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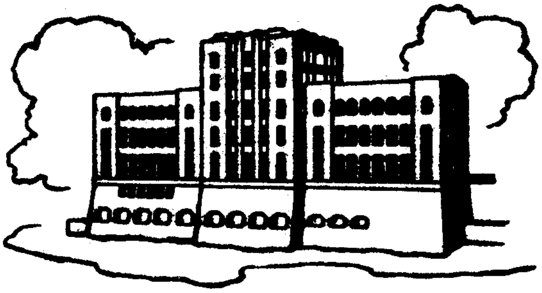

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ABSTRACT

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A Digital Indicator for a Novar-Nixon Model 403 Probe is described. The instrument, consisting of indicator plus probe, is capable of measuring mean velocities in water flows over the range of 2.50 to 150 cm/sec with three-significant-digit resolution over the entire range. A three-digit display, in conjunction with the indicator control settings and a calibration curve, permits the operator to determine the fluid velocity. Ease of operation is a main feature of the indicator, and it requires no routine adjustment. In addition, it will operate at temperatures down to -20°C.

ACKNOWLEDGEMENTS

Development of this instrument was sponsored by the Iowa Institute of Hydraulic Research, and grateful acknowledgement is extended to Dr. John F. Kennedy, Director of the Institute, for his support. In addition, the authors wish to thank Mr. Ernest E. Schwab of the Institute's staff who constructed the instrument.

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DIGITAL INDICATOR FOR A ROTARY-TYPE WATER VELOCITY PROBE

I. INTRODUCTION

The instrument that has been developed is designed to measure mean velocities in water flows over the range of 2.50 to 150 cm/sec with three-significant-digit resolution. Such an instrument was needed because it is more accurate and convenient to use than the Prandtl-Pitot tube, particularly at low velocities.

The electronic portion of the instrument will furnish the required excitation to a Novar-Nixon Model 403 velocity-sensing probe, detect and count pulses generated by the probe, and display the count. The count, in conjunction with the settings of the MULTIPLIER and COUNTING TIME controls, permits the operator to determine the frequency of the pulses, which is related to the fluid velocity by a calibration curve. The display consists of three digits plus an OVERFLOW indicator which is turned on if the counting capacity of the instrument is exceeded.

Counting times of one, ten and one-hundred seconds may be selected to permit measurements to three-significant-digits over the entire velocity range of the probe, and to give the operator a choice of averaging periods. The MULTIPLIER control causes pre-division of the input frequency by one, ten or one-hundred to permit retention of the most signigicant digits when dealing with high frequencies and/or long counting periods.

Either manual or automatic cycling of the count-display sequence may be selected. In the MANUAL mode of operation, the instrument must be reset manually for each cycle; in the AUTO mode, the instrument is automatically reset at the end of the display time, which is variable from one to ten seconds.

Simplicity of operation was a primary design goal, and this has been achieved; the indicator requires no routine calibration or adjustment. However, the probe must be calibrated to establish the relationship between frequency and velocity. The design makes maximum use of both linear and digital integrated circuits to achieve reliability, economy and compactness. In addition, military-specification-grade components were employed to permit operation of the instrument at temperatures down to -20°C for use in the Institute's Low-Temperature Flow Facility.

II. DESCRIPTION OF INSTRUMENT

The following description of the instrument is based on the simplified block-diagram shown in Fig. 1.

A. Analog Circuits. The analog portion of the indicator provides excitation for the velocity-probe, detects the signal generated by the probe and conditions it into a pulse train suitable for driving TTL counting circuits in the digital portion. Sections of the analog circuitry, as indicated in Fig. 1, are described below and shown schematically in Figs. 3 and 4.

1. Probe. The velocity-sensing element used is the Novar-Nixon Model 403 Streamflo Probe. It consists of a 5/16-inch diameter, 5-bladed plastic rotor mounted at the end of a stainless-steel shaft 18 inches in length. The probe is positioned in the flow so that the rotor is at the point at which the velocity is to be measured, and it is oriented so that the axis of rotation of the rotor is parallel to the direction of flow. Flow past the rotor causes it to rotate with a frequency proportional to the linear velocity of the fluid. As each blade passes the base of the shaft, it modifies the current path between an electrode imbedded in the base and the shaft itself, which serves as the return electrode. This causes an increase in the electrical resistance of the probe. Thus, an appropriate electrical model of the probe is simply a resistance that varies periodically about an average value with frequency proportional to the velocity of the fluid driving the rotor (see Fig. 2).

2. Probe Excitation. In order to transform the varying probe resistance into a more useful varying voltage signal, the probe is connected in series with resistor R6 to form a voltage divider which is driven sinusoidally at approximately 125 KHz (see Fig. 3). The output signal, taken directly across the probe, is an amplitude modulated signal with the frequency of modulation being identically the frequency of the resistance

variation of the probe. The 125 KHz carrier frequency was chosen as a compromise to satisfy the conflicting requirements of ease of filtering on one hand and of minimizing the effect of cable capacitance in parallel with the probe on the other. Direct-current excitation was rejected because it would cause undesirable electrolysis at the probe electrodes.

The 125 KHz signal is produced by an Intersil 8038BM voltage-controlled oscillator. Transistors Q1 and Q2 provide amplification and isolation to supply a 25-volt peak-to-peak signal, which is A.C. coupled to the probe network by capacitor C2.

Darlington-coupled transistors Q3 and Q4 provide isolation between the probe and detector circuits. Capacitor C3, in conjunction with the input resistance of the isolation stage, forms a high-pass filter with a cutoff frequency of 10 KHz to reduce any 60-Hz noise present in the probe signal.

3. Signal Detection and Conditioning. Detection of the amplitude-modulated signal is accomplished by a standard diode-detector circuit (see Fig. 4). The output of the detector is A.C. coupled by capacitor C4 to amplifier A1 which has a gain of 101. The amplifier is biased so that for zero input the output is -2.5 volts; this prevents the following bi-stable circuit from triggering on noise present on the information signal. A low-pass filter composed of capacitor C5 and resistor R17 at the output of the amplifier completes the filtering of the carrier frequency. The output of this stage is a 15-volt peak-to-peak signal that is suitable for driving the bi-stable circuit.

