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CONTROL SYSTEMS LABORATORY

A CAPACITANCE PROBE FOR RECORDING WATER WAVES

Report R-84

December, 1956

Contract DA-36-039-SC-56695
D/A Sub-Task 3-99-06-111

UNIVERSITY OF ILLINOIS · URBANA · ILLINOIS

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A CAPACITANCE PROBE FOR RECORDING WATER WAVES

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By

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SUMMARY

A convenient, reliable and linear method of recording wave height, or wave energy resident in any band of the spectrum of small waves, in conjunction with the local wind speed is described. The method is based upon the detection of the capacity change of a small capacitance probe immersed in water of variable height. The probe capacity, linearly dependent on wave height, modulates the repetition rate of a blocking oscillator which generates a Miller run-down waveform and also triggers a boxcar to measure the run-down depth. The latter provides an output proportional to wave height over a dynamic range of 1000 : 1 and with a sensitivity limited by interference of the smallest waves by the probe.

INTRODUCTION

Due to the complexity of wind-wave dynamics, the development of a complete theory of wind generated water waves requires the support of comprehensive data on all the characteristics of the wind-wave dynamic system. A great deal of data is available for statistical kinematic analysis of primary[*] waves, and some for the dynamic analysis of primary wave generation. The development of the theory is handicapped, however, by a lack of quantitative observations on secondary[*] waves, and in particular the initiation and early growth of wind waves. The secondary waves control important phenomena such as the wind drag[1**] and radar back scattering. Limited laboratory investigations[2] have yielded a little quantitative information on early wave growth, but knowledge of naturally generated small waves is still largely qualitative[3]. To aid in removing this deficiency, and to supplement the primary wave data, an instrument has been designed and developed at the Control Systems Laboratory to measure and record, in conjunction with the local wind speed, the water height at a point. The instrument is capable of reliable transmission of signals from a small wave sensing device over long cables which are often necessary in order to avoid extreme inconvenience in field work; further, it has a sensitivity range adaptable to investigations of the initiation of waves from a relatively calm water surface or to investigations of primary waves.

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[*] Primary and Secondary Waves are defined as those of wave length greater and less than one foot respectively (see Ref. 1).

[**] References are given at the end of the report.

Although the instrument was primarily designed for the purpose of measuring water heights, the basic circuitry may be used to measure fairly rapid and small changes of quantities convertible into resistance or capacity. The adaption to such purposes will be clear from the discussion of the circuit in Sect. 2.

The paper is divided into three sections. In the first the method of wave measurement is discussed; the second section deals with the circuitry developed for the method; the final section is devoted to the complete instrument and its practical operation.

1. METHOD

The unsuitability of primary wave measuring techniques for secondary wave measurements has rendered it necessary to develop a new method; of the primary wave techniques the optical methods are generally very difficult in data reduction, mechanical methods in the form of pressure transducers are too insensitive, and in the form of floats are inacceptable due to inertia and their disturbance of the water surface. Electronic methods using a resistance or capacity probe as the wave sensing device satisfactorily overcome these shortcomings: a continuous signal is provided upon which any operation may be performed and the results readily recorded; sensitivity is very good, and the small size of the probe offers little interference with the water motion. A capacity probe has been chosen for the present application since the resistance probe is subject to contamination, a serious problem in field work. The capacity probe was originally suggested by the National Institute of Oceanography, and employed by Tucker and Charnock[4] to measure waves of up to fifty centimetres height.

A dielectric-coated metal rod when placed in water acts as a variable capacity to the water, the capacity being linearly dependent on the depth of immersion providing the coating is uniform. A continuous measurement of this capacity therefore provides the waveform of any disturbance on the water surface as it passes the rod. This measurement has been achieved by the circuitry described in Sect. 2 and provides a voltage output proportional to the water height.

2. ELECTRONIC CIRCUIT

The circuit design conditions are governed by the following requirements:

(i) A small wave detector unit to be placed in positions inaccessible, and possibly far from, the recording apparatus.

(ii) Reliable transmission of signals from the wave detector to the recorder.

(iii) High sensitivity and linearity.

