AN45
High voltage current monitoring using the ZXCT series in power supplies

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Introduction

Power supply monitoring requirements

All power supplies and charging units have some current measurement requirement. The current levels measured will vary dependent upon the application. Operating input and required output voltage levels will differ in accordance with the system. For example, battery charger modules for PDA's can operate below 20V whilst measuring 1A to 2A, however a power supply for a bus converter will have very different requirements. A 700W power supply module will typically have current measuring requirements of tens of amps. By carefully setting the sense voltage to be used and determining the corresponding sense resistor, R_S, the ZXCT series in their basic form can cope with all of these.

Sometimes, it is necessary to monitor high side current circuits with operating voltages in excess of what the ZXCT series were designed for. The circuits outlined below demonstrate how a 20V current monitor can be used in applications with supply rails up to 250V and above.

High side high voltage current monitoring

One of the key benefits of the Zetex range of current-output current monitors (COCM's) is the very fact that their output is a current which, unlike their voltage-output (VOCM) counterpart, does not require an absolute ground reference to function. This means that the COCM device can be floated at a higher voltage and still ensure that its output current is available at a lower potential for translation to a ground-referenced output voltage.

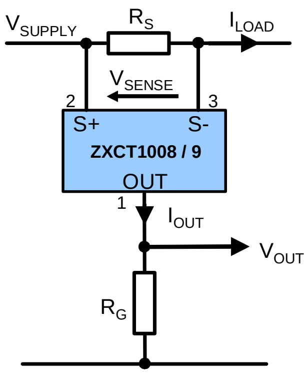

Figure 1 Simplest 3-terminal COCM

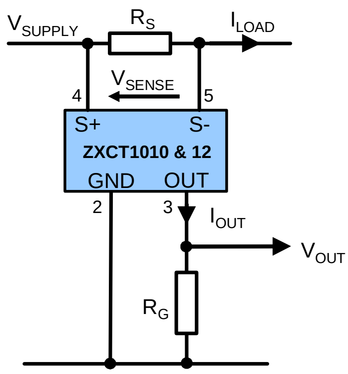

Figure 2 Simplest 4-terminal COCM

Figure 1 and Figure 2 show the basic configuration of 3- and 4-terminal current-output current monitors. In this form, the maximum operating voltage will be limited to that of the COCM itself (typically 20V, 40V or 60V). However, with the addition of only one or three components, the range of operation can be extended to much higher voltages. The methods for achieving this are illustrated in Figure 3, Figure 4 and Figure 5

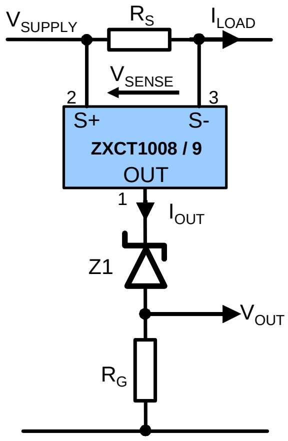

Figure 3 Simplest supply range extension

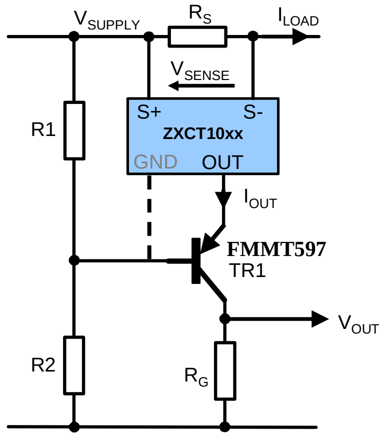

Figure 4 Improved supply range extension

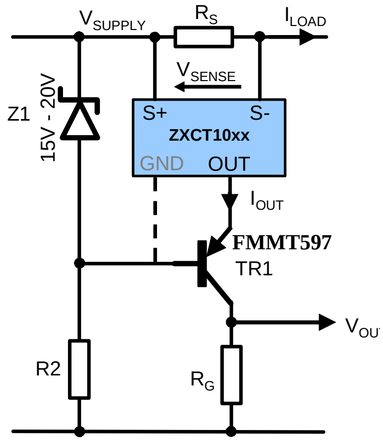

Figure 5 Best supply range extension

Suitable devices: All COCM's

Circuit explanation

The three circuits are discussed in detail below.

