## A Precision 3½ Digit Multimeter

Model 3435A Digital Multimeter is a 3½ digit instrument that has better accuracy (0.1%) than Model 3476A, a wider frequency range for ac signals (to 100 kHz), and higher sensitivity for resistance measurements (10-mΩ resolution). It measures dc and ac volts with full-scale ranges from 200mV to 1200V, resistance from 20Ω full-scale to 20 MΩ, and dc and ac current ranging from 200 μA full-scale to 2000 mA, with automatic polarity indication and either manual or automatic range selection (except when measuring current). Lighted front-panel annunciators show the function and range selected.

An optional "touch-hold" probe enables a voltage reading to be retained on display when a pushbutton switch on the probe body is pressed. This facilitates measurements in situations where it may be difficult to hold the probe in position while looking away to read the measurement.

Pressing the button on the probe grounds the amperes input, which is converted to a logic input whenever the instrument is switched to either the dc or ac volts mode. Grounding the amperes input interrupts the voltmeter's logic circuits so voltage sampling is stopped and the most recent reading is retained on display. Releasing the button restores normal operation.

Model 3435A is powered by a sealed lead-acid storage battery that can give more than 10 hours of continuous operation with only 12 hours recharge (a built-in charger is included). With a new high-efficiency LED display, the voltmeter dissipates only three watts, not only extending battery life, but also enhancing accuracy, stability, and reliability by keeping internal temperatures low.

Model 3435A uses the fine-line resistors and the single-reference A-to-D converter described in the accompanying article, giving it high-grade performance at low cost. Servicing and calibration costs are also low because there are only four potentiometers and two capacitors that require adjustment during routine calibration procedures.

The instrument is housed in a tough plastic case, well suited for applications requiring portability. The carrying handle doubles as a bail, being able to rotate through 15 positions, each secured by a positive locking detent. An optional version (Opt. 002) is in a modular cabinet that can be racked or stacked with other HP modular instruments (see photo below).

an attenuator, using a switched feedback network for the various ranges as shown in Fig. 4a. The operational amplifier establishes a virtual ground at the summing point at its inverting input where the switches are. The problem with MOS transistor back-gate bias is thus eliminated. The problem with the ON resistance remains, however. The ON resistance in series with the 1-kΩ resistor of Fig. 4a must satisfy the following relationship if it is to introduce less than a one-count error in a full-scale reading in a 2000-count (3½-digit) voltmeter:

$$R_{ON} \leq \frac{1000\Omega}{2000} = 0.5\Omega$$

This is a value much lower than that realizable at the present time.

The effect of the MOS transistor ON resistance can be reduced significantly by shifting the summing point to the other side of the MOS switches and then using additional MOS switches to connect the appropriate summing point to the amplifier's inverting input, as shown in Fig. 4b. The ON resistance of a MOS switch in series with the 10-MΩ input resistance easily satisfies the relationship (for a 1-count error in a 2000-count voltmeter):

$$R_{ON} \leq \frac{10\times10^{6}\Omega}{2000} = 5000\Omega$$

The switches between the summing points and the amplifier's inverting input contribute negligible errors because very little current flows through them.

To prevent errors from source-to-substrate leakage currents in the OFF switches, the MOS switch fabrication process must be carefully controlled. A 200-mV input to the attenuator of Fig. 4 results in a mere 20 nA flowing through the 10-MΩ resistor. This corresponds to 10 pA per count in a 2000-count volt-

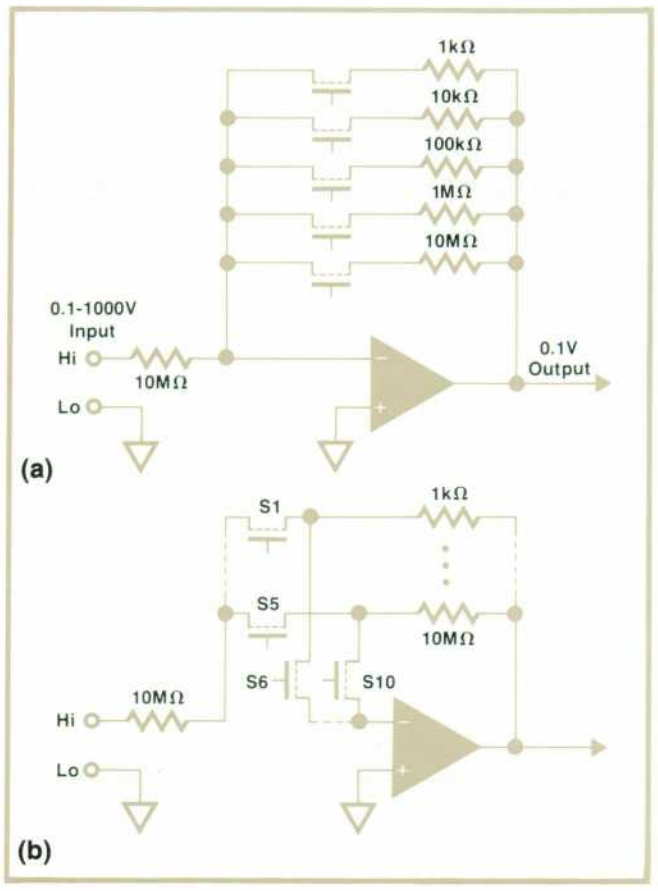



**Fig. 4.** *(a) Range-switching arrangement. (b) Modification that reduces effect of MOS-transistor "on" resistance. Here, S1 and S6 are switched on to select one range, S2 and S7 (not shown) select another, and so on to S5 and S10.*

