Dual transistor improves current-sense circuit

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In multiple-output power supplies in which a single supply powers circuitry of vastly different current draws, two perplexing steps are sensing the current that each output draws and deactivating the power supply in the event of an overload on that output. These issues are especially important in protecting the fragile PCB (printed-circuit-board) traces in low-level circuits. A typical circuit would use the base-emitter threshold voltage of approximately 0.6V of a bipolar transistor to trigger the power-supply-protection circuits. Although economical, the transistor's threshold varies excessively over temperature; hence, the protection level is unstable.

The circuit in **Figure 1** essentially eliminates the base-emitter-voltage temperature-variation problem as the derivation of the output voltage and as a function of the load current. By using dual bipolar devices in one case, the manufacturer nearly perfectly matches the two devices. Although this Design Idea describes a positive power supply, you can realize a similar negative-output-supply current-sense circuit using a dual NPN transistor in place of the dual PNP that the **figure** shows.

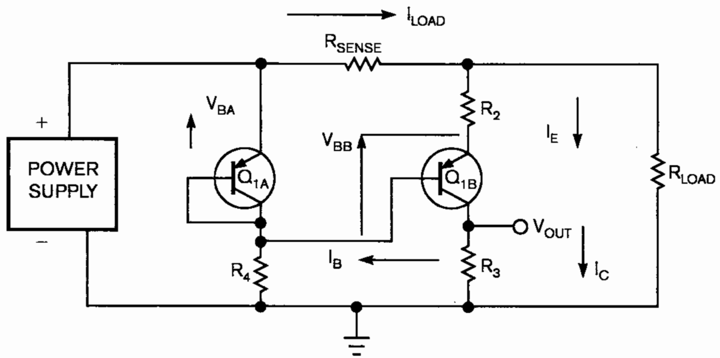

Figure 1 This simple two-transistor circuit provides a voltage output proportional to the current through sense resistor R_{SENSE}.

The following **equations** show the derivation of the output voltage as a function of the load current (referring to **Figure 1**):

$$V_{BA}+(I_{LOAD}\times R_{SENSE})+(I_E\times R_2)-V_{BB}=0.$$

$$[(V_{BA}-V_{BB})+(I_{LOAD}\times R_{SENSE})]-I_ER_2=0.$$

$$I_C+I_B=I_E.$$

$$(V_{BA}-V_{BB})+(I_{LOAD}\times R_{SENSE})-(I_C+I_B)R_2=0.$$

$$I_B=I_C/\beta.$$

$$V_{BA}-V_{BB}+I_{LOAD}\times R_{SENSE}-(I_C+I_C/\beta)R_2=0.$$

$$V_{BA}-V_{BB}+I_{LOAD}\times R_{SENSE}-[I_C\times(\beta+1)/\beta]R_2=0.$$

$$V_{OUT}=I_CR_3.$$

$$I_C=V_{OUT}/R_3.$$

$$V_{BA}-V_{BB}+I_{LOAD}\times R_{SENSE}-(V_{OUT}/R_3)(\beta+1/\beta)R_2=0.$$

If $V_{BA}=V_{BB}$, then $V_{BA}-V_{BB}=0$, and

$$I_{LOAD}\times R_{SENSE}-(V_{OUT}/R_3)(\beta+1/\beta)R_2=0.$$

$$V_{OUT}=I_{LOAD}\times R_{SENSE}[R_3/(\beta+1)](\beta/R_2).$$

If β is high, then $\beta/(\beta+1)\beta)\approx1$, and

$$V_{OUT}=(I_{LOAD}\times R_{SENSE}\times R_3)/R_2.$$ **EDN**

Improving High-Side Current Measurements

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An IC that combines a high-side current-sense amplifier with an analog voltage multiplier can easily measure the power dissipated in a load. One multiplier input connects to the load voltage and the other to an internal analog of the load current (i.e., a proportional voltage produced by the internal current-sense amplifier). The multiplier output ($V_L \times I_L$) is then a voltage proportional to load power.

The internal multiplier also can enable extra accuracy in high-side current measurements, for applications in which the current signal is digitized by an analog-to-digital converter (ADC). Whether the ADC's voltage reference is internal or external to the ADC, the accuracy of the digitized load-current measurement depends strongly on the accuracy and stability of that reference.

To minimize this dependency on voltage-reference accuracy, connect the multiplier's external input to the reference voltage through a resistive divider (Fig. 1). The current measurement is then ratiometric. Any error or drift in the reference voltage has a proportional effect on the ADC's input, and thereby achieves a first-order cancellation of full-scale error caused by the reference voltage.

The circuit shown can measure battery charge and discharge currents in a wide range of applications. It works equally well with a voltage reference internal to the ADC, driving the R1-R2 divider.