High voltage Option 1

Figure 3 is the simplest to use if the supply voltage is essentially fixed and does not vary much and satisfies the following criteria,

$$\Delta V_{SUPPLY} \leq V_{MAX} - V_{DO} \quad \textbf{Equation 1}$$

$$V_{SUPPLY(\min)} \geq V_{DO} + V_{OUT(\max)} + V_Z \quad \textbf{Equation 2}$$

$$V_{SUPPLY(\max)} \leq V_{WM} + V_Z \quad \textbf{Equation 3}$$

where,

V_Z = Zener operating voltage

V_{MAX} = Maximum operating voltage (20V in most cases)

$V_{SUPPLY(min)}$ = Minimum supply operating voltage,

$V_{SUPPLY(max)}$ = Maximum supply operating voltage,

V_{DO} = Drop-out voltage (absolute minimum voltage across device, S+ & OUT pins)

It can only be used with a 3-terminal COCM. If the supply varies too much and/or it is required to use a 4-terminal COCM, either Figure 4 or Figure 5 will have to be used.

Besides the limitations in Equation 1 and Equation 2, the only other limitation on this method is the power dissipation in the zener diode.

Design Example 1

It is required to measure the load current of a 100V power supply which delivers 5A into the load. The supply's tolerance is stated at ±5%. The output voltage needs to be scaled to 5V at full load.

Solution

The minimum to maximum supply range is 95V to 105 representing a change of 10V. This change is well within the operating range of the ZXCT1009 of 2.5V to 20V and meets the requirements of Equation 1. Therefore use the option in Figure 3.

Transposing Equation 1 above,

Equation 4

$$V_Z \leq V_{SUPPLY(\min)} - (V_{DO} + V_{OUT(\max)})$$
$$V_Z \leq 87.5V$$

Transposing Equation 2 above,

Equation 5

$$V_Z \geq V_{SUPPLY(\max)} - V_{WM}$$
$$V_Z \geq 85V$$

Hence, the zener diode's voltage rating needs to be between 85V and 87.5V. If the range of zener voltage does not cover common standard values, as in this case, the required voltage could be made up with two zener diodes in series. For example it is possible to use two 43V zeners in series to form an 86V zener diode.

The next parameter to check is to make sure that the zener diode(s) dissipation is taken into consideration. For this it is necessary to know what I_{OUT} is. This can be approached in one of two ways, either from the input to the output or, from the output to the input depending on which parameter there is greater control of. If optimum accuracy is paramount and it is possible to have full control of the choice of zener dissipation, work from the input. If zener dissipation is a given, then work from the output. In either case the set of equations required are the same except that they need to be worked iteratively to make sure they are not breaking any of the design parameters.

So, assume that a zener diode rated at 300mW. As a general rule, it is necessary to apply a derating factor to this, for example 50%. Hence I_{OUT} is given by:

Equation 6

$$I_{OUT} = \frac{P_Z}{V_Z} \cdot 0.5 = \frac{0.3 \cdot 0.5}{86} = 1.74mA$$

Since V_{OUT} is known, R_G can now be determined, but it is wise to determine R_S first in case of the need to adjust I_{OUT} to take into consideration the range limitations of V_{SENSE}, power dissipation in R_S and the limited choice of R_S values. There is far more freedom in choosing R_G than in R_S which is typically less than 1 Ohm.

Check for sensible values of R_S and V_{SENSE} to obtain an output current of around 1.74mA.

$$V_{SENSE} = \frac{I_{OUT}}{G_T} = \frac{1.74}{0.01} = 174mV$$

Which will require an R_S value of

$$R_S = \frac{V_{SENSE}}{I_{LOAD}} = \frac{0.174}{5} = 34.8m\Omega$$

It is unlikely to find a 34.8mΩ resistor so it is necessary to choose the nearest standard value. 33mΩ, a value within the E12 value series, is more likely and represents only -5% deviation from the calculated value (remember the zener power is derated by 50%, so there is plenty of margin).

Using this value, the true values of V_{SENSE} and I_{OUT} will be

$$V_{SENSE} = R_S \cdot 5 = 0.033 \cdot 5 = 165mV$$

$$I_{OUT} = G_T \cdot V_{SENSE} = 0.01 \cdot 0.165 = 1.65mA$$

which is even less than the original estimate, so it is known to be within acceptable limits.

Finally R_G can be determined by,

$$R_G = \frac{V_{OUT}}{I_{OUT}} = \frac{5}{1.65} = 3.03k\Omega$$

So, use a 3kΩ resistor for a cumulative error of 1%, or determine if 3.03kΩ can be found in higher electrical (E) series, or make up this value with a series or parallel resistor combination. For example 3k in series with 30Ω or 3k3 in parallel with 36k or 39k.