meter. Thus, the sum of *all* leakage currents must be less than 10 pA to avoid errors from this source.

### Lower-Cost Circuits

New ideas in circuit design continue to reduce the number and precision of parts used in multimeters. An example is the dual-slope A-to-D converter widely used in digital multimeters. A simplified diagram of one such converter is shown in Fig. 5. If R1 and S2 were removed from this diagram, the result would be an autozeroed single-polarity ($V_{in} \leq 0$) converter of traditional design.

The conversion cycle starts in autozero with S1 to ground and the voltage building up on C2 causing the current flow through C1 to go to zero. The resulting voltage on C1 is the difference between the integrator and comparator offset.

Next, S4 opens with C2 holding the zeroing voltage and S1 connects to the input voltage. Integrator capacitor C1 now charges for a fixed time established by the control circuit. Then, S1 switches to ground, S3 closes, and C1 discharges until it reaches the autozero voltage. At this time, the comparator changes states signaling the end of discharge. The time to discharge is proportional to the input voltage.

Dual-polarity operation has been added to this basic circuit by switching R2 to a −10V reference or by using an op amp circuit that inverts the +10V reference to create a negative reference, or by charging a capacitor with the +10V reference and switching both ends of the capacitor to create a negative reference. The same result can be accomplished by

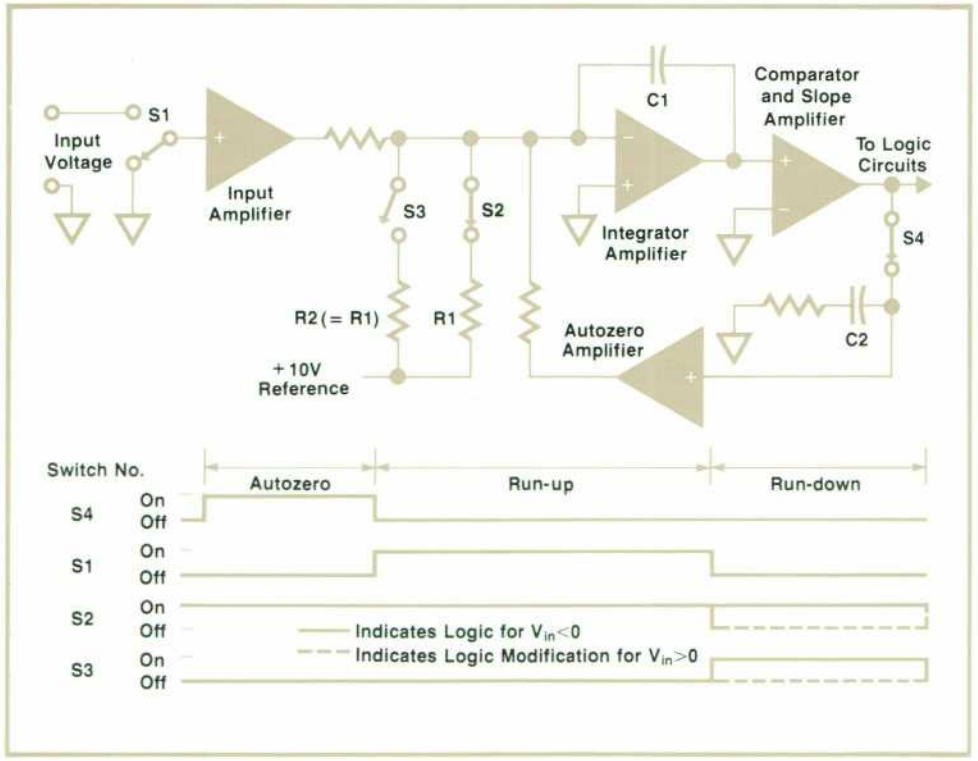


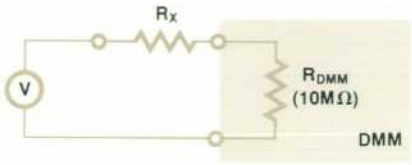

**Fig. 5.** *Single-reference, dual slope A-to-D converter is autozeroed while switch S2 is closed. Opening S2 during integrator discharge is then equivalent to switching to a negative reference.*

# Extending the Ranges of a Digital Multimeter

Present-day digital multimeters typically have four to seven ranges for each function but by taking advantage of the high input impedances and low input bias currents characteristic of today's multimeters in the voltmeter mode, resistances and currents beyond those specified for the multimeter can be measured.

