



## A New Digital DC Voltmeter with Automatic Range and Polarity Selection

**T**HE illustration below shows a new digital dc voltmeter that automatically and rapidly measures positive or negative dc voltages anywhere within the range from 1 millivolt to 999 volts and displays the measured value, including polarity and decimal point, in large illuminated digits. The instrument thus considerably facilitates situations such as equipment performance testing and production work where simplicity, speed and accuracy in making dc measurements are important.

The instrument also permits automatic logging of measurements, since it is designed to directly drive the -hp- high-speed digital recorder to produce printed records of measurements. Fig. 4 (page 3) indicates the type of print-out obtained when the voltmeter-

recorder combination is used. Function coding, polarity and decimal location can all be included in the printed record.

Electrically, the new voltmeter has a calibration accuracy of  $\pm 0.2\%$  and in other respects has the supporting characteristics necessary for accurate measurements in a wide range of applications. It has a high input impedance of 11 megohms, and its input circuit is floating so that it can measure voltage sources that are up to  $\pm 500$  volts off ground. Overload protection is also provided. Hum rejection is 50 db or more with the result that hum peaks as large as  $\frac{1}{3}$  of the dc in a circuit being measured cause an effect of only  $\pm 1$  count in the least place of the readout. The instrument includes a self-check feature such that accuracy can be tested at any time by



Fig. 1. New -hp- digital dc voltmeter has been designed as a fully automatic instrument for measuring voltages from 1 millivolt to 999 volts of either polarity. Coded outputs are provided for automatic data logging in conjunction with -hp- digital recorder or for driving other data handling equipment. Readout system includes a window of light-polarizing material which virtually eliminates effect of external light and gives a very dark, soft background of maximum contrast for ease in reading.

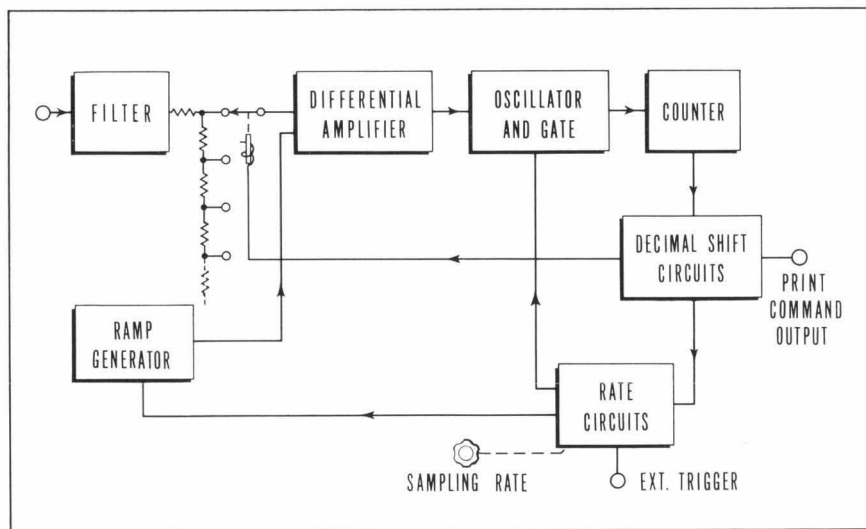


Fig. 2. Basic circuit arrangement of new voltmeter. Use of ramp-type design offers significant advantages for general-purpose instrument, as described in text.

pushing a panel switch. Finally, the instrument is fast, having a sampling rate adjustable from 5 measurements per second to 1 per 5 seconds or externally electrically or manually controllable.

#### DESIGN APPROACH

The new voltmeter uses a simple, straightforward circuit (Fig. 2) wherein an accurate, linearly-rising voltage ramp is generated and compared with the attenuated dc to be measured. Coincident with the start of the ramp, a gate on a clock oscillator is opened and kept open for the time interval needed for the ramp to become equal to the voltage being measured, at which moment the gate is closed. During this interval the number of clock pulses that have been gated out are counted by an electronic counter circuit. By suitably relating the slope of the ramp to the clock frequency (the time needed for the ramp to increase 1 voltage unit is made equal to 1 oscillator cycle period), the counter display is made to equal the measured voltage. Suitable sensing circuitry in the counter causes the input attenuator to be switched automatically to the optimum position and also automatically positions the

decimal point in the counter display. The display system itself consists of 1" nixie tubes, giving a large, bright, easily-read display using industry-standard components.