The bi-stable stage, consisting of amplifier A2 and associated components, employs sufficient positive feedback to provide a 1-volt hysteresis loop in the transfer characteristics of the circuit. This serves to prevent multiple triggering due to noise on the information signal. The output of the amplifier is a ±15-volt square wave; this is transformed by a 4.5-volt Zener diode D2 and resistors R24 and R25 to TTL-compatible voltage levels. Thus the output signal of the signal detection and conditioning circuits is a square wave suitable for driving a TTL monostable multivibrator.

B. Digital Circuits. The digital portion of the instrument performs several functions. It must count the number of positive transitions of the information signal that occur during a specified period of time, display the count for a sufficient time interval, and then reset all counters in preparation for a new count-display cycle. One cycle of operation proceeds as follows:

1. The counting period begins on the first clock pulse received after all counters have been reset. During the counting period, positive-going transitions of the information signal are counted. The count is continuously displayed.
2. When counter stages in the time-base generator have detected a pre-determined number of clock pulses, all counters, both in the counter-and-display and time-base generator sections are stopped.
3. The display period begins when the counting period ends. The number displayed is the count registered by the counter circuits at the end of the counting period.
4. The display period ends after a pre-determined display time has elapsed. In the AUTO mode, the display time is variable from one to ten seconds and is determined by the DISPLAY TIME control. In the MANUAL mode, the display period ends only when the RESET button is depressed.
5. At the end of the display period, a reset pulse is generated. It resets all counters in preparation for a new cycle of operation. The end of the reset pulse completes the cycle; receipt of the first subsequent clock pulse begins a new cycle.

The various sections of the digital portion of the instrument, as indicated in Fig. 1, are described below and illustrated in Figs. 5 through 8. The digital portion is composed entirely of TTL integrated circuits employing positive logic. Thus a logical zero level is nominally 0.1 volt, and a logical one nominally 3.5 volts.

1. Time-Base Generator. The time-base generator employs a 60-Hz frequency to perform its timing functions. This clock signal is obtained

from the A.C. power line by stepping down the voltage with a filament transformer and limiting it with Zener diode D3 and resistors R26 and R27 to make it TTL-compatible (see Fig. 5). The resulting signal is used to drive the Schmitt-trigger input of single-shot multivibrator number 5 (SS5) which supplies clock pulses to the counters determining the length of the counting period (see Fig. 6).

Clock pulses must pass through NAND gate 1.3 (NAND 1.3) which is closed by NANDs 3.1 and 3.2 during the display period and for the duration of the reset pulse; otherwise NAND 1.3 is open. The gated clock pulses drive the cascaded counters which divide the 60-Hz frequency by 120, 1200 and 12000 to give zero logic levels at the outputs of divide-by-ten counters 3, 4 and 5 for 59, 599 and 5999 periods of the clock frequency, respectively. The output selected by the COUNTING TIME switch is gated by NAND 2.3 with the output of the first flip-flop in the divide-by-twelve counter. This gives the additional period required in each case to cause the output of NAND 2.3 to go to zero after exactly one, ten or one hundred seconds (60, 600 or 6000 periods). The zero from NAND 2.3 causes NAND 2.2 to go to zero, which disables NAND 2.4 (see Fig. 7) and thus stops the counting process. In addition, the one-to-zero transition of NAND 2.2 triggers SS1 (Fig. 8).

Flip-flop number 3 (FF3) synchronizes the opening of NAND 2.4 with the first clock pulse of the operation cycle. That pulse sets the Q-output of FF3 (FF3Q) to one, which enables NAND 2.1 and consequently opens NAND 2.4. FF3Q is returned to zero by a pulse from SS2 immediately after the counting period ends.

2. Counter and Display. The TTL-conditioned square-wave output of the bi-stable circuit (Fig. 4) in the analog section drives the Schmitt-trigger input of SS4 (see Fig. 7). Output pulses, taken from SS4$\bar{Q}$, have transition times suitable for driving the counter circuits; they are passed through NAND 2.4 during the counting period and inhibited otherwise.

The gated pulses are supplied directly to the MULTIPLIER switch in the XI position; they also drive the divide-by-ten counters 1 and 2 for pre-division by 10 or 100. Thus the MULTIPLIER switch can select the original information frequency, or that frequency divided by 10 or 100. The output of the MULTIPLIER switch drives the units binary-coded-decimal (BCD) counter.

Three BCD counters are cascaded so that the first counts units, the second counts tens and the third counts hundreds of negative transitions of the input signal from the MULTIPLIER switch. Each counter supplies its count in BCD form to a decoder-driver, directly in parallel with it, via four lines. Each decoder-driver transforms the BCD input into outputs suitable for driving a seven-segment display directly in parallel with it. Thus each display unit provides a visual indication of the decimal number residing in its associated counter. Displays used are a TTL-compatible, incandescent type.

When the 2^3-bit in the hundreds BCD counter makes a one to zero transition, the OVERFLOW indicator is turned on. This signifies that a count of 1000 has been reached which exceeds the capacity of the display. The transition causes SS6 to fire which sets FF2Q to one. This turns on transistor Q5, which turns on the OVERFLOW light-emitting-diode (LED). The indicator remains on until a reset pulse from SS3$\bar{Q}$ resets FF2Q to zero.

3. Control Circuits. At the end of the counting period, the control circuits are activated. They determine the length of the display period in the AUTO mode and automatically generate a reset pulse to reset all the counters at the end of the period. In the MANUAL mode, the display period ends when the RESET button is depressed. In addition, depressing the RESET button in either mode will reset the instrument except during the display period in the AUTO mode.

At the end of the counting period, NAND 2.2 goes to zero, which triggers SS1 (see Fig. 8). The pulse width of SS1 is varied from one to ten seconds by adjusting the DISPLAY TIME control. This determines the length of the display period in the AUTO mode. When SS1 fires, the one to zero transition at the $\bar{Q}$ output triggers SS2 which sets FF1$\bar{Q}$ to zero and FF3Q to one. The zero from FF1$\bar{Q}$ disables NAND 1.3 via NANDs 3.1 and 3.2 and thus stops the time-base generator during the display period. It also sets NAND 1.1 to one.

In the AUTO mode of operation, SS1Q is connected to FF1$\bar{R}$; when SS1Q goes to zero at the end of the display period, it sets FF1$\bar{Q}$ to one which sends NAND 1.1 to zero. This transition triggers SS3, which produces a reset pulse. The other input to NAND 1.1 comes from SS7$\bar{Q}$, which is one unless the RESET button is depressed. Depressing the RESET button when FF1$\bar{Q}$ is one (i.e., anytime except during the display period) causes a reset pulse to be generated.

