Precise Current Sense Amplifiers Operate from 4V to 60V

by Jun He

Introduction

The LTC6103 and LTC6104 are versatile, precise high side current sense amplifiers with a wide operation range. The LTC6103 is a dual current sense amplifier, while the LTC6104 is a single, bi-directional current sense amplifier—it can source or sink an output current that is proportional to a bi-directional sense voltage.

Due to the amplifiers' wide supply range (60V), fast speed (1µs response time), low offset voltage (85µV typical), low supply current (275µA/channel typical) and user-configurable gains, they can be used in precision industrial and automotive sensing applications, as well as current-overload protection circuits.

Other features include high PSRR, low input bias current and wide input sense voltage range. Both parts are available in an 8-lead MSOP.

LTC6103 Theory of Operation

Figure 1 shows a block diagram of the LTC6103 in a basic current sense circuit. A sense resistor, R_{SENSE}, is added in the load path, thereby creating a small voltage drop proportional to the load current.

An internal sense amplifier loop forces –IN to have the same potential as +IN. Connecting an external resistor, R_{IN}, between –IN and V_{BATT} forces a potential across R_{IN} that is the same as the sense voltage across R_{SENSE}. A corresponding current

$$I_{OUT} = \frac{(I_{LOAD} + I_S) R_{SENSE}}{R_{IN}}$$

flows through R_{IN}. The high impedance inputs of the sense amplifier do not conduct this input current, so the current flows through an internal MOSFET to the OUT pin. In most application cases, $I_S << I_{LOAD}$, so