These requirements have been met by employing a grounded capacitance blocking oscillator unit (requirement (i)) feeding strong pulses whose attenuation does not affect their repetition rate (requirement (ii)). Requirement (iii) has been met by the linearity of the waveforms generated in the circuit, and high sensitivity of the blocking oscillator grid circuit to capacity changes.

The circuit (Fig. 2) described below is designed specifically to measure changes in small capacities (20 to 300 $\mu\mu$f.) from d.c. to frequencies up to a few hundred cycles/sec. Details of application to the secondary wave problem may be found in Sect. 3, where the sensitivity of the complete measuring system is discussed.

As mentioned previously, the circuit is adaptable to measurements of either capacity or resistance. The fundamental operation of the circuit is the detection of changes in the time constant of a resistance-capacity network, so that variations in any of the network's elements may be measured. In the present application the capacity probe is the variable element, and the probe in series with a resistor R_1 (Fig. 2) forms the network.

A block diagram of the circuitry is shown in Fig. 1a, output waveforms of the succeeding stages in Fig. 1b, and the circuit in Fig. 2. The operation of the circuit is as follows. The probe capacity and resistor R_1 form the high voltage grid return time constant of a blocking oscillator. Since the initial linear portion of the grid rise is utilized, the pulse repetition interval of the blocking oscillator (T, Fig. 1b.1) is proportional to the capacity of the probe. The circuitry following the blocking oscillator is used to generate a Miller run-down waveform (Fig. 1b.5) by switching at the suppressor grid of tube V5 (Fig. 2). The start of the Miller run-down is held at a constant voltage by a diode d.c. chain, and the run-down depth, E (Fig. 1a.5), is directly proportional to the pulse repetition interval and therefore the probe capacity. This run-down waveform is then presented to the bidirectional diode switch (the boxcar) V7 (Fig. 2). The multivibrator waveform from the anode opposite to that used to switch the Miller (Fig. 1b.4), triggers another blocking oscillator to deliver large positive pulses (Fig. 1b.6) about 1 microsecond before the Miller run-down reaches its bottom point. The anticipation of the pulse is necessary in order to avoid any confusion with the rising part of the Miller waveform. It is clearly necessary, then, that this pulse must be initiated by the multivibrator used to generate the slightly delayed Miller waveform. These pulses are used to switch on the boxcar circuit which delivers the voltage at the bottom of the Miller run-down to the cathode follower V8 (Fig. 2), (Fig. 1b.7). The Helipot (R37 Fig. 2) in the cathode follower may be adjusted for any desired attenuation of the boxcar signal. The cathode follower then delivers a voltage directly proportional to the capacity of the probe and consequently to the water immersion depth of the probe.

The voltage output as a function of capacity is very linear and ripple, due to the small fraction of the Miller run-down waveform fed through the boxcar, is of order 0.01 volt r.m.s. The voltage calibration curve, and repetition interval of the blocking oscillator, are shown as a function of capacity in Fig. 3. The repetition interval was measured by means of a pulse counter, and was averaged over periods of 1 second. Successive counts indicated a stability of the oscillator frequency to less than 0.1 per cent. Both calibration curves are for R_1 approximately 5 megohms. The limits of frequency over this calibrated range are from about 1 to 4 kilocycles/sec., a range chosen to give a capacity "sampling time" at least ten times less than the period of the shortest waves to be encountered in the wave studies. Residual capacity in the calibration experiment is seen to be about 20 μμf., corresponding to a short length of coaxial feed from probe to blocking oscillator.

Only the simplest elements have been employed for the Miller circuit and bidirectional diode switch. A higher degree of linearity, if desired, may be obtained by modifying the Miller to a Bootstrap, and the ripple fed through the boxcar may be eliminated by the use of an additional tube.

3. APPLICATION TO SECONDARY WAVE STUDIES

3.1 Probe

The investigation of secondary waves dictates the use of a capacity probe capable of measuring wave heights from 5 to 0.02 cm., but long enough to avoid swamping by the larger primaries often encountered in areas of interest on lakes. A 15 cm. probe was chosen to fulfill the requirements, made of drill steel and thereby stiff enough to obviate support at both ends but small enough in diameter to detect high frequency waves down to 0.2 cm. in wave length (a wave of frequency 100 cycles/sec has a wave length of 0.36 cm., and a limiting breaking height of 0.05 cm.).