In the MANUAL mode of operation, FF1$\bar{R}$ is connected to SS7$\bar{Q}$; thus FF1$\bar{Q}$ goes to one when and only when the RESET button is depressed. This ends the display period. The second input to NAND 1.1 is now the output of NAND 1.2, which goes to one when and only when SS7$\bar{Q}$ is zero. Whenever SS7$\bar{Q}$ goes to zero, FF1$\bar{Q}$ either is one or it becomes one; therefore a one from NAND 1.2, which occurs when the RESET button is depressed, always causes NAND 1.1 to go to zero to trigger SS3.

The reset pulse itself is generated when SS3 is fired. The Q output of SS3 resets the counters in the time-base generator directly; the $\bar{Q}$ output of SS3 is inverted by NAND 1.4 and resets counters in the counter-and-display section. NAND 1.4 serves only to share the load presented by the ten units to be reset. In addition SS3$\bar{Q}$ sets FF2Q to zero to turn off the OVERFLOW indicator. It is important to note that the reset pulse must be of longer duration than the pulse generated by SS6 (Fig. 7). This is required so that, if the 2^3 output of the hundreds BCD counter is reset from one to zero, the zero on FF2$\bar{R}$ remains after the zero on FF2$\bar{S}$ has ended, and the OVERFLOW indicator is turned off.

Finally, SS3$\bar{Q}$ keeps NAND 1.3 disabled, via NANDs 3.1 and 3.2, to prevent a clock pulse from flipping FF3 while the counters are being reset. If FF3 were flipped, the counting period would not be synchronized with the clock pulses.

III. OPERATING PROCEDURE

Operation of the instrument is quite simple. The necessary steps and some related considerations are set forth below:

1. Connect the probe to the instrument with the furnished cable.
2. Plug the power cord into a 110V, 60-Hz receptacle; turn the power switch to ON.
3. Insert the probe into the flow so that the rotor is at the point at which the velocity is to be measured. The probe

must be aligned so that the arrow inscribed at the base of the connector is in the direction of flow. Fig. 9 illustrates the directional characteristics of the probe.

4. Select MANUAL or AUTO operation. In the MANUAL mode, the instrument must be reset by depressing the RESET button for each reading; the display is held until reset occurs. In the AUTO mode, the instrument resets itself at the end of the display period and automatically begins taking a new reading. The display is held from one to ten seconds as determined by the setting of the DISPLAY TIME control. In either mode, the instrument can be reset at any time during the counting period by depressing the RESET button.

5. Select a COUNTING TIME of 1, 10 or 100 seconds, as desired.

6. Set the MULTIPLIER control to obtain the desired number of significant digits. The MULTIPLIER and COUNTING TIME settings must be selected in such a way as to prevent the OVERFLOW indicator from lighting. To illustrate their interaction, the following tables show the counts that would be reached for frequencies of 4, 40 and 400 Hz for various settings of the controls.

f = 4 Hz

	MULTIPLIER		
COUNTING TIME	1	10	100
1	4	0	0
10	40	4	0
100	400	40	4

f = 40 Hz

	MULTIPLIER		
COUNTING TIME	1	10	100
1	40	4	0
10	400	40	4
100	*4000	400	40

f = 400 Hz

	MULTIPLIER		
COUNTING TIME	1	10	100
1	400	40	4
10	*4000	400	40
100	*40000	*4000	400

* indicates that the OVERFLOW indicator is lighted.

In all cases, only the lowest 3 digits are displayed.

7. Determine the frequency of revolution of the probe rotor by:

$$f(\mathrm{Hz}) = \frac{\text{COUNT X MULTIPLIER}}{\text{COUNTING TIME}}$$

8. Read the fluid velocity corresponding to the rotor frequency from the calibration curve. See Fig. 10 for a typical calibration curve.

