AN833

SUB-1 V CURRENT SENSING WITH THE TS1001, A 0.8 V, 0.6 µA OP-AMP

1. Introduction

Current-sense amplifiers can monitor battery or solar cell currents, and are useful to estimate power capacity and remaining life. However, if the battery or solar source is a single cell, it's difficult to find a low voltage solution that works below 1V and draws just microamps. A new class of nanopower analog ICs, namely the TS1001 0.8 V/ 0.6 µA op amp, makes a sub-1 V supply current sense amplifier shown in Figure 1 possible. This discrete circuit operates from as low as 0.8 V and draws 860 nA at no load while providing a 0–500 mV output for measured currents of 0–100 mA, though the scale can be adjusted by changing the values of a few resistors. With its extremely low power, the circuit can simply remain "always on," providing a continuously monitored, averaged indication of current which can subsequently be read periodically by a microcontroller, without causing too much current drain in the battery.

2. Overview

The circuit can be used to estimate the impedance of a small coin-cell type alkaline battery to determine its condition, its ability to source power, and estimate its remaining life. Measuring the battery voltage (without knowing the load) generally provides only a crude estimate, and performing "pulse tests" as recommended by some battery manufacturers can be disruptive to the circuit the battery is powering.

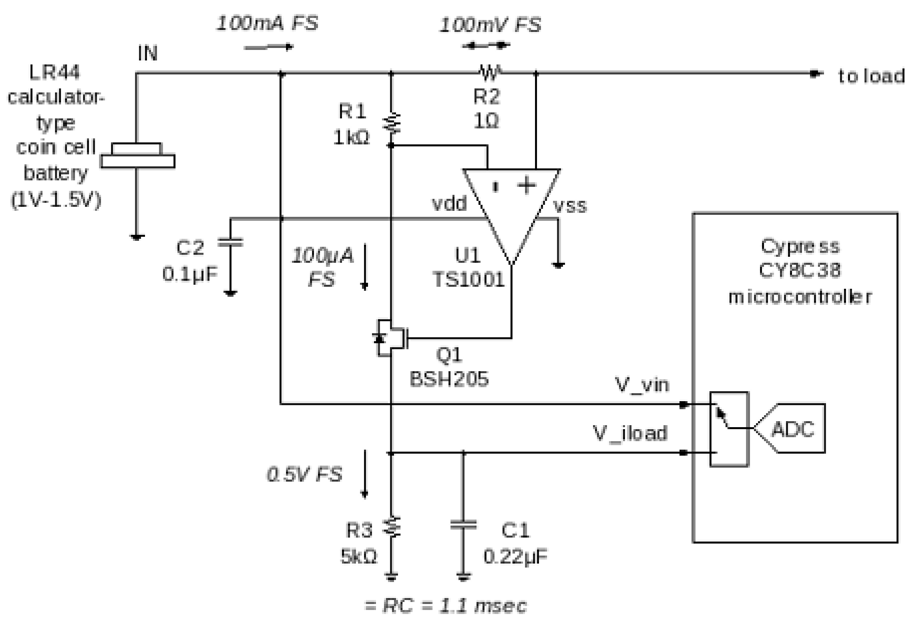


Figure 1. Low Voltage Current Sense Amplifier Utilizing Nanopower Op-Amp and Low-Threshold P-Channel MOSFET

The TS1001 is configured to servo P-channel MOSFET Q1 in a current source configuration, drawing current through R1 to compensate for the voltage drop across R2 caused by the current flow from IN to the load. R3 converts Q1's drain current to a voltage and C1 provides filtering. The filtering is critical in allowing the current sense amplifier to continuously provide an averaged current output, enabling the microcontroller to sleep for long periods and save power, waking only periodically to read this mean current level.

