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A New 10 CPS–600 KC High Stability VTVM

LAST spring *-hp-* introduced a vacuum tube voltmeter* of a special new design which operated up to more than 4 mc and which had an extremely high stability. This voltmeter has become one of the most popular instruments *-hp-* has ever produced.

SEE ALSO:
"Waveform Effects on Voltmeters," p. 3

The same basic design has now been extended to a new companion voltmeter which operates from 10 cps to 600 kc, measures voltages as low as 0.3 millivolt, is virtually unaffected by line voltage levels from 103 to 127 volts, and has a high input impedance of 10 megohms shunted by 25 mmf.

An accuracy curve typical of the performance of the new voltmeter is shown below. This curve shows not only the constancy of the voltmeter accuracy as a function of frequency but also includes any errors introduced by low or high line voltages. Typically, a change in line voltage from 105 to 127 volts will cause in the voltmeter reading a change which is scarcely perceptible in the middle region and which is less than 0.5% at the ends of the frequency range. Rated accuracy for the instrument is within 2% of full scale from 20 cps to 100 kc and within 3% of full scale from 10 cps to 600 kc. This accuracy applies for any line voltage in the 103-127 volt range.

The instrument covers a voltage range from 3 millivolts full scale to 300 volts full scale in 11 ranges. Since readings can easily be made down to at least one-tenth of full scale, voltages as low as 0.3 millivolt can be measured. Dbm calibrations on the meter face can be used in combination with dbm

*John Zevenbergen, "Wider Range and Higher Stability in the New -hp- 4 MC Voltmeter," Hewlett-Packard Journal, Vol. 5, No. 9, May, 1954.

Fig. 1. *New -hp- Model 400AB operates from 10 cps to 600 kc, is accurate within 3%. Voltages as low as 0.3 millivolt can be measured. Output terminals permit use as high-gain amplifier. Collapsible bail on bottom permits meter to be tilted.*

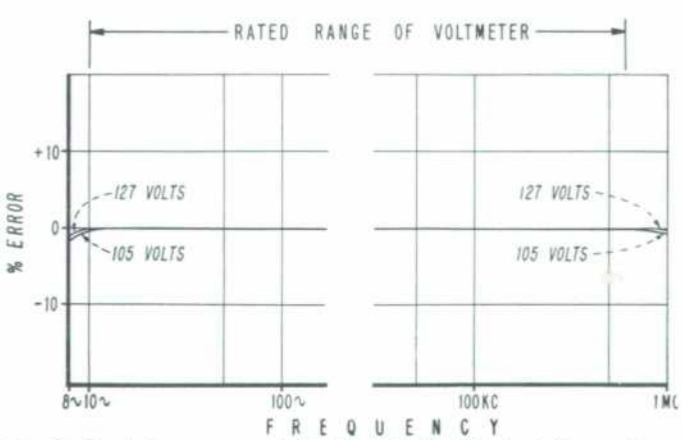

Fig. 2. *Typical accuracy of Model 400AB. Effect of line voltage changes from 105 to 127 volts is perceptible only at extremes of range.*

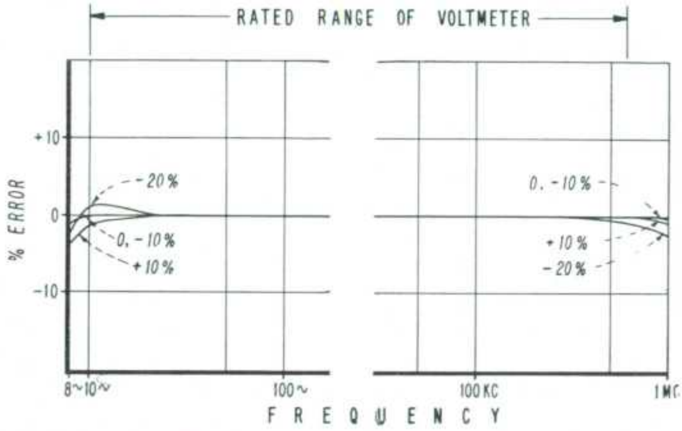

Fig. 3. *Typical effect of +10 to −20% G_m variations in tubes in Model 400AB.*

calibrations on the range switch to permit readings to be made directly in dbm in a 600-ohm circuit over a range from −60 to +50 dbm with 0 dbm equal to 1 milliwatt in 600 ohms.