### Very High Resistances

Resistances well into the gigaohm region are easily made with the aid of an external source and the set-up shown in the diagram. The multimeter is in the dc volts mode.




The unknown is found by evaluating the formula:

$$R_x = R_{DMM}\left(\frac{V_{SOURCE}-V_{DMM}}{V_{DMM}}\right)$$

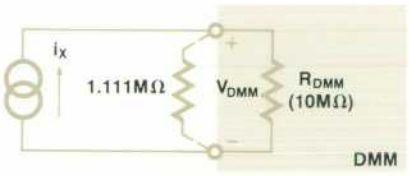
For example, if $V_{SOURCE}$ is 10V dc, $R_{DMM}$ is 10 MΩ, and $V_{DMM}$ is 100 mV,

$$R_x = 10\,M\Omega\left(\frac{10-0.1}{0.1}\right) = 990\,M\Omega$$

If the DMM input resistance is very high, say $>10^{10}$, it is a simple matter to arrive at reasonable numbers by paralleling the input with a 10 MΩ resistor.

### Very Low Currents

A digital multimeter can be used in the dc volts mode as a nanoammeter where the multimeter's input resistance serves as the current shunt, as shown in the diagram below.




The unknown current, $i_x$, is derived by evaluating the formula:

$$i_x = \frac{V_{DMM}}{R_{DMM}}$$

If $V_{DMM}$ were 100 mV and $R_{DMM}$ were 10 MΩ, $i_x$ would be 10 nA. If the input were paralleled by a 1.111 MΩ resistor, the effective $R_{DMM}$ would be 1 MΩ and the multimeter would then read in nanoamperes directly.

### Pitfalls

Obviously, a manufacturer could include these ranges in the original design. Why doesn't he? The primary limiting factor is input bias current. No matter how good the input amplifier may be, there is a small amount of bias current, typically 10 to 100 pA, that can interfere with the measurement, and this current can change drastically with temperature. A voltage reading taken with the unknown impedance connected while no signal is applied will indicate the amount of error attributable to the input bias current.

A second limiting factor is the voltage applied in the ohms mode. To prevent component damage in the circuit under test, the open-circuit voltage of most DMMs in the ohms mode is limited to 5 volts dc. No such constraint exists when an external source is used but the operator should evaluate the possibilities for damage beforehand. Also, if very high voltages are used for very high resistances, prudent shielding should be the rule and a high-quality capacitor ought to be connected across the multimeter input to reduce noise.

### Trading Resolution for Reduced Burden

There are times when making measurements of current or resistance at less than 10% of full scale may result in more meaningful results. In measurements of current, for example, a typical voltage burden (voltage drop across the DMM input terminals) of 100 mV would be reduced to 10 mV by switching to the next higher range. Measurement accuracy and resolution are reduced by a factor of 10, but may still be high enough for many measurements. The disturbance to the measurement caused by the voltage burden, on the other hand, is also reduced, so measurement accuracy may actually be increased.

For resistance measurements, a typical 1-volt burden is reduced to 0.1 volt by going to the next higher range. In many instances this would reduce errors caused by conduction in solid-state devices, again enhancing accuracy.

using only R1 and S2, as shown in Fig. 5. S2 is left on during autozero so the effect of its current is nulled, just like other currents flowing into the integrator. S2 is left closed continuously until a negative current is required at the integrator. Then by opening S2, the removal of the precision positive current through R1 appears to the integrator like the application of a precision negative current.


### Acknowledgments

Contributors to the design of the Model 3476A Digital Multimeter were Roy Buck, Tom Mills, Mike Allender, and Don Aupperle (industrial design); to the Model 3435A, Bill Hale, Gary Stadele, Bob Jarvis, Marsh Faber, Bob Moomaw, Bob Livengood, Ed Pennington, John Shea, Dave Connell, and Jim Berry (industrial design); to the Model 3465A, Craig Walters (Group leader), Ed Pennington, Francis Fiedler, Jim Fulbright, and John Pennington (industrial design). Bob Jeremiasen developed the fine-line, thin-film resistor sets.

# 1-μV Resolution in a Low-Cost 4½ Digit Multimeter

Model 3465A/B Digital Multimeter has a 20-mV full-scale dc voltage range that gives a resolution of 1 μV, very useful for measuring the outputs of strain gages and thermocouples or drift in precision voltage sources. The maximum resolution on ac voltage measurements is 10 μV, on measurements of current (ac or dc) it is 10 nA, and on resistance measurements, 10 mΩ. Open-circuit voltage on the most sensitive ohms range does not exceed 5 volts to prevent damage to most semiconductor devices.

Midrange dc accuracy is ±0.02% ± 1 digit. The frequency range for ac measurements is 40 Hz to 20 kHz.