$$I_{OUT} \approx \frac{I_{LOAD} \bullet R_{SENSE}}{R_{IN}}$$

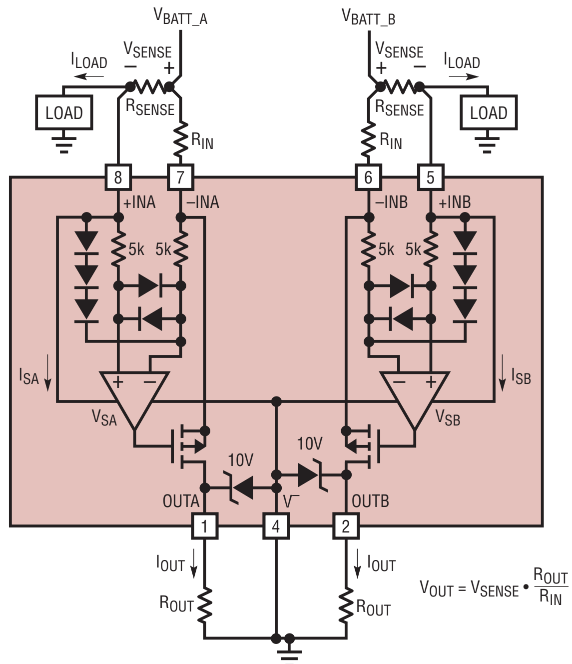

Figure 1. The LTC6103 block diagram and typical connection

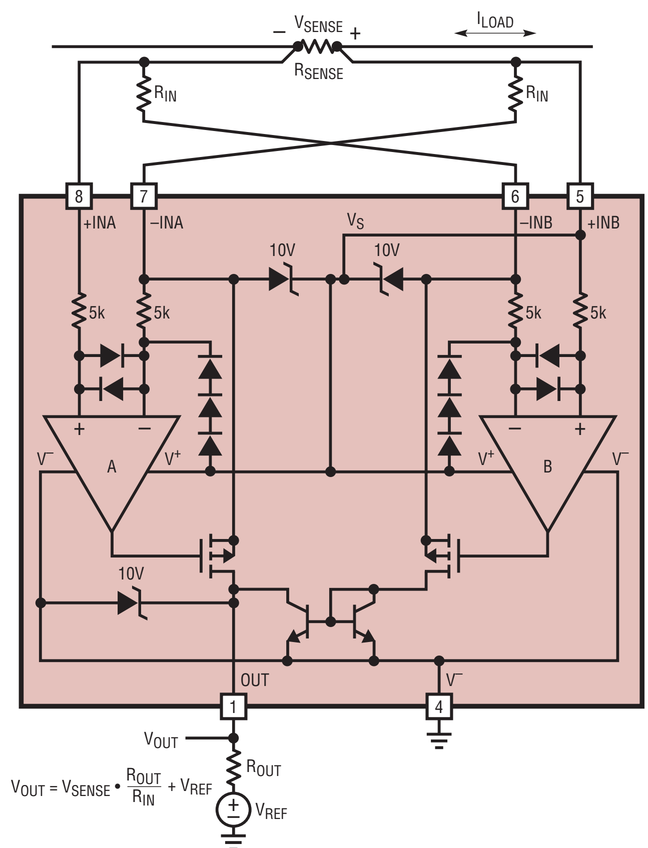

Figure 2. The LTC6104 block diagram and typical connection

The output current can be transformed into a voltage by adding a resistor from OUT to V^-. The output voltage is then

$V_{OUT} = (V^-) + (I_{OUT} \bullet R_{OUT})$

LTC6104 Theory of Operation

Figure 2 shows a block diagram of the LTC6104 in a basic current sense circuit.

Similar to the operation of the LTC6103, the LTC6104 can transfer a high side current signal into a ground-referenced readout signal. The difference is that the LTC6104 can sense the input signal in both polarities.

Only one amplifier is active at a time in the LTC6104. If the current direction activates the "B" amplifier, the "A" amplifier is inactive. The signal current goes into the –INB pin, through the MOSFET, and then into a current mirror. The mirror reverses the polarity of the signal so that current flows into the "OUT" pin, causing the output voltage to change polarity. The magnitude of the output is

$$V_{OUT} = \frac{V_{SENSE} \bullet R_{OUT}}{R_{IN}} + V_{REF}$$

Keep in mind that the OUT voltage cannot swing below V^-, even though it is sinking current. A proper V_{REF} and R_{OUT} need to be chosen so that the designed OUT voltage swing does not go beyond the specified voltage range of the output.

Sources of Current Sensing Error

As the output voltage is defined by

$$V_{OUT} = \frac{I_{LOAD} \bullet R_{SENSE} \bullet R_{OUT}}{R_{IN}}$$

any error of the external resistors contributes to the ultimate output error. If current flowing through the sense resistor is high, Kelvin connection of the –IN and +IN inputs to the sense resistor is necessary to avoid error introduced by interconnection and trace resistance on the PCB.

Besides external resistors, the dominant error source is the offset voltage of the sense amplifier. Since this is a level independent error, maximizing the input sense voltage improves the dynamic range of the system. If practical, the offset voltage error can also be calibrated out.

Care should be taken when designing the printed circuit board layout. As shown in Figure 3, supply current flows through the +IN pin, which is also the positive amplifier input pin (for the LTC6104, this applies to the +INB pin only). The supply current can cause an equivalent additional input offset voltage if trace resistance between R_{SENSE} and +IN is significant. Trace resistance to the -IN terminals is added to the value of R_{IN}. In addition, the internal device resistance adds approximately 0.3Ω to R_{IN}.

