The GENERAL RADIO
EXPERIMENTER

VOL. VI. No. 10 MARCH, 1932

ELECTRICAL COMMUNICATIONS TECHNIQUE
AND ITS APPLICATIONS IN ALLIED FIELDS

THE MICHELSON VELOCITY OF LIGHT EXPERIMENT

We are indebted to Mr. E. C. Nichols of the Department of Instrument Design at the Mount Wilson Observatory, Pasadena, for the accompanying description of the latest experiment to determine the velocity of light in a vacuum.—EDITOR.

THE following is a brief description of the Michelson velocity of light experiment in vacuum. This experiment, made at the Irvine ranch near Santa Ana, California, during the period from May, 1930, to July, 1931, by A. A. Michelson of the University of Chicago, F. G. Pease of the Mount Wilson Observatory, and F. Pearson of the University of Chicago, was an endeavor to determine more accurately the velocity of light. The investigation was carried out jointly by the Mount Wilson Observatory of the Carnegie Institution of Washington and the University of Chicago.

In this experiment two systems of measurement were used: the first, that of time; the second, that of distance. In the case of the latter measurement it was felt that the direct measurement of a short base line without the additional triangulation might yield a higher order of accuracy. This was accomplished with a vacuum tube one mile long, the light traversing it eight or ten times. The base line was measured by Commander Garner of the United States Coast and Geodetic Survey. The results of this measurement have a probable error of ±0.47 mm. or one part in 3,400,000.

TIME MEASUREMENT

Two clocks were used in the time measurement. One was a ship's chronometer beating seconds on a relay and omitting every 59th second. The rate of the chronometer changed frequently, rarely remaining the same for 24 hours. The other clock was a constant-frequency oscillator of General Radio make, controlled by an oscillating quartz crystal, the period of which was increased by two multivibrators. The seconds relay and the syncro-clock of the constant-frequency oscillator were operated on a shaft driven by a unipolar motor. The unipolar motor was in turn operated by the multivibrators.

The rate of the constant-frequency oscillator was decidedly more constant than the ship's chronometer. Comparisons were made on a chronograph having two ink pens operated by relays. The chronograph was driven by a synchronous motor and had a peripheral speed of one inch per second. Time signals were also recorded on the chronograph. These signals were received from Arlington four times a day on 1700 meters.

DESCRIPTION OF APPARATUS

The mile-long three-foot diameter vacuum tube consisted of 60-foot lengths of riveted and soldered corrugated galvanized pipe No. 14 gauge, joined with rubber balloon tire inner tubes and cemented to the pipe ends with rubber cement. At each end two steel tanks were included in the tube to house the mirrors and their controls for the optical system. These tanks were fabricated from ⅜-inch steel plate and welded. They rested on base plates of the same material and were sealed with a lead wire and hydroseal; no bolts were necessary. All joints were painted with several coats of Glyptal. Not a single machined surface was necessary in the entire vacuum container, which had a volume of 40,000 cubic feet and resisted a total collapsing pressure of 53,000 tons.

The mirror mountings and their controls in the tanks were supported independently on separate concrete piers by steel columns extending up through openings in the base of the tanks. These openings were sealed off by rubber sleeves. All adjustments to the mirrors inside the tube were made with small motors operated by remote control through a motor generator Selsyn system operated from the head station at the south end of the tube. Two Kinney vacuum pumps having a total capacity of 450 cubic feet of free air per minute were used to evacuate the tube. A vacuum of 0.5 millimeters was obtained.

THE OPTICAL SYSTEM

Light from an arc lamp was imaged by a condensing lens onto a slit. The light coming through the slit passed above a small right-angle prism and onto the upper half of one of the faces of the 32-sided rotating mirror. This mirror rotated at approximately 500 revolutions per second. From the rotating mirror the light was reflected through a plane-parallel window into the tank to a diagonal flat mirror and then at right angles to a 50-foot focus concave mirror, which changed the light into a parallel beam. From the concave mirror the light passed over a 22-inch diameter flat mirror and fell upon another 22-inch flat one mile away at the north end of the tube. Thence the light was reflected nine times back and forth the length of the tube between the two 22-inch mirrors, finally emerging through the window in the tank over the same path but slightly lower and striking the lower half of the rotating mirror on a face adjacent to the one from which it was originally reflected. From this face the light was reflected into the small right-angle prism and thence onto the cross wire and was observed in the eyepiece. The single vertical cross wire was mounted in a micrometer which had divisions reading to 0.001 inch.