After the external voltage has been measured, the circuit continues automatically to re-measure the external voltage at a repetition rate determined by the setting of a panel control. The operator, however, continues to see an uninterrupted display which changes only when the measured voltage changes. The measuring cycle occurs rapidly (200 milliseconds) so that up to 5 repetitive measurements per second can be made, except that on the initial measurement, where it is possible that the circuit may have to scan all its ranges to find the optimum, the measurement can require up to 2 seconds. Successive readings of the same voltage can then occur at 5 per second.

#### RAMP DESIGN CONSIDERATIONS

For a general-purpose type of dc voltmeter, the ramp type circuit outlined above offers a number of advantages. For one thing it results in an economical design commensurate with the character of a general-pur-

pose instrument. At the same time it gives a performance that is about an order of magnitude higher in nearly all respects than that of the conventional vacuum-tube dc voltmeter. Accuracy, for example, is 0.2% as compared with a maximum of 2% for a conventional instrument, while resolution is 0.1% compared with 1% of full scale for an instrument using a D'Arsonval type display. This higher performance, of course, is combined with automatic operation, a digital display, and the potential for automatic data logging.

From the standpoint of possible automatic-type circuits, too, the ramp circuit offers advantages for general-purpose work. To the user one of the most apparent is that the ramp-type instrument always produces a measurement for voltages within its range. Where a slightly unstable voltage is being measured, for example, the ramp-type circuit measures the voltage at a discrete point in time and displays the value measured. Subsequent measurements will then show the amount of instability present in the voltage. Continuous-comparison type arrangements, on the other hand, frequently tend to be confused by an unstable voltage with the result that such circuits continuously hunt without producing a reading.

Finally, reliability considerations favor the ramp-type circuit. In an automatic type instrument, where the high speed of measurement may lead to several thousand or more measurements in a single day, reliability considerations make it desirable to minimize the use of mechanical switching or other mechanical devices. Excluding the very costly type of analog-digital converter, however, all automatic type circuits involve these in one function or another. In this respect the ramp-type circuit possesses the advantage that switching mechanisms are not used in the normal measurement, being

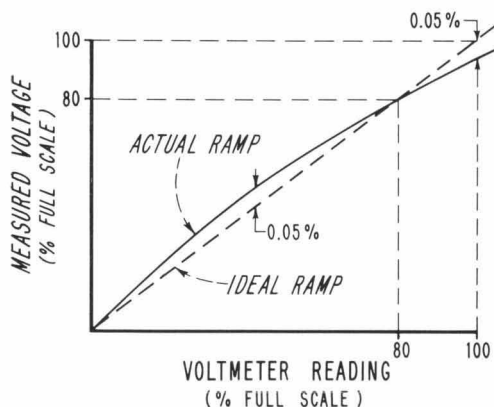


Fig. 3. Diagram illustrating nature of non-linearity of internal ramp voltage used for comparison purposes with non-linearity shown on exaggerated scale for clarity. Voltmeter calibration check described in text maintains ramp crossover at 80% point, as illustrated.

required only for range-changing purposes. In itself, this enormously reduces the number of operations required of the switching mechanism but, in addition, the Model 405AR is arranged so that a panel control will hold the instrument on one range. For repetitive measurements such as are encountered in production work where readings are all to be made on one range, this means that no switching mechanism is involved in the measurements, yet the capability for automatic ranging is present for applications that require it.

#### SELF-CHECK FEATURE

The voltmeter is arranged so that the user can easily check its calibration at any time from the front panel. The self-check arrangement consists of a panel push switch that connects the voltmeter input circuit to an accurate internal reference voltage. The value of this reference is approximately 7 volts, its precise value in each case being marked on the instrument panel. Pushing the panel switch causes the instrument to read this reference value. If needed, the calibration can be adjusted by a screwdriver-type control available at the panel. This control can also be used in special situations where maximum accuracy may be desired in a special voltage region and where an accurate external reference voltage in or near this region is available for calibration purposes.

The internal reference voltage is derived from a zener diode housed in

a temperature-regulated oven. The oven warmup time from room temperature is about 10 minutes, so that calibration can be checked any time after this interval.

#### ACCURACY

In addition to other factors, one of the new automatic voltmeter's advantages is that its accuracy ( $\pm 0.2\%$   $\pm 1$  count) applies to the reading displayed, rather than to the full scale value of the range on which the measurement is obtained, as in conventional instruments.