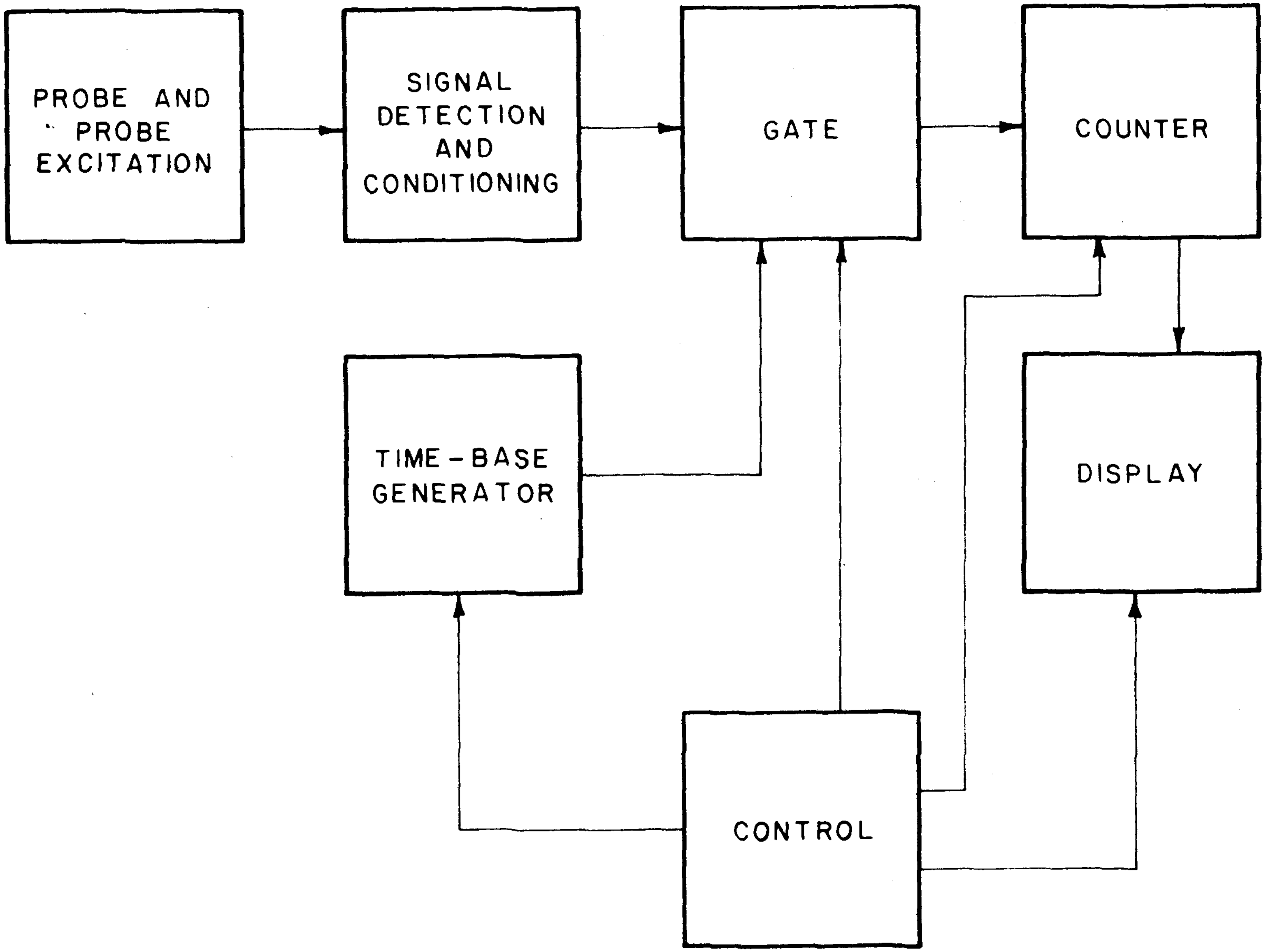

Figure 1. Simplified Block Diagram.

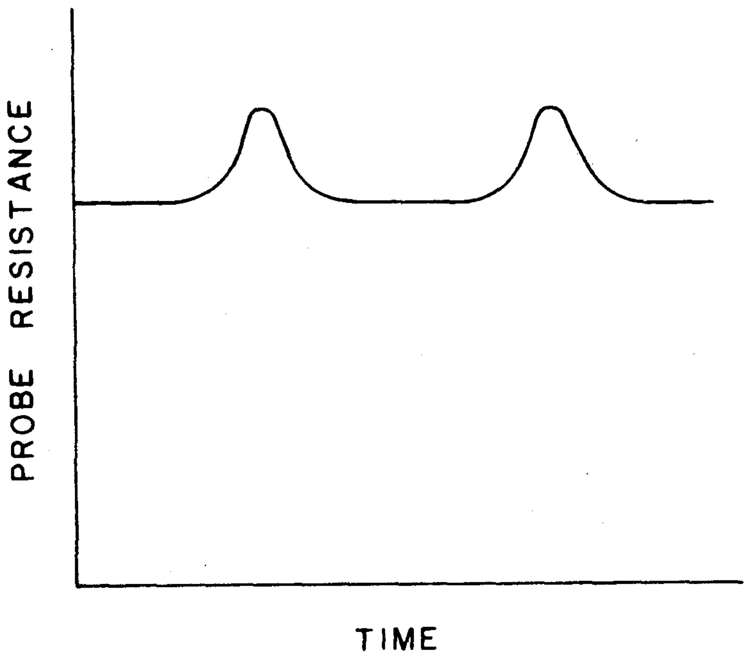

Figure 2. Qualitative Probe-Resistance Characteristics.

