Application Note 39

Current Measurement Applications Handbook

Contents

Introduction

Current measurement within electronic circuitry is a common requirement in portable, handheld equipment, through to automotive applications. This application handbook explores these factors for AC and DC current measurement and the implications on cost and performance for different approaches. Basic application topologies are explored including typical example calculations for configuration.

Basic application types

Closed loop systems

- Current is measured and is modified to a reference value by some control element. AC response can be critical here. Examples include:

1) Switching power supplies with current limiting functions or switch mode battery charging circuits.
2) PWM control of solenoids (automotive valve applications).
3) RF transmit control loops in portable cellular equipment, where transmitted power is adapted with distance.
4) Control of bias currents in (RF) power amplifiers.

- Current is compared to some preset value and is switched off if exceeded. Examples include:

1) Electronic fuses, internal fault limiting in equipment on distributed power systems.
2) Auto shutdown functions for DC motor control (replacing slipping mechanical clutches).

Open loop systems

- Current is measured and made available for some other system, usually less time critical.

1) Current measurement in instrumentation (bench power supplies, ammeters, current probes).
2) Power consumption measurement circuitry, especially portable battery powered consumer items.

Factors that determine the type of methods used

- Magnitude of current
- The need for electrical isolation
- Accuracy
- AC response
- Cost

Summary matrix of methods and performance

Figure 1 below shows the methods described in this handbook and a rough comparison between the most common factors found in current measuring application.

Figure 1 Matrix of common measurement methods

Type	Current range	Isolated	Accuracy	AC response	Non-intrusive	Cost
Resistive	V.low-high	No	High	Medium-high	No	Low-medium
Magnetic	Med-v.high	Yes	Medium	Medium	Yes	High
Opto-coupled resistive	Med-high	Yes	Low-medium	Low-medium	No	Low-medium

Chapter 1:
Resistive DC current measurement

The applications addressed by this chapter include steady state DC and potentially those requiring recovery of high frequency components modulating DC currents and bi-directional measurement also.

Inserting a resistance into the current path has the great advantage of converting that current to voltage for other circuits in a linear way as it inherently follows Ohm's law;

Voltage (V) = Current (A) x Resistance (Ω).

Its inherent disadvantage is that introducing resistance to electrical circuits produces power loss manifested as heat and by definition increases source impedance of the supply.

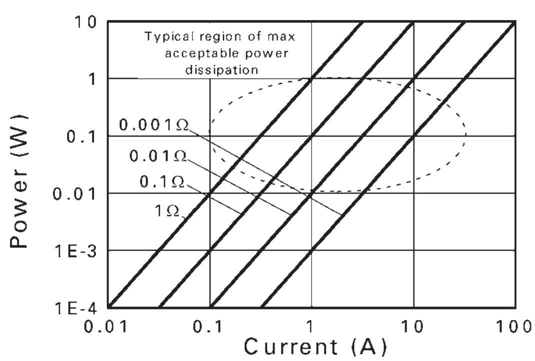
Power dissipated (W) = Current^2 (A) x Resistance (Ω).

Ideally then, resistance inserted is as close to zero as possible.

In accordance with this, the lowest value of resistance will produce the lowest power dissipation. The resistance cannot be zero, since a voltage is required to produce a corresponding output current. As this voltage decreases, circuit offset voltages become a larger fraction of the measured voltage and therefore accuracy is reduced.

Therefore a balance between required accuracy and power dissipated for a given current must be chosen.

Figure 2 Power dissipated vs current measured



1.1 Low-side resistive measurement

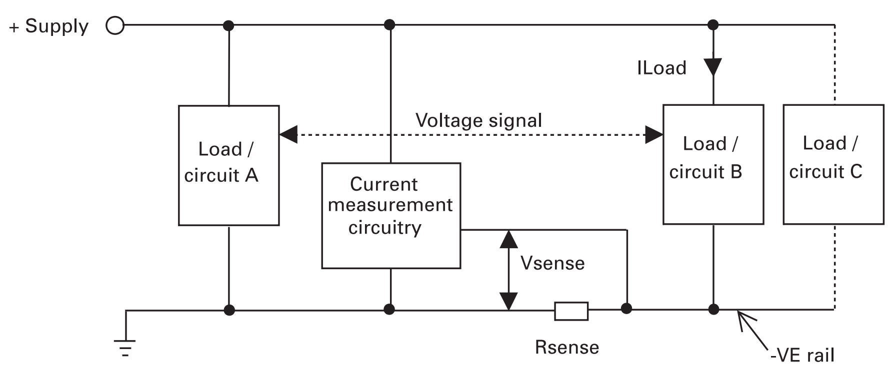
Low-side (negative or ground potential) measuring circuits generally offer the simplest solutions because the resulting signal is already ground referenced. One such method is to insert a small resistance into the ground plane between the supply's ground and the load to be measured, shown in figure 3. The resulting proportional voltage that is developed across that resistance can be used directly or amplified.

Care must be taken to add further circuitry on the correct side of R_{sense}. Circuit C will contribute additional current to that of Circuit B; this may or may not be desirable. To avoid this happening, other circuits should be place in the position of circuit A so their currents do not pass through R_{sense}.

A more subtle consequence of placing resistance in the ground plane is that any voltage signal that crosses R_{sense} will have an offset relative to ground, '-VE rail' is now at the potential of V_{sense}, which will change with ILoad. This will be unacceptable with most analog signals. An important property of the current measurement circuitry is that it should be able to accept V_{sense}, a signal of typically tens of millivolts from ground – input offset can be a consideration here.

Zetex has no integrated products currently to address low-side current measurement circuitry, suffice to say that the advice given regarding power and accuracy still apply and that operation amplifier based circuits to boost the sense voltage signals are common.

Figure 3 Low-side measurement



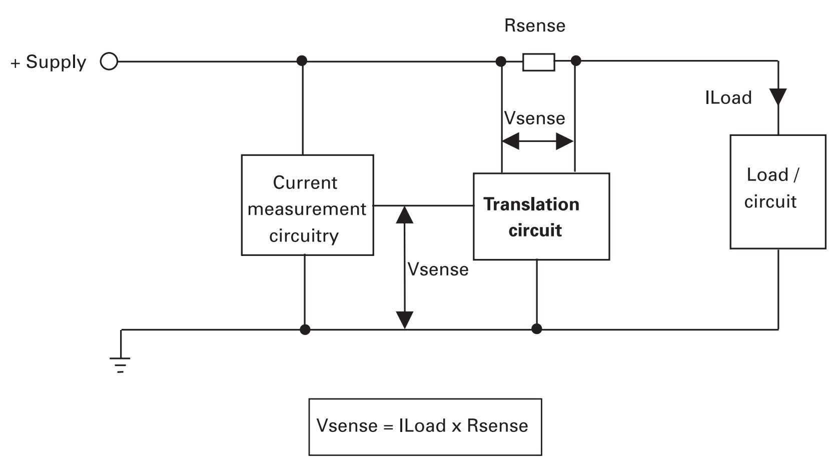
Vsense = ILoad x Rsense

1.2 High-side resistive measurement

In some applications, the loss of true ground cannot be tolerated because of the inter-circuit offsets incurred, as mentioned opposite. Sometimes, regardless of whether the effects of disrupting the ground plane could be ignored or tolerated, it is not possible to adopt this method. Where a system uses a common ground in the form of a metal chassis, for example automotive environment, components that are connected mechanically to it may not have the first method as an option. It is then necessary to measure the current in the supply (high-side).