As may be suspected from a 0.2% accuracy rating, the chief uncertainty is introduced by the high-impedance attenuator at the voltmeter input. The attenuator used has an accuracy rating of  $\pm 0.1\%$ , which constitutes 50% of the overall measurement tolerance.

The second main component of measurement tolerance is concerned with the internal voltage ramp. Ideally, the ramp should be linear, but practical methods for generat-

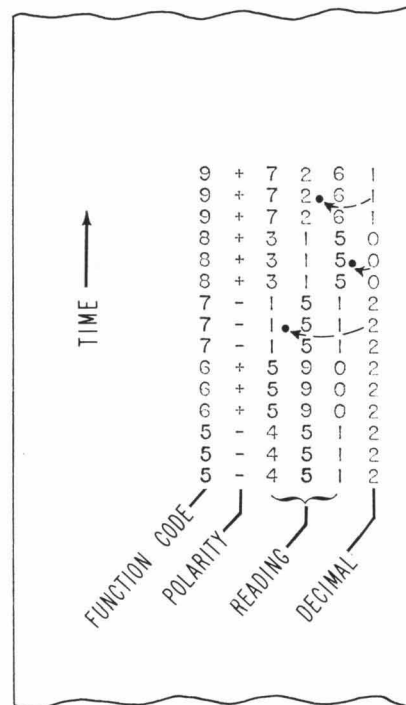
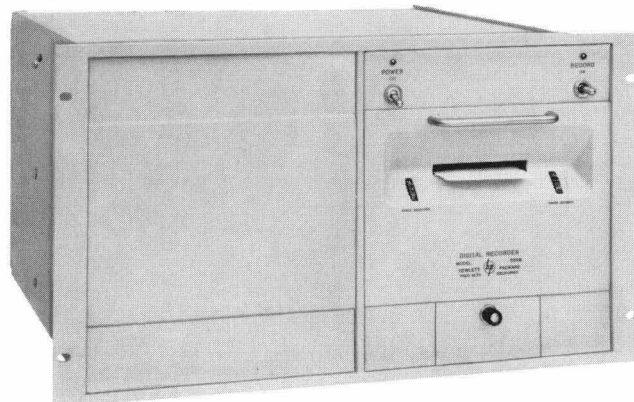


Fig. 4. Typical print-out obtained when voltmeter is used with hp digital recorder and operated with a programmer for multi-point measurements. First column identifies measured test point, while remaining columns indicate measured voltage.

ing ramps result in some non-linearity. Although non-linearity can be reduced to any desired degree, such reduction must be balanced against economic considerations. Very acceptable linearity is achieved, however, since the ramp is within 0.05% of an ideal rise at all points (Fig. 3). This factor constitutes the second main part of the overall measurement tolerance.

The  $\pm 1$  count tolerance arises from the ambiguity inherent in an

Fig. 5. hp-10-wire code input digital recorder (No. HO1 561B) recommended for use with new voltmeter for automatic logging. hp staircase-input recorder (Model 560A) can be used equally well, although its full capabilities are not required.



arbitrary gate used with discrete pulses, in this case the pulses from the clock oscillator. Actually, since the gate opening in the instrument is phase-locked to the oscillator, the theoretical error is not as great as  $\pm 1$  count but is thus rated for simplicity.

#### AUTOMATIC DATA LOGGING

In many applications, such as making equipment performance or checkout tests, it will be advantageous to use the new voltmeter with an *-hp-* digital recorder to obtain printed records of measured data. Fig. 4 shows the type of printout produced when the voltmeter-recorder combination is used. The right-hand column of the printout indicates the location of the decimal point, as demonstrated in the illustration. The extreme left column indicates the source of the measured data according to whatever pro-

gramming system has been used, while the column second from left shows polarity<sup>†</sup>.

The voltmeter-recorder combination can operate at a sampling rate determined by the setting of the panel control on the voltmeter, although in system work where a programmed switch connects the voltmeter to the various test points it will usually be necessary to place the voltmeter under the control of the switch. This can easily be done by arranging for the switch to supply a +20-volt or larger pulse to the voltmeter as the command pulse. Typical program switches can also be easily arranged to supply a coded function signal to the printer for the

<sup>†</sup>If the recorder has not been equipped to print polarity, this column will show an asterisk (\*) for negative polarities and a blank space for positive polarities.

extreme left column of the printout.