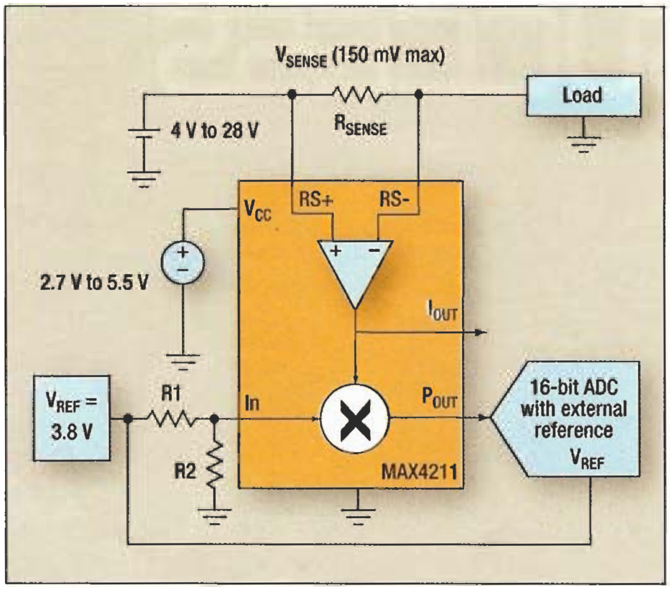

Fig. 1. *This circuit uses a high-side power/current monitor (MAX4211) plus an ADC with external reference voltage to measure battery-charge currents with a high level of precision.*

The IC's multiplier output (P_{OUT}) feeds a 16-bit ADC whose input voltage range is 0 V to V_{REF}. V_{REF}, provided here by an external voltage regulator, should be between 1.2 V and 3.8 V (3.8 V in this case). The multiplier input must be limited to a range of 0 V to 1 V, which is accomplished by dividing the 3.8-V reference voltage with the R1-R2 resistor divider.

Assuming R2 = 1 kΩ and R1 = 2.8 kΩ, then V_{IN} = 1 V. The IC has a gain of 25 between V_{SENSE} and I_{OUT}, and a sense-voltage range (V_{SENSE}) of 0 V to 150 mV, which produces (at both P_{OUT} and I_{OUT}) an output range of 0 V to 3.75 V.

Thus, the use of P_{OUT} (instead of I_{OUT}) confers an advantage: the signal fed to the ADC, which is proportional to current in the load, is scaled by V_{REF}. The following equation relates the P_{OUT}/V_{REF} ratio to I_{LOAD}, R_{SENSE}, and the values of R1 and R2:

$$P_{OUT}/V_{REF} = I_{LOAD} \times R_{SENSE} \times 25 \times V_{REF} \times R2/(R1+R2)/V_{REF} = I_{LOAD} \times R_{SENSE} \times 25 \times R2/(R1+R2).$$

Note that the ratio of ADC input to ADC full scale (P_{OUT}/V_{REF}) does not depend on the accuracy of V_{REF}.

Overall accuracy of the current measurement depends on many factors: resistor tolerance, amplifier gain error, voltage offset and bias current, reference voltage accuracy, ADC errors and drift versus temperature for all the above. This circuit improves accuracy by eliminating only one of these causes: the reference voltage inaccuracy. V_{REF} is affected by at least three sources of error: initial dc error as a percentage of the nominal value, V_{REF} changes with load and V_{REF} changes with temperature.

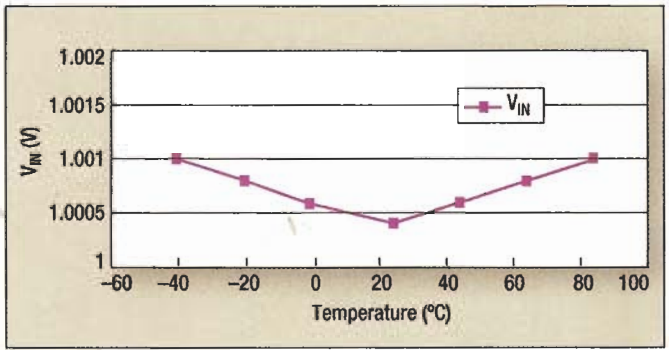

Fig. 2. *The input voltage to the multiplier (IN) in Fig. 1 varies as a function of temperature, reflecting the voltage reference's variation over temperature (V_{CC} = 5 V and V_{SENSE} = 100 mV).*

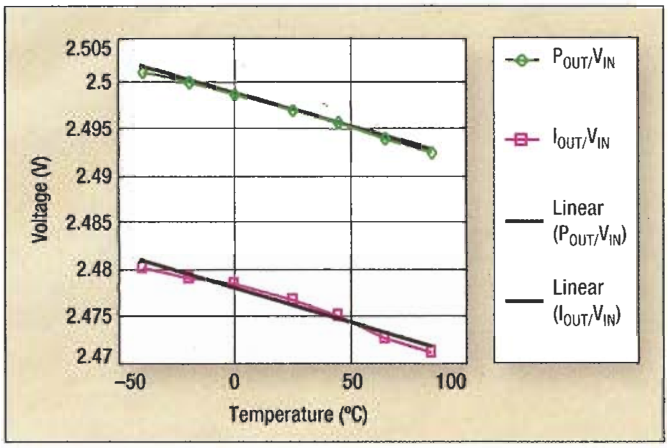

Fig. 3. *The measured P_{OUT}/V_{IN} ratio in Fig. 1. is the same as the expected (linear) value of this ratio over temperature, unlike the measured I_{OUT}/V_{IN} ratio (V_{SENSE} = 100 mV).*

A graph of the multiplier input (IN) versus temperature, with V_{CC} = 5 V and V_{SENSE} constant at 100 mV, shows the affect of temperature on the reference voltage (Fig. 2). To see the advantage of the ratiometric output at P_{OUT}, compare the P_{OUT}/V_{IN} ratio and its linear ideal with the I_{OUT}/V_{IN} ratio and its linear ideal, as they vary with temperature (Fig. 3). Note that the ratiometric P_{OUT} output (top) does not deviate from the ideal. **PETech**