Model 3465A/B is manual ranging with autopolarity and autozero. Like Model 3435A, it can work with the optional "touch-hold" probe to retain a measured value on display whenever the pushbutton on the probe is pushed.

This multimeter is available in two versions. Model 3465A is in a modular cabinet that is readily combined with other modules for rack mounting or bench stacking. It has a variety of power options, including rechargable Nicad batteries with internal charger, throw-away type-D dry cells (alkaline cells give 60 hours continuous operation), or ac line. The dry-cell version can also operate on dc supplied from hand-held calculator battery chargers.

Model 3465B is housed in a streamlined plastic case with carrying handle. It is powered by ac line and rechargable Nicad batteries.

Like Models 3476A and 3435A, Model 3465A/B achieves quality performance at low cost by extensive use of computer-aided testing, laser-trimmed fine-line resistors in the attenuator, and a single-reference bipolar A-to-D converter.



**Roy D. Barker**

Roy Barker graduated with a BSEE degree from the University of Oklahoma in 1962 and worked in satellite-tracking instrumentation and microwave data links before joining Hewlett-Packard in 1967. At HP, Roy was initially involved in production engineering, then became involved in IC design and production before becoming section manager for digital voltmeters. In his off hours, Roy likes to go cross-country skiing, often with his wife and 8-year-old son, and he also enjoys woodworking.

**Virgil L. Laing**

Virgil Laing first worked in IC development upon joining HP in 1968, subsequently becoming project leader for the NMOS process used for the 9800-series Calculator ROMs. He then designed a major part of the IC used in the 970A Probe Multimeter. Then he became project manager for the Model 3435A Multimeter. He has bachelor's, master's, and PhD degrees in electrical engineering, all from the University of Minnesota. Virgil enjoys the Colorado outdoors, going pheasant hunting and taking his family on hiking and camping trips.

# SPECIFICATIONS

## HP Model 3476A/B Digital Multimeter

**DC VOLTMETER**

| RANGE | ACCURACY (90 days, 20 to 30°C) |
|---|---|
| ±0.110V | ±(0.3% of reading + 2 digits) |
| ±1.10V<br>±11.0V | ±(0.3% of reading + 1 digit) |
| ±110V<br>±1100V<br>(1000V max) | ±(0.4% of reading + 1 digit) |

TEMPERATURE COEFFICIENT: ±(0.05% of reading + 0.2 digit)/°C.
COMMON MODE REJECTION (1kΩ unbalance): >100 dB at 50 Hz, 60 Hz.
INPUT RESISTANCE: 10 MΩ±5%.
INPUT PROTECTION: 1100V peak.

**AC VOLTMETER**

| RANGE* | ACCURACY (90 days, 20 to 30°C; % of reading + no. of digits) | | |
|---|---|---|---|
| | 45 Hz to 2 kHz | 2 to 5 kHz | 5 to 10 kHz |
| 0.110V | ±(2% + 6) | ±(5% + 6) | ±(18% + 10) |
| 1.10V<br>↓<br>1100V<br>(700V rms max) | ±(1.5% + 4) | ±(3% + 6) | ±(8% + 10) |

*Ranges usable above 3% of full scale.

TEMPERATURE COEFFICIENT: ±(0.05% of reading + 0.5 digit)/°C.
COMMON MODE REJECTION (1kΩ unbalance): >80dB @ 50 Hz, 60 Hz.
INPUT RESISTANCE: 10 MΩ±5%.
INPUT CAPACITANCE: <30 pF.
INPUT PROTECTION: <1100V peak.

**DC AMMETER**

| RANGE | ACCURACY (90 days, 20 to 30°C) |
|---|---|
| ±0.110A<br>±1.10A | ±(0.8% of reading + 2 digits) |

TEMPERATURE COEFFICIENT: ±(0.05% of reading + .2 digit)/°C.
IMPEDANCE: 1—1.5 ohm constant
CURRENT PROTECTED: 1.5A fuse.

**AC AMMETER**

| RANGE* | ACCURACY (90 days, 20 to 30°C; % of reading + no. of digits) | |
|---|---|---|
| | 45 Hz to 2 kHz | 2 to 5 kHz |
| 1.1A | ±(2% + 4) | ±(3.5% + 6) |
| 0.11A | ±(2.5% + 6) | ±(5.5% + 6) |

*Ranges usable above 3% off full scale.

TEMPERATURE COEFFICIENT: ±(0.05% of reading + 0.5 digit)/°C.
IMPEDANCE: 1—1.5 ohm constant.
CURRENT PROTECTED: 1.5A fuse.

