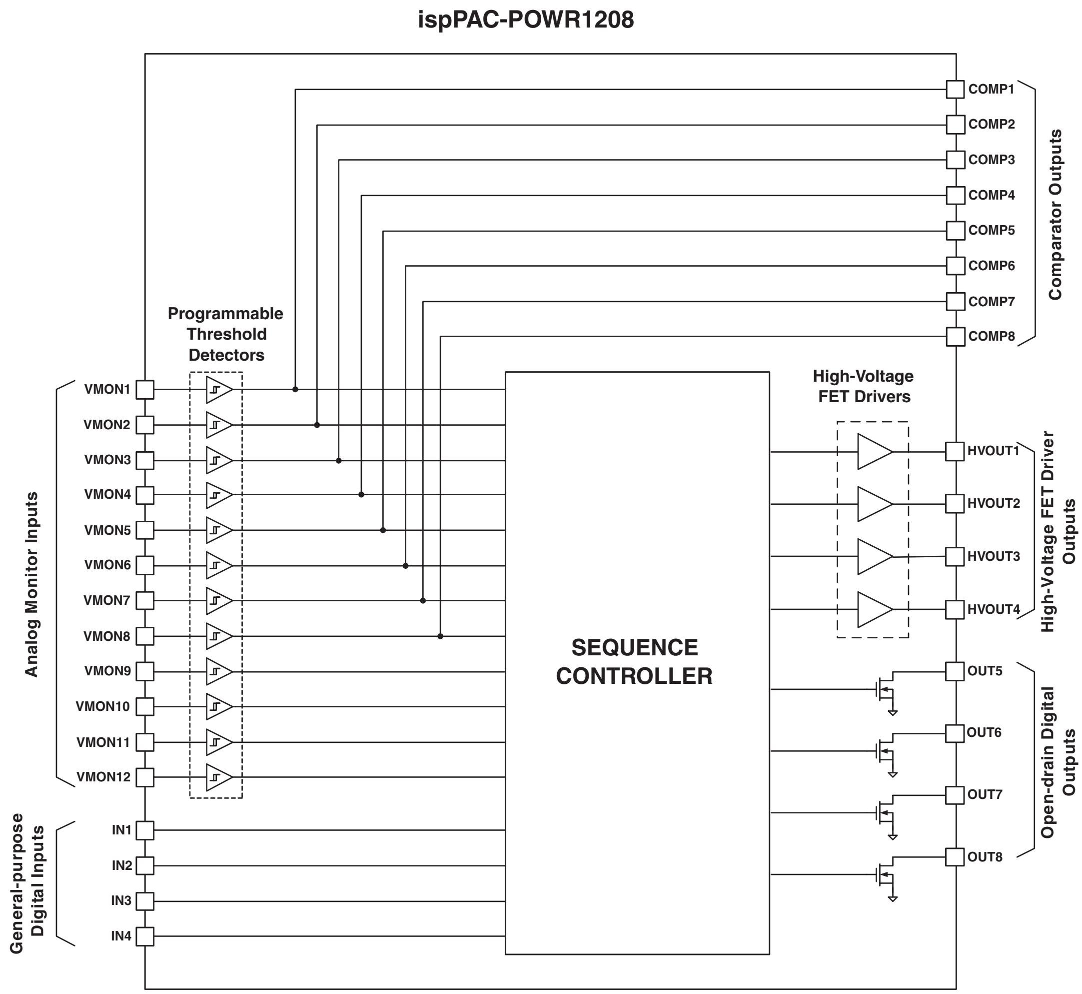
High-side Current Sensing Techniques for Power Manager Devices

April 2008 Application Note AN6049

# Introduction

The ispPAC®-POWR1208 provides a single-chip integrated solution to power supply monitoring and sequencing problems. Figure 9-1 shows a simplified functional block diagram of the ispPAC-POWR1208. This device offers 12 independent analog monitor inputs, four general-purpose digital inputs, four general-purpose digital outputs, and four digital outputs which may be configured either for digital open-drain operation, or as high-voltage MOSFET drivers. Additionally, the outputs of the threshold detectors associated with VMON1-VMON8 are also brought out to pins for external expansion. A PLD-based sequence controller forms the functional core of the ispPAC-POWR1208, supporting the creation of complex control sequences, as well as combinatorial logic functions.

