APPLICATION NOTE 4050

Current Sensing on a Negative Voltage Supply Rail, using a Precision Instrumentation Amplifier

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Abstract: Applications like ISDN and telecom systems need a negative voltage, current-sense amplifier. This application note describes one method for designing a negative-rail, current-sense amplifier. The design is quite flexible and can be easily changed for monitoring different negative rails. The MAX4460 single-supply instrumentation amplifier is used to demonstrate the design.

Introduction

High-side current-sense amplifiers are used principally for monitoring the current from a positive supply rail. Applications like ISDN and telecom power supplies, however, require current-sense amplifiers that operate at negative rail. This application note describes one method for designing a negative-rail, current-sense amplifier.

Application Example
Figure 1 shows a block diagram of the power-distribution network in a typical telephone exchange. A rectifier converts the AC at the power mains to DC, and the DC output from the rectifier is used to charge a 48V lead-acid battery. The battery powers the user telephones through the telephone line. The battery polarities are connected so that the line voltage is negative (-48V). A negative line voltage helps to reduce the corrosion from electrochemical reactions occurring on a wet telephone line. A telecom network also uses several DC-DC converters to derive intermediate power-supply rails from the -48V DC input. The intermediate power supply rails power the switches, radios, routers, ATX computers, and other electronic equipment in the telephone exchange. A current-sense amplifier oversees the system health by monitoring the -48V power-supply current.

Circuit Description
Figure 2. Negative-rail, current-sense amplifier using the MAX4460.

The circuit in Figure 2 shows an implementation of the negative-rail, current-sensing block. It uses an instrumentation amplifier like the MAX4460 or the MAX4208 and some discrete components.

The zener diode, D1, protects the instrumentation amplifier from overvoltage damage while providing sufficient supply voltage for its operation. The current to be monitored flows to the negative supply through the sense resistor, RSENSE. The instrumentation amplifier must have a single supply and operate with a ground-sensing capability.

The MAX4460's output provides the gate drive for MOSFET M1. Negative feedback ensures that the voltage drop across resistor R3 equals VSENSE, the voltage across RSENSE. Consequently, R3 sets a current proportional to the load current:

$$I_{OUT} = \frac{I_{LOAD} \times R_{SENSE}}{R_3} = \frac{V_{SENSE}}{R_3} \quad \text{(Eq. 1)}$$

R2 is chosen so that the output voltage lies within the desired range of the following circuit, typically an ADC. The drain-source breakdown voltage rating of the MOSFET must exceed the total voltage drop between the two supply rails (+125V in this case). An additional op-amp buffer can be used at VOUT if the ADC does not have a high-impedance input. If the sense current increases above the rated value during a fault condition, then the output voltage goes negative. Diode D2 protects the ADC from damage by limiting the negative voltage at output to one diode drop.

Design Steps

The above design can easily be adapted to add high-voltage, negative supply, current-sense monitoring
capability. This flexibility is illustrated by choosing -120V as the negative rail. By using the following straightforward steps, one can design a current-sense amplifier for a different supply rail.

1. Specify the Zener Regulator

It is important to bias the zener on a point in its transfer characteristic that gives a low dynamic resistance (i.e., well into its reverse breakdown region) to prevent PSRR errors. Figure 3 shows a plot of the zener current versus the zener voltage for a standard zener diode configured in reverse bias. Data show that the zener voltage is not well-regulated close to the breakdown voltage. A general rule then is to select the bias point to be about 25% of the maximum current specified by the power rating. This bias point gives a low dynamic resistance without wasting too much power. The bias point is set to the desired value by choosing the resistor, $R_1$, based on the following equation:

$$R_1 = \frac{(V_{CC} + |V_{NEG}| - V_Z)}{IR_1} = \frac{V_M + I_S}{I_Z}$$  \hspace{1cm} (Eq. 2)

Where:
- $V_{CC}$ = Positive rail-supply voltage
- $V_Z$ = Regulated zener voltage
- $|V_{NEG}|$ = Absolute value of the negative-rail voltage
- $I_S$ = Supply current for MAX4460
- $I_Z$ = Current through the zener diode

$R_1$ must have a suitable power rating and be able to withstand the large voltages across it. Alternatively, one can use a series-parallel combination of lower wattage resistors to ease these constraints.

![Zener Transfer Characteristic, $V_Z = 4.7V$](image)

Figure 3. 1N750 Zener diode transfer characteristic, $V_Z = 4.7V$.

2. Select the Power Transistor

The n-channel MOSFET, or JFET, must have a drain to source breakdown voltage rating greater than $|V_{NEG}| + V_{CC}$. This is an important constraint if the negative supply voltage is high.

3. Choose $R_{SENSE}$
Select $R_{\text{SENSE}}$ so that the full-scale, sense voltage across $R_{\text{SENSE}}$ is less than or equal to 100mV.

4a. Select $R_3$

There is considerable flexibility in choosing $R_3$. A good selection is influenced by the following two observations:
1. As $R_3$ is reduced, Equation 1 implies that for a fixed gain, the dissipated power increases.
2. The thermal noise and leakage current of the FET set the upper limit on the selected value of $R_3$.

4b. Select $R_2$

The ratio of resistors $R_2$ and $R_3$ equals the voltage gain of the resulting current-sense amplifier. The output voltage is given as:

$$V_{\text{OUT}} = V_{\text{CC}} - I_{\text{OUT}} \times R_2$$  \hspace{1cm} (Eq. 3)

From Equations 1 and 3 we get:

$$V_{\text{OUT}} = V_{\text{CC}} - (V_{\text{SENSE}} \times R_2/R_3)$$

Differentiating with respect to $V_{\text{SENSE}}$:

Voltage gain, $A_v = -R_2/R_3$  \hspace{1cm} (Eq. 4)

The negative sign represents the inverting relationship between the output voltage and the input sense voltage. From Equation 4, $R_2$ can thus be determined.

Results

Figure 4 plots the resulting typical output voltage as a function of the sense voltage. The following typical parameters can be inferred for the current-sense amplifier:

Input referred offset voltage = $(5 - 4.9831)/49.942$

$= 338\mu\text{V}$

Gain = -49.942
Conclusion

This application note demonstrates the use of a precision, instrumentation amplifier like the MAX4460 for current sensing of a negative voltage. The described circuit can be easily redesigned for monitoring different negative rails by following the design steps listed above.

A similar article appeared in the August, 2007 issue of Power Electronics Technology magazine, a Penton Publication.

### Related Parts

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<tr>
<th>Part Number</th>
<th>Description</th>
<th>Free Samples</th>
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</thead>
<tbody>
<tr>
<td>MAX4208</td>
<td>Ultra-Low Offset/Drift, Precision Instrumentation Amplifiers with REF Buffer</td>
<td>Free Samples</td>
</tr>
<tr>
<td>MAX4460</td>
<td>SOT23, 3V/5V, Single-Supply, Rail-to-Rail Instrumentation Amplifiers</td>
<td>Free Samples</td>
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<tr>
<td>MAX9918</td>
<td>-20V to +75V Input Range, Precision Uni-/Bidirectional, Current-Sense Amplifiers</td>
<td>Free Samples</td>
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<tr>
<td>MAX9919</td>
<td>-20V to +75V Input Range, Precision Uni-/Bidirectional, Current-Sense Amplifiers</td>
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<td>-20V to +75V Input Range, Precision Uni-/Bidirectional, Current-Sense Amplifiers</td>
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</tbody>
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