**OHMMETER**

| RANGE | ACCURACY (90 days, 20 to 30°C) |
|---|---|
| 1.1 kΩ<br>11 kΩ | ±(0.5% of reading + 1 digit) |
| 110 kΩ<br>1100 kΩ | ±(0.3% of reading + 1 digit) |
| 11,000 kΩ | ±(0.5% of reading + 1 digit) |

TEMPERATURE COEFFICIENT: ±(0.05% of reading + 0.2 digit)/°C.
OPEN CIRCUIT VOLTAGE: <4V.
INPUT VOLTAGE PROTECTION: <30 Vrms continuous, fuse protected from 30V to 250Vrms.

### General

**RANGING:** Automatic, Range Hold.
**OVERLOAD INDICATION:** Horizontal bars.
**COMMON TO GROUND:** <500 V (peak).
**SAMPLE RATE:** ~3/second.
**OPERATING ENVIRONMENTAL CONDITIONS:** 0 to 40°C, <95% RH.
**POWER:** 3476A and 3476B ac line, <6 VA.

| | |
|---|---|
| STANDARD | 104-127V; 54-66 Hz |
| OPTION 001 | 86-106V; 54-66 Hz |
| OPTION 002 | 86-106V; 48-54 Hz |
| OPTION 003 | 190-230V; 48-54 Hz |
| OPTION 004 | 208-250V; 48-54 Hz |

3476B BATTERIES: 4 rechargeable nickel cadmium sub-C size. Typical continuous operating time using fully charged batteries: 8 hours at 25°C.
Typical battery charging time: 14 hours at 25°C with instrument turned off. Trickle charge with instrument on.

**WEIGHT:** 3476A, 0.77kg (1 lb. 11 oz.); 3476B, 0.97kg (2 lb. 2 oz.).
**DIMENSIONS:** 58 mm high × 168 mm wide × 206 mm deep (2.3 03302 6 6 03302 8.1 inches).
**PRICES IN U.S.A.:** 3476A, $225; 3476B, $275.

## HP Model 3435A Digital Multimeter

### DC Voltmeter

| Ranges | Maximum Display |
|---|---|
| ±200mV | ±199.9mV |
| ±2V | ±1.999V |
| ±20V | ±19.99V |
| ±200V | ±199.9V |
| ±1200V | ±1199V |

**SENSITIVITY:** 100μV on 200mV range.
**MAXIMUM INPUT:** 1200V (dc + peak ac).
**RANGING:** Automatic or manual.
**POLARITY:** Automatically sensed and displayed.
**ACCURACY** (1 year, 15 to 30°C at 95% RH):

| Range | Specifications |
|---|---|
| 200mV | ±(0.1% of reading + 2 digits) |
| 2V to 1200V | ±(0.1% of reading + 1 digit) |

**TEMPERATURE COEFFICIENT** (0 to 15°C and 30 to 55°C):
±(.018% reading + 0.1 digit)/°C.
**INPUT RESISTANCE:** 10 MΩ ± 1%.
**INPUT TYPE:** Floating; 500V maximum, common to ground.
**NORMAL MODE REJECTION:** 40dB at 50/60 Hz ±.1 Hz.
**EFFECTIVE COMMON MODE REJECTION** (1kΩ unbalance): >120 dB at 50/60 Hz ±0.1%.
**RESPONSE TIME:** <0.7 seconds to within 1 digit of final value on one range. Add 1 second for each range change.

### DC Current

| Ranges | Maximum Display |
|---|---|
| ±200μA | ±199.9μA |
| ±2mA | ±1.999mA |
| ±20mA | ±19.99mA |
| ±200mA | ±199.9mA |
| ±2000mA | ±1999mA |

**SENSITIVITY:** 100nA on 200μA range.
**MAXIMUM INPUT:** Current, 2A (fuse protected); voltage, 250V.
**RANGING:** Manual only.
**POLARITY:** Automatically sensed and displayed.
**ACCURACY** (1 year, 15 to 30°C at 95% RH):

| Range | Specifications |
|---|---|
| 200μA to 20 mA | ±(0.3% of reading + 2 digits) |
| 2000mA | ±(0.6% of reading + 2 digits) |

**TEMPERATURE COEFFICIENT** (0 to 15°C and 30 to 55°C): ±(.028% of reading + 0.1 digits)/°C
**VOLTAGE BURDEN:**

| Range | Maximum at Full Scale |
|---|---|
| 200μA to 20mA | <220mV |
| 200mA | <240mV |
| 2000mA | <400mV |

**RESPONSE TIME:** 0.7 seconds on any range to within 1 digit of final value.

### AC Voltmeter

**AC CONVERTER:** Average responding, rms calibrated.

| Ranges | Maximum Display |
|---|---|
| 200mV | 199.9mV |
| 2V | 1.999V |
| 20V | 19.99V |
| 200V | 199.9V |
| 1200V | 1199V |

**SENSITIVITY:** 100μV on 200mV range.
**MAXIMUM INPUT:** 1700V (dc + peak ac), $10^7$ volt-Hz max.
**RANGING:** Automatic or manual.
**ACCURACY** (with display of >20 digits; 1 year, 15 to 30°C at 95% RH):

| Range | Specifications |
|---|---|
| 30 Hz—50 Hz | ±(1.5% of reading ± 3 digits) |
| 50 Hz—20 kHz | ±(0.3% of reading ± 3 digits) |
| 20 kHz—100kHz | ±(1.5% of reading ± 10 digits) |

**TEMPERATURE COEFFICIENT** (0 to 15°C and 30 to 55°C):
±(0.04% of reading + 0.2 digit)/°C.
**INPUT IMPEDANCE:** 5 MΩ//50 pF.