The challenge now, if the resistive sensing option is adopted, is to translate this small common mode sense voltage on the supply rail to a ground referenced signal, as further circuitry in most cases will require this. Zetex has created the ZXCT range for this requirement.

Figure 4 High-side measurement



1.3 Properties of high-side to low side translation circuits

1.31 Accuracy

Accuracy is conditional on the size of the sense voltage for a given circuit design. Consider a fixed input offset of say 1mV on a translation circuit. A 100mV sense voltage would then have a theoretical best accuracy of 1% (**A**) and a 10mV sense voltage, 10% error (**B**). Discrete transistor circuits are not going to give more than a modest performance in this application. For any tolerances better than 5% max, operational amplifiers and dedicated ICs are needed.

1.32 Frequency or transient response

This may not be at all important in some circuits, automatic shutdown of DC motors probably won't require less than a few milliseconds response time. Whereas cycle by cycle current limiting in a switching power supply might well need small signal responses in the order of a microsecond or even down to the tens of nanoseconds. Closed loop power supply systems which are monitoring average current will require response times in the 10s or 100s of microseconds.

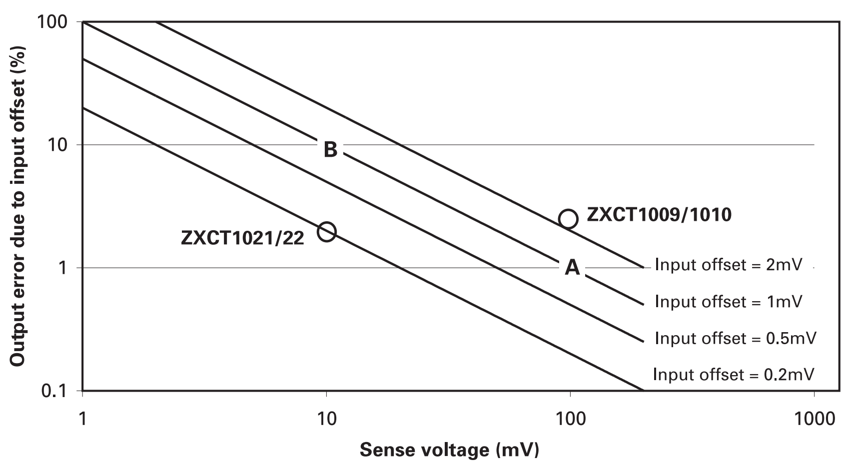
1.33 Power consumption

Current is required to drive parasitic and load capacitances so the speed requirement will always be a balance with supply current – usually only important in battery portable applications. For example to drive a signal of 1 volt into 5pF of load capacitance at 10kHz you need only hundreds of nanoamps of signal current and so bias currents will dominate. If you want to drive a signal with 10ns edges at a volt into the same load you'll need hundreds of microamps, changing the biasing of the circuit in a way which make it less suitable for battery applications. One circuit will not give you both microamp operating currents and excellent ac performance, so choice has to be made.

1.34 Maximum allowed sense voltage

Even if the magnitude of the sense voltage is not critical from a power dissipation perspective, i.e. if small currents are being measured, there may be a maximum voltage drop for supply headroom in the measured circuit.

Figure 5 Output error vs input offset



1.4 Considerations for sense resistors

1.41 Power dissipation

Power dissipation in resistors causes heating effects, the question is how much can be tolerated and what further consequences are experienced. For currents under 1A, in general this is unlikely to pose any problems as a typical sense voltage would yield power dissipations of less than 100mW, handled by most surface mount and through-hole resistors. As figure 2 infers, the power dissipation is directly linked to the accuracy required. It would be more critical for a large current to have a low sense voltage in order to minimise power dissipation and so for a given accuracy the translation circuit tolerances must be lower.

Example: 20A current must be sensed with maximum 500mW of dissipated power and with typical 3% accuracy. We must determine the allowable input offset.

Power $= I^2 \times R_{sense}$

$$\therefore\ R_{sense} = \frac{P}{I^2} \Rightarrow \frac{0.5}{400}$$

$= 1.25m\Omega$
(4 x 5mΩ resistors in parallel)

V_{sense} at 20A,
$V = I.\ R \Rightarrow 20 \times 1.25\times10^{-3} = 25$ mV.
So the circuit must have a typical input offset of 3% of 25mV => *0.75mV or less.*

The ZXCT1021 and ZXCT1022 were created to meet design requirements such as these; they are rated at 3% accurate at a 10mV sense voltage. In the case above they allow a power dissipation of 200mW for the same typical accuracy.

The other important reason to keep the self-heating of the resistors low is to minimise the further loss of accuracy caused by the temperature coefficient of the sense resistor.

Component to ambient thermal resistances of surface mount resistors on a PCB could be in the order of 200°C/W – i.e. a 250mW dissipation would cause a temperature rise of 50 degrees above ambient.

Consider a resistor with a temperature coefficient of 100ppm/°C, this would give a further 0.5% error from the self-heating effects which must be factored into the assessment of circuit tolerances, this does not take into account the operating temperature range.

Type of resistor

In most cases surface mount resistors are preferred and for larger currents and their associated power levels small arrays of series or parallel resistors can be used to share the dissipation. Wire-wound resistors provide higher operating temperatures, but usually have higher temperature coefficients and higher inductance, which might cause problems for high frequency signals. If absolute tolerance is not critical a simple PCB trace can be used for small resistance values, it should be noted that copper has a typical temperature coefficient of +0.393% / °C., see page 11.

Figure 6 below shows the range of current monitoring solutions and their associated performances and costs. It shows that where this function is not built in to some other IC, good performance at a reasonable cost can be achieved with the Zetex ZXCT range and other competitor devices.

