



Wider Range and Higher Stability in the New -hp- 4 MC Voltmeter

-hp- electronic voltmeters have always been characterized not only by accuracy but by the other properties that make voltmeters easy to apply in practical work. These properties include a wide frequency range, high input impedance, and high sensitivity. For example, the Model 400A, introduced nearly fifteen years ago, had a frequency range of 1 megacycle, an impedance of 1 megohm, and a maximum sensitivity of 30 millivolts full scale. Some five years ago, the Model 400C was introduced with a range of 2 megacycles, an impedance of 10 megohms, and a sensitivity of 1 millivolt full scale.*

Developing an economical voltmeter that will better the flexibility of these designs constitutes a challenging design problem. But such a voltmeter has been developed,

thoroughly proved, and assigned the model number 400D. In developing this voltmeter, particular care has been taken to insure that the high standards of -hp- voltmeters have been maintained and that a significant contribution to the voltmeter art has resulted. As an indication that these requirements have been met, the salient features of the new design are summarized below:

- Frequency range: 10 cps to 4 mc.
- Maximum sensitivity: 1 millivolt full scale; voltages as low as 100 microvolts can easily be read.
- Stability: A reduction in G_m of 25% in *all* tubes causes less than 0.5% change in readings from 20 cps to 1 mc.
- Accuracy: Within 2% from 20 cps to 1 mc, 3% from 20 cps to 2 mc, and 5% from 10 cps to 4 mc.
- Input impedance: 10 megohms shunted by 25 mmf on lower six ranges or by 15 mmf on higher six ranges.

As a further introduction to the performance of this voltmeter, the curves of Figs. 3 and 5 are presented (next page). But before discussing these curves, it is desirable to describe briefly the circuit arrangement of the voltmeter. This is shown in basic form in Fig. 2. The voltmeter input terminals feed into a cathode follower with a high grid impedance of 10 megohms. High stability for the cathode follower is insured by 35 db of local feedback. Since it extends down to



Fig. 1. New -hp- Model 400D measures voltages from 10 cps to 4 megacycles down to levels as low as 100 microvolts. Output terminals permit use as wide-band amplifier.

*This discussion pertains to the -hp- high-sensitivity voltmeters rather than to the extremely wide range -hp- Model 410B 700-megacycle voltmeter.

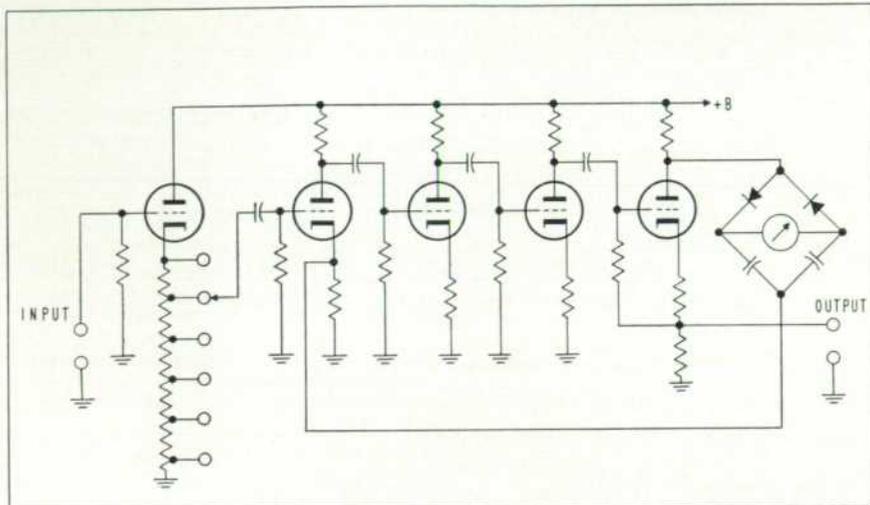


Fig. 2. Basic circuit arrangement of voltmeter.

d-c, this feedback not only suppresses effects of G_m changes by a factor of 56:1, but also suppresses the G_m changes themselves by holding I_p constant. Range switching for the voltmeter is accomplished by tapping the resistor of the cathode follower as shown.