**RESPONSE TIME:** 1.6 seconds to within 3 digits of final value on one range. Add 1.2 seconds for each range change.
**INPUT TYPE:** Floating, 500V maximum common to ground.

### AC Current

| Ranges | Maximum Display |
|---|---|
| 200μA | 199.9μA |
| 2mA | 1.999mA |
| 20mA | 19.99mA |
| 200mA | 199.9mA |
| 2000mA | 1999mA |

**MAXIMUM INPUT:** Current, 2 A (fuse protected); voltage, 250V.
**RANGING:** Manual only.
**SENSITIVITY:** 100nA on 200μA range.
**ACCURACY** (with display of >20 digits; 1 year, 15 to 30°C @ 95% RH):

| Range | Specification (% of reading + no. of digits) | |
|---|---|---|
| 2000mA | | |
| 200mA | ±(2% +4) | ±(1.2% +4) |
| 200μA | ±(1.7% +4) | ±(0.9% +4) |
| | 30 Hz | 50 Hz — 10 kHz |

Frequency of Input Signal

**TEMPERATURE COEFFICIENT** (0 to 15°C and 30 to 55°C):
±(0.05% of reading + 0.2 digits)/°C.
**VOLTAGE BURDEN:**

| Range | Maximum at Full Scale |
|---|---|
| 200μA to 20mA | <220mV rms |
| 200mA range | <240mV rms |
| 2000mA range | <400mV rms |

**RESPONSE TIME:** 1.6 seconds on any range to within 3 digits of final value.
**INPUT TYPE:** Floating, 500V maximum common to ground.

### Ohmmeter

| Ranges | Maximum Display |
|---|---|
| 20Ω | 19.99Ω |
| 200Ω | 199.9Ω |
| 2 kΩ | 1.999 kΩ |
| 20 kΩ | 19.99 kΩ |
| 200 kΩ | 199.9kΩ |
| 2MΩ | 1.999MΩ |
| 20MΩ | 19.99MΩ |

**SENSITIVITY:** 10 milliohm on 20Ω range.
**INPUT PROTECTION:** 250V rms.
**RANGING:** Automatic or manual.
**ACCURACY** (1 year, 15 to 30°C @ 95% RH):

| Range | Specifications |
|---|---|
| 20Ω | ±(0.5% of reading + 10 digits) |
| 200Ω—2MΩ | ±(0.2% of reading + 2 digits) |
| 20MΩ | ±(0.8% of reading + 2 digits) |

**TEMPERATURE COEFFICIENT** (0 to 15°C and 30 to 55°C):

| Range | Specifications |
|---|---|
| 20Ω—2MΩ | ±(0.04% of reading + 0.2 digits)/°C |
| 20MΩ | ±(.18% of reading + 0.2 digits)/°C |

**CONFIGURATION:** 2 wire.
**OPEN CIRCUIT VOLTAGE:** <5V.
**CURRENT THROUGH UNKNOWN:**

| Range: | 20Ω | 200Ω | 2 kΩ | 200 kΩ | 2 MΩ | 20 MΩ |
|---|---|---|---|---|---|---|
| Current: | 5mA | 5mA | 500μA | 5μA | 500nA | 50nA |

**RESPONSE TIME:** 0.8 seconds to within 1 digit. Add 0.8 seconds for each range.

### General

**CALIBRATION:** Data sheet specifications guaranteed for 1 year.
**READING RATE:** 2.4—4.7/sec, depending on input level.
**OPERATING TEMPERATURE:** 0 to 55°C.
**HUMIDITY:** 95% RH, +15 to +40°C.
**POWER:** AC line: 48-440 Hz, 86-250V
BATTERY: rechargeable lead-acid 10 hours minimum continuous operation with full charge. Recharge time: 16 hours operating, 12 hours nonoperating.
TOTAL INSTRUMENT POWER DISSIPATED: ac only: 3 watts; with charger, 8 watts.
**DIMENSIONS:** 238.1 mm wide × 98.4 mm high × 276.2 mm deep (9-3/8 × 3⅞ × 10⅞ inches). Opt 002, 210 × 85.7 × 26.7 mm (8¼ × 3⅜ × 10½ in).
**WEIGHT:** 2.41 kg (5 lb., 5 oz); Opt 001, 1.84 kg (4 lb., 1 oz).
**PRICES IN U.S.A.:** 3435A, $400; without batteries (Opt. 001), less $65. Rack-and-stack case Opt 002 (ac line power only), less $35. 34112A Touch-Hold Probe, $40.