Figure 6 Current monitoring solutions

Possible current sensing solutions	Zetex ZXCT series	Competitor solutions	Operational amplifiers (+transistor)	Internal function in other ICs	Discrete transistors
Brief description	Dedicated IC for general current monitoring		1 op-amp driving a discrete transistor emitter follower OR wide CM op-amp with differential configuration	Similar IC circuit built into ASSP	Commonly 2 discrete matched pairs with 4 external resistors
Component count / PCB area	1 SOT23(5) 1 or 2 external resistors	1 SOT23-5 or MSOP8 1 or 2 external resistors (poss. internal Rsense)	1 op-amp, 1 discrete, 3 to 6 external resistors depending on CM range	No additional component count or 1 Rsense	2 SOT23-5 4 resistors
Total	2 or 3	1,2 or 3	5 to 8	0 or 1	6
Functionality options	Unipolar, comparator	Unipolar, bi-directional comparator	Just unipolar, with component above	Any other functionality	Just unipolar, with components above
Volume price	ZXCT1009/1010 low	General purpose medium	Low to medium depending on spec (but dual or quad op-amps give other functionality)	Almost free for simple current monitoring	Low
	ZXCT1021/1022 low-med	Precision high			
Typical accuracy @100mV	ZXCT1009/1010 1%	0.5 -2%	0.5 – 4%	0.5 – 10% (depends on design and IC process)	4 – 10%
	ZXCT1021/1022 3% @ 10mV				
Thermal performance	ZXCT1009/1010 fair	Good	Fair – good	Depends on design. Fair to Good	Poor - fair
	ZXCT102x good				
Supply range (V)	2.2V-20V (100V+ with apps cct)	2.7V – 28V 3V – 36 or 60V	Depends on op-amp, typically 18-36V	Depends on IC process	40 – 100V max with little extra cost

Chapter 2:
Zetex ZXCT product description

The Zetex ZXCT current monitor range has been designed specifically for resistive DC current measurement discussed in chapter 1.

The ZXCT1009 high side current sense monitor is the simplest product available with only 3 connections, it is intended for cost effective applications. Its constant current output is proportional to the voltage sensed across a resistor; this allows a wide current range to be measured accurately when the appropriate sense resistor is chosen. This principle holds for all the ZXCT range.

For example consider a 50mV sense voltage, a 1mA current could be sensed with a 50Ω sense resistor or a 50A current could be measured with a 1mΩ sense resistor.

This output current is then converted into a voltage with a user defined output resistor allowing flexible scaling.

The ZXCT1010 adds a separate ground connection to the ZXCT1009 to remove the IC supply current from the output, reducing output current offset.

2.1 Performance summary

The ZXCT1009/1010 output a current corresponding to a sensed voltage.

The ZXCT1021/1022 are precision high side current sense monitors which output a voltage. The ZXCT1021 provides a fixed gain of 10 while the ZXCT1022 has a gain of 100, for applications where minimal sense voltage is required.

The very low offset voltage enables a typical accuracy of 3% for sense voltages of only 10mV, giving better tolerances for small sense resistors necessary at higher currents.

The wide input voltage range of 20V down to as low as 2.5V make it suitable for a range of applications. With a minimum operating current of just 25µA, combined with its SOT23-5 package make it suitable for portable battery equipment too.

The ZXCT1030 is a high-speed version with internal 1.2V bandgap reference and comparator for over-current applications. The current monitor and comparator have large signal step response times of around 200ns.

Figure 7 Performance summary

Part number	Description	Accuracy @ Vsense	Typ. quiescent current (µA)	Gain (output/ Vsense)	Bandwidth (MHz)	Package
ZXCT1009F	Simple current monitor	±2.5% @ 100mV	5	User defined	2	SOT23
ZXCT1010E5	Enhanced offset	±2.5% @ 100mV	4	User defined	2	SOT23-5
ZXCT1021E5	For low V_{sense}	±3.0% @ 10mV	25	10	2	SOT23-5
ZXCT1022E5	For low V_{sense}	±3.0% @ 10mV	25	100	2	SOT23-5
ZXCT1030X8	w/reference & comparator	±3.0% @ 100mV	270	10	6	MSOP8

Chapter 3:
ZXCT application notes

ZXCT1009/1010 application notes

3.1 Basic calculations for use

The following lines describe how to scale a load current to an output voltage.

Figure 8 Typical application circuit

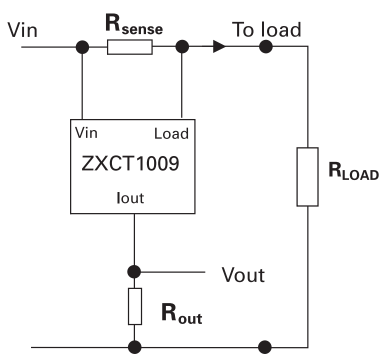


Figure 8 shows the basic configuration for monitoring a current. R_{LOAD} represents any load, such as a DC motor, charging battery or any other circuit which requires a current monitor.

Vsense = V_{in} - V_{LOAD} = R_{sense} x I_{LOAD}

Vout = 0.01 x V_{sense} x R_{out}

Example calculation

A 2A current is to be represented by a 100mV output voltage:

1. Choose value of R_{sense} to give 50mV>V_{sense}>500mV

   e.g. V_{sense} = 100mV at 1.0A

   $\therefore$ R_{sense} = 0.1 / 1.0 = 0.1Ω

2. Choose R_{out} to give V_{out} = 100mV, when V_{sense} = 100mV

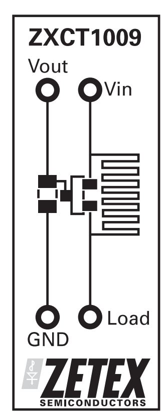
   R_{out} = V_{out} / (V_{sense} x 0.01)

   R_{out} = 0.1 / (0.1 x 0.01) = 100Ω

3.2 Low cost solution

When cost is a critical factor in the solution, the copper trace of the PCB can be used for R_{sense} (figure 9), instead of a conventional surface mount resistor.

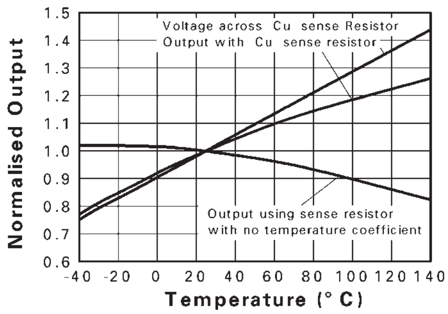
Figure 9 PCB resistive trace used for R_{sense}



Total circuit solution: 2 components.

Shows area of approximately 50mΩ sense resistor compared to SOT23 package.

Figure 10 Effect of sense resistor material on temperature performance



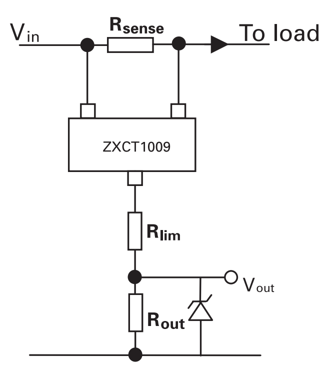
Practical tolerance of the PCB resistor might be around 5% depending on manufacturing methods.

Temperature coefficient of the resistance of Copper is around +0.4% / degree.

3.3 Transient protection

In certain applications, especially those which contain inductive elements, high voltage transients can be present. An additional resistor R_{lim} can be added in series with R_{out} (figure 11), to limit the current from I_{out}. Any circuit connected to V_{out} will be protected from input voltage transients. A zener diode can also be placed between V_{out} and ground as optional protection for connecting circuitry.