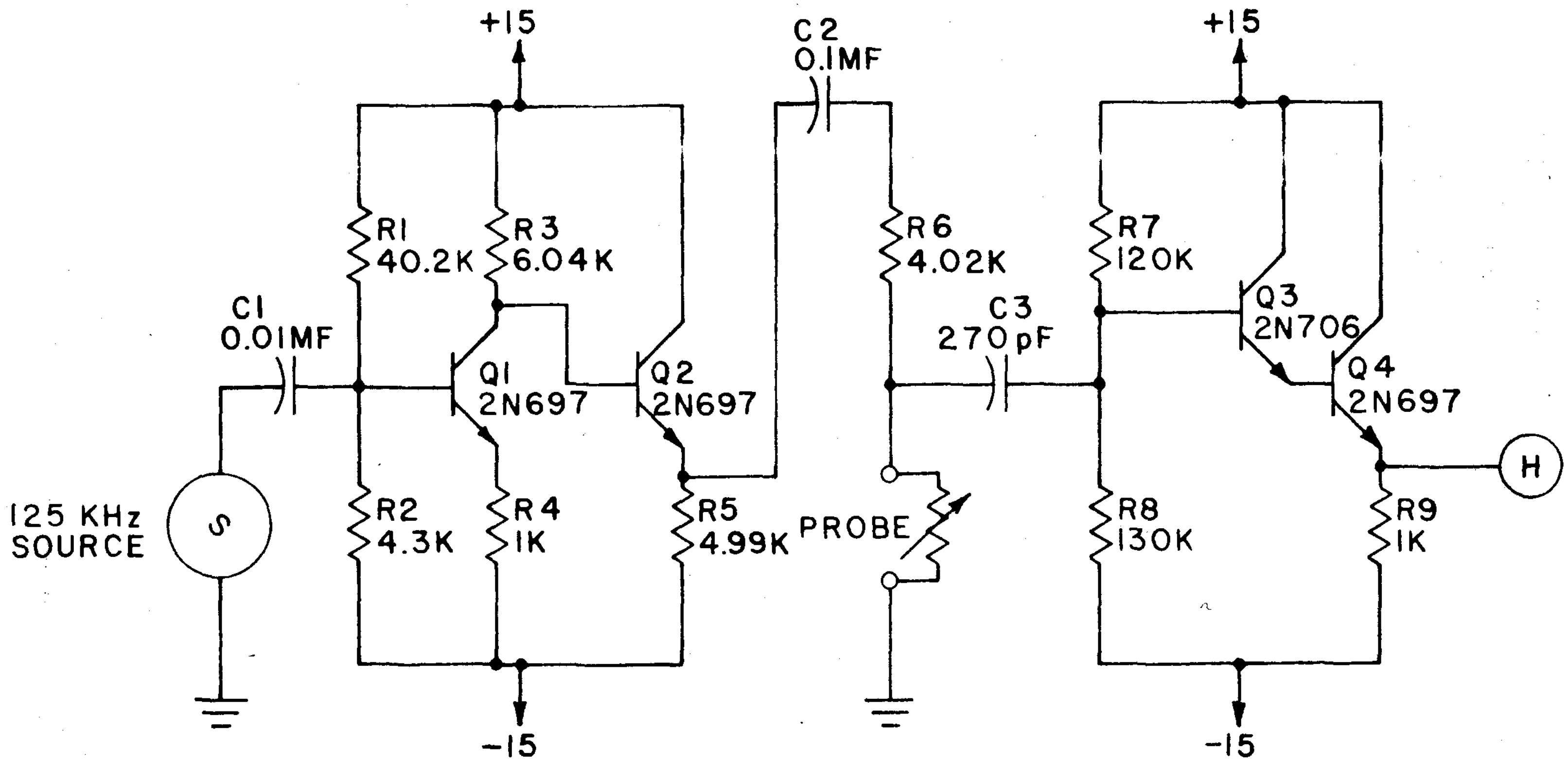

Figure 3. Probe Excitation Circuits.

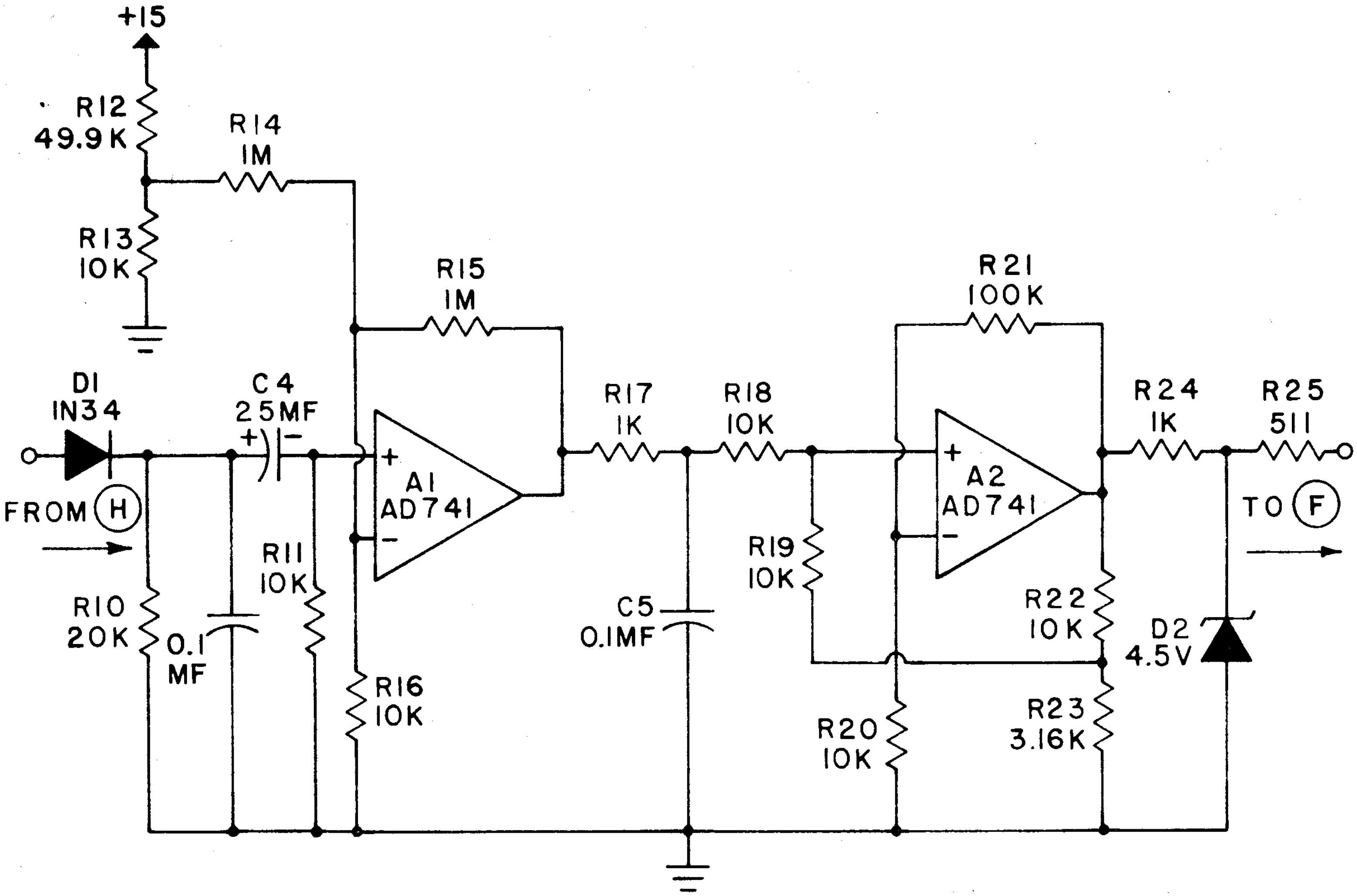

Figure 4. Signal Detection and Conditioning Circuits.

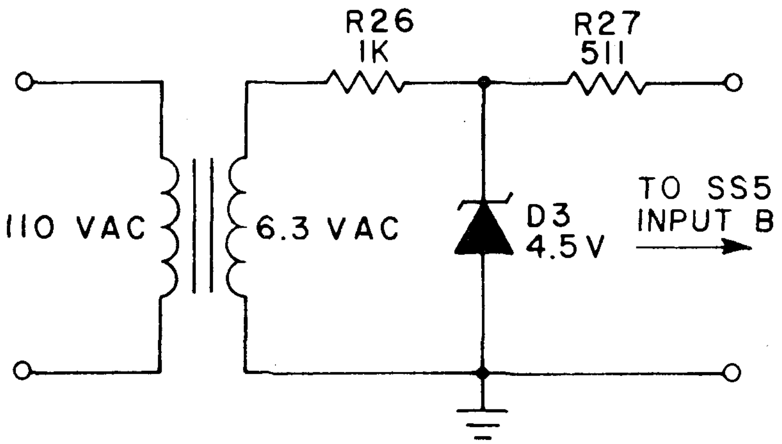

Figure 5. 60 Hz Source.