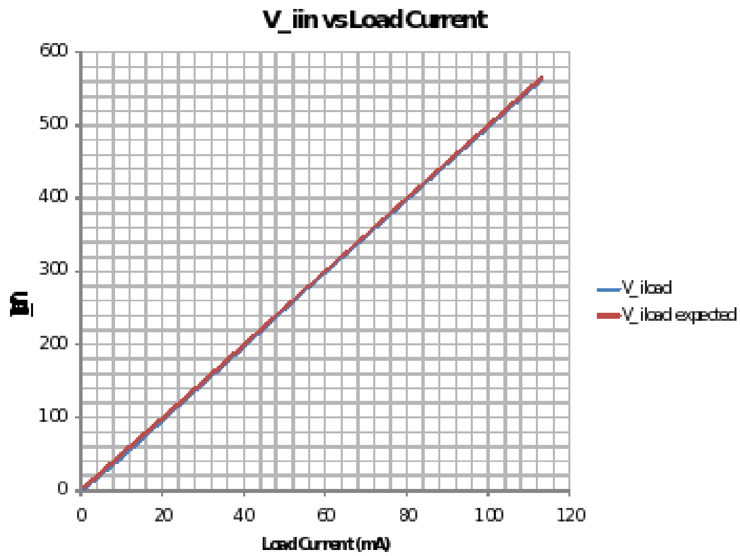


Figure 2. Measured V_iload vs. Input Current

Table 1. Current Sense Amplifier Circuit Supply Current vs. Load Current

Load Current	Current Used by the Current Sense Amplifier
0	860 nA
50 mA	48.1 µA

Amplifier input offset voltages need to be considered carefully in this circuit. The TS1001 op amp is specified with ±3 mV maximum input offset voltage at 25 °C, which corresponds to ±3 mA of error. Figure 2 shows an offset of approximately 2.5 mA. Another consideration is that Q1 exhibits drain-source leakage current of a few 10s of nanoamps at 25 °C and can approach 1µA over the commercial temperature range. Since the current through Q1 is effectively controlled by the TS1001's loop, any drain-source leakage from Q1 appears as a current floor and generates a corresponding minimum voltage output across R3 below which current cannot be measured until the op amp "takes over" at higher measured currents. Therefore, normal methods of removing the current sense amplifier input offset voltage by subtracting the zero-load voltage at V_iin will not work, since the offset voltage due to the op amp's Vos and the current floor from Q1's drain-source leakage cannot be separated.

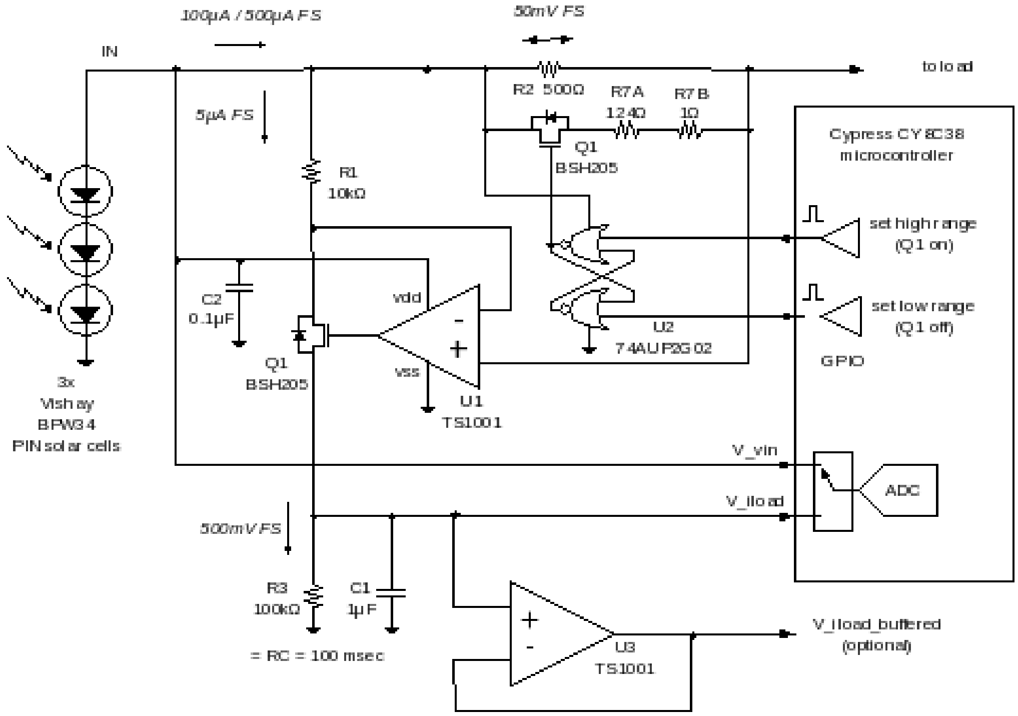


Figure 3. Ultra-Low Supply Current Amplifier Circuit with Amplifier Offset Voltage Correction

Figure 3 shows an alternative configuration which provides a means for calibrating out the amplifier offset voltage. The circuit is set up for measuring very low currents, in this case from three series-connected PIN solar cells. The circuit can be used as part of an energy harvesting system in a maximum-power-point-tracking (MPPT) scheme, where the microcontroller adjusts the loading of the cells to maximize V x I and yield the maximum available power.

The circuit works in a similar way to Figure 1, but it has been scaled for a selectable 100 µA/500 µA full scale current where the full-scale sensed voltage across R2 has been decreased to 50 mV to improve efficiency. With this lower voltage, the ±3 mV specified input offset voltage of the TS1001 causes up to a 6% offset error, which may be unacceptable.