Figure 11 ZXCT1009 with additional current limiting resistor



Assuming the worst case condition of V_{out} = 0V; providing a low impedance to a transient, the minimum value of R_{lim} is given by:-

$$R_{lim}(\min) = \frac{V_{pk} - V_{\max}}{I_{pk}}$$

V_{pk} = Peak transient voltage to be withstood (V)

V_{max} = Maximum working voltage = 20V

I_{pk} = Peak output current = 40 mA

The maximum value of R_{lim} is set by V_{in}(min), V_{out}(max) and the dropout voltage (see transfer characteristic on page 3) of the ZXCT1009:-

$$R_{lim}(\max) = \frac{R_{out}\,[V_{in}(\min) - (V_{dp} + V_{out}(\max))]}{V_{out}(\max)}$$

V_{in}(min) = Minimum supply operating voltage (V)

V_{dp} = Dropout voltage (V)

V_{out}(max) = Maximum operating output (V)

3.4 Extended supply range

The ZXCT1009 has a maximum operating voltage of 20V. Where higher voltages are used, the following circuits can be considered.

3.41 Simplest circuit for V_{in} > 20V:

In the case where the supply voltage *range* (V_{in} min to max) is not more than the range of the ZXCT1009 (20V - 2.5V => 17.5V), 1 zener diode can be added in series with Rout. (Figure 12).

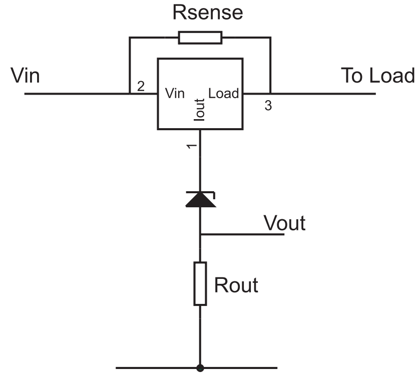
The zener voltage is chosen to make Vin – V_{Iout} $\leq$ 20V, at the max input voltage.

E.g. Supply voltage range = 15V to 30V, V_{out} between 0V and 1V.

Choose a 10V zener diode.

Consider I_{out} as the device's ground connection, the ZXCT1009 will be supplied with:

Figure 12 Extended supply range using a Zener diode

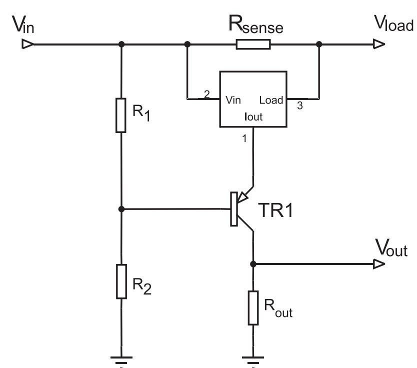


15V - 10V – 1V => 4V minimum - ok
30V – 10V – 0V => 20V maximum - ok

3.42 For V_{in} > 20V with larger input voltage supply range

This circuit (figure 13) can be used for correct operation during transients or high input voltages and is only dependent on the voltage rating of the chosen transistor; V_{CEO}.

Figure 13 Extended supply range using additional transistor



TR1 is used in common base configuration and is used to drop most of the supply voltage between collector and emitter. When the current gain is reasonably high (>100), $I_C \approx I_E$ and I_{out} still flows through R_{out} and hence V_{out} can be calculated in the normal way.

R_1 must be chosen to preserve the ZXCT1009's normal supply range, large enough in value to provide the minimum operating voltage to the device at the lowest supply voltage but not too large that the maximum device operating voltage is exceeded at the highest input voltage.

E.g. V_{in} = 20 to 100V, V_{out} > 2V

Choose the R_1/R_2 current to be 0.5mA to keep the power dissipation in R_2 low.

At V_{in} 100V, choose R_1 to supply the device with 20V.

V_{R1} is then 20V (ignore the V_{BE} of TR1).

R_1 = 20/ 0.5 x 10E-3 => 40kΩ. Choose NPV 39kΩ.

V_{R2} is 100V – (39x10E3 x 0.5x10E-3) => 80.5V

R_2 = 80.5V / 0.5 x 10E-3 => 161kΩ. Choose NPV 180kΩ.

Now check for minimum device voltage:

$[20 \times (R_1 / (R_1 + R_2))] - 1V_{BE} = 3.56V - 0.6V \Rightarrow 2.96V$ – ok.

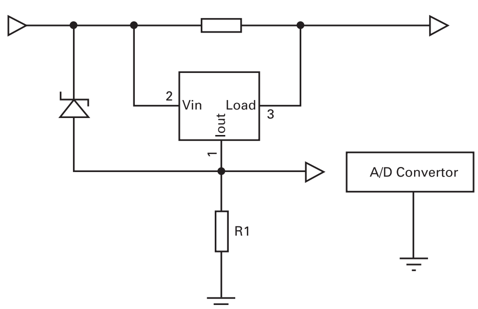
And maximum device voltage:

$[100 \times (R_1 / (R_1 + R_2))] - 1V_{BE} = 17.8V - 0.6V \Rightarrow 17.2V$ – ok.

3.43 High voltage/reverse protection.

In addition to the methods already described to protect the ZXCT1009 against over voltage, figure 14 shows how a zener diode can be connected between I_{out} and V_{in}.

Figure 14 High voltage / reverse protection



This will keep the ZXCT1009 within its permissible operating voltage by conducting at its zener voltage. R1 is used as normal to scale an appropriate output voltage.

In a condition whereby V_{in} becomes negative with respect to ground, the diode will become forward biased and conduct, protecting the device.

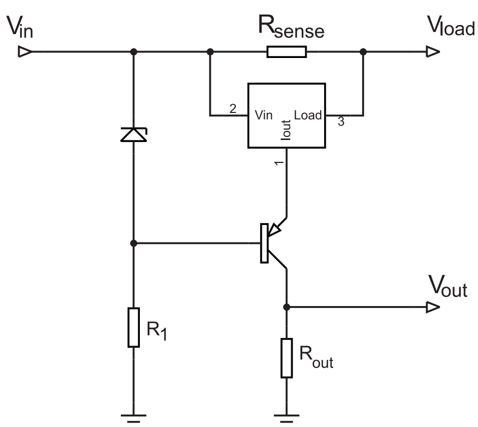
3.44 For V_{in} > 20V with large supply ranges

If a larger supply voltage range is needed a zener diode can be used to sustain a suitable operating voltage for the ZXCT1009, e.g. 4V7.

