Current Sensor Selection for Demanding Applications

Following on from the general approach we adopted in PEE 8-2007, we now concentrate our attention on the three principle technologies used where accurate, reliable and cost-effective current measurement is required. With this article we will restrict current sensor types to the three major types, namely shunts with and without galvanic isolation, open-loop hall-effect current sensors and closed-loop hall-effect current sensors. **Warren Pettigrew, CTO Raztec Sensors, Christchurch, New Zealand**

At this point, we should now analyse the major aspects affecting current sensor performance that should be considered when identifying the most suitable sensing technology for a given application.

Effects of temperature

Maintaining accuracy over the automotive temperature range of -40 to 125°C can be a challenge for a number of reasons. Just about everything drifts with temperature!

Additionally, the failure rate of many components accelerates at high temperatures, particularly if there is significant self-heating in the device. Closed loop sensors (Figure 1) have considerable self-heating which severely restrict their application at high temperatures. In fact, very few closed-loop sensors are available with a 125°C rating.

Shunts (Figure 2) also have considerable self-heating, particularly at high current, and if the shunt resistance is high so as to give a good signal amplitude. This can lead to considerable variations of resistance with current. Additionally, unless materials are very carefully selected and temperature gradients are minimised, thermoelectric voltages can completely distort low current readings. Ultimately, it is thermoelectric generated voltages combined with input offset voltage drift of the interface amplifier that limits the low current measuring capability of a shunt.
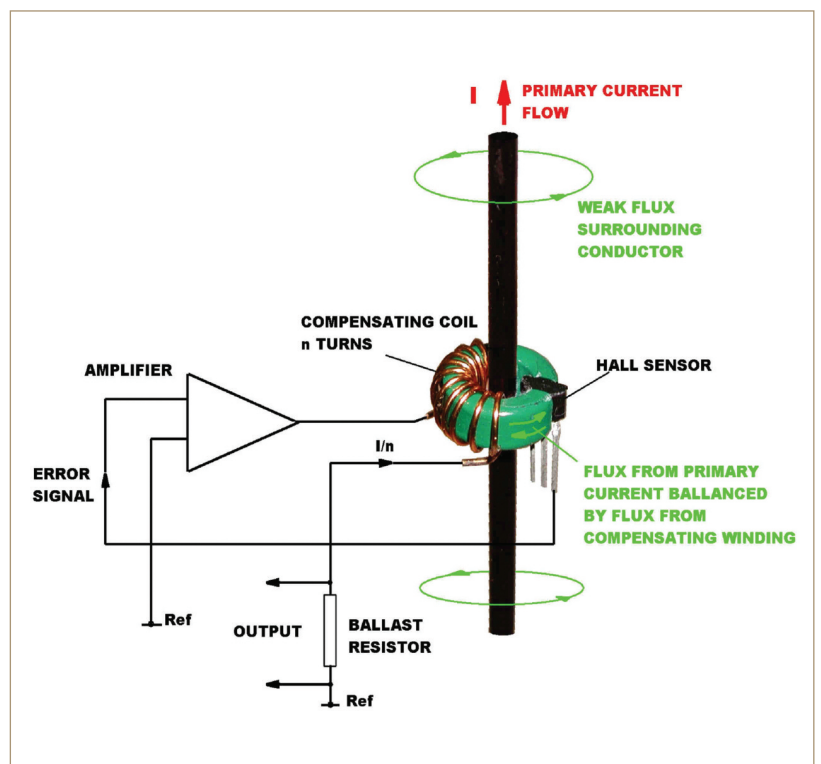

Figure 1: **Closed loop current sensor operation**

Open-loop sensors (Figures 3 and 4) are also not without their problems either at high temperatures or, more importantly, temperature shift. Provided the primary conductor is appropriately proportioned, open loop sensors have insignificant self-heating with low frequency current flow, but their performance may change with temperature. These sensors are prone to drift of offset and gain, but temperature stable devices are available. However, an open loop sensor is unlikely to match the gain stability of closed loop.
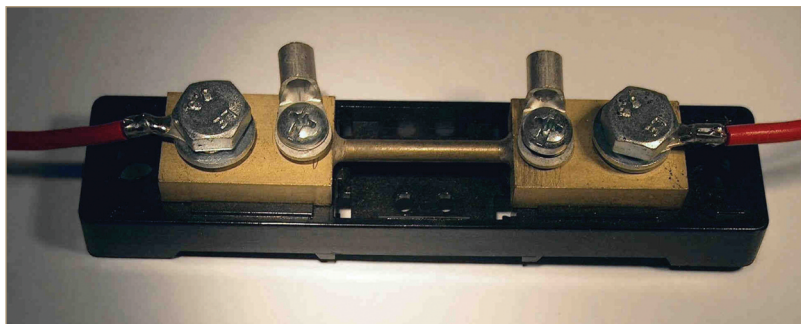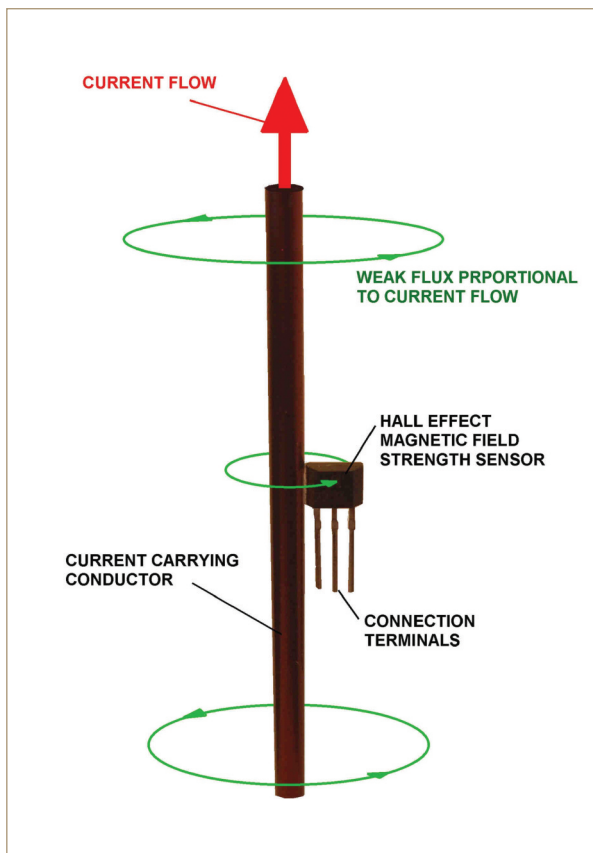

Figure 2: **Shunt with four terminals**

changes cause offset