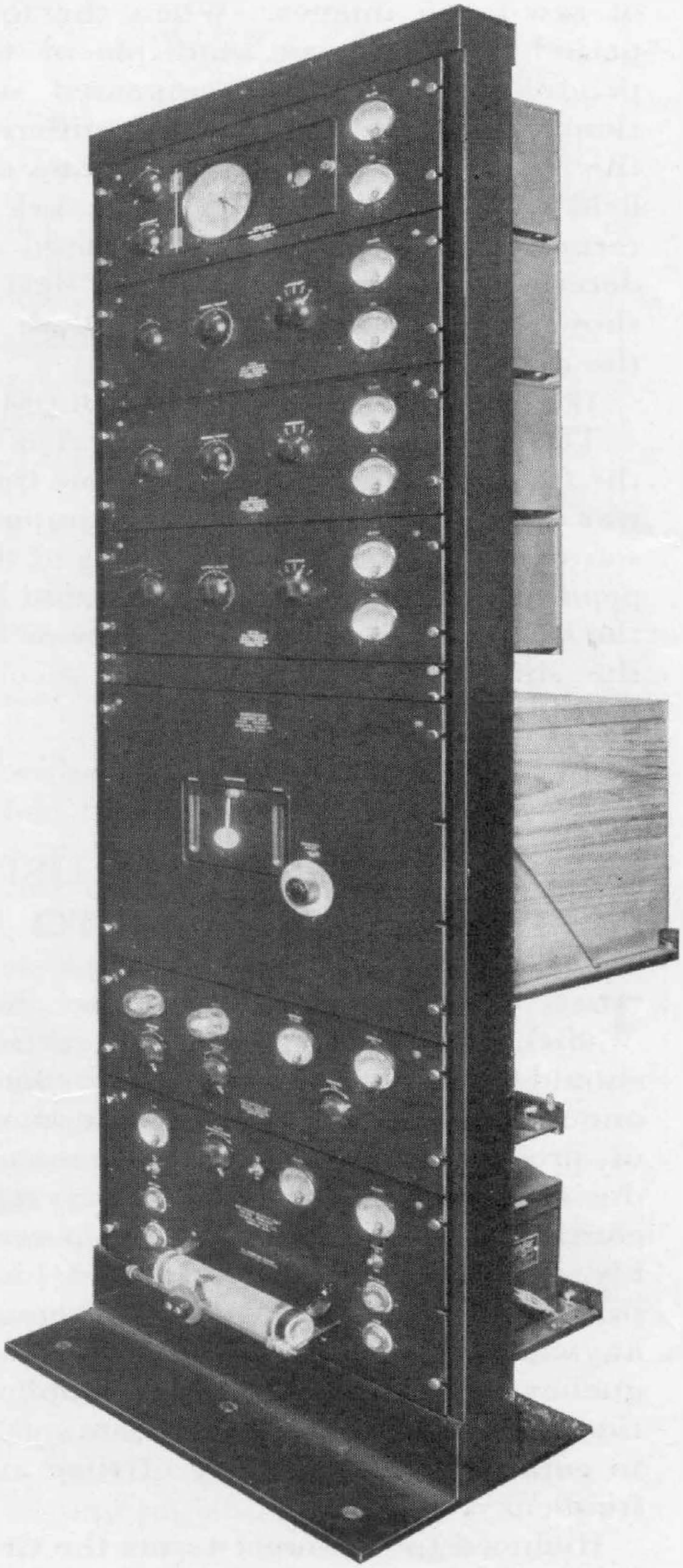
The rotating mirror was driven by a small compressed air turbine mounted directly on the mirror spindle.