ZETEX SEMICONDUCTORS

3.5 Bi-directional current sensing

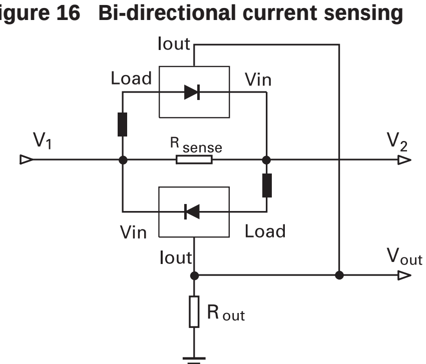
Figure 15 Extended supply range using additional transistor and Zener



The ZXCT1009 / ZXCT1010 can be used to measure current bi-directionally, if two devices are connected as shown in figure 15.

If the voltage V_1 is positive with respect to the voltage V_2 the lower device will be active, delivering a proportional output current to R_{OUT}. Due to the polarity of the voltage across R_{SENSE}, the upper device will be inactive and will not contribute to the current delivered to R_{OUT}. When V_2 is more positive than V_1, current will be flowing in the opposite direction, causing the upper device to be active instead.

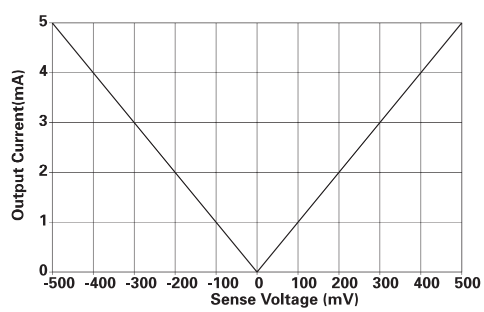
Figure 16 Bi-directional current sensing



Non-linearity will be apparent at small values of V_{SENSE} due to offset current contribution, therefore the ZXCT1010 would be preferred to minimise this. Devices can use separate output resistors if the current direction is to be monitored independently.

In normal unidirectional current sensing applications the grey internal diodes (part of the internal circuitry) are not biased, in this bi-directional application care must be taken not to forward bias them too hard. This will not happen for sense voltages less than ±500mV. For applications needing to take the load pin more than 500mV above V_{in}, the grey resistors must be added to limit the forward current to 1mA max. The input current to the load pin will cause an extra error voltage across the limiting resistor, but in most cases this is small. 10k is a suitable value which provides reverse voltages up to 10V above V_{in} and the error voltage, which adds to V_{sense}, is 1mV with the worst case input current of 100nA.

Figure 17 Bi-directional transfer function



3.6 Short circuit protection / over-current applications

The circuit in figure 17 senses the current in R1 - 22 mΩ, which is fitted between optional reservoir capacitors (C1 & C2) and the load in question. The small voltage developed across R1 is converted by the ZXCT1009 into a proportional current in resistance R3.

When monitoring an inductive load where voltage transients may be present, R2 and C4 provide filtering to ensure correct operation. If the load is purely resistive these components can be omitted.

Transistor Q1 serves to reduce the voltage seen by U1 and operates as a zener diode in its reverse V_{be} breakdown mode. Q1 is not needed when operating with supplies below 20 volts.

The voltage developed across R3 is then fed to U2 (ZR431L) which is a programmable voltage reference used as a comparator. When the voltage on the Vref pin exceeds 1.24 volts, the device conducts, pulling the open collector output low. The required pull-up resistor can be connected to any supply rail of choice up to 20V. The advantage of using the ZR431L as a level detector in preference to a transistor Vbe or a FET V_T is that the voltage sense level is virtually independent of temperature.

The sensitivity of the current limit can be increased or reduced by adjusting the value of R3 to develop the required 1.24 volts at different currents. C3 provides a time delay to prevent false triggering.

Value of current that causes the output to switch can be calculated by rearranging the datasheet formula:

$V_{out} = V_{ref} = 0.01 \times V_{sense} \times R_{out}$
(V_{ref} = 1.24V, R_{out} = R3 and
$V_{sense} = I_{LOAD} \times R1$)

So the trip current will be:

$$Itrip = \frac{1.24}{0.01 \times R1 \times R3} \text{ (A)}$$

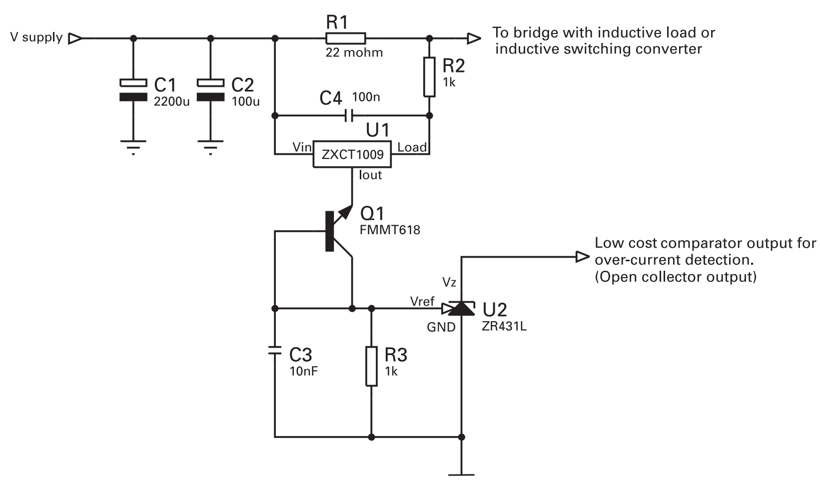
For the example in the application circuit:

$$Itrip = \frac{1.24}{0.01 \times 0.022 \times 1000} \text{ (A)}$$

Itrip = 5.6A

For a more integrated solution for over-current applications see the ZXCT1030 with internal comparator and reference.

Figure 18 Over-current detection



ZXCT1021/1022 application notes

3.6 Basic calculations for use

The following equations are used for configuring the ZXCT1021/22. No output-scaling resistor is required for these devices.

$$\mathbf{V_{out} = Gain \times V_{sense}}$$

$$\mathbf{V_{sense} = Vin - V_{load}}$$

ZXCT1021: Gain = 10

ZXCT1022: Gain = 100

Figure 19

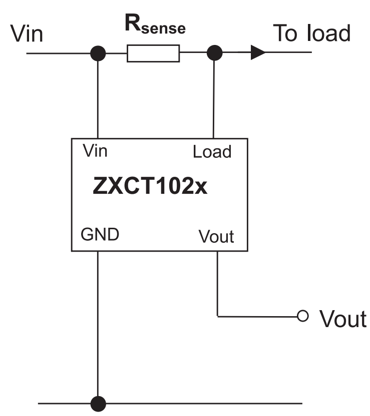


Figure 19 shows how a single sense resistor is required to measure current.

Example 1:

A 20A current must be sensed with a maximum of 500mW dissipated power within an accuracy of 3%.

Power = $I^2 \times R$

$\therefore R_{sense}$ = 1.25mW

4 x 5mΩ resistors in parallel

V_{sense} at 20A = 25mV

So the circuit must have a typical input offset of 3% at 25mV ≤ 750µV.

The ZXCT1021/22 were created to meet these design requirements such as these. They are rated at ±3% at 10mV sense voltage

Example 2:

10A is to yield an resulting output voltage of approximately 2.56V for an ADC input. R_{sense} must be smaller than 10mΩ to minimize power loss.