This offset may be calibrated out using the principal of making two measurements of the same parameter at the two gain settings. The offset then can be found as:

$$V_{OFFSET} = V_{ILOAD\_G2} * \frac{R_{G1}}{R_{G1} - R_{G2}} - V_{ILOAD\_G1} * \frac{R_{G2}}{R_{G1} - R_{G2}}$$

where Viload_G1 and Viload_G2 are the measurements made with low range and high range mode, respectively, and where:

$$R_{G1} = R_2$$

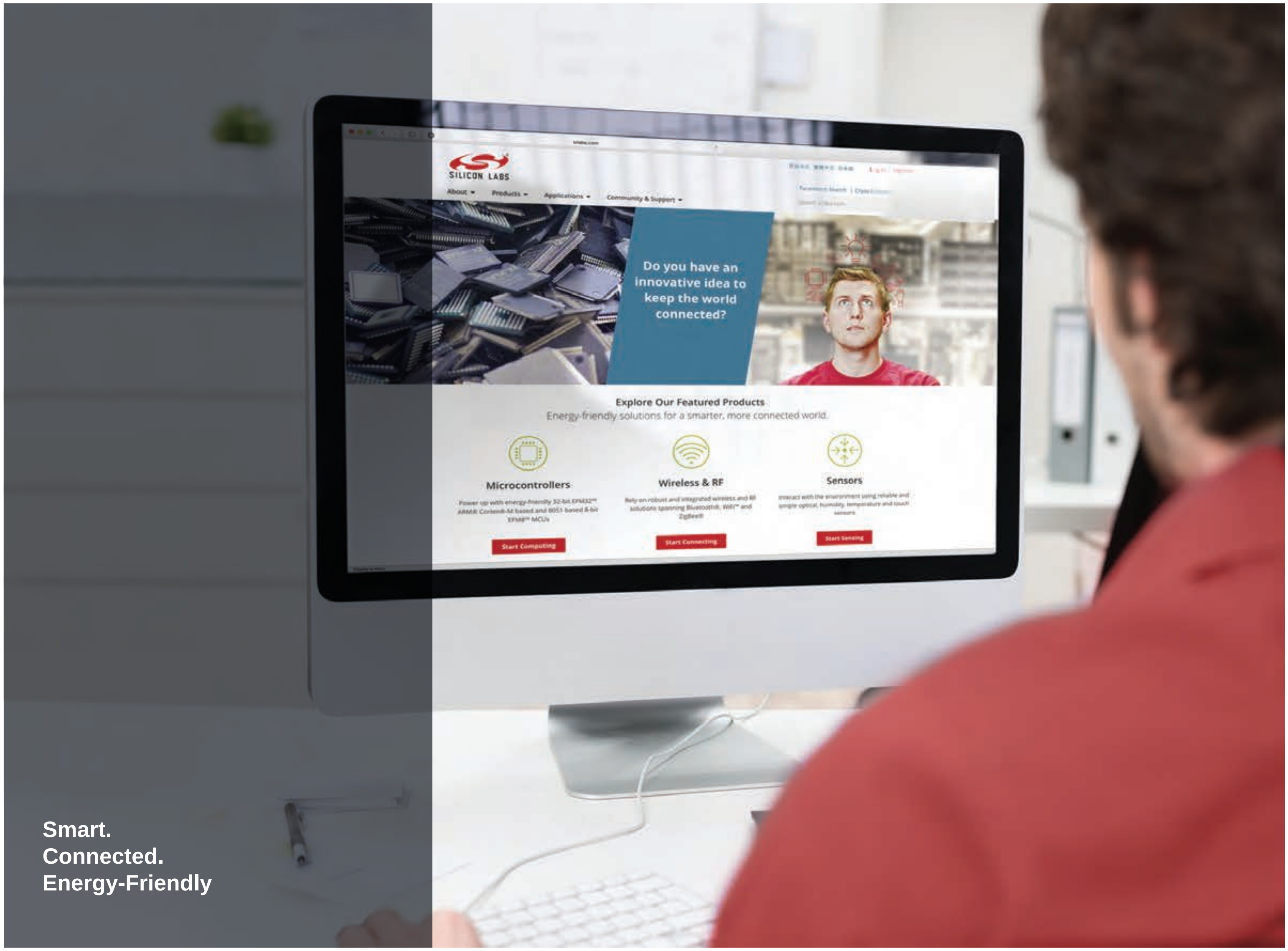
$$R_{G2} = \frac{R_2 R_7}{R_2 + R_7}$$

Microcontroller-based systems power budgets have dropped dramatically in recent years, enabling these systems to be powered from sources such as coin batteries and miniature solar cells. Analog circuits such as this micropower current-sense amplifier, which remain always on, draw very little power from the power source, and are becoming increasingly useful to save yet more system power by allowing the microcontroller to remain sleeping while the circuit stays awake monitoring and averaging battery parameters. For additional information, see the TS1001 Op Amp documentation.

Document Change List

Revision 1.0 to Revision 1.1

- Updated document title.



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