The solution of the problem is shown below in Figure 6.

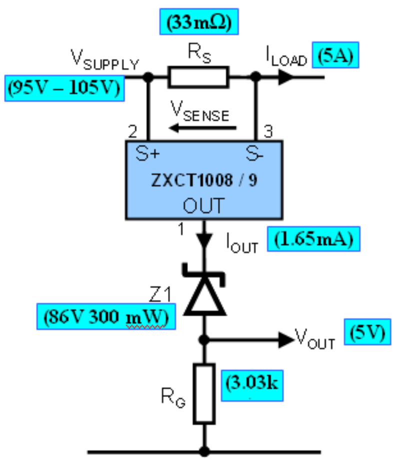

Figure 6 Solution to Design Example 1

High voltage Option 2

The previous example in Figure 3 has a very limited supply variation range. Figure 4 is a little more flexible as it dynamically varies the voltage drop across both R1 and R2 to compensate for varying supply voltage.

TR1 is used in the 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_G and hence V_{OUT} can still be calculated in the normal way.

Ideally, R1 must be chosen to keep within the ZXCT'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.

Procedure 1 - Design steps for Figure 4

1. Determine or estimate I_{OUT} (it doesn't need to be precise at this stage)
2. Determine the required minimum supply voltage, $V_{SUPPLY(min)}$.
3. Determine device's maximum working voltage, V_{MAX}.
4. Calculate transistor bias current I_B from $I_B = \frac{I_{OUT}}{h_{FE(\min)}}$
5. Calculate bias resistor RB from

$$R_B = \frac{(V_{SUPPLY(\min)} - V_{DO} - V_{eb})}{I_B} = \frac{(V_{SUPPLY(\min)} - V_{DO} - V_{eb}) \cdot h_{FE(\min)}}{I_{OUT}} = \frac{R1 \cdot R2}{R1 + R2}$$

6. Calculate R1 from $R1 = \left(\frac{V_{SUPPLY(\max)}}{V_{SUPPLY(\max)} - V_{MAX}} \right) \cdot R_B$
7. Calculate R2 from $R2 = \left(\frac{V_{SUPPLY(\max)}}{V_{MAX}} \right) \cdot R_B$

High voltage Option 3

In a situation where a higher supply voltage is required or where the supply voltage varies over a wide range, the scheme in Figure 5 could be used where resistor R1 in Figure 4 is replaced with a zener diode rated within the maximum working voltage of the COCM. The design steps are similar to those in Procedure 1 but slightly simpler.

Procedure 2- Design steps for Figure 5

1. Determine or estimate I_{OUT} (it doesn't need to be precise at this stage)
2. Determine device's maximum working voltage, V_{MAX}.
3. Chose the value of Z1 to be within V_{MAX} e.g. V_Z=15V for a 20V_{MAX} device.
   In general, make sure $(V_{DO} + V_{be}) < V_Z \leq V_{MAX}$
4. Determine the required minimum supply voltage, $V_{SUPPLY(min)}$.
5. Compute transistor bias current I_B from $I_B = \frac{I_{OUT}}{h_{FE(\min)}}$
6. Compute resistor R2 from

$$R2 = \frac{(V_{SUPPLY(\min)} - V_Z)}{I_B} = \frac{(V_{SUPPLY(\min)} - V_Z) \cdot h_{FE(\min)}}{I_{OUT}}$$

High voltage Option 4

Both Options 2 and 3 (Figure 4 and Figure 5) provide wider range operation than is possible with Figure 3. However neither would be suitable for devices such as ZXCT1050 whose common mode range include ground. What is required is a scheme that extends the supply voltage (or common mode) range but does not at the same time raise it from ground. Figure 7 below shows how this can be done.

A resistor, R3, is connected from the S- pin to ground so as to form a potential divider with the transconductance resistor, R_{GT}. The S+ pin is similarly connected to another potential divider formed by R1, R2. It must be ensured that the ratios (not the absolute values) of the two potential dividers are exact. In other words, R1/R2 must be equal to R_{GT}/R3. Failure to observe this rule will result in massive common mode error that would render the scheme practically useless. In addition, the resistors themselves need to be very closely matched to much better than 1%.