Output terminals are provided on the voltmeter to permit use as a high-gain amplifier or to permit viewing the waveshape being measured on an oscilloscope. Approximately 0.5 volt open circuit is available from the output terminals from a source impedance of 600 ohms. Response at the output terminals is essentially identical to the response of the voltmeter at frequencies above 20 cps.

TUBE REPLACEMENTS

Like its 4 mc counterpart, the new voltmeter has an extremely low sensitivity to variations in the G_m of replacement tubes. This occurs not only because substantial feedback is used to stabilize the voltmeter, but also because the feedback is treated in a special manner.

In the voltmeter amplifier type 6AH6 pentodes and type 6BK7 dual triodes are used. Nominal G_m's for these tubes in the circuits in which they are operated are 6,500 and 5,100 micromhos, respectively. The effect on the performance of the voltmeter of wide G_m variations from +10% to −20% in *all* tubes in the voltmeter amplifier is shown in Fig. 3. In the worst case it will be seen that the voltmeter accuracy is altered by 2% and this occurs only at the lowest rated frequency of 10 cps. The fact that G_m's lower than design center value cause the gain of the voltmeter to increase a little is the result of the special feedback treatment used.

GENERAL

Care has been taken in many ways to make the new voltmeter convenient to use. A collapsible bail on the bottom permits the unit to be tilted for easy viewing of the meter. The instrument uses the easily-read *-hp-* linear meter face. Switching transients have been suppressed so that only a partial scale deflection of less than a second's duration occurs when changing ranges. Measured frequencies which lie near or at the power line frequency cause little reaction.

Constructionally, the new instrument is compact and requires only $7\frac{1}{4}''$ x $8\frac{1}{4}''$ of bench surface. Etched circuitry is used to give a clean layout and good accessibility to components. All except low-voltage electrolytic capacitors are of the "long life" type which have proved highly successful.

—John Zevenbergen

SPECIFICATIONS
-hp-
MODEL 400AB VACUUM TUBE VOLTMETER

VOLTAGE RANGE: 0.3 mv to 300 volts. 11 ranges, selected with front panel switch. Full scale readings of:

0.003 volts	0.1	3.0	100
0.01	0.3	10.0	300
0.03	1.0	30	

FREQUENCY RANGE: 10 cps to 600 kc.

ACCURACY: With nominal line voltage ±10% (103 volts to 127 volts), overall accuracy is within ±2% of full scale, 20 cps to 100 kc, ±3% 10 cps to 600 kc.

CALIBRATION: Reads rms value of sine wave. Voltage indication proportional to average value of applied wave. Linear voltage scales, 0 to 3 and 0 to 1.0; db scale, −12 db to +2 db, based on 0 dbm = 1 mw in 600 ohms, 10 db intervals between ranges.

INPUT IMPEDANCE: 10 megohms shunted by 25 $\mu\mu$f.

AMPLIFIER: Output terminals are provided so voltmeter can be used to amplify small signals or monitor waveforms under test with an oscilloscope.

POWER: 115/230 volts ±10%, 50/1000 cps, approx. 70 watts.

SIZE: Cabinet Mount: 11¼" high, 7¼" wide, 7" deep. Rack Mount: 19" wide, 7" high, 7½" deep.

WEIGHT: Cabinet Mount: Net 15 lbs.; shipping weight 25 lbs. Rack Mount: Net 15 lbs.; shipping weight 26 lbs.

ACCESSORIES AVAILABLE: -hp- AC-60A Line Matching Transformer, $25.00. -hp- Model 452A Capacitive Voltage Divider, $100.00. -hp- Model 454A Capacitive Voltage Divider, $25.00. -hp- Models 470A-470F Shunt Resistors.

PRICE: -hp- Model 400AB Vacuum Tube Voltmeter, cabinet mount, $200.00. -hp- Model 400ABR Vacuum Tube Voltmeter, rack mount, $205.00.

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

The accompanying article (next page) describing the effect of harmonics on VTVM readings should prove both interesting and useful to all who use VTVM's. The material to be presented includes original data on the effect of combined harmonics such as are encountered in distortion measurements. These data will be summarized in a series of curves which can easily be applied in practical cases.

The article will be published in three parts.