For high sensitivity the probe should have as large a capacity per unit length as possible, implying a very thin dielectric coating. Considerable trouble has been experienced in seeking a suitable dielectric and method of coating. Polystyrene Q-dope was finally selected, and was applied to the cleaned and polished steel rod by spinning and slowly withdrawing the rod from a container filled with the dope. Very thin coats (about 0.001 inch/dip) may be applied in this way, and yield capacities greater than 100 μμf/inch.

Each probe must be calibrated separately, and in Fig. 4 a typical calibration curve is shown. The calibration is made with a cathetometer onto which the probe is mounted, the latter being lowered into a tank of water to vary the immersion depth. The voltage output is fairly linear, irregularities (corresponding to about 0.05 cm.) being due to the nonuniformity of coating, with a sensitivity of about 8 volts per cm. of water displacement. The ripple voltage of the boxcar output then corresponds to a water displacement of about 0.001 cm., which is sufficiently below the smallest water displacements to be expected. For this particular calibration, a water displacement of 9 cm. corresponds to a pulse frequency range of 0.5 to 3 kilocycles/sec, which exceeds by an order of magnitude the maximum wave frequencies to be measured.

The small size of the probe offers little interference with the water motion, and the probe's static (steady water level) sensitivity is limited only by the uniformity of the insulating dielectric coating; with sufficient care and development in coating techniques, this difficulty could be overcome.

No controlled attempts have been made to take dynamic calibrations. The dynamic performance has been qualitatively evaluated by noting the waveform purity of a wave record, and for secondary wave studies appears to be satisfactory. However, meniscus lag on the probe during dynamic operation is expected to have some effect on measured amplitudes, but no determinations of this effect have been made. If very small water movements are to be accurately detected, it has been found that the coating, due to an uncertain cause, has serious shortcomings in producing an accurate waveform.[5] In practice, the water disturbances to be measured in secondary wave systems somewhat exceed this limit of reproducability, which occurs at displacements of the order 0.01 cm.

3.2 Wind Wave Recording Apparatus

In the application of the instrument to secondary wind wave systems analysis it is used in conjunction with a band pass filter and recorder. The Helipot output (R37, Fig. 2) is fed to a 330A Krohn-hite band pass filter to select any frequency band of the water waves as desired. The filter, which has an attenuation of 24 db/octave outside the pass band, also serves as a buffer to the small voltage ripple generated by the pulse circuitry. The selected signal is then recorded on one channel of the BL-202 double channel Brush recorder which is preceded by the BL-928 Brush amplifier. The maximum sensitivity of the amplifier-recorder combination is 0.05 volts/m.m. pen deflection, which, with the probes presently being used, corresponds to a water displacement of 0.005 cm. This limit of sensitivity cannot as yet be practically realized due to the limitation on the dynamic response of the probe mentioned in Sect. 3.1.

Various operations may be performed on the waveform delivered by the filter, and among these one of the most useful is in taking r.m.s. values of the waveform. This may be done with a vacuum thermocouple, operating down to a few cycles/sec. As in the case of the thermocouple wind gauge (see below) pre-recorder amplification of the signal is necessary. Instead of recording wind speeds, the second channel of the recorder may be used to compare the unfiltered waveform with the energy or amplitude in any frequency band recorded on the first channel. In this way, instabilities of the water surface which correspond to high frequency disturbances may be accurately located on the water surface. This application is vividly demonstrated in Fig. 5, together with samples of the recording with wind speed only.

Wind speeds at the probe are measured by means of a Hastings model H thermocouple wind gauge. The output of this gauge is 10 millivolts maximum, so that a preamplifier is necessary to supply the recorder.

The probe blocking oscillator has been built as a separate unit in order to place it near to the probe. This eliminates the inactive capacity of a long coaxial lead in the blocking oscillator grid circuit, and fulfills requirement (i), Sect. 2. The probe is supported directly from a soldered joint in a connector, the connector being rigidly attached to a specially built rig for suspension of the probe from the lake edge. For lake experiments a 300 ft. length of coaxial cable feeds the blocking oscillator pulses to the main body of the apparatus. The mobility of the sensing unit therefore allows measurements some distance from the bank of the lake if desired; a submerged tripod may be used for the support in this case. Including the stabilized power supply (300 v, -150 v, filaments) the total power requirement of the double channel recording equipment for wind and waves is of the order of 400 watts, which is provided by a 1 KW gas driven generator.