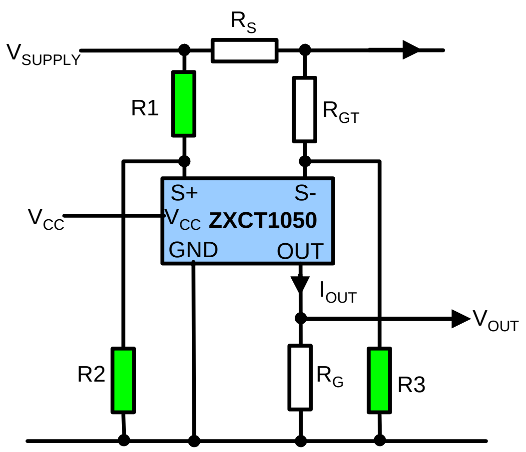

Figure 7 Extending the CM range of the ZXCT1050 (using precision resistors)

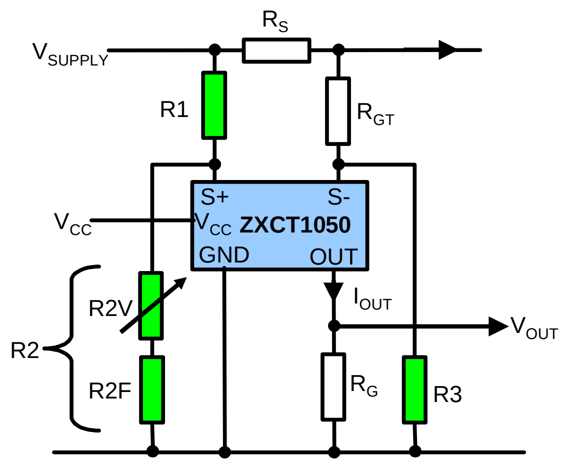

Figure 8 Using non-precision resistors to extend CM range (using standard resistors)

Hence, one resistor could be replaced by a trimmable resistor to balance both legs. This way, less than precise values could be used to start with as shown in Figure 8. Here, R2 has been replaced by the combination of a fixed and a variable resistor[1]. Now, the resistors do not have to be low tolerance ones and standard 1% or even 2% resistors can be used. What is more important is stability. So, in any case, always make sure that high stability resistors are used. Metal film resistors are generally very good for this.

Procedure 3- Design steps for extending CM range and Figure 7 and Figure 8

1. Determine the maximum required supply voltage, $V_{S(max)}$.
2. Calculate R3 from $R3 = \frac{R_{GT}}{\left(\frac{V_{S(\max)}}{V_{CC}-2}\right)-1}$
3. Make R3 the nearest lower preferred value. E.g. if the result of 2 above were 69.35k, then choose 68k as the nearest lower preferred value.

4. Next, determine R1 and R2 from $\frac{R1}{R2} = \frac{R_{GT}}{R3}$. The easiest thing to do is to simply make $R1=R_{GT}$ and R2=R3. It's possible to make $R1=\boldsymbol{n}R_{GT}$ and R2=***n***R3 where ***n*** is any arbitrary number, preferably not less than 1. The advantage of making ***n*** greater than 1 is that the current down the potential divider network formed by R1, R2 can be kept to a minimum. Be careful however not to make ***n*** too high as it then begins to introduce offset errors into the circuit. A value of ***n*** between 1 and 10 is quite reasonable.

[1]Note that it is not recommended to make all of R2 variable as this would result in very low resolution, increased potential for long term drift and make the circuit more susceptible to thermal and mechanical shock effects.

This is all that is required as far as using high precision resistors is concerned (Figure 7). In order to use standard resistors however (Figure 8) the following steps are required as well.

5. Determine the tolerance, Tol, of resistors being used, e.g. 1%.
6. Calculate R2V from $R2V \geq \frac{8 \cdot Tol}{100} \cdot R2$ and select the nearest higher preferred value.
7. Calculate R2F from $R2F \leq \left(1 - \frac{4 \cdot Tol}{100}\right) \cdot R2$ and select the nearest lower preferred value.

Make sure that R2V is a good quality variable resistor (e.g. cermet type). If the circuit is going to be subjected to a wide temperature range, it would also be advisable to make sure that the temperature coefficient of R2V is comparable to that of the fixed resistors.

Conclusion

Current output current monitors have a limited voltage range. However, use of a few extra components allows their voltage capability to be extended to hundreds of volts. Several techniques have been discussed which shows the flexibility and usefulness of current output current monitors.

Recommended further reading

1. AN39 - Current Measurement Applications Handbook
2. DN77 - Transient and noise protection for current monitors

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