electric Oscillator adapts it for use with the new units in the same manner.

On the front of the bakelite panel are mounted rheostats for controlling the amount of power delivered to the heaters. Depending upon their adjustment, the power delivered to the unit will range between 41 and 71 watts.

The Type 547-A Temperature-Control Box utilizes a mercury-type of thermo-regulator which may be adjusted to operate at any temperature between 40 degrees and 60 degrees Centigrade. Once the regulator has been adjusted, the temperature of the air inside the chamber is held to within ±0.1 degree Centigrade for a variation in room temperature of ±20 degrees Centigrade (±11 degrees Fahrenheit). This temperature variation in a quartz plate will keep the frequency of a piezo-electric oscillator within limits satisfactory for practically all purposes. The thermo-regulator operates the heater circuit through the relay shown on the front of the panel, a six-volt battery being required.

Once the thermo-regulator in the Type 547-A Temperature-Control Box has been adjusted to the desired value, the operating temperature cannot be changed without removing it from the inside of the box. Sometimes, as we have previously mentioned, it is desired to adjust the operating temperature while the unit is in operation. At a sacrifice in the degree of constancy with which the temperature is maintained, the Type 547-B Temperature-Control Box has been made available.

It makes use of a bi-metallic thermo-regulator that depends for its operation upon the unequal temperature-coefficients of two strips of metal. It is rugged enough so that it controls the heater current directly without the necessity for a relay, which, of course, eliminates the need for the six-volt supply.

The temperature may be adjusted to any value between 40 degrees and 60 degrees Centigrade, and the air within the chamber will remain within ±1.0 degree Centigrade for a room temperature variation of ±20 degrees Centigrade (±11 degrees Fahrenheit). This unit is recommended for use only where the ability to change the temperature while the unit is in operation is of importance.

Both units are primarily intended for operation near 50 degrees Centigrade where the room temperature

Figure 2. Type 547-B Temperature-Control Box

variations occur around a mean of 20 degrees Centigrade. Inspection of the above specifications might lead one to expect that good control of temperature might be obtained for an operating temperature of 40 degrees and a room temperature of 40 degrees. That control could be had under this condition is improbable, and in localities where the temperature of the room might rise to 40 degrees Centigrade, the operating temperature should be kept higher, 50 degrees, if possible.

The commercial data on these instruments are as follows:

TYPE 547-A Temperature-Control Box. Code Word, BURLY. Price $150.00.

TYPE 547-B Temperature-Control Box. Code Word, BUXOM. Price $140.00.

They will be ready for delivery on November 15.

MISCELLANY

By THE EDITOR

WITH the September issue of the *Experimenter* we enclosed a card which readers were asked to return if they wished to continue on the mailing list. Although the percentage of returned cards has been large, we feel that there are still some interested readers who have neglected to return them. If it is your intention to return the card, please do so at once.

None of the changes requested on returned cards have been made, and no names have as yet been dropped from the list because no card was returned. It may be of interest here to state that on the average of one card in every four calls for a change in the address stencil.

Should you have mislaid your return card, a letter or a postal card with the following information will replace it:

(a) Your name and mailing address (printed for the sake of legibility)
(b) Your business affiliation
(c) The kind of business in which your firm is engaged
(d) Your position
(e) The technical field in which you are particularly interested.

If you can return the address label from the *Experimenter* mailing envelope, so much the better, inasmuch as our files are arranged alphabetically.

These cards were sent out for the purpose of correcting our mailing list and of removing from it those persons who are no longer interested in reading the General Radio *Experimenter*. The additional information about each reader is being used to analyze the circulation so that the editor may know the different classes of readers for whom he is preparing material.

CONTRIBUTORS

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