***Figure 9-1. ispPAC-POWR1208 Simplified Block Diagram***




Although the ispPAC-POWR1208 provides analog voltage monitor inputs, there are many power-control applications in which one needs to monitor current. Current-monitoring functions can be easily added to the ispPAC-POWR1208, however, through the use of a few external components.

There are two fundamental ways of sensing electrical current. The first is by measuring the voltage drop associated with current passing through a known resistance, and the other is by measuring the magnetic field surrounding a conductor through which current passes. This application note will discuss both of these current sensing techniques.

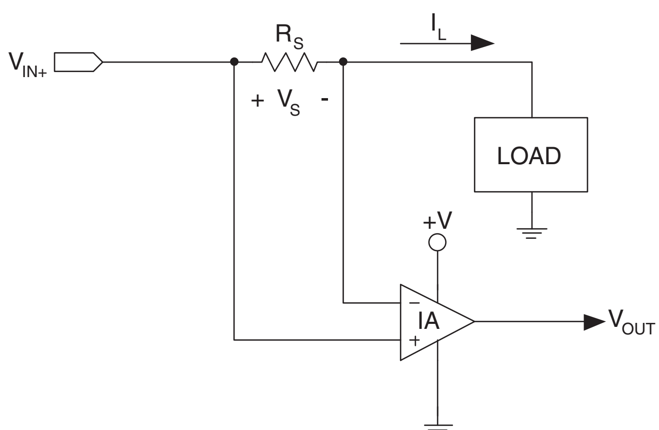
## Resistive Current Sensing

Resistive current sensing is the most commonly used technique for measuring electrical current on printed circuit board assemblies at low to moderate current levels. For power-supply measurements in the range of a few Amperes, a low-value sense resistor is inserted in series with the supply line in which one wants to measure the current. A measurable voltage drop ($V_S$) then appears across the resistor.

Using a stable resistor is important when attempting to accurately sense current. One 'technique' that is often suggested in switched power systems is that of using the power switch's (typically a MOSFET) low on-resistance for sensing current. The main problem one encounters when trying to implement this scheme is that this resistance can vary considerably, both as a result of unit-to-unit variation and from variations in operating conditions such as temperature and the amount of current being carried. When trying to measure current with resistive sensing techniques, one is usually better off using a resistor designed for this purpose.

One of the major challenges of sensing current is in measuring the small differential voltage $V_S$ developed across the current-sense resistor when it is in a high-side power-supply line. This is because the power supply line presents a large common mode voltage of VIN+ against which the differential voltage must be measured. One of the most common techniques for measuring a small differential voltage in the presence of a large common-mode voltage is with an instrumentation amplifier, as shown in Figure 9-2.

***Figure 9-2. High-side Current Sensor Using an Instrumentation Amplifier***




The instrumentation amplifier performs two functions in this circuit. The first function is to amplify the differential sense voltage ($V_S$) to usable levels. To minimize voltage drop across the sense resistor, it is often sized to deliver a sense voltage of a few tens of millivolts at maximum load current. This signal must be amplified into the range of a few volts before it can be fed into an ispPAC-POWR1208. The second function performed by the instrumentation amplifier is to convert the differential sense voltage into a single-ended, ground-referenced format.

As an example, if $R_S = 10\ m\Omega$, 10mV ($V_S$) will be developed across the sense resistor for every Ampere of load current ($I_L$). For measuring currents over a range of 0-5A, a maximum voltage of 50mV will be developed, which is not of sufficient magnitude for measurement by the ispPAC-POWR1208. Using an instrumentation amplifier with a gain of 100, however, will provide a $V_{OUT}$ signal of 1V (100 x 10mV) per Ampere, resulting in a full-scale range of 0V to 5V, which can be fed directly into one of the ispPAC-POWR1208's analog monitor inputs.