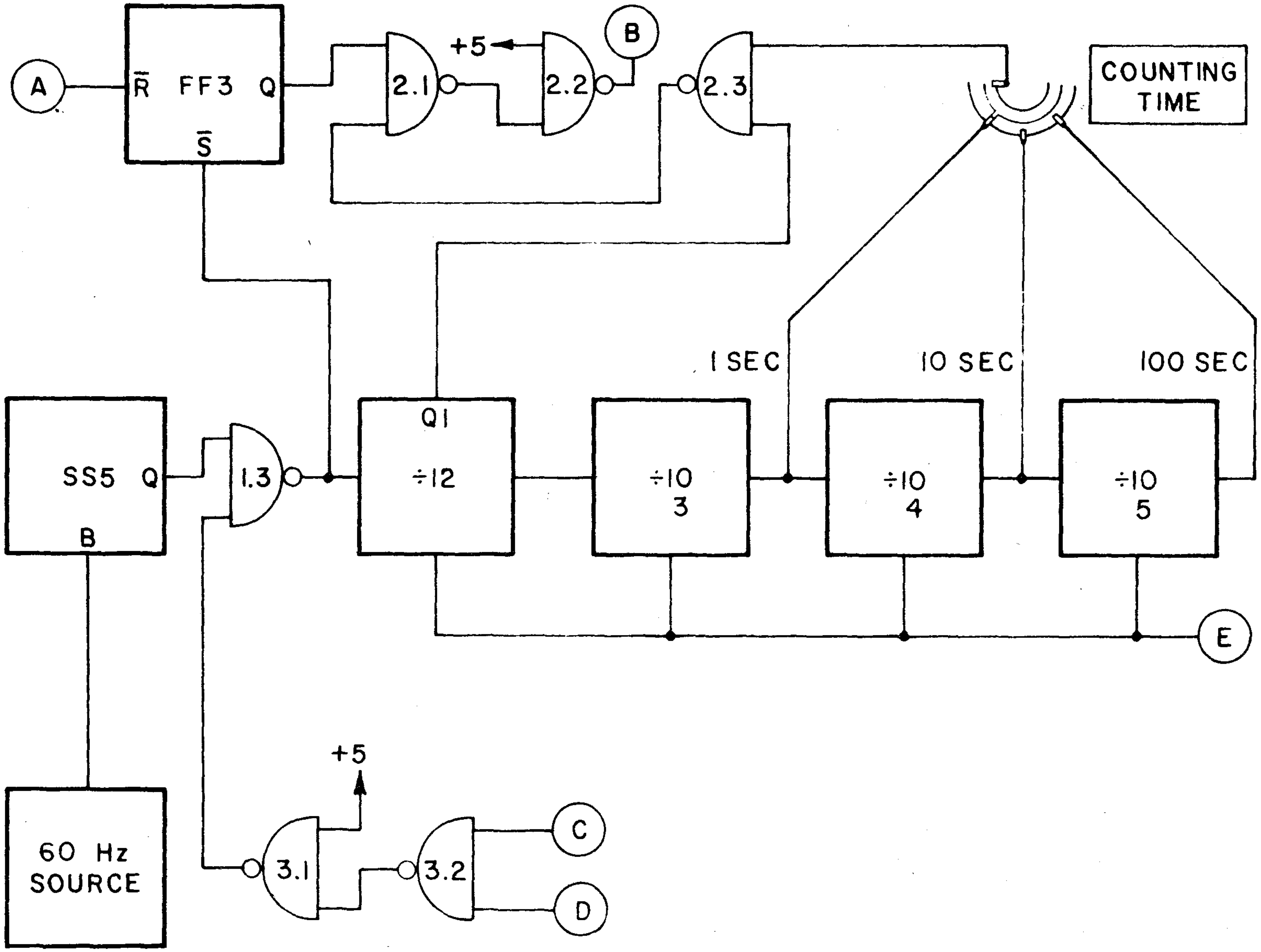

Figure 6. Time-Base Generator.