SYSTEM OF MEASUREMENT

In the null method used, the light emerged from one face of the rotating mirror and was received on the adjacent face. As the mirror started rotating the image gradually passed from the field of view, later to reappear from the opposite side of the field as the mirror approached its proper speed. The rotating mirror was brought into synchronism with a tuning fork whose period of vibration had to be measured. The slight angle in which the return beam differed from 1/32 revolution was measured with the micrometer. The distance remained fixed. The time interval to be measured, therefore, was that during which the rotating mirror turned from one face to the next, plus or minus a small angle observed in the eyepiece.

The period of the fork was then determined by stroboscopic methods in terms of free-pendulum beats. As the rotating mirror accelerated, light from a 6-volt lamp was reflected from a small mirror on the tuning fork onto a polished face of the nut clamping the rotating mirror to its spindle. As the mirror continued to accelerate, the image from the tuning fork passed through a series of vibrating and stationary states to a final stationary state for which the beats heard between the fork and the rotating mirror ceased. At this point a second observer made a setting on the return image formed by the light traversing the tube and read off the micrometer. A reversal of the direction of rotation of the mirror eliminated any necessity for making zero readings.

In checking the tuning fork with the pendulum, light from a small lamp was focused on a narrow slit and passed into the pendulum case, whence it was reflected by a small mirror on the pendulum and focused on the edge of the tuning fork. When the fork vibrated, flashes of light from the mirror on the pendulum illuminated the fork in various positions, thus producing a series



The standard-frequency assembly used in the Michelson experiment was similar to the one shown above, except that one of the multivibrators was replaced by an amplifier for the 0.1-second pulses from the syncro-clock of saw-tooth images. When the fork period was an exact multiple of the pendulum, the images appeared stationary. When the periods differed, the teeth appeared to travel across the field of view. The period of the fork in terms of the free pendulum could be determined from the number of flashes shown in traveling from one tooth to the next.

TRUE PERIOD OF FREE PENDULUM

The determination of the period of the free pendulum in terms of true time was done in two steps. First a comparison was made between the beats of the pendulum and a flash box, operated by the constant-frequency oscillator or by the ship's chronometer. The second comparison was made between the chronograph records of second-marks from the chronometer and the time signals from Arlington. Light from the flash box was reflected from a small fixed mirror inside the pendulum case and from a small mirror placed on the axis of the pendulum. These two reflections returned to a transparent scale in the flash box where the time of their coincidence could be observed.

Accuracy in determining the pendulum period depended upon the precise operation of the flash box shutter. The superior performance of the General Radio Standard-Frequency Assembly in operating the shutter was a very great advantage. — E. C. Nichols.