**Joe E. Marriott**

A 1969 graduate of the University of Utah (BSEE), Joe Marriott joined HP that same year, going to work on the Model 3403A True-rms Voltmeter. Returning to HP following a tour of duty with the National Guard, Joe contributed to the 970A and 3465A Voltmeters. While working on the 3476A/B Joe became project manager. Along the way, he earned an MSEE degree at Colorado State University in the HP Honors Co-op program. Married, and with a 2-year-old daughter, Joe cross-country skis, hikes, plays volleyball, and occasionally does some photography.

**H. Mac Juneau**

Mac Juneau joined HP in 1967, going to work on the Model 3480A Digital Voltmeter and then on high-speed A-to-D converters as project manager. For three years, Mac was product assurance manager with time out as project manager for the Model 3476A Multimeter. He is now manager of the HP Loveland facilities IC lab. He has a BSEE degree from Swarthmore College (Philadelphia) and MSEE and PhD degrees from the University of Minnesota. With children 8 and 5, Mac contributed to a school playground design. He also does some woodworking and creates welded sculptures.

# SPECIFICATIONS

## HP Model 3465A/B Digital Multimeter

### DC Voltmeter

| Ranges | Maximum Display |
|---|---|
| ±20mV | 19.999 |
| ±200mV | 199.99 |
| ±2V | 1.9999 |
| ±20V | 19.999 |
| ±200V | 199.99 |
| ±1000V | 1000.0 |

**SENSITIVITY:** 1 microvolt on lowest range.
**MAXIMUM INPUT:** 1000V max dc and peak ac.
**POLARITY:** Automatically sensed and displayed.
**ACCURACY** (1 year, 23°C ±5°C at 95% RH):

| Range | Specifications |
|---|---|
| 20mV | ±0.03% of reading ± 2 digits |
| 200mV thru 200V | ±0.02% of reading ± 1 digit |
| 1000V | ±0.025% of reading ± 1 digit |

**TEMPERATURE COEFFICIENT** (0°C to 50°C):
±0.003% of reading/°C.
**INPUT RESISTANCE:**

| Range | Specifications |
|---|---|
| 20mV thru 2V | $>10^{10}\Omega$ |
| 20V thru 1000V | 10MΩ ± 1% |

**INPUT TYPE:** floating, 500V maximum common to ground.
**NORMAL MODE REJECTION:** >60 dB at 50/60 Hz ± .1%
**EFFECTIVE COMMON MODE REJECTION** (1 kΩ unbalance): >120 dB at 50/60 Hz ± .1%.
**RESPONSE TIME:** 1 second to within 1 digit.

### DC Current

| Ranges | Maximum Display |
|---|---|
| ±200μA | 199.99 |
| ±2mA | 1.9999 |
| ±20mA | 19.999 |
| ±200mA | 199.99 |
| ±2000mA | 1999.9 |

**SENSITIVITY:** 10nA on lowest range.
**MAXIMUM INPUT:** 2A from <250V source (fuse protected).
**POLARITY:** Automatically sensed and displayed.
**ACCURACY** (1 year, 23°C ±5°C at 95% RH):

| Range | Specifications |
|---|---|
| 200μA, 2mA | ±0.07% of reading ± 1 digit |
| 20mA | ±0.11% of reading ± 1 digit |
| 200mA, 2000mA | ±0.6% of reading ± 1 digit |

**TEMPERATURE COEFFICIENT** (0°C to 50°C):

| Range | Specifications |
|---|---|
| 200μA | ±0.006% of reading/°C |
| 2mA, 20mA | ±0.004% of reading/°C |
| 200mA, 2000mA | ±0.01% of reading/°C |

**VOLTAGE BURDEN**
HIGHEST RANGE: <700mV FS.
ALL OTHER RANGES: <250mV FS.
**RESPONSE TIME:** 1 second to within 1 digit.

### Ohmmeter

| Ranges | Maximum Display |
|---|---|
| 200Ω | 199.99 |
| 2 kΩ | 1.9999 |
| 20 kΩ | 19.999 |
| 200 kΩ | 199.99 |
| 2000 kΩ | 1999.9 |
| 20 MΩ | 19.999 |

**SENSITIVITY:** 10 milliohm on lowest range.
**INPUT PROTECTION:** 350V (dc + peak ac)/250V rms.
**ACCURACY** (1 year, 23°C ± 5°C @ 95% RH):

| Range | Specifications |
|---|---|
| 200Ω | ±0.02% of reading ± 2 digits |
| 2 kΩ thru 2 MΩ | ±0.02% of reading ± 1 digit |
| 20 MΩ | ±0.1% of reading ± 1 digit |