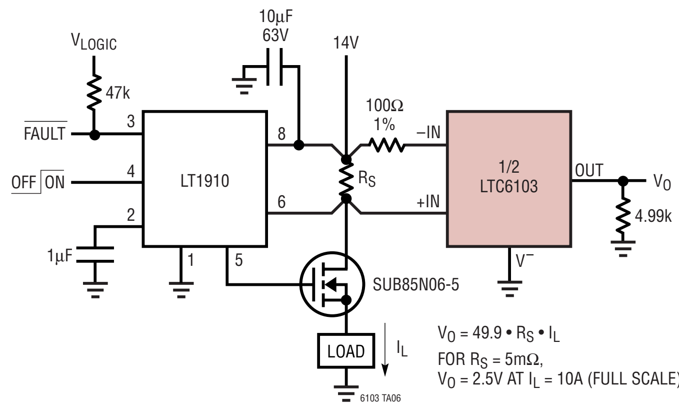

Figure 4. Automotive smart-switch with current readout

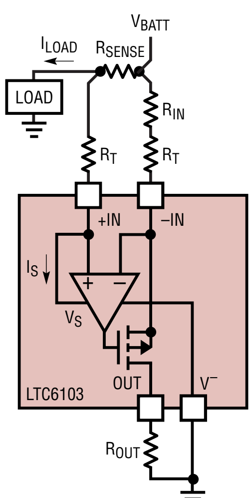

Figure 3. Error Due to PCB trace resistance

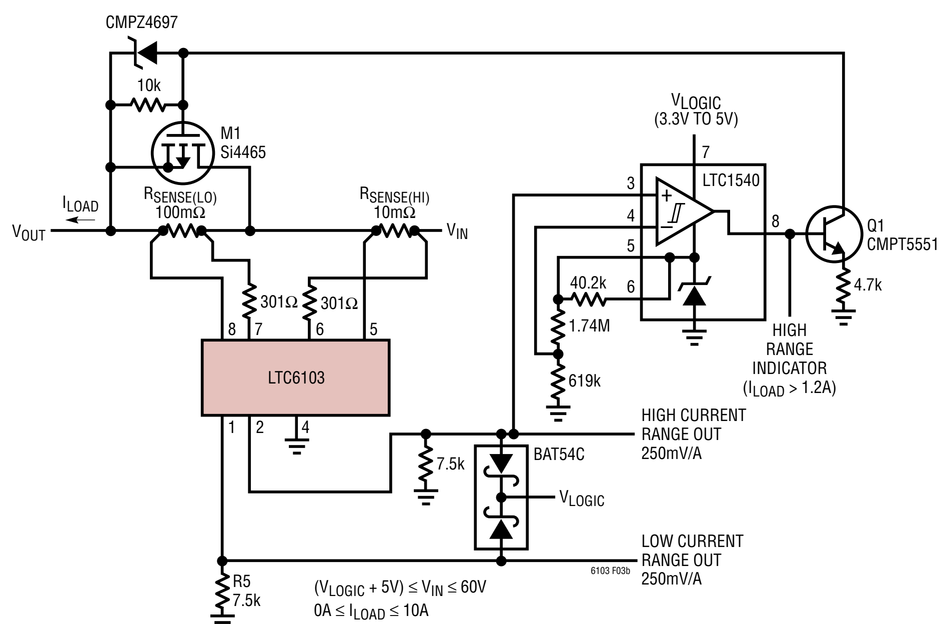

Figure 5. The LTC6103 allows high-low current ranging

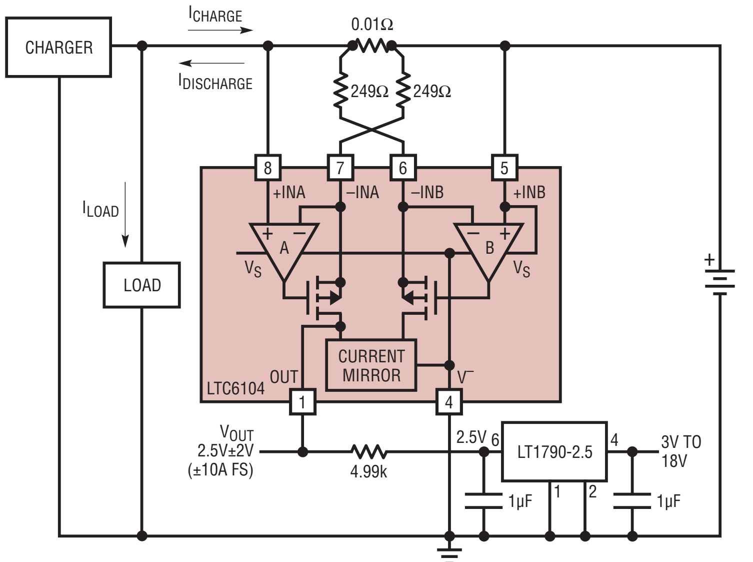

Figure 6. The LTC6104 bi-direction current sense circuit with combined charge/discharge output

Applications

The LTC6103 and LTC6104 operate from 4V to 60V, with a maximum supply voltage of 70V. This allows them to be used in applications that require high operating voltages, such as motor control and telecom supply monitoring, or where it must survive in the face of high-voltages, such as with automotive load dump conditions. The accuracy is preserved across this supply range by a high PSRR of 120dB (typical).

Fast response time makes the LTC6103 and LTC6104 the perfect choice for load current warnings and shutoff protection control. With very low supply current, they are suitable for power sensitive applications.