Although the instrument is currently being used for secondary wave analysis, it may be used for almost any scale of wave measurement by suitable selection of probe. For stability investigations the sensitivity could be slightly increased, although it is probably sufficient in the present configuration, and for primary wave measurements either a longer and stiffer probe or a double ended supported wire would be required. Since the capacitance of the probe for the latter application increases, the time constant network of the blocking oscillator grid circuit must be adjusted to retain a time constant small enough for "capacity sampling." This may be accomplished merely by reducing the value of the resistor R_1.

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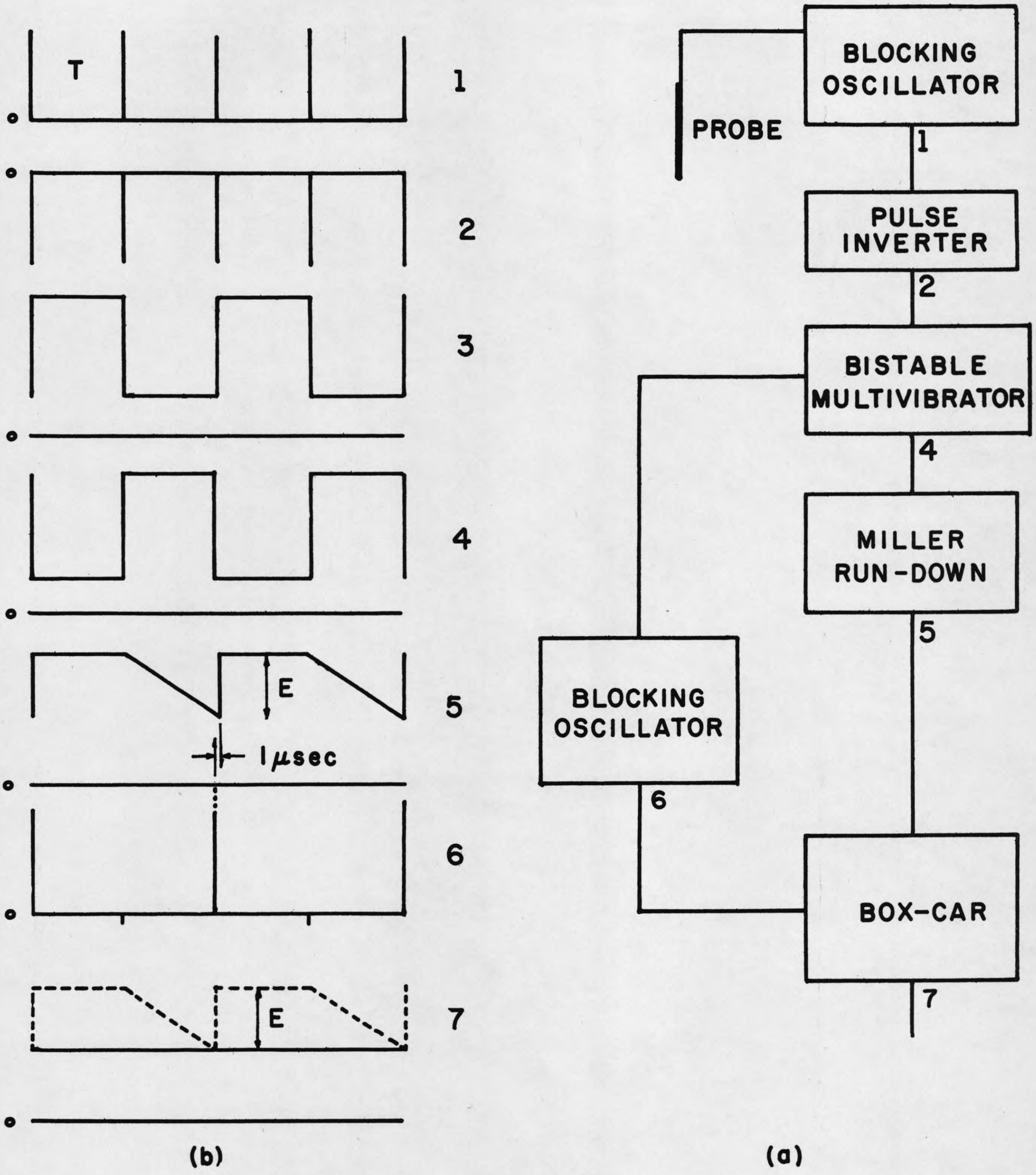