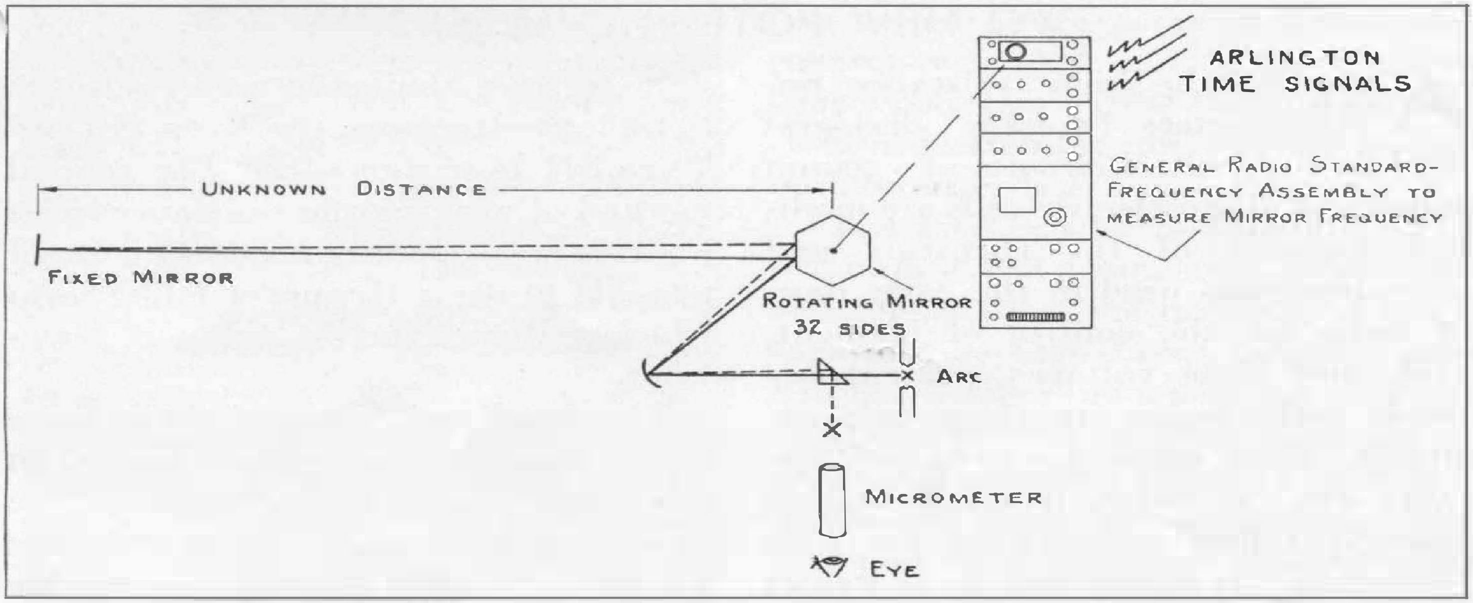
* * *

THE POSSIBILITY OF USING A STANDARD-FREQUENCY ASSEMBLY TO MEASURE DISTANCE

The experiment described by Mr. Nichols in the foregoing article should be of particular interest to everyone who has followed the development of precision frequency measurements during the past few years. The crystal-controlled standard-frequency assembly was of course designed and built primarily for measuring frequencies anywhere in the communication-frequency spectrum and its direct application to a time measuring problem serves to emphasize the identity of time and frequency.

Reduced to its lowest terms the time measuring problem in the Michelson experiment is nothing more than the determination of the rotational frequency of the rotating mirror. The use of the standard-frequency assembly to measure without intermediate steps this rotational frequency is a possibility that will suggest itself to most of us who are accustomed to think in terms of frequency rather than in terms of time. It becomes a problem of measuring a frequency of some 500 cps. with the greatest possible accuracy, say, one part in three million. If the tuning fork used in the Michelson experiment could be replaced by a frequency derived from a standard-frequency assembly, the question of determining this rotational frequency in terms of a standard time interval would be considerably simplified.

With this simplification in mind it may be of interest to consider a suggestion made several years ago by Major William Bowie of the United States



This is how the Michelson experiment might, so to speak, be inverted to measure distance in terms of the velocity of light and time. The rotational frequency of the mirror would be measured by a standard-frequency assembly, thus yielding the length of time required for the mirror to move an adjacent face into position

Coast and Geodetic Survey: that distance be measured in terms of the known velocity of light and time. A measurement of this kind would have important practical applications in geodesy where the difficulties of laying down precise base lines in mountainous countries and in archipelagoes are serious when done by present methods.

The experimental basis for such a measurement of distance was laid by an earlier experiment of Dr. Michelson when he measured the velocity of light between two stations — one located on Mount Wilson and the other on Mount San Antonio 22 miles away. The distance between these two stations was measured by the United States Coast and Geodetic Survey with a probable error of one part in 6,800,000 and the time was measured by methods somewhat similar to those just described by Mr. Nichols.

In measuring distance the experimental procedure would be reversed, and, instead of measuring the time it takes light to traverse a known distance, we would measure the time taken by light to traverse the unknown distance and then work out the distance from the known velocity of light. The compactness, portability, and high precision of a standard-frequency assembly would readily adapt it to this use since the elimination of as much bulky apparatus as possible would be desirable from the experimenter's point of view.

Some time we hope to see the experiment tried. It certainly has many interesting possibilities.

—JOHN D. CRAWFORD.