The gain of the LTC6103 and LTC6104 is completely controlled by external resistors, making them flexible enough to fit a wide variety of applications.

Monitor the Current of Automotive Load Switches

With its 60V input rating, the LTC6103 is ideally suited for directly monitoring currents on automotive power systems without need for additional supply conditioning or surge protection components.

Figure 4 shows an LT1910-based intelligent automotive high side switch with an LTC6103 providing an analog current indication. The LT1910 high side switch controls an N-channel MOSFET that drives a controlled load and uses a sense resistor to provide overload detection. The sense resistor is shared by the LT6103 to provide the current measurement.

The LTC6103 supplies a current output, rather than a voltage output, in proportion to the sense resistor voltage drop. The load resistor for the LTC6103 may be located at the far end of an arbitrary length connection, thereby preserving accuracy even in the presence of ground-loop voltages.

High-Low Range Current Measurement

Figure 5 shows LTC6103 used in a multi-range configuration where a low current circuit is added to a high current circuit. A comparator (LTC1540) is used to select the range, and transistor M1 limits the voltage across $R_{SENSE(LO)}$.

Battery Charge/Discharge Current Monitor

Figure 6 shows the LTC6104 used in monitoring the charge and discharge current of a battery. The voltage reference LT1790 provides a 2.5V offset so that the output can swing above

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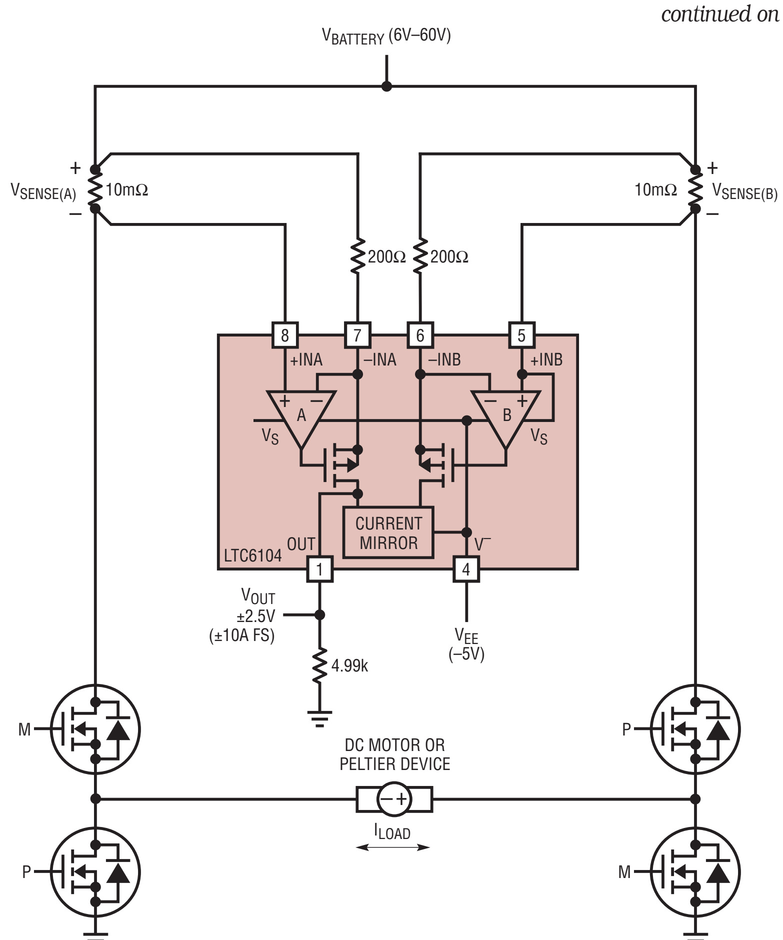

Figure 7. Current monitoring for an H-bridge application

V1 rises above 10.8V. The transition from the V2 to V1 is accomplished by slowly (10ms) turning off Q2 and Q3 allowing the Q1 to turn on rapidly when V_S matches V1. The H1 output is open until the E1 input drops below the V_{REF} voltage level. The V1 V_{FAIL} is determined by:

$$V_{FAIL} = V_{ETH} \bullet \frac{R2A + R2C}{R2C}$$
$$= 1.222V \bullet \frac{158k + 24.9k}{24.9k}$$
$$= 8.98V$$