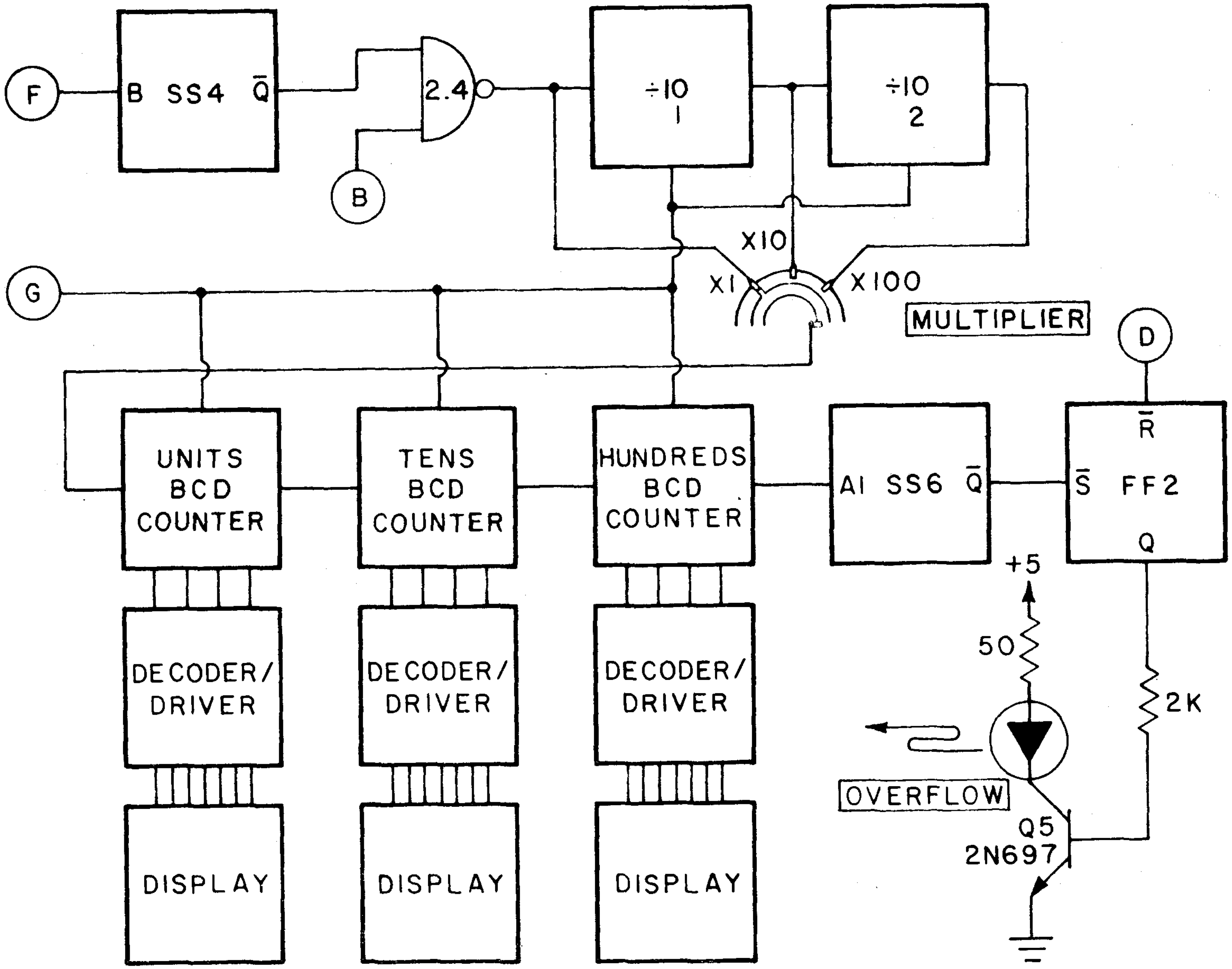

Figure 7. Counter and Display Circuits.

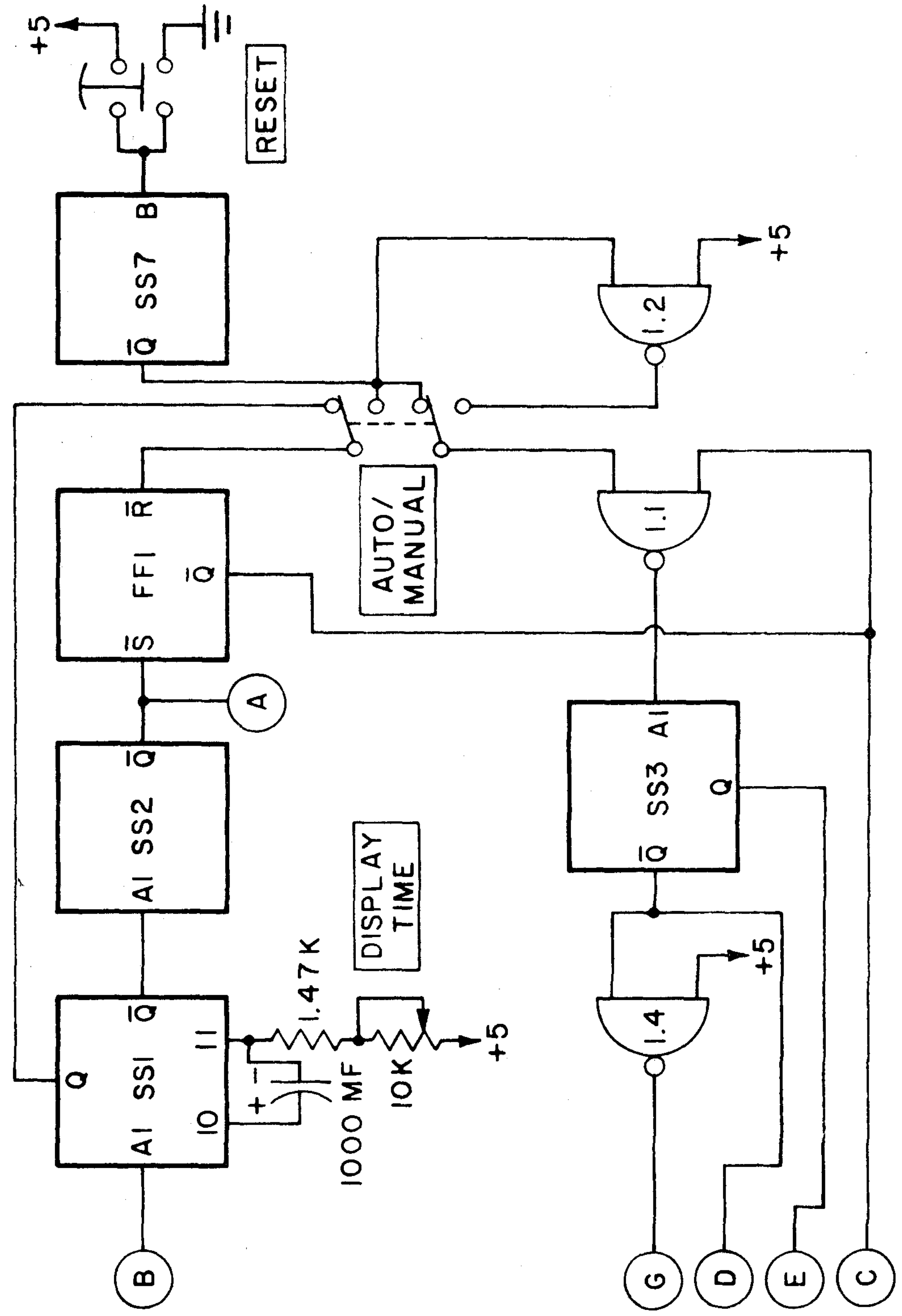

Figure 8. Control Circuits.