For operating external equipment such as the digital recorder discussed above, or other types of data-handling equipment, the voltmeter provides both staircase coded and 10-wire coded outputs. A decimal-coded or a pure binary output can also be obtained. The staircase output permits the voltmeter to be used in installations where an *-hp-* Model 560A Digital Recorder is at hand. To interconnect the voltmeter with the Model 560A, a small junction box available from *-hp-* is required. For cases where the Model 560A is not already available, the 10-wire output enables the voltmeter to be used with the lower-cost *-hp-* HO1 561B 10-wire code type digital recorder.

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#### SPECIFICATIONS

##### *-hp-* MODEL 405AR

##### AUTOMATIC DC DIGITAL VOLTMETER

Range: .001 to 999 volts dc, positive or negative.

Presentation: Three significant figures.

Accuracy: Within  $\pm 0.2\%$  of reading  $\pm 1$  count.

Floating Input: Permits measurements of systems operating within  $\pm 500$  vdc of power line ground.

Range and Polarity Selection: Automatic. A hold control disables the automatic selection and permits manual range selection.

Ranging Time: 1/5 second to 2 seconds depending on range change required.

Input Impedance: 11 megohms to dc on all ranges.

Sample Rate: Internal: 4 to 5 per second maximum to fewer than 1 every 5 seconds by front panel control. External: By 20 volt positive pulse, maximum rate of 5 per second.

Response Time: Approx. 1 second to step function.

AC Rejection: 3 db at approx. 1 cps; at least 50 db at 60 cps.

Digital Recorder Output: Connector at rear provides for operating specified *-hp-* Digital Recorders; special cable required.

Input Terminals: *-hp-* type binding posts on front; 3 prong AN-type connector at rear.

External Trigger Input: BNC female connector at rear.

Dimensions: Rack Mount: 7" high, 19" wide, 13 1/4" deep behind panel.

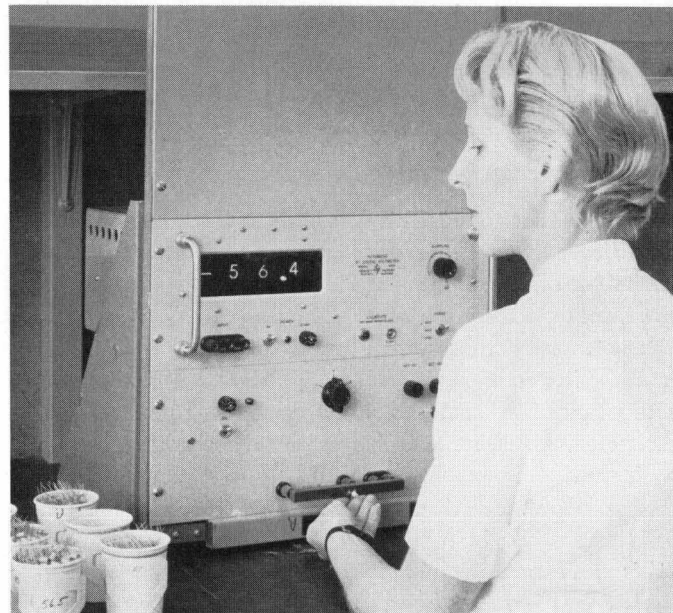
Weight: Net 26 lbs., Shipping 38 lbs.

Power: 115/230 volts  $\pm 10\%$ , 50-60 cps, 180 watts.

Price: Model 405AR Automatic DC Digital Voltmeter, Rack Mount, \$825.00.

Complementary Equipment: *-hp-* Spec. No. HO1 561B 10-wire code Digital Recorder for use with *-hp-* Model 405AR Digital Voltmeter; includes necessary interconnecting cable; Rack Mount: \$1085.00; Cabinet Mount: \$1100.00.

Prices f.o.b. Palo Alto, California  
Data subject to change without notice



The illustration above shows a typical production operation where in the new digital voltmeter discussed in the accompanying article facilitates production and reduces operational cost. Here a non-technical operator classifies semiconductor diodes by zener value. Measurements such as this where ordinarily

only one measuring range is used are facilitated by a panel switch on the voltmeter that prevents it from changing ranges. Non-technical operators are thus always presented with the same type of display, reducing reading-error possibilities and simplifying assimilation of the procedures for the operator.