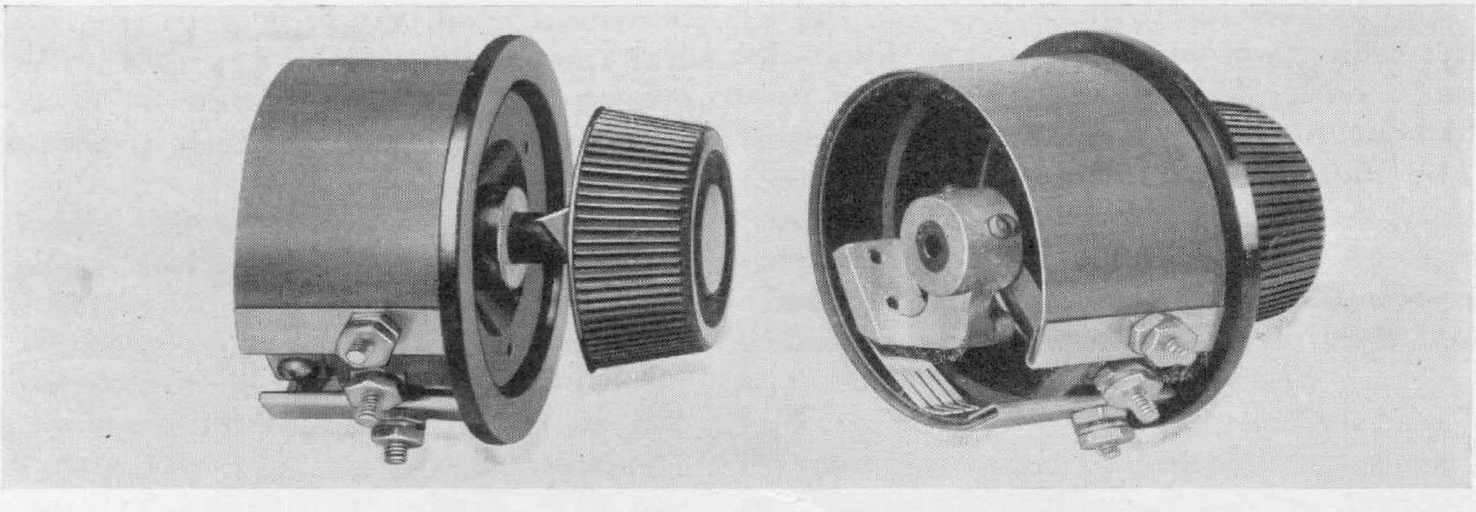
TWO NEW POTENTIOMETERS

Although the high resistance potentiometers (voltage dividers) used in the control circuits of vacuum tubes and photo-electric cells are modified versions of the rheostats and potentiometers used in the early days of radio for the control of filament, grid, and plate voltages, present-day needs make many improvements desirable. Since many vacuum-tube circuits are calibrated it is, of course, important that resistors for use with them be fairly stable and be as free as possible from vagaries due to changes in contact resistance, skipping, and other ills.

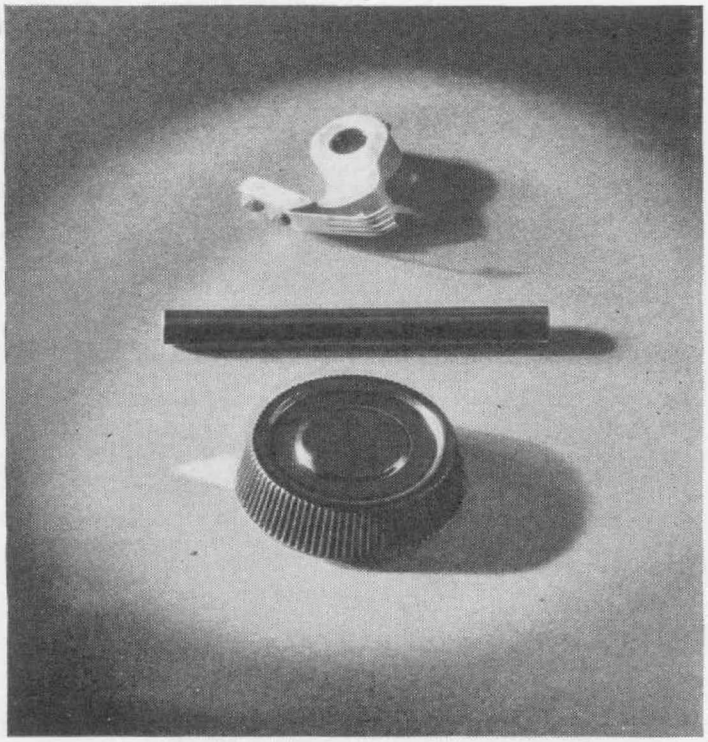
For the past several years General Radio Type 214 and Type 371 Potentiometers have met most all requirements except in high-quality, voice-frequency circuits where special logarithmic volume controls have been designed. It has been felt that some improvement could be made in controls for other circuits and the Type 314 and Type 471 Potentiometers about to be described are the result of work in this direction.