We have the choice of a gain of 10 or 100, which gives the best value of V_{sense}?

$V_{sense} = V_{out}$ / Gain:

V_{sense} = 2.56/10 = <u>256mV</u> or

V_{sense} = 2.56/100 = <u>25.6mV</u>

To obtain these 2 V_{sense} values at 10A, R_{sense} must be:

R_{sense} = 256mV / 10A = <u>25.6mΩ or</u>

R_{sense} = 25.6mV / 10A = <u>2.56mΩ</u>

R_{sense} is to be less than 10mΩ so we choose a gain of 100 i.e. the ZXCT1022 with a 2.5mΩ sense resistor, which could be two 5mΩ resistors in parallel. This yields 2.50V at 10A.

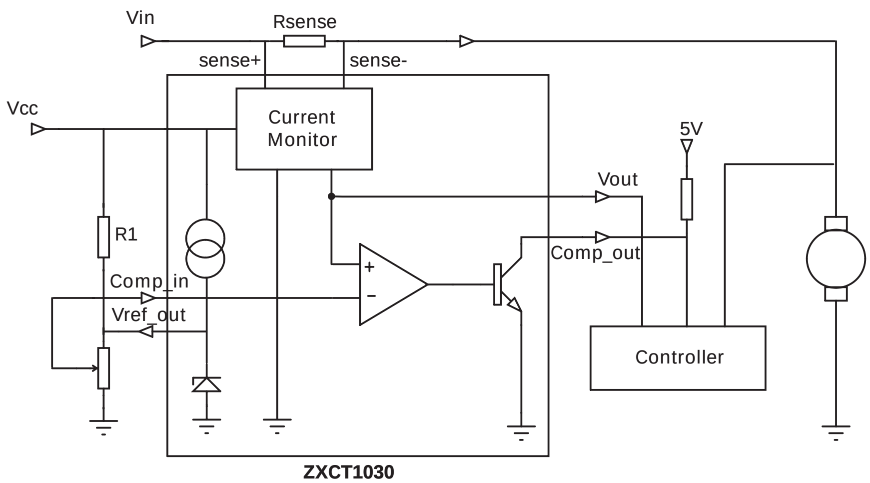
3.7 ZXCT1030 applications

3.71 Basic calculations for use.

The ZXCT1030 takes a voltage across the sense resistor and transfers its from a large common mode supply voltage, to a ground referenced signal with a gain of 10.

$$V_{out} = V_{sense} \times 10$$

Figure 20 Typical application circuit for ZXCT1030



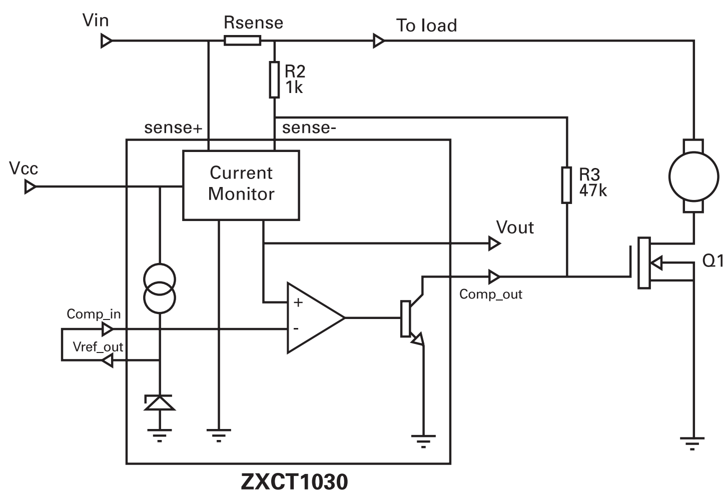
3.72 ZXCT1030 with latching switch

The ZXCT1030 device incorporates an on board comparator with an open collector output. The output will usually be connected to the supply rail via a pull up resistor. This signal can then be applied to other circuit elements to assist in control over various circuit functions. A potential divider resistor network can be connected between Vref_out and Comp_in to modify this. Resistors R3 and R4 have been used to latch the comparator. The potential difference at Vsense- must be greater than that at Comp_in for the device to latch.

Once the device is in the latched state, the N-channel FET will remain off. To unlatch the device, V_{out} can be taken to ground potential, or the power can be reset.

The circuit in figure 21 shows how the ZXCT1030 can be used to measure the current flow into a dc motor. The output from the comparator is connected to a MOSFET device which can switch the motor off. The output level at which the MOSFET will switch is determined by the trip level of the comparator, which is set by the reference . The diagram above the comparator is connected to Vref_out and comp_in for a 1.2V trip level.

Figure 21 Measuring current into a motor with latching switch configuration



General ZXCT application notes

In the case where extra sense resistance cannot be inserted in the supply circuitry and a Mosfet line switch is already being used, it can double up as a sense resistor where the MOSFET R_{DS}(on) is the value of R_{sense}.

It must remembered that the MOSFET R_{DS}(on) will not be well defined and that its value can change over 60% with extremes of temperature. The 10kΩ resistor is only needed in cases where the load voltage could be higher than Vin, for example in the case where the load is a battery, where upon, the ZXCT device's Vin and Load pins could be turned round to monitor circuit consumption from a battery if required.

Measuring currents in full (H) bridges can achieved with one resistor in the top (or bottom) of the supplies to the bridge, but the circuit below shows a way of measuring the forward and reverse currents in motor, or the applied and circulating currents in a solenoid.

The separate outputs could be connected together by a small signal MOSFET to form one signal if required when using the ZXCT1009 or ZXCT1010 constant current output devices.

Figure 22 Using a MOSFET as R_{sense}

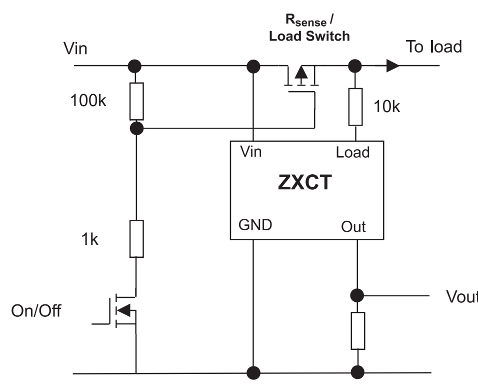
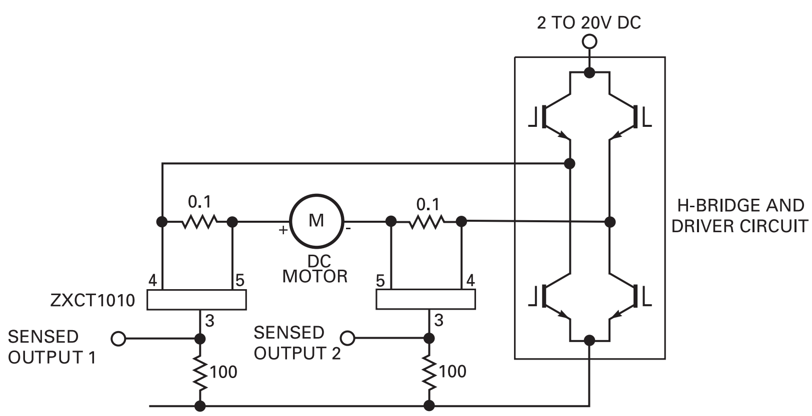


Figure 23 Measuring forward and reverse currents separately



Chapter 4:
Magnetic AC and DC current measurement

This chapter provides a functional overview of the Zetex range of magnetoresistive sensors for indirect current measurement. For an in-depth article on magnetic sensor principles please see AN37.