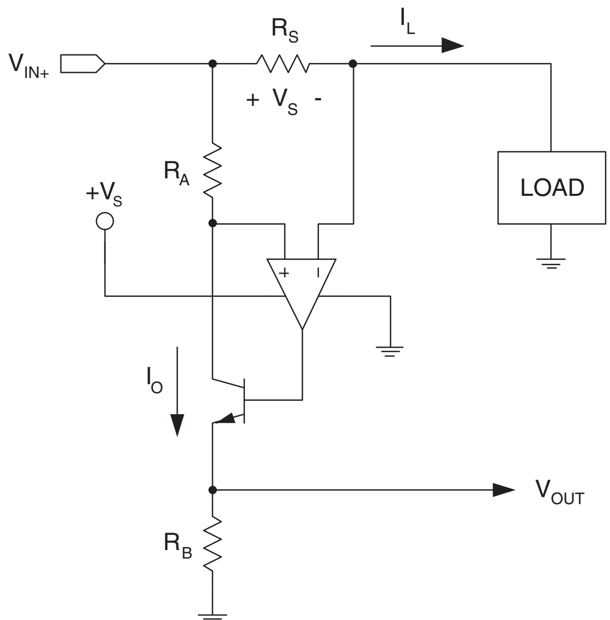
One of the major design tradeoffs in a resistive current-measurement system is that of selecting a resistor voltage drop which provides a sense voltage which is large enough to measure, yet does not deleteriously affect the voltage seen by the load. A larger voltage drop results in an easier-to-measure differential signal, and reduces the offset voltage and common-mode rejection requirements of the instrumentation amplifier used. A smaller voltage drop increases the demands (and cost) of the instrumentation amplifier, but also provides more voltage to the load.

One additional requirement placed on the instrumentation amplifier is that of being able to handle the common-mode range of the input signal. Providing an independent power supply (+V) for the instrumentation amplifier can simplify this problem if it of a sufficiently higher magnitude than VIN+. Alternatively, a few instrument amplifiers are available which have an common-mode input voltage range which exceeds their supply rail voltages.

## An Op Amp Current Sensing Circuit

An alternative to using an instrumentation amplifier is to use an operational amplifier and a few external resistors, as shown in Figure 9-3.

***Figure 9-3. High-Side Current Sensor Using Op Amp***




This circuit converts the differential voltage ($V_S$) measured across $R_S$ into an output current ($I_O$) which is then converted back into a ground referenced voltage through $R_B$. $V_S$ is impressed across resistor $R_A$, which in turn results in a current $V_S/R_A$. To maintain a stable feedback condition, where the two input terminals of the op amp are maintained at the same voltage, the op amp's output must bias the output transistor so as to draw this current out of the node, and pass it down to $R_B$. The relationship between load current and the resulting voltage $V_{OUT}$ can be expressed:

$$V_{OUT} = \frac{I_L R_S R_B}{R_A} \quad (1)$$

The main demands placed on the op amp are that it have an offset voltage significantly lower than the magnitudes of $V_S$ being measured, and that its input common-mode range extends to VIN+. An output range that comes to within a diode drop of ground is also necessary. These requirements are all met by using an op amp with rail-to-rail I/O.