The Type 314 and Type 471 Potentiometers are similar in many respects to their predecessors, the Type 214 and Type 371 Potentiometers. The general method of winding the resistance units is similar, except that it has been found possible to use a thinner winding form which reduces the inductance somewhat.

The total resistance of these units has in the past been severely limited in the high resistance ranges by the smallness of the wire. Even with the use of wire of the greatest practicable resistivity, it has been found almost impossible to go to values much greater than 50,000 ohms even on the large size form used for the Type 371 Potentiometer. The small size wire causes an appreciable amount of spoilage during manufacture and even the finished product is liable to damage if handled roughly. The new units are provided with a bakelite strip which surrounds the form carrying the resistance wire. This acts as a mechanical protection and practically eliminates the possibility of damage to it during its installation in experimental equipment.



Type 314 Potentiometers. The fine wire used in winding the new potentiometers is protected from accidental damage by a thin strip of linen bakelite

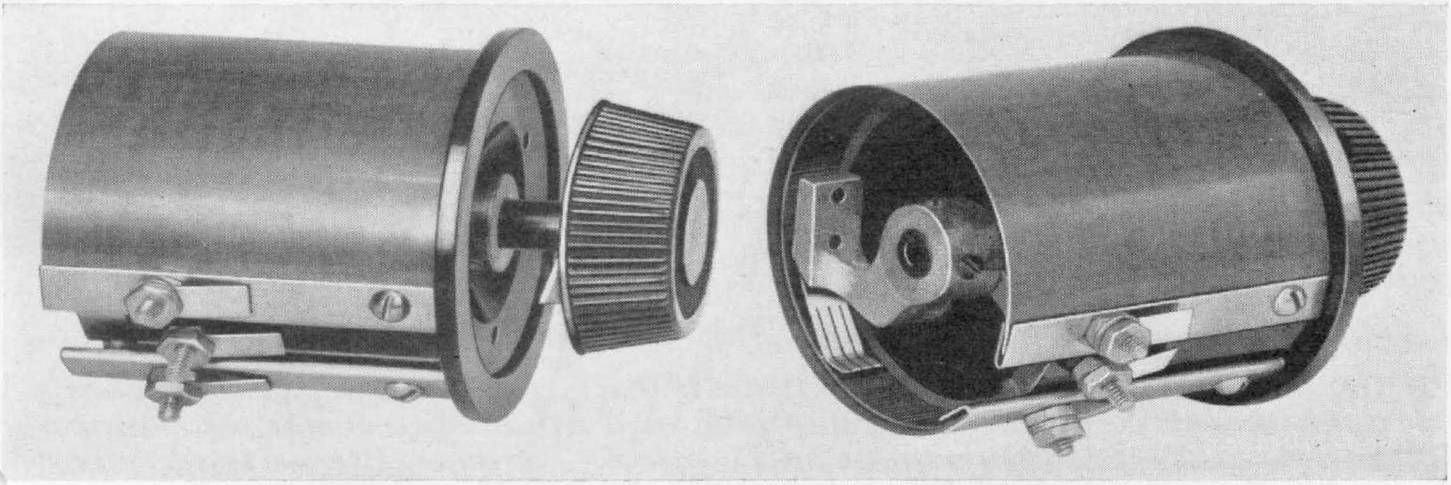


The contact arm, bakelite shaft, and large knob used in the new Type 314 and Type 471 Potentiometers

Another limitation due to the small wire size used in earlier designs was the possibility of getting imperfect contact with the slider used. The new units use a new type of slider having four fingers which bear lightly on the wire. The pressure needed to secure good contact and, therefore, the amount of wear which results is considerably reduced by this method. The four contact members also serve to reduce the contact resistance and render it more nearly constant. Thus the stability of circuits containing these units is materially improved.

