

# Amplifier Senses Currents At Large Negative Voltages

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In telecom and other systems with high-voltage negative supply rails, a simple combination of an instrumentation amplifier and discrete components enables high-side current sensing for circuit protection.

High-side current-sense amplifiers (CSAs) are principally used for monitoring the current from a positive supply rail. However, applications like ISDN and telecom power supplies require CSAs that operate on a negative rail. One method for designing a negative-rail CSA uses a precision instrumentation amplifier IC and several discrete components.

A similar approach, using a dual-supply op amp to sense current through a -5-V rail, was discussed in a previous article.<sup>[1]</sup> But here, the design is extended for sensing much higher negative-rail voltages, while using an amplifier IC that operates on a single supply. Though the example presented here is for a -120-V supply, the design can be modified for monitoring negative rails at other voltage levels.

## Application Example

Fig. 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 48-V lead-acid battery. The battery powers the user telephones through the telephone line, thus eliminating the need for a back-up battery at the user end.

The battery polarities are connected so that the line voltage is negative (-48 V). A negative line voltage reduces 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 -48-Vdc input. These intermediate rails power the switches, radios, routers, ATX computers and other electronic equipment in the telephone exchange.

A fault condition can damage the power supply if the load current exceeds the maximum rated value; therefore, output protection is required. A time-tested method is to build a circuit breaker using a CSA and a power transistor.

The CSA intensifies the small voltage drop across a sense resistor that is added in series with the battery. The circuit breaker is triggered whenever the battery current rises to the maximum rated value, typically 120% to 140% of the nominal current.

The sense resistor can be placed either between the load and the ground (low-side current sensing) or between the load and the negative terminal of the 48-V battery (high-side current sensing). These two alternatives require a tradeoff in different areas. The low-side resistor adds undesirable resistance in the ground path. Moreover, not all faults can be detected using the low-side scheme.<sup>[2]</sup>

The high-side or negative supply current sensing has to handle a larger power supply and common-mode signal, but

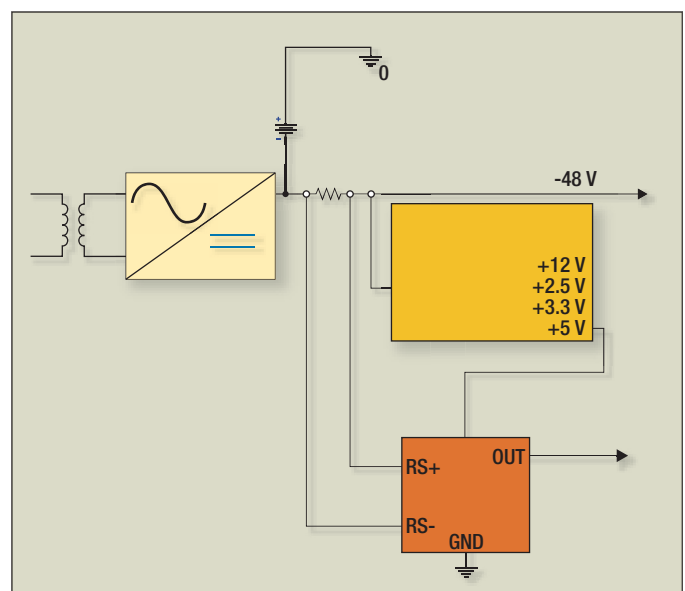


Fig. 1. A telephone central-exchange power-supply system requires a current-sense amplifier on the -48-V battery supply to implement a circuit breaker that protects against excessive load currents.

it can detect any fault caused by inadvertent shorts with the ubiquitous ground plane. The CSA discussed in this article follows the high-side approach.

## Circuit Description

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

The MAX4460/MAX4208 are instrumentation amplifiers with a novel architecture called indirect current feedback.<sup>[3]</sup> This topology enables the input common-mode voltage range to cover ground (i.e., the amplifier's negative rail) unlike traditional three op-amp architecture.<sup>[4]</sup>

In the indirect current-feedback architecture, load current through  $R_{SENSE}$  creates a differential voltage between IN+ and IN- of the instrumentation amplifier. This differential voltage is converted to an internal differential current by transconductance amplifier  $g_{M1}$ . The transconductance amplifier  $g_{M2}$ , again with identical transconductance, seeks to cancel this internal differential current by using a high-gain amplifier in a negative feedback loop. Due to the matched transconductance, the feedback action reproduces the input-differential voltage between IN+ and IN- across the pins FB and GND.

