Two-chip ammeter measures currents down to picoamperes

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An ammeter circuit that can measure currents ranging from picoamperes to amperes may be built with two operational amplifiers, one having a low input bias current and offset voltage and the second having a high output-current capability. The accuracy of the meter is within 1%.

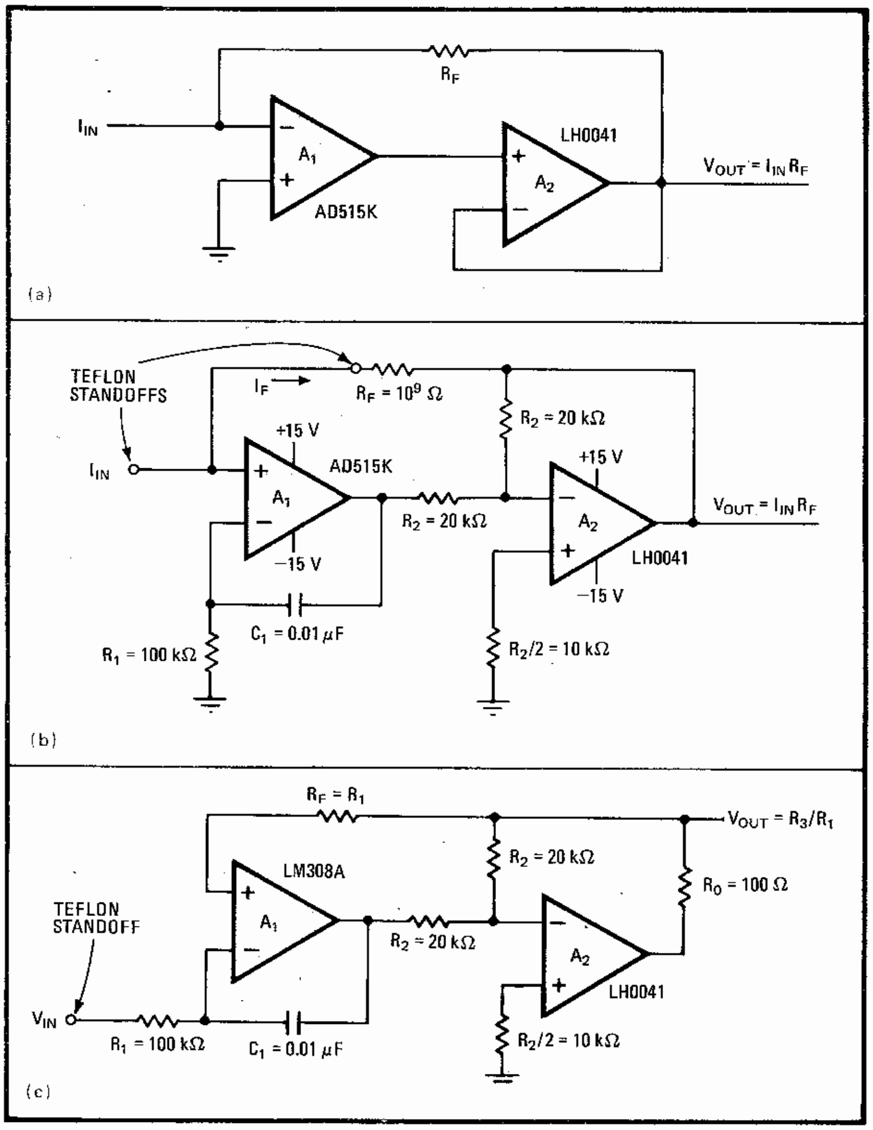
The basic configuration of the circuit (a) establishes A_1 as a field-effect–transistor input device that is internally compensated and A_2 as the power stage. The feedback arrangement of the circuit is technically possible but not practical because A_2's gain-bandwidth product is much less than that of A_1. This factor is due to A_2's high-output capacity. As a consequence, the circuit is unstable and oscillates near the unity-gain crossover point of A_2, because of a phase-shift around the feedback loop exceeding 360°.

Converting A_1 into an integrating comparator (b) stabilizes the circuit, thereby increasing the op amp's response time without introducing an additional phase shift to the feedback loop. Input current I_{in} flowing to the noninverting terminal of A_1 produces a positive voltage at its output and across integrating capacitor C_1. A_2, serving as an inverting, unity-gain amplifier, then raises its output to a voltage that causes I_f to equal I_{in}.

As a result, the output voltage corresponding to this input current is $V_o = I_{in}R_f$. The circuit accuracy is determined strictly by the tolerance of R_f. The input offset voltage of A_1 (1 millivolt maximum) and its correspondingly low offset current (0.15 picoampere maximum) have virtually no adverse effect on circuit accuracy. As for A_2's output offset voltage, which is a maximum of 6 mV, it is canceled in the feedback loop. In order to maintain a virtual short at its input, A_1 develops a voltage across C_1. When this voltage is applied to A_2 through R_2, A_2's offset voltage is canceled. This cancellation effect is independent of the second stage gain given by $A = -R_3/R_2$.

Feedback resistor R_f sets the current range. To measure currents in the region of 1 pA for display on a 3½-digit digital voltmeter (resolution is 1 mV), R_f should be 10^9 ohms and be proportionally lower for higher currents. The circuit's input port A_1, should be protected against leakage currents by Teflon standoffs or otherwise be guarded. This measure also holds true for mounting the selectable resistor R_f.

The picovoltmeter in (c) is much the same as in (b), but is configured as a low-input bias current, low-offset buffer amplifier whose gain is established by $A = R_3/R_2$. This circuit takes advantage of the best features of both op amps but suppresses their limitations. Including resistor R_o in the circuit will stabilize the amplifier for capacitive loads. Incidentally, the LH0041 allows a user to select current limiting. The circuits discussed are not limited to the op amps listed in the figures. Any device with similar characteristics may be used. □



Infinitesimal. This ammeter, using one op amp having a low offset and another with a high-output driver, measures current from 1 pA to 1 A. Feedback resistor R_f determines the range of measurement. Based on the rudimentary circuit of (a), ammeter (b) is self-compensating and stable, providing accuracy to within 1%. Test currents are converted to corresponding voltage for display by 3½-digit digital voltmeter. A version for measuring low potentials (c) is similar. The LH0041 op amp allows users to select current limiting.