Since high resistance units are likely to be used in vacuum-tube circuits of high impedance, the question of stray capacitances introduced into the system by the operator's hand on the control knob is often of importance. If an associated amplifier happens to have a substantial gain, it may happen that the coupling to the hand may be sufficient to introduce an appreciable amount of 60-cycle hum picked up from power-supply wiring in the vicinity. This effect has been practically eliminated in the new design by the use of an insulating bakelite shaft. This shaft is larger than the metal shaft used on earlier models, so that nothing has been sacrificed in the way of mechanical ruggedness by the change.

An added feature is the use of a larger knob and a non-metallic pointer. This knob is much easier to handle than the smaller one and its use is therefore worth while. The pointer has a dull white finish which eliminates the ob-



Type 471 Potentiometers. Contact resistance, wear, and skipping are reduced by the new four-wiper contact arm

jection to confusing reflections which were sometimes encountered when metal pointers were used in unfavorable light.

Most of these features can be seen by careful examination of the accompanying photographs. It will be noticed, of course, that the TYPE 314 and TYPE 471 Potentiometers are practically identical in design features. The difference is merely a matter of size of the form upon which the resistance wire is wound. This is the same difference that describes the old TYPE 214 and TYPE 371 Potentiometers.

The following table lists the resistance, current carrying capacity, code word, and price of each of the new units normally carried in stock.

TYPE 314 Potentiometers

Resistance	Current	Code Word	Price
200 ohms	165 milliamperes	ENATE	$4.00
600 ,,	95 ,,	ENDOW	4.00
2000 ,,	52 ,,	ENEMY	4.00
6000 ,,	30 ,,	ENJOY	4.00
20,000 ,,	16 ,,	ENROL	4.00

TYPE 471 Potentiometers

Resistance	Current	Code Word	Price
50,000 ohms	14.7 milliamperes	ERODE	$6.00
100,000 ,,	10.4 ,,	ERUPT	6.00
200,000 ,,	7.3 ,,	ESKER	6.00

TYPE 214 POTENTIOMETERS

TYPE 214 Rheostats and Potentiometers are now supplied as potentiometers only. In other words, each unit has three terminals—one connected to the sliding contact and the other two to either end of the resistor. This change is a simplification that will benefit the user, because it will make it unnecessary for him to make any changes in a unit when the direction of rotation is to be reversed.

Prices on two sizes of these units have been reduced, and all orders placed since February 8 have had the benefit of the reduction.

The following table shows the total resistance, maximum current, and prices for all of the TYPE 214 Potentiometers regularly carried in stock (for TYPE 214-B, Table Mounting as well as for TYPE 214-A, Panel Mounting). Only panel mounting models are regularly carried in stock, however.

Resistance	Current	Price	
		Old	New
0.75 ohm	4 amperes	$1.50	$1.50
2 ohms	2.5 ,,	1.50	1.50
7 ,,	1.3 ,,	1.50	1.50
20 ,,	0.75 ampere	1.50	1.50
50 ,,	500 milliamperes	1.50	1.50
100 ,,	350 ,,	1.50	1.50
200 ,,	250 ,,	1.50	1.50
400 ,,	175 ,,	1.50	1.50
1000 ,,	110 ,,	1.75	1.50
2500 ,,	70 ,,	2.00	1.50

TYPE 371 POTENTIOMETERS

Effective February 8 the prices of all stock sizes of TYPE 371 Potentiometers were reduced. These are listed on pages 28 and 126 of Catalog F and on page 12 of Bulletin 933. The linear models (TYPE 371-A) are reduced to $4.00 and the tapered model (TYPE 371-T) is reduced to $5.00.

* * *

THE GENERAL RADIO COMPANY mails the Experimenter, without charge, each month to engineers, scientists, and others interested in communication-frequency measurement and control problems. Please send requests for subscriptions and address-change notices to the

GENERAL RADIO COMPANY
30 State Street - Cambridge A, Massachusetts

PRINTED IN U.S.A.