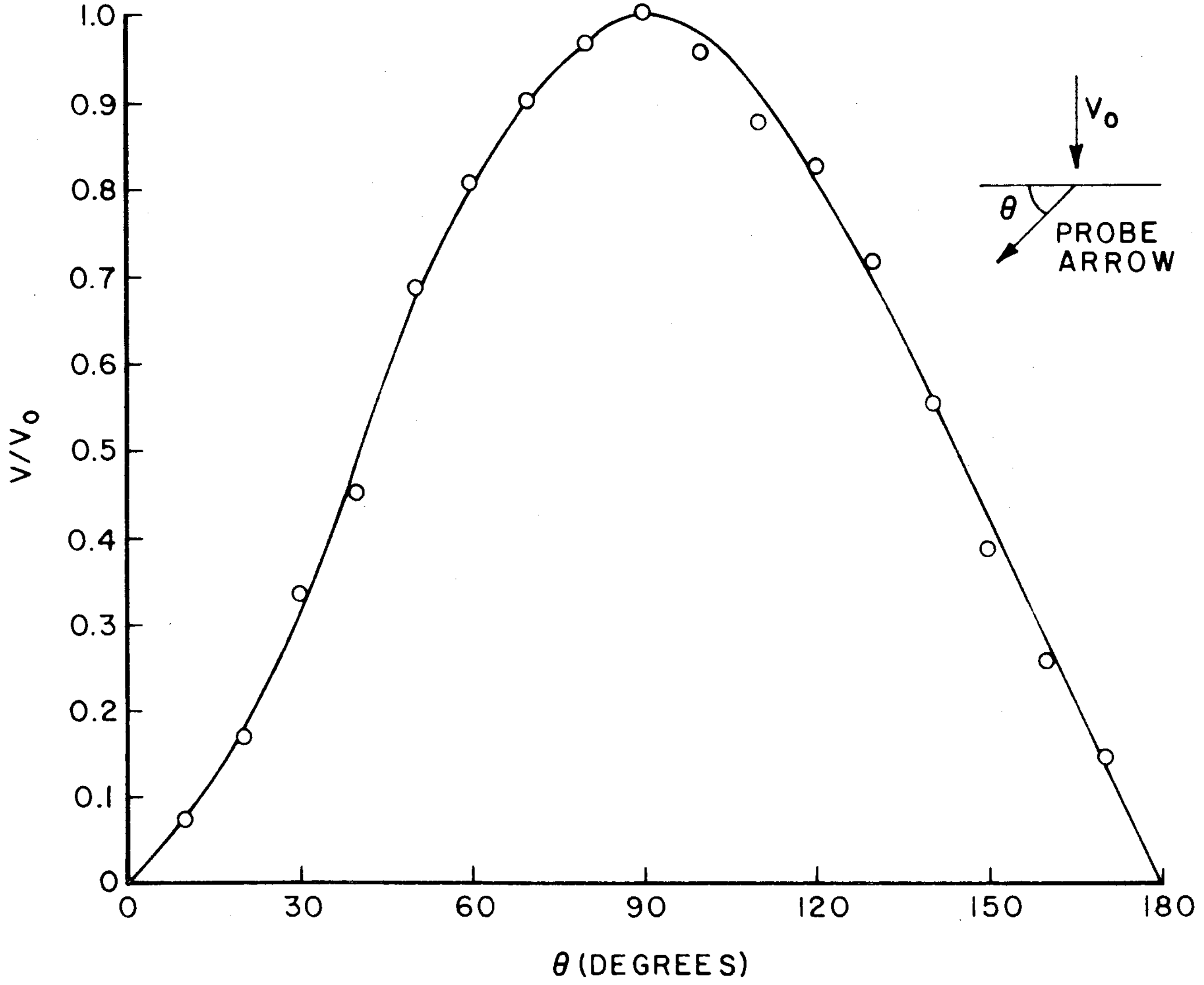

Figure 9. Directional Characteristics of Probe.

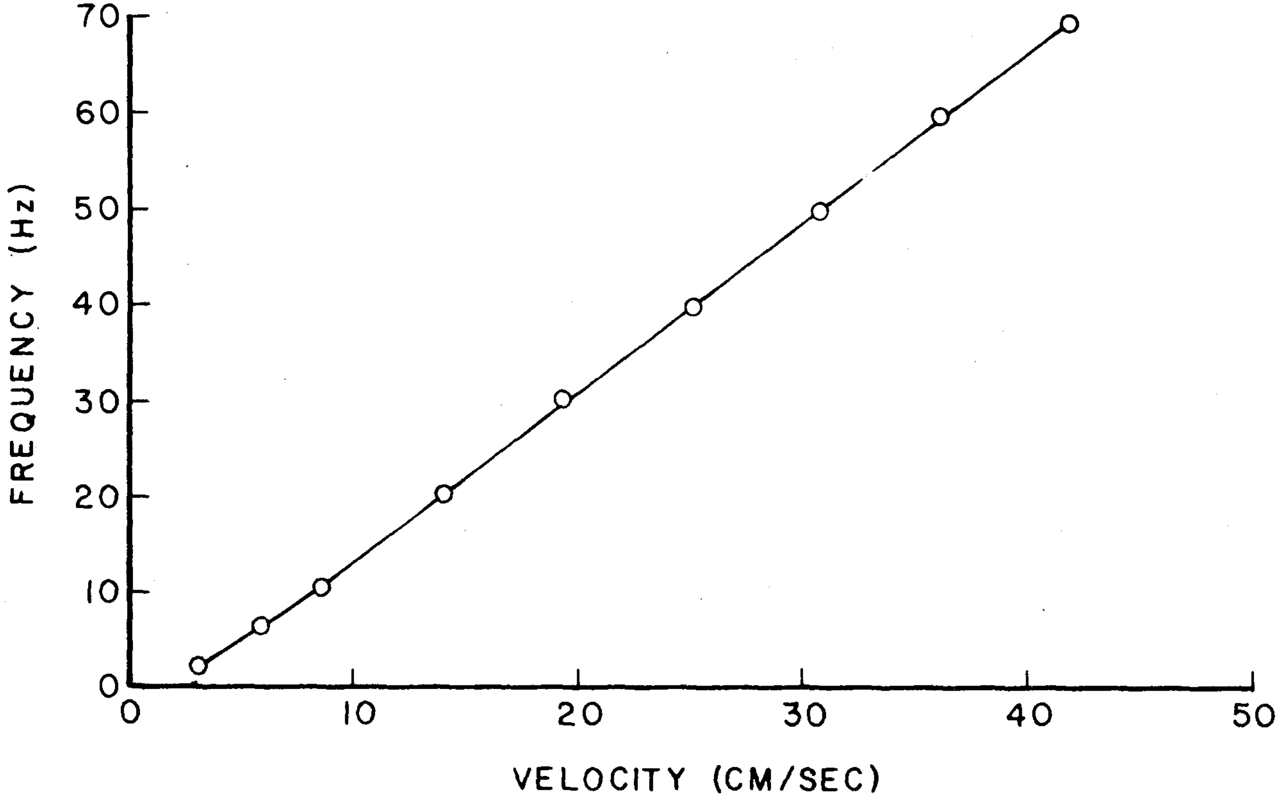

Figure 10. Typical Calibration Curve.