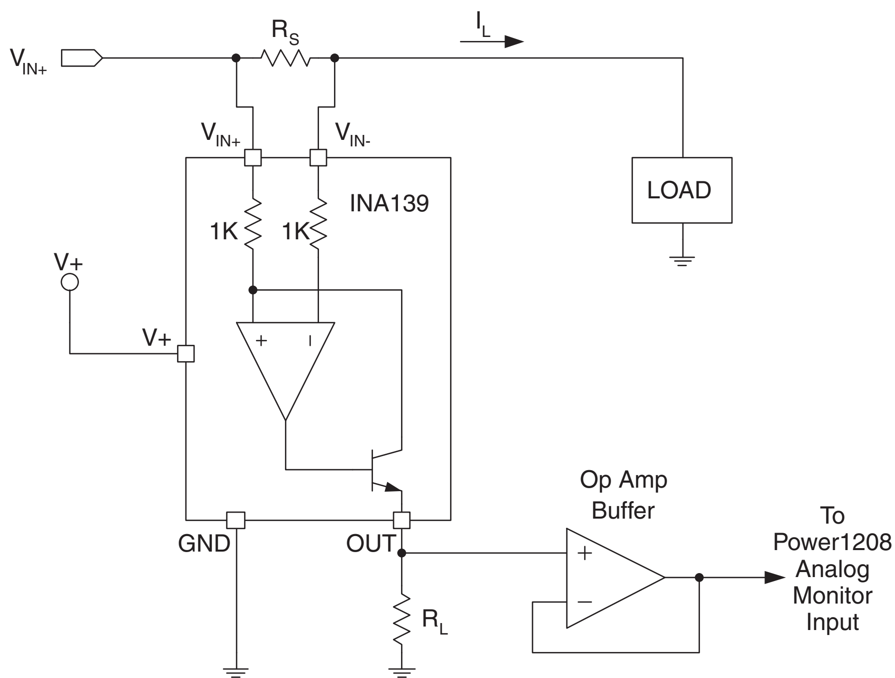
As an example, consider the implementation of a 0A to 5A current sensing application using this circuit and a 10 mΩ sense resistor. In this case we would like an output voltage range of 0V to 2.5V to correspond to the input range. By setting $V_{OUT} = 2.5V$, $R_S = 0.01\Omega$, and $I_L = 5A$ we can solve for the ratio of $R_B/R_A$.

$$\frac{R_B}{R_A} = \frac{V_{OUT}}{I_L R_S} = \frac{2.5V}{5A \times 0.01\Omega} = 50 \quad (2)$$

A further constraint on the $R_A$ and $R_B$ resistor values is imposed by the ispPAC-POWR1208's input impedance. Each of the ispPAC-POWR1208's analog monitor inputs presents a 100kΩ load to the outside world. This means that to provide an accurate measurement, the source driving the ispPAC-POWR1208 must have a significantly lower output impedance, such as 1kΩ. To meet this source impedance requirement, let's set $R_B$ = 1kΩ. This will result in a value of 20Ω being used for $R_A$.

As mentioned above, one of the limitations faced when using both this circuit and instrument amplifier-based schemes is that of having a common-mode input range that extends up to the voltage rail in which current is being measured. This can make it difficult to measure current in the highest supply rails in a given system. One solution to this problem can be found in the INA139 by Texas Instruments (Figure 9-4). This device contains an amplifier especially designed to have an effective extended positive common-mode range (up to +40V), while running from a V+ power supply as low as 2.7V. This device also integrates some of the external components, such as $R_A$ and the output transistor; gain is programmed by selecting an external resistor ($R_L$). Because $R_A$ is fixed at 1kΩ, fairly large external resistors are required to implement high gains. To implement a gain of 50 would require that $R_L$ = 50kΩ. To interface the ispPAC-POWR1208 to this high a source impedance would require that the output voltage be buffered with an external op amp follower circuit.