FIG. 1 WAVEFORMS AND BLOCK CIRCUITRY

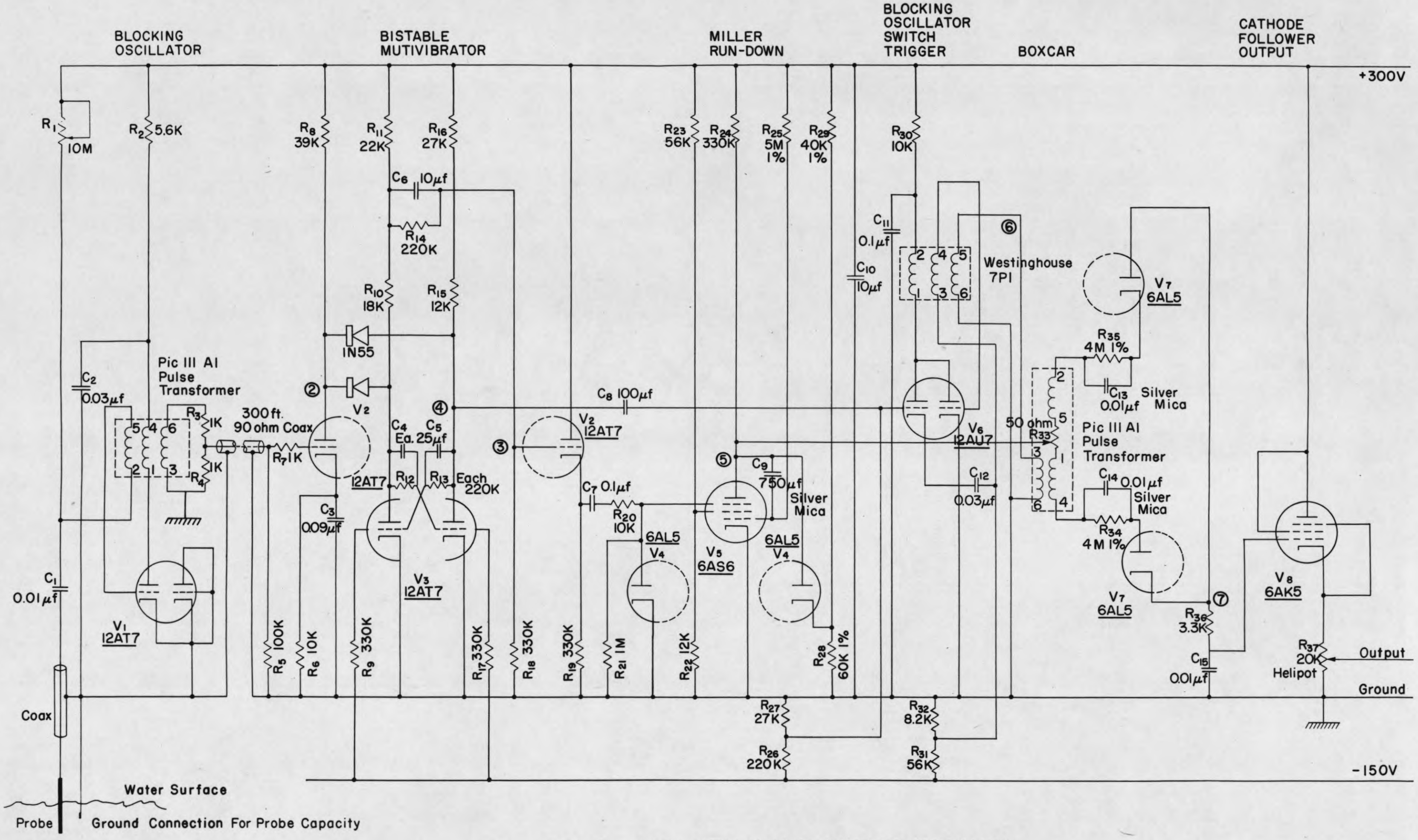

FIG. 2 - CAPACITY