The MAX4460's output provides a suitable gate drive for MOSFET  $M_1$ . The voltage drop across resistor  $R_3$  equals  $V_{SENSE}$ , the voltage across  $R_{SENSE}$ . Consequently,  $R_3$  sets a current proportional to the load current:

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

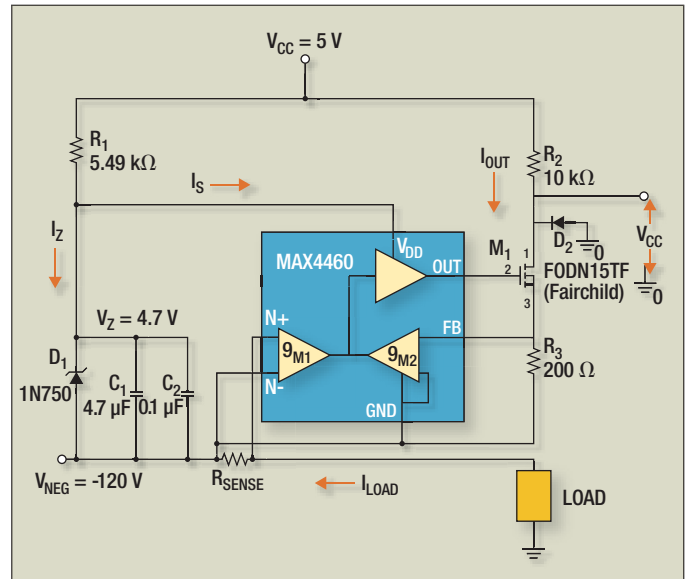
The drain-source breakdown-voltage rating of the MOSFET must exceed the total voltage drop between the two supply rails (+125 V, in this case).  $R_2$  is chosen so that the output voltage lies within the desired range of the following circuit, typically an analog-digital converter (ADC). As explained later,  $R_2$  and  $R_3$  set the gain of the CSA. An additional op-amp buffer can be used at  $V_{OUT}$ , if the ADC does not have a high-impedance input.

Zener diode  $D_1$  protects the instrumentation amplifier from overvoltage damage, while providing sufficient supply voltage for its operation. If the sense current increases above the rated value during a fault condition, then the output voltage goes negative. Diode  $D_2$  protects the ADC from damage by limiting the negative voltage at output to one diode drop.

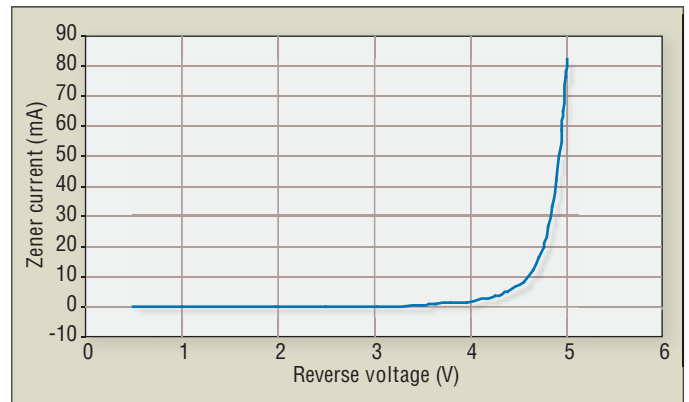
## Design Steps

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

*Step 1: Specify the zener regulator.* It is important to bias the zener on a point in its transfer characteristic that gives a



**Fig. 2.** This negative-rail current-sense amplifier leverages the indirect current-feedback architecture of the MAX4460 instrumentation amplifier, which enables the input common-mode range of the amplifier IC to cover ground.



**Fig. 3.** To ensure it exhibits low-dynamic resistance, zener diode  $D_1$  (1N750) in Fig. 2 should be biased at approximately 25% of its maximum current rating ( $V_z = 4.7\text{ V}$ ).

low dynamic resistance (i.e., well into its reverse breakdown region) to prevent PSRR errors. Fig. 3 shows a plot of the zener current versus the zener voltage for a standard zener diode configured in reverse bias.