Magnetic current sensing devices offer intrinsic galvanic isolation; the signal voltage develops as a result of changes in the IC's permalloy structure due to the imposed field from a load-carrying conductor (integrated in the package) or from a high current wire (external).

These parts are specifically chosen when isolation between load and measurement circuitry is required, or when ultra-low insertion losses are essential, as the parts generally carry a cost premium over the resistive method.

The Zetex ZMC product series (magnetic sensor on internal flat current conductor) provides up to 2kV isolation for high voltage environments and practically no insertion loss. The Zetex ZMY(M)/ZMZ(M) product series (sensor only) offers even higher isolation and potentially higher current measurement when the external conductor placed at a suitable distance from the sensor.

As there is no electrical connection, there is no insertion loss and no power supply restriction between the measured current and the corresponding output voltage.

Furthermore, there are no competing factors in the choice of high side or low side current measurement, indeed the current in any circuit, regardless of potential (up to the maximum isolation voltage) can be obtained with no extra complications.

Unfortunately, magnetic sensing ICs are also prone to non-linearity and temperature coefficient problems, although contemporary processing techniques greatly ease these considerations.

4.1 AMR magnetic field sensor description

The ZMC/ZMY/ZMZ series magnetic sensors use AMR technology. AMR sensors (anisotropic magnetoresistive sensors) are made of a nickel-iron alloy ($Ni_{81}Fe_{19}$) thin film permalloy deposited on a silicon wafer and patterned as a resistive strip. The film's properties cause it to change resistance by 2 – 3% in the presence of a magnetic field.

In most applications, a single AMR-resistor would not be suitable, as it does not provide a zero reference. This disadvantage as well as the temperature dependence of the resistance can be avoided by using a Wheatstone bridge (AMR-bridge). Furthermore, the output signal of an AMR-bridge is twice as high as with the single AMR-resistor. The figures below explain how the AMR-bridge is laid out and the corresponding electrical connections.

4.2 Basic introduction to the current measurement with AMR sensors

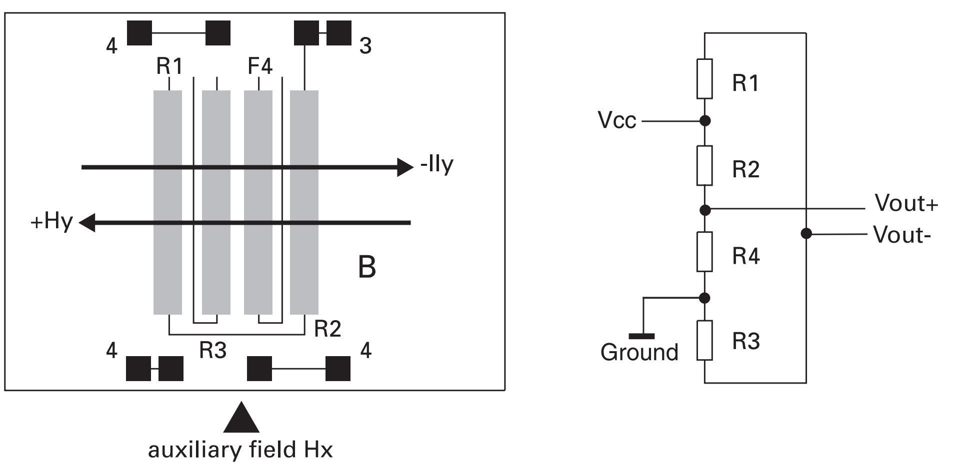
This application chapter provides a very basic introduction to anisotropic magnetoresistive (AMR) sensors for those users who may be unfamiliar with their characteristics and modes of operation.

The thin films are arranged into a Wheatstone bridge wired so that 2 of the 4 resistors increase when a field is applied and the other 2 decrease. The bridge is balanced by laser trimming. By comparing the mid-point voltages with a differential amplifier, an extremely sensitive field sensor can be made.

The electrical current in a cable or wire creates a magnetic field that surrounds this element.

The H-field decreases as the reciprocal of distance from the current element. An AMR bridge sensor can be used to detect or to measure this H-field and consequently either DC or AC currents. Pulsed currents of AC content up to 100kHz can be reliably measured.

Figure 24 Physical and electrical sensor connections



4.21 Sensor position for external conductors

A large diameter cable (see figure 25) makes the line of flux cutting through the sensor relatively flat (you could also consider a smaller diameter conductor with the same distance from the centre to the sensor).

This means if the position of the sensor or cable were to change by a small amount the measure field would remain almost constant.

However a relatively small cable placed on top of the package (figure 26) will have a very curved field and the sensor's output will be sensitive to any change of relative postion.

Figure 27 shows how the flat conductor in the ZMC products has a very flat lines of flux near the sensor which ensures a predictable sensitivity.