The output of the cathode follower is applied to a maximally flat-maximally stable four-stage amplifier which is stabilized with 56 to 60 db of negative feedback at midband. This magnitude of feedback accounts for the very high voltmeter stability mentioned earlier.

The output of the amplifier is applied to a full-wave rectifier circuit which has been carefully designed to achieve a flat frequency characteristic over the 4 mc range of the instrument. The rectifier in turn feeds a d-c indicating meter. The indicating circuit responds to the average value of the current waveform, although the meter face is calibrated to indicate the rms value of an applied sine wave. This type of circuit has no turnover effect and further offers good accuracy on wave-forms having moderate harmonic content.

VOLTMETER STABILITY

In the design of electronic voltmeters, one of the important considerations from the standpoint of the user is the effect that replacing tubes

will have on the overall performance of the voltmeter. In general, the user seldom has available a means of precisely checking the accuracy of a wide-range voltmeter after replacing one or more tubes. He must therefore rely on the stability that the designer has incorporated into the instrument.

In the new Model 400D, the amplifier tubes are all type 6CB6 pentodes. In the design of the amplifier the center G_m value for these tubes was selected to be 6,200 micromhos. From the standpoint of tube replacement, the worst possible demand on stability would occur when all of the amplifier tubes were replaced with tubes whose G_m 's all departed widely and in the same direction from the design center value. A similar situation could prevail after extensive use of the voltmeter had resulted in aging the amplifier tubes to the point where all G_m 's had dropped to a comparatively low value.

The effect of using complete sets of replacement tubes that all have either low or high G_m 's is illustrated in Fig. 3. Between 20 cps and 2 megacycles the G_m 's can depart widely from the design center value with only approximately 1% variation in the gain of the voltmeter. At 3 megacycles the gain variation in the worst case is only 2%. At 4 megacycles, it is necessary for the

G_m 's of all tubes to be nearly 15% below the design value before the voltmeter exceeds its rated error.

It should be noted that Fig. 3 is based on complete sets of replacement tubes each having the G_m shown in the curve. Variations of individual tubes will have much smaller effects than shown by Fig. 3. For example, if two 6,500 micromho tubes and two 5,500 micromho tubes are used, the voltmeter characteristic would be very nearly that shown by the 6,000 micromho G_m curve. If two 5,500 and two 6,000 micromho tubes were used, the characteristic would lie between the 5,500 and 6,000 micromho curves of Fig. 3.

Since Fig. 3 shows that a wide range of tube G_m 's can be used with only a small effect on the voltmeter, the next matter to consider is how the G_m of a typical type 6CB6 tube can be expected to relate to this range of G_m 's. In an attempt to obtain an answer to this question, a sampling was made of the G_m 's of 800 type 6CB6 tubes as received from the tube manufacturer. The results of these measurements are shown in Fig. 4. Applying these results to the performance curves in Fig. 3, it will be seen that no single tube in the lot would cause a change in calibration greater than approximately 1% anywhere below the 4-megacycle rated limit for the voltmeter if the other tubes are near their rated G_m value.

In any case, Fig. 3 shows that replacement tubes can be selected quite readily by measuring the G_m 's of the intended tubes. There is another aspect of the curves of Fig.

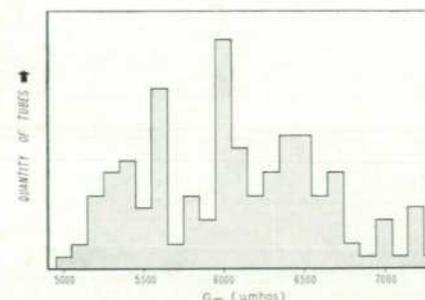


Fig. 4. Measured distribution of G_m 's of 800 type 6CB6 tubes.