Some Effects of Waveform on VTVM Readings

WHEN using a vacuum-tube voltmeter calibrated in rms values, how is the peak-to-peak value of a square wave obtained from the voltmeter reading? Or what is the effect on the reading of the presence of 10% third harmonic? In practice, numerous questions such as these occur as to how waveforms other than pure sine waves influence the voltmeter reading. Before questions of this nature can be answered, however, it is necessary to know the operating principle of the voltmeter being used.

-hp- voltmeters are of two types: those in which the meter deflection is proportional to the average value of a rectified cycle of the applied waveform and those in which the deflection is proportional to the positive peak value. Equivalent circuits of these types are shown in Fig. 1. In the *-hp-* average-reading type the applied waveform is amplified to a convenient high level. It is then rectified and the resultant current pulses applied to a d-c milliammeter calibrated in terms of the input voltage. The ballistic characteristics of the meter integrate the moments of force in the meter movement to produce a steady deflection of the meter pointer. Any d-c component in the applied voltage is excluded from the measurement because of the input blocking capacitor.

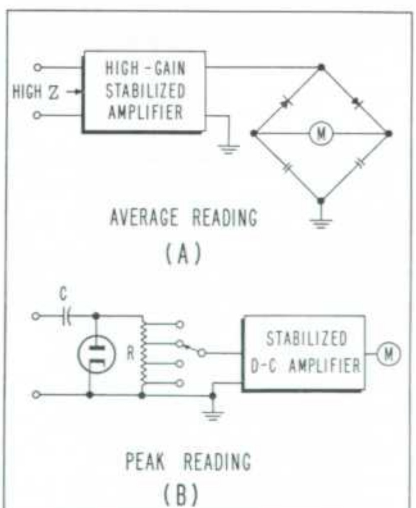

Fig. 1. *(a) Average-reading type circuit used in -hp- 400 series voltmeters to obtain relative freedom from waveform effects as discussed in accompanying article. (b) Peak-reading type circuit used in -hp- 410 voltmeters. Although this circuit has greater sensitivity to waveform effects, it is possible, through suitable design to operate the circuit up to hundreds of megacycles as in the -hp- 410B 700-megacycle voltmeter.*

In the *-hp-* peak-reading type circuit (Fig. 1[b]) the positive peak of the applied waveform charges a capacitor through a diode. The resulting d-c voltage, or a known fraction of it, is then applied to a stabilized d-c amplifier. A voltage-calibrated meter monitors the amplifier output. Again, any d-c component is excluded.

Both of these circuits are calibrated so that they indicate the rms value of an applied pure sine wave. That is, the average-reading type reads 1.11 times the average value of a rectified cycle of any applied wave; the peak-reading type reads 0.707 times the positive peak. The rms calibration of (or scale used with) both meters applies as long as the input is a pure sine wave. But when the meters are used to measure complex waves, the readings must be correctly interpreted because the ratios of rms to average and rms to peak are usually not the same in a complex wave as in a sine wave. In general the average-reading meter gives readings on complex waves which are closer to the true rms values than does the peak reading meter.

(a)

-hp- Model 400D 10 cps - 4 megacycle voltmeter uses average-reading type circuit.

(b)

-hp- Model 410B 700-megacycle voltmeter uses peak-reading type circuit.

Fig. 2

EXTREMES OF ERROR, AVERAGE-READING METERS

In a square wave the unique relation exists that the average, rms, and peak values are all the same. Since an average-reading meter indicates 1.11 times the average value, it will indicate 11% high for the rms value of a square wave. Further, a square wave has the lowest ratio of rms value to absolute average value of any wave. It follows, then, that an average-reading meter will never read more than 11% high.

At the other extreme consider a series of short duty cycle pulses having a given rms value. As the duty cycle approaches zero, the pulse amplitude need only increase as

$1/\sqrt{\text{duty cycle}}$ to keep the rms value constant. Thus, the absolute average value of the wave approaches zero. It is conceivable, then, that an average-reading meter would indicate as much as 100% low. Excluding short duty cycle pulse waveforms, however, an average-reading meter seldom reads more than 20% low on complex waves.

SECOND HARMONIC WITH AVERAGE-READING METERS

The accuracy with which an average-reading meter will indicate the rms value of a wave with harmonic content depends not only on the amplitude of the harmonic but on its phase and order as well. In the case of a wave with second harmonic content, the difference between the true rms value of the wave and the reading indicated by an average-reading voltmeter will be small for most waves encountered in practice.