Figure 25 Sensing large diameter cables

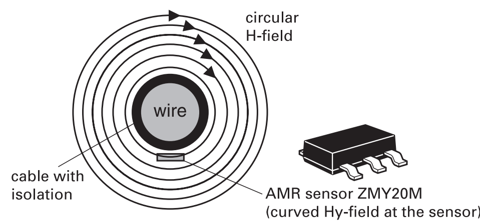


Figure 26 Sensing small diameter cables

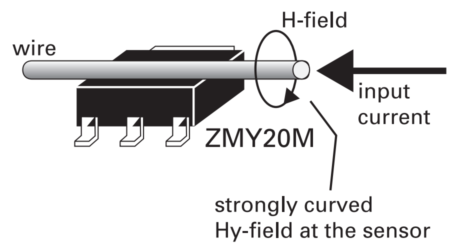


Figure 27 Internal cross-section of ZMC products

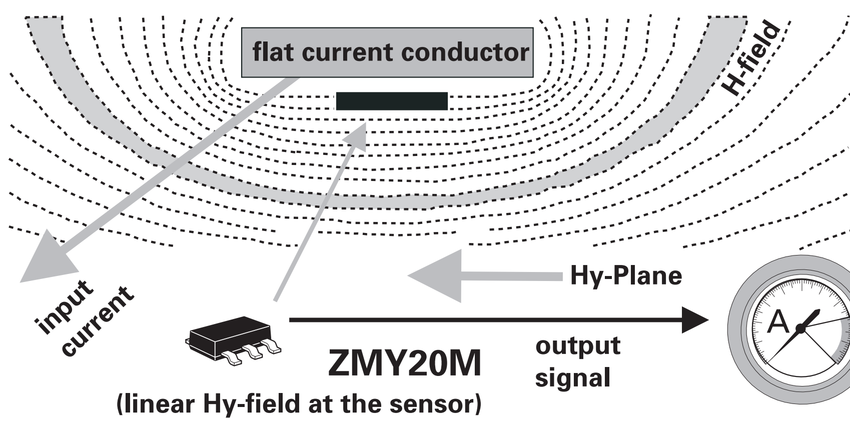
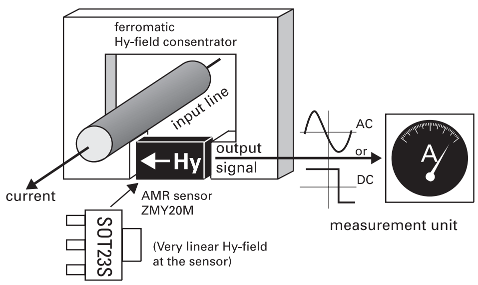


Figure 28 Using a magnetic core



A core of ferromagnetic material, for example iron for mains frequencies, can be used to enclose all the lines of flux from a conductor which has the following properties:

1) The conductor will induce the same magnetic field strength in the sensor regardless of position within the loop.
2) The enclosing of all lines of flux yields maximum sensor sensitivity for a given current.
3) The core will exclude imposed magnetic fields providing a level of external noise immunity.
4) The disadvantage is extra cost, size and weight.

4.22 Temperature coefficients

If the user wishes to measure fields accurately over a wide temperature range, bear in mind that the sensitivity in mV/V itself has a temperature coefficient of –0.3%/K. There are two ways to cancel this, either via temperature-dependent circuitry in the external amplifier or by using constant current drive to the bridge. Using constant current, the +0.3%/K coefficient of the bridge resistance results in the bridge voltage rising at +0.3%/K which cancels out the –0.3%/K decrease in the sensitivity. This is because the output is in mV/V, so a 0.3% greater bridge voltage results in 0.3% more mV. One problem here is that the absolute bridge resistance has a tolerance of ±30%, so the current must be set up for the particular bridge, otherwise the output voltage would be excessively low for low resistance bridges.

It will often be preferable to supply the bridge with a regulated voltage and design an amplifier with a temperature coefficient of gain of +0.3%/°C to avoid having to set up particular bridge currents.

4.23 Frequency response

It is useful to know the two effects, which limit the frequency response of AMR sensors. One is the "magnetic inertia" of the permalloy, which means that the magnetic domains take a finite time to align themselves with the external field. This means that the magnetic sensitivity rolls off at 1MHz and the field sensors can not be used above this.

In addition, the conductor carrying the current to be measured is subject to the "skin effect" (only the outer portion of the conductor carries current) which means that the field is not proportional to the current above 100kHz. The AMR chip measuring this field will therefore give erroneous readings and the ZMC series can not be used above this frequency.

It is important to remember that while the ZMY products have a theoretically higher frequency response, any external current carrying conductors will exhibit skin effects at some frequency. If large currents are to be measured at frequencies above 100kHz, fewer problems might be encountered using the resistive method.

Chapter 5:
Zetex ZMC product description

The ZMC05, in an SM8 package, measures currents up to 5 amps. The ZMC10 device measures up to 10 amps. The ZMC20 measures up to 20 amps.

The current conductor in the ZMC series runs under a magnetic sensor and is isolated from the leadframe by a glass insert capable of withstanding 200 volts on the ZMC05 and 2000 volts on the ZMC10/20. The 2000 volt types are ideal for measuring high-side currents, e.g. in 3 phase mains.

Figure 29 ZMC products summary

Part number	Supply voltage	Max. measureable input/output current	Isolation		Operating frequency	Nonlinearity error of open circuit sensitivity	Package
	V	A	nA	@V	kHz		
ZMC05	12	5	100	200	100	-	SM8
ZMC10	12	10	5	2000	100	< | 12% |	DIL-14
ZMC20	12	20	5	2000	100	< | 12% |	DIL-14

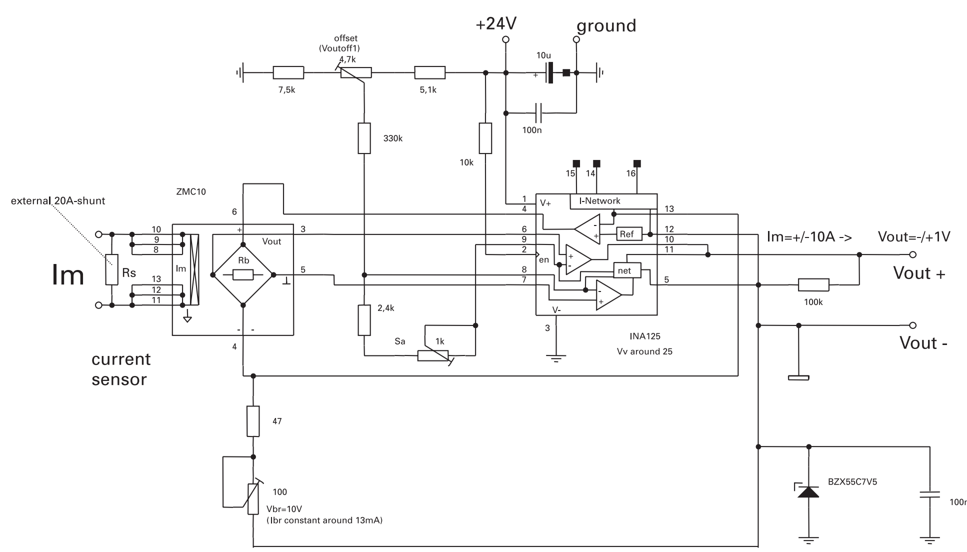
Chapter 6: ZMC10 application notes

The 4.7kΩ pot is used to zero any offsets in the circuit and the 100Ω pot adjusts the bridge current to be 10mA. Constant current drive improves the temperature coefficient as explained earlier. Note that having two bridges in parallel halves the total bridge resistance. A Burr-Brown INA125 is used as an instrumentation amplifier and gives an output of ± 1 volt for an input current of ±10 amps.

An evaluation board for the ZMC10 is available which has 2 devices and so can measure and compare 2 currents. It has comparators and 6 LEDs, which give an indication of various current measurements being performed.

There are also analog test points to look at the various voltages, enabling the user to understand the operation of AMR sensors as current measuring devices. The sensor constant current can be set by links, enabling the user to understand how the operating conditions affect the accuracy of the measurements.

Figure 28 ZMC10 sensor application with external Rshunt (about 0,7mOhm) Im can be 20A



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