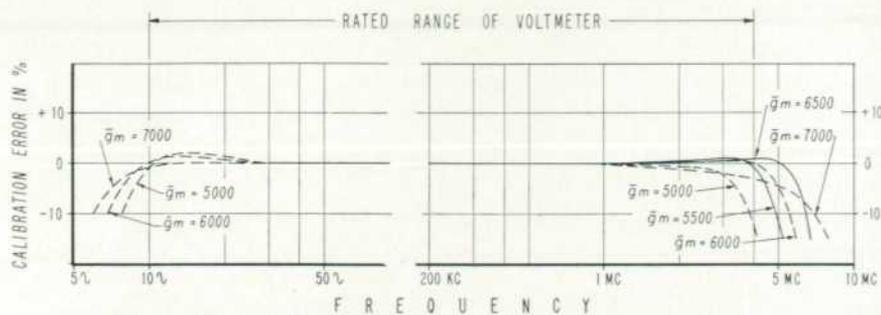


Fig. 3. Typical effect on voltmeter calibration accuracy of using tube sets having various G_m 's.

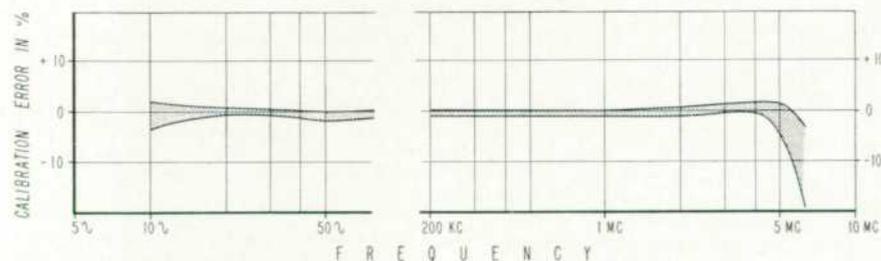


Fig. 5. Range of calibration error of 50 Model 400D voltmeters.

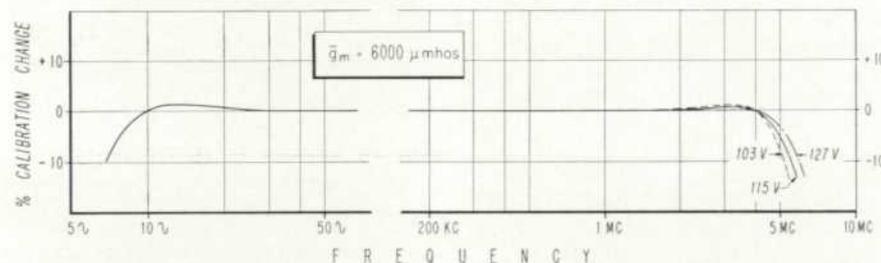


Fig. 6. Effect of line voltage on accuracy of typical Model 400D.

3, however, that is of interest to amplifier designers. Examination of Fig. 3 shows that tubes having G_m 's higher than the design center value cause the gain of the amplifier to decrease at the lowest and highest frequencies over the case resulting from using tubes having center-value G_m 's. The explanation for this apparent anomaly lies in the special design of the amplifier. This design is such that the feedback is substantially more effective at the higher frequencies than in the conventional case.

From the standpoint of the user, this feature of gain-reduction by high G_m tubes as well as low G_m tubes offers an alternate method for replacing tubes. Since Fig. 3 shows that tubes having G_m 's either significantly above or significantly below the design center value will cause the amplifier gain to fall off, the user can replace a tube merely

by choosing the tube that causes the highest reading at the high frequency end of the voltmeter. Conservative maintenance policy would not dictate, however, that this procedure be used to the exclusion of an actual calibration check, if means are available for so doing.

The effect of variations in the G_m 's of tubes was presented in Fig. 3 for a single production instrument. When any manufactured item is produced in quantity, some variation in performance is obtained regardless of the product being manufactured. In this regard it is interesting to examine Fig. 5, which shows the overall performance of 50 Model 400D voltmeters.

In the production of the voltmeters it is not economically practical to select and use only design-center G_m tubes. All tubes that lie within the tolerances of the tube type are used unless they have some other

defect. For this reason Fig. 5 is an interesting doublecheck on the data in Fig. 3 as well as Fig. 4.

Fig. 5 further shows that the 4-megacycle high-frequency limit established for the voltmeter is conservative. It is apparent that the voltmeter can be put to good use in many applications approaching 6 megacycles, especially if care is taken to use tubes having a geometric mean G_m of 6,200 micromhos.