Data shows 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:

$$I_{R1} = (V_{CC} + |V_{NEG}| - V_z)/R_1 = I_s + I_z, \quad (\text{Eq. 2})$$

where  $V_{CC}$  is the positive-rail supply voltage,  $V_z$  is the regulated zener voltage,  $|V_{NEG}|$  is the absolute value of the negative-rail voltage,  $I_s$  is the supply current for the MAX4460

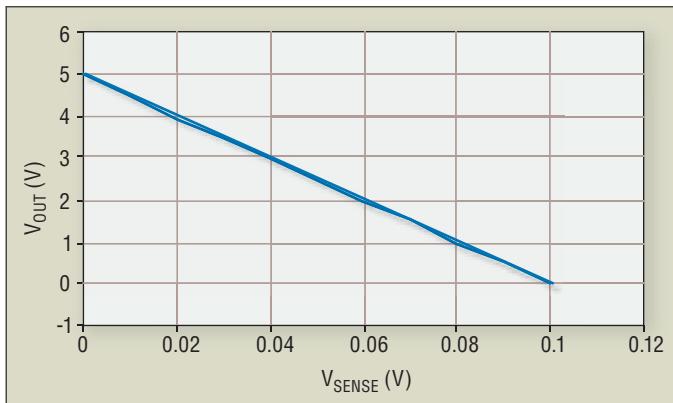


Fig. 4. The output voltage ( $V_{OUT}$ ) in Fig 2. varies linearly with the sense voltage at  $T = 25^{\circ}\text{C}$ . The common mode voltage at  $R_{SENSE}$  is  $-120\text{ V}$ .

and  $I_z$  is the 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.

**Step 2. Select the 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.

**Step 3. Choose  $R_{SENSE}$ .** Select  $R_{SENSE}$  so that the full-scale sense voltage across  $R_{SENSE}$  is less than or equal to 100 mV.  $R_{SENSE}$  must be able to dissipate the  $I^2R$  losses. If the resistor's rated power dissipation is exceeded, its value may drift or it may fail altogether.

**Step 4a. Select  $R_3$ .** There is considerable flexibility in choosing  $R_3$ . A good selection is influenced by two observations: As  $R_3$  is reduced, Eq. 1 implies that for a fixed gain, the dissipated power increases. In addition, the thermal noise and leakage current of the FET set the upper limit on the selected value of  $R_3$ .

**Step 4b. Select  $R_2$ .** The ratio of resistors  $R_2$  and  $R_3$  equals the voltage gain of the resulting CSA. The output voltage is given as:

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

From Eqs. 1 and 3, we get:  $V_{OUT} = V_{CC} - (V_{SENSE} \times R_2 / R_3)$ .

Differentiating with respect to  $V_{SENSE}$ :

$$\text{Voltage gain, } A_v = -R_2 / R_3 \quad (\text{Eq. 4})$$

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

## Results

Fig. 4 plots the resulting typical output voltage as a function of the sense voltage. The following typical parameters can be inferred for the CSA: Input referred offset voltage =  $(5\text{ V} - 4.9831\text{ V}) / 49.942 = 338\ \mu\text{V}$ , where gain =  $-49.942$ . The accuracy of the resulting CSA is a function of the tolerance of the resistors. All the resistors (except for  $R_1$ ) must have a tolerance of 1% or better. **PETech**

## References

1. Yang, Ken, "Precision Circuit Monitors Negative Supply Current," *Power Electronics Technology*, Sept. 1, 2005, p 78.
2. Maxim Integrated Products, Application Note 746, "High-Side Current-Sense Measurement: Circuits and Principles," March 26, 2001.
3. Huijsing, Johan Hendrik, and Shahi, Behzad, "GM-Controlled Current-Isolated Indirect-Feedback Instrumentation Amplifier," U.S. Patent 6,559,720, Oct. 26, 2001.
4. Maxim Integrated Products, Application Note 4034, "Three is a Crowd for Instrumentation Amplifiers," April 12, 2007.

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