WAVE METER CIRCUIT

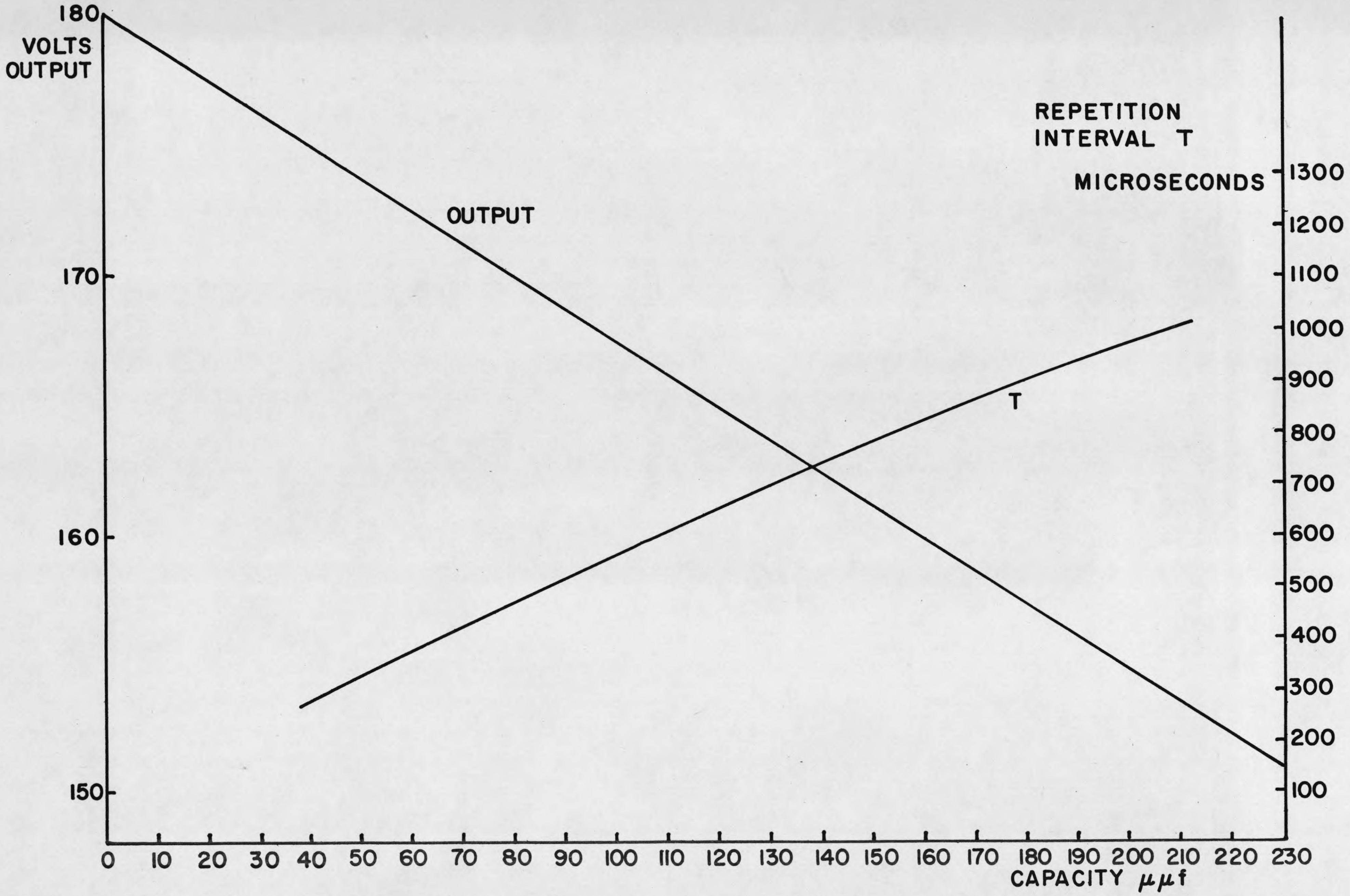

FIG. 3 CIRCUIT CALIBRATION CURVES