Determine V1 $V_{RESTORE}$ by:

$$V_{RESTORE} = V_{ETH} \bullet \frac{\left(R2A + \left(R2C \| R2E\right)\right)}{R2C \| R2E}$$
$$= 1.222V \bullet \frac{158k + \left(24.9k \| 105k\right)}{24.9k \| 105k}$$
$$= 10.81V$$

Undervoltage and Overvoltage Shutdown

Figure 2 shows an application that disables the power to the load when the input voltage gets too low or too high. When V_{IN} starts from zero volts, the load to the output is disabled until V_{IN} reaches 5.5V. The V1 path is enabled and the load remains on the input until the supply exceeds 13.5V. At that voltage, the V2 path is disabled. As the input falls, the voltage source is reconnected to the load when the input drops to 12V and the V2 path is enabled. Finally, the load will be removed from the input supply when the voltage drops below 5V.

Undervoltage

$$V_{FAIL} = V_{ETH} \bullet \frac{R1A + R1C}{R1C}$$
$$= 1.222V \bullet \frac{75k + 24.3k}{24.3k}$$
$$= 4.99V$$

$$V_{RESTORE} = V_{ETH} \bullet \frac{\left(R1A + \left(R1C \| R1D\right)\right)}{R1C \| R1D}$$
$$= 1.222V \bullet \frac{75k + \left(24.3k \| 182k\right)}{24.3k \| 182k}$$
$$= 5.497V$$

Overvoltage

$$V_{FAIL} = V_{ETH} \bullet \frac{R2A + R2C \,||\, R2E}{R2C \,||\, R2E}$$
$$= 1.222V \bullet \frac{221k + 24.9k \,||\, 187k}{24.9k \,||\, 187k}$$
$$= 13.51V$$

$$V_{RESTORE} = V_{ETH} \bullet \frac{R2A + R2C}{R2C}$$
$$= 1.222V \bullet \frac{221k + 24.9k}{24.9k}$$
$$= 12.07V$$

The over and undervoltage lockout circuits are shown here working in tandem. It is possible to configure the circuit for either over or undervoltage lockout by using only one of the voltage paths and eliminating the components from the other. Only one PFET is required in this case. The LTC4416-1 should be used in this configuration rather than the LTC4416 because the LTC4416-1 turns off rapidly if an over or undervoltage condition is detected.

Conclusion

The LTC4416 provides power supply switchover solutions that cannot be easily generated using off-the-shelf components. The LTC4416 also provides power efficiencies not available with traditional NFET Hot Swap controllers. These efficiencies reduce the IDD of the solution by not having active switching gate drivers. The power losses are also reduced by decreasing the voltage drop across the PFETs to 25mV. The LTC4416 provides a smoother transition between the backup and the secondary power supplies.

The LTC4416-1 dual gate drivers provide a single controller solution to not only protect loads from overvoltage conditions, but also undervoltage conditions. The user can externally program the overvoltage and undervoltage thresholds using simple external resistor networks. These resistor networks also provide hysterisis to prevent chattering between the power source and the load.

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and below this point. Make sure that the lowest expected output level is higher than pin 4 (V^-) by at least 0.3V to ensure that negative going output swings remain linear.

H-Bridge Load Current Monitor

The H-bridge power-transistor topology remains popular as a means of driving motors and other loads bi-directionally from a single supply potential. In most cases, monitoring the current delivered to the load allows for real-time operational feedback to a control system.

Figure 7 shows the LTC6104 used in monitoring the load current in an H-bridge. In this case, the LTC6104 operates with dual supplies. The output resistance is connected directly to ground instead of connected to a voltage reference. The output ranges from 0V to 2.5V for V_{SENSE_A} = 0mV to 100mV, and from 0V to –2.5V for V_{SENSE_B} = 0mV to 100mV.

Conclusion

The LTC6103 and LTC6104 are precise high side current sensing solutions. The parts can operate to 60V, making them ideal for high voltage applications such as those found in automotive, industrial and telecom systems. Low DC offset allows the use of a small shunt resistor and large gain-setting resistors. The fast response time makes them suitable for overcurrent-protection circuits. Configurable gain means design flexibility. In addition, the open-drain output architecture provides an advantage for remote-sensing applications.

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