LINE VOLTAGE RESPONSE

Another consideration of importance to the user of a voltmeter concerns the line voltage from which the voltmeter is to be operated. In the Model 400D the high order of negative feed-back virtually eliminates the effect of line voltage changes over the rated frequency range. In the region between 4 and 6 megacycles, some line voltage effect is obtained (Fig. 6), but it is small.

AMPLIFIER USE

The 400D is provided with a set of output terminals to permit the instrument to be used as a wide-band amplifier as well as a voltmeter. At a full scale meter reading on a sine wave, the output voltage from these terminals is approximately 0.15 volt rms. The frequency characteristic at the output terminals is very nearly the same as that of the voltmeter at frequencies above 20 cps.

Accuracy of the voltmeter is independent of the load on the amplifier at frequencies below 1 megacycle. At higher frequencies, up to 100 mmf of shunting capacity can be tolerated. Resistive loads of any value cause no error, so terminated cables of any impedance and length can be used. The internal impedance at the amplifier terminals is approximately 50 ohms over the complete frequency range.

METER SCALE ARRANGEMENT

Fig. 7 is a half-size reproduction of the meter face used in the 400D (and in most other *-hp-* voltmeters). This face possesses several advan-

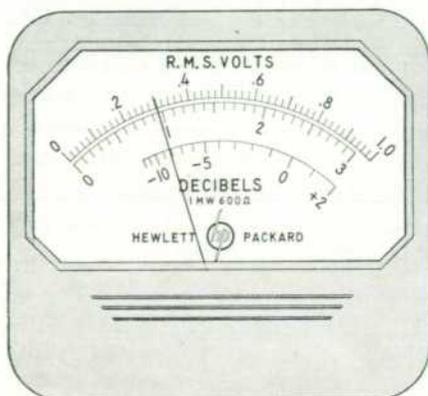


Fig. 7. Half-size reproduction of Model 400D meter face.

tages worthy of special mention, since they contribute materially to the ease of readability and use of the voltmeter.

The meter is provided with two linear voltage scales. One scale is calibrated from 0 to 1 and the second from 0 to 3. This arrangement is such that readings can always be made on one scale or the other in the upper two-thirds of the scale where highest accuracy is obtained. In addition, with the linear scale, a high order of readability is obtained. Since each scale retains the same calibration divisions and spacing throughout the scale, the possibility of reading errors arising from misinterpretation of the calibration marks is reduced.

600-OHM DB SCALE

The two linear voltage scales on the meter face are related by a factor 3.16 to 1, or 10 db. This arrangement permits a single, open db scale to be used on the meter face so that measurements can be made directly in db if desired. The db scale is calibrated with 0 db equal to the industry-standard value of 1 milliwatt in 600 ohms.

Since the voltage ranges on the voltmeter are related by 10 db, each position of the range switch extends the db scale on the meter face by 10 db. Suitable calibrations on the range switch make the db scales direct-reading from -72 to +52 dbm.

The meter itself is a specially-selected 1% movement with a knife-edge pointer.

TRANSIENT SUPPRESSION

In the Model 400D care has been taken to minimize deflection of the meter pointer when switching voltage ranges. Except for one range, switching transients cause less than a one-third scale transient deflection and this dies out in less than one second. This suppression is accomplished without using a specially-damped meter and the response of the meter is quick.

60-CYCLE EFFECT

In high-sensitivity a-c amplifiers, there is normally an effect on the output voltage when the frequency of the amplified signal is near the power line frequency. This effect, commonly called "60-cycle beating", is often unnoticed in other applications, but in voltmeters it causes an oscillation of the meter pointer when the two frequencies are near one another.

In the 400D, 60-cycle beating has been held to a low value of not more than 1%. Generally, it is but one-quarter to one-half of 1%.

MEASURING SMALL CURRENTS

A voltmeter with a full-scale sensitivity of a 1 millivolt can be made into an extraordinarily flexible a-c microammeter through use of the -hp- Model 470 series of precision resistors. These resistors are designed in values of 0.1, 1, 10, 100, 600, and 1,000 ohms. Using the 1,000-ohm resistor with the voltmeter will permit measurement of currents as low as 0.1 microampere with a device having a resistance of only 1,000 ohms.