**TEMPERATURE COEFFICIENT** (0°C to 50°C):

| Range | Specifications |
|---|---|
| 200Ω thru 2 MΩ | ±0.0015% of reading/°C |
| 20 MΩ | ±0.004% of reading/°C |

**CONFIGURATION:** 2 wire.
**OPEN CIRCUIT VOLTAGE:** <5V max.
**CURRENT THROUGH UNKNOWN:**

| Range | Current |
|---|---|
| 200Ω | 1mA |
| 2 kΩ | 1mA |
| 20 kΩ | 10 μA |
| 200 kΩ | 10 μA |
| 2000 kΩ | 1 μA |
| 20 MΩ | 0.1 μ |

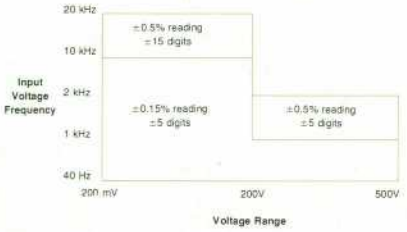
**RESPONSE TIME:** 2 seconds to within 1 digit.

### AC Voltmeter

**AC CONVERTER:** average responding, rms calibrated.

| Ranges | Maximum Display |
|---|---|
| 200 mV | 199.99 |
| 2V | 1.9999 |
| 20V | 19.999 |
| 200V | 199.99 |
| 500V | 500.0 |

**SENSITIVITY:** 10μV on lowest range.
**MAXIMUM INPUT:** Full scale to 10 kHz decreasing linearly to 50% of full scale at 20 kHz except 500V range which has 2-kHz maximum frequency.
**ACCURACY** (1 year, 23°C ± 5°C @ 95% RH):




**TEMPERATURE COEFFICIENT** (0°C to 50°C): ±0.005% of reading ± .2 digit.
**INPUT IMPEDANCE:** 1 MΩ//<100 pF.
**INPUT TYPE:** floating, 500V maximum common to ground.
**OVERLOAD PROTECTION:** dc, 600V max; ac, 500V rms, 800V peak.
**RESPONSE TIME:** 5 seconds to within 1 digit.

### AC Current

| Range | Maximum Display |
|---|---|
| 200μA | 199.99 |
| 2mA | 1.999 |
| 20mA | 19.999 |
| 200mA | 199.99 |
| 2000mA | 1999.9 |

**SENSITIVITY:** 10nA on lowest range.
**MAXIMUM INPUT:** 2A from <250V source (fuse protected). Full scale to 10 kHz decreasing linearly to 50% full scale at 20 kHz on lowest 3 ranges, 2 kHz max on 200mA range; 1 kHz max on 2000mA range.
**ACCURACY** 1 year, 23°C ± 5°C @ 95% RH):


**TEMPERATURE COEFFICIENT** (0°C to 50°C): ±0.01% of reading/°C.
**VOLTAGE BURDEN:**
1A RANGE: <700mV fs.
ALL OTHER RANGES: <250mV fs.
**RESPONSE TIME:** 5 seconds to within 1 digit.

### General

**READING RATE:** 2½ readings per second.
**OVERLOAD INDICATION:** display blanks.
**HUMIDITY RANGE:** 95% at 40°C
**OPERATING TEMPERATURE:** 0°C to +55°C (nickel-cadmium batteries, 0°C to +40°C).
**WEIGHT:** 2.04 kg (4 lbs., 8 oz.).
**DIMENSIONS:** 101.6 mm high × 212.7 mm wide × 279.4 mm deep (4 × 8-3/8 × 11 in.).
**POWER:** ac line, 86-127V, 176-250V; 48-440 Hz.
BATTERIES: rechargeable nickel cadmium standard.
Continuous operating time from full charge is 6 hours. Recharge time is 8 hours with instrument off. Trickle charge with instrument on.
OPTION 002: type D alkaline dry cells (U-2 cells in Europe). 60 hours continuous use at 23°C. Includes receptacle to use Model 82002A battery eliminator (82002A not included).
**PRICE IN U.S.A.:**
3465A, $530; Opt. 001: ac line only, −$20; Opt. 002, −$105.
3465B, $500. 34112 Touch-Hold Probe, $40.
**MANUFACTURING DIVISION:** LOVELAND INSTRUMENT DIVISION
815 Fourteenth Street S.W.
Loveland, Colorado 80537 U.S.A.


Hewlett-Packard Company, 1501 Page Mill Road, Palo Alto, California 94304

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**Technical information from the Laboratories of Hewlett-Packard Company**

Hewlett-Packard Central Mailing Department
Van Heuven Goedhartlaan 121
Amstelveen-1134 The Netherlands
Yokogawa-Hewlett-Packard Ltd., Shibuya-Ku
Tokyo 151 Japan

**Editorial Director • Howard L. Roberts**
**Managing Editor • Richard P. Dolan**
**Art Director, Photographer • Arvid A. Danielson**
**Illustrator • Susan E. Wright**
**Administrative Services, Typography • Anne S. LoPresti**
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