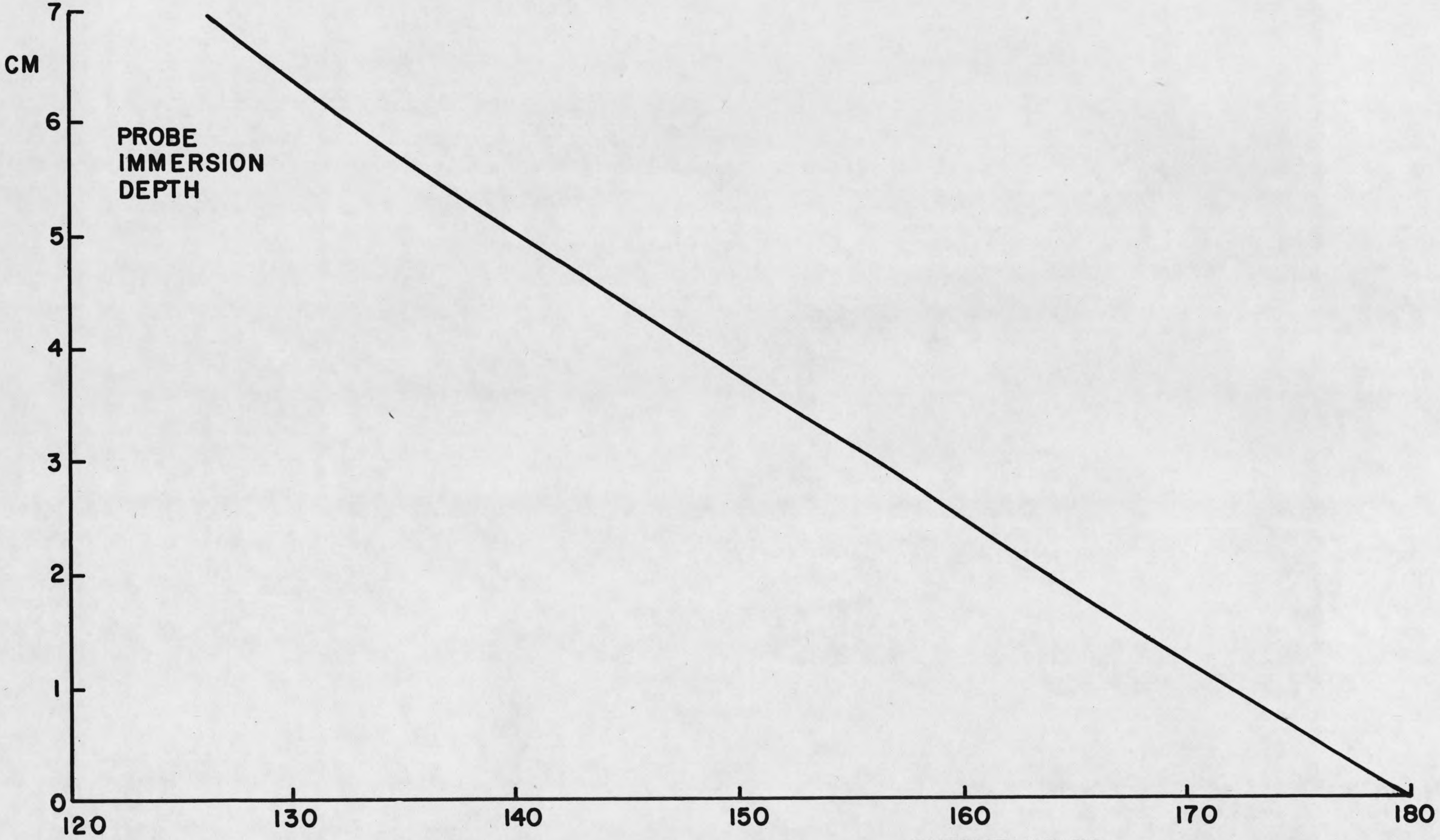

FIG. 4 PROBE CALIBRATION CURVE

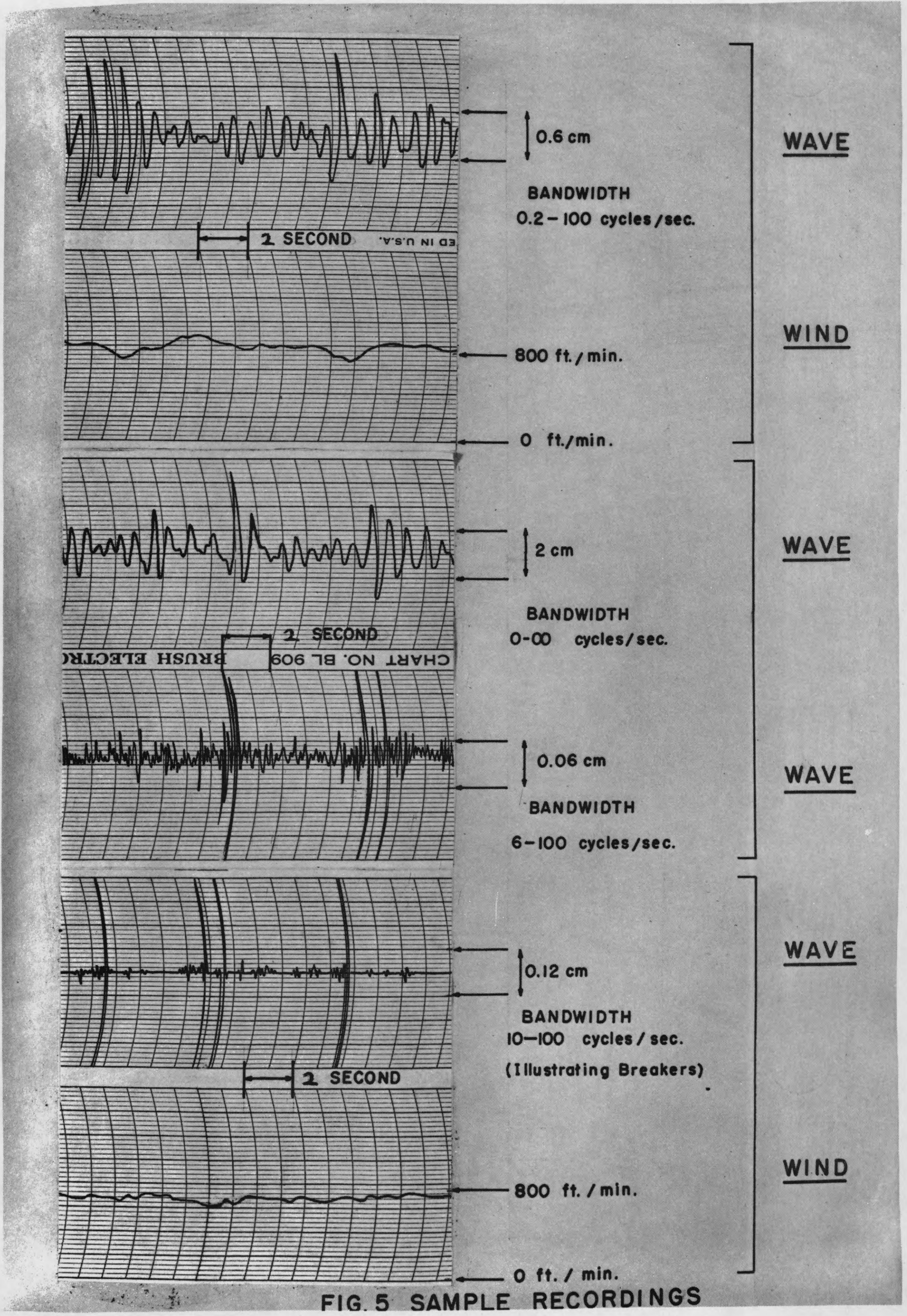

FIG. 5 SAMPLE RECORDINGS

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