***Figure 9-4. Using the Texas Instruments INA139***




## Magnetic Current Sensing

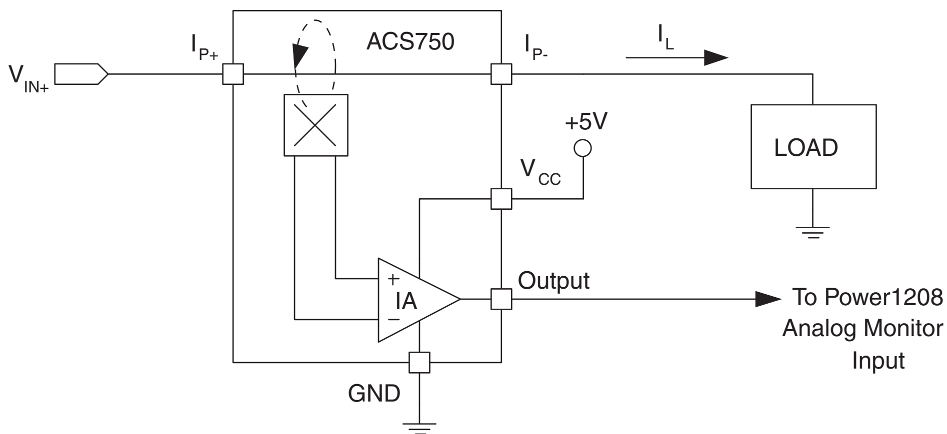
While resistive current sensing techniques are useful in many applications, they suffer from three inherent drawbacks:

- Supply-line voltage drop
- Insertion power loss
- Common-mode errors

The supply-line voltage drop is a necessity in resistive current sensing, as one must sacrifice some of the supply voltage to obtain a voltage drop across a sense resistor. Insertion power loss is related to both the voltage drop across and current through the sense resistor, and is given by $I^2R$. When measuring very high currents, the amount of power dissipated in the current sense resistor can become substantial. Finally, when the voltage of the supply line is either very high, or negative, it can be difficult to perform accurate differential voltage measurements without resorting to complex isolation schemes.

While all of these issues are readily surmounted when sensing low to moderate amounts of current on low-voltage supply lines, they can become significant as either currents or voltages increase. One solution which becomes especially attractive when trying to measure currents at higher levels (>10A) or where the supply line is at a high (e.g. 48V) voltage is to use magnetic current sensors. A magnetic current sensor works by measuring the magnetic field surrounding a current-carrying conductor. This induced magnetic field has both a magnitude and direction directly corresponding to that of the current flow. Various technologies, such as magneto-resistors or Hall-effect devices can be used to measure this magnetic field. While one can implement magnetic current sensors from discrete Hall-effect or magneto-resistive devices and suitable magnetic components, complete integrated solutions are now becoming available which provide the complete function in finished form. One example of such a device is the Allegro Microsystems ACS750, shown schematically in Figure 9-5.

***Figure 9-5. Allegro Microsystems ACS750 Magnetic Current Sensor***




This device uses a Hall-effect sensor to detect the magnetic field surrounding a conductor running through the device (IP+ to IP- terminals), and provides a 0V to 5V output signal which corresponds to an input current range of +/-100A. Because no sense resistor is required, this device provides very low voltage drop between the sense leads, and correspondingly low insertion losses. Because the input terminals are electrically isolated from the output electronics, it can be used to monitor currents at a wide range of common-mode voltages. Finally, the output is low-impedance, and can be directly connected to ispPAC-POWR1208's analog monitor inputs with no external buffering necessary.

## Conclusion

This application note has presented several ispPAC-POWR1208-compatible methods of sensing electrical current in low-voltage positive power supply lines. Both resistive and magnetic techniques were described, as were several specialized ICs specifically designed to aid in this type of measurement.

## References

- INA139/169 Data Sheet - Texas Instruments, Inc., December 2000
- ACS750 Preliminary Specification - Allegro Microsystems, Inc., January 2003

## Related Literature

- *ispPAC-POWR1208 Data Sheet*

## Technical Support Assistance

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# Revision History

| Date | Version | Change Summary |
|---|---|---|
| February 2003 | 01.0 | Initial release. |
| April 2008 | 01.1 | Title changed from “High-side Current Sensing Techniques for the isp-PAC-POWR1208” to “High-side Current Sensing Techniques for Power Manager Devices.” |