Fig. 3 shows the calculated range of absolute average values of a wave consisting of a fundamental with various amounts of second harmonic. The upper and lower limits of the shaded area are determined by the phase of the harmonic with respect to the fundamental. Consider, for example, a wave consisting of a fundamental combined with an "in-phase" second harmonic, i.e., a second harmonic whose zero-axis intercepts coincide with the corresponding fundamental intercepts as shown in Fig. 4(a). In each half cycle of the fundamental, the second harmonic contributes a positive component and a negative component which are equal in area and so do not alter the average value of the rectified wave. An in-phase second harmonic will thus cause no change in the meter reading until the harmonic reaches a value such that its initial slope (slope at 0, 2π, 4π, etc., radians) exceeds the slope of the fundamental. For such higher slopes the complex wave acquires additional crossings of the zero axis. When this happens, the harmonic adds area to the rectified wave and the average value begins to increase. Since the initial slope of a second harmonic does not exceed the slope of the fundamental until the harmonic reaches a value of 50%, the average value of the wave will remain constant until an in-phase second harmonic reaches this value. The lower boundary of the shaded area in Fig. 3 shows this case.

The condition for which a second harmonic will cause the average value of the complex wave to follow most closely the rms sum of the components is where the harmonic has a "quadrature" relation to the fundamental, i.e., the peaks of the harmonic occur at the time the fundamental intercepts the zero axis, as illustrated in Fig. 4(b). This is also the condition usually encountered in practice. A square law term in a transfer characteristic, for example, produces a quadrature relation for the second harmonic.

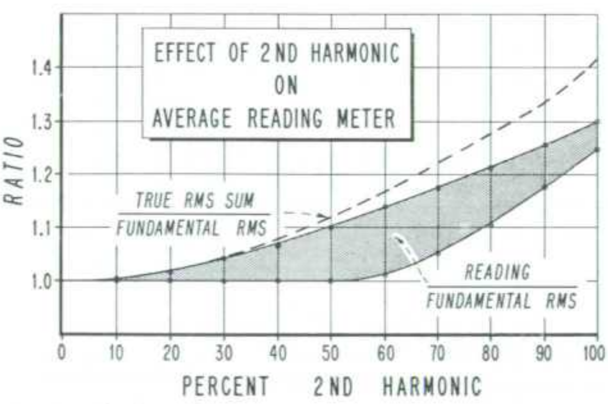

Fig. 3. *Calculated limits (shaded area) of absolute average value of wave consisting of fundamental and various amounts of second harmonic. Small circles show experimental verification of calculated data. Dashed line shows true rms value.*

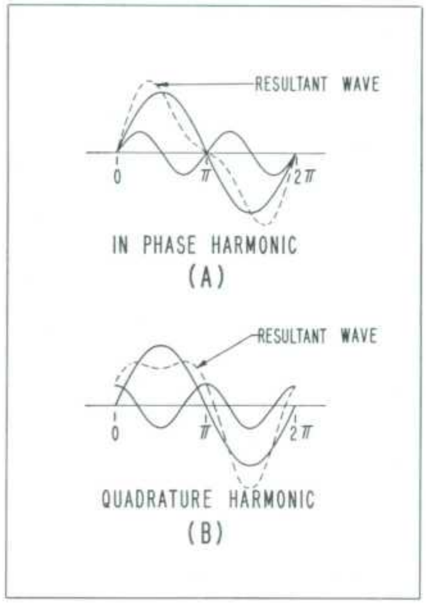

Fig. 4. *(a) In-phase harmonic causes lowest readings on average-reading voltmeter. (b) Quadrature harmonic causes average-reading voltmeter to follow rms value most closely. Quadrature relation is case usually encountered in practice.*

The calculated average values for a wave consisting of a fundamental with various amounts of a quadrature second harmonic are plotted in Fig. 3 as the upper boundary for the shaded area.

The calculated data in Fig. 3 were verified experimentally by establishing a "fundamental" and a "second harmonic" and adjusting these so that they caused a slow beat on an *-hp-* 400D average-reading type meter. The limits of the beat were then observed. The data obtained in this manner are plotted as small circles on the curve. The close agreement is apparent.

In examining Fig. 3 it will be seen that for second harmonics of typical magnitudes the average-reading type meter will give readings quite close to the true rms sum. For a second harmonic of 25% magnitude, for example, the error of the average-reading meter is but 3% and this applies in the case of an in-phase harmonic. With a 10% second harmonic, the error is less than 1%.

(Continued in next issue)

—B. M. Oliver