MEASURING VOLTAGES TO 25 KILOVOLTS

The 400D by itself measures voltages as high as 300 volts rms. This range can be extended to 1,500 volts by use of the -hp- Model 454A Capacitive Divider or to 25,000 volts by use of the -hp- 452A Capacitive Divider.

-John Zevenbergen

SPECIFICATIONS

-hp-

MODEL 400D

VACUUM TUBE VOLTMETER

VOLTAGE RANGE: 0.1 millivolts to 300 volts. (Extended to 1,500 volts with -hp- 454A, 25 kilovolts with -hp- 452A. See below.) 12 ranges, selected with front panel switch. Full scale readings of:

0.001	0.03	1	30
0.003	0.1	3	100
0.010	0.3	10	300 volts.

FREQUENCY RANGE: 10 cps to 4 megacycles.

ACCURACY: With line voltages from 103 volts to 127 volts, overall accuracy is:

within $\pm 2\%$ of full scale value, 20 cps to 1 mc;
within $\pm 3\%$ of full scale value, 20 cps to 2 mc;
within $\pm 5\%$ of full scale value, 10 cps to 4 mc.

LONG TERM STABILITY: Reduction in G_m of amplifier tubes to 75% of nominal value results in error of less than 0.5%, 20 cps to 1 mc.

CALIBRATION: Reads rms value of sine wave. Voltage indication proportional to average value of applied wave. Linear voltage scales, 0 to 1 and 0 to 3; 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 15 mmfd on 1 volt to 300 volt ranges; 25 mmfd on 0.001 volt to 0.3 volt ranges.

AMPLIFIER: Output terminals are provided so voltmeter can be used to amplify small signals or to monitor waveforms under test with an oscilloscope. Output approximately 0.15 volts rms on all ranges with full scale meter deflection. Amplifier frequency response same as that of voltmeter. Internal impedance approximately 50 ohms over entire frequency range.

POWER SUPPLY: 115/230 volts $\pm 10\%$, 50/1,000 cps, approx. 70 watts.

SIZE: Cabinet, 10 $\frac{3}{4}$ " high, 7" wide, 10 $\frac{1}{2}$ " deep. Rack mounting on 19" x 7" panel available at \$5.00 additional.

WEIGHT: 19 lbs.; shipping weight, approximately 24 lbs.

PRICE: \$225.00 f.o.b. Palo Alto, California.

ACCESSORIES AVAILABLE: -hp- 452A Capacitive Voltage Divider. Safely measures power-frequency voltages to 25 kilovolts. Division ratio, 1000:1. Input capacity, 15 mmfd ± 1 mmfd. Price \$100.00.

-hp- 454A Capacitive Voltage Divider. Accuracy $\pm 3\%$. Division ratio, 100:1. Input impedance, 50 megohms, resistive, shunted with 2.75 mmfd capacity. Maximum voltage 1,500 volts. Price \$25.00.

-hp- 470A-470F Shunt Resistors. For measuring currents as small as 1 microamp full scale. Accuracy $\pm 1\%$ to 100 kc, $\pm 5\%$ to 4 mc. (470A, $\pm 5\%$ to 1 mc). Maximum power dissipation 1 watt.

-hp- 470A,	0.1 Ω	\$15.00;
-hp- 470B,	1.0 Ω	7.50;
-hp- 470C,	10.0 Ω	7.50;
-hp- 470D,	100 Ω	7.50;
-hp- 470E,	600 Ω	7.50;
-hp- 470F,	1,000 Ω	7.50.

-hp- AC-60A Line Matching Transformer. For connecting voltmeter to balanced 135- or 600-ohm circuits. Frequency range, 5 kc to 600 kc. Insertion loss, less than 0.2 db at 100 kc. Frequency response, less than 0.5 db reduction at 5 kc and 600 kc from mid-frequency value. Balance, better than 40 db over entire frequency range. Power capacity, +22 dbm (10 volts across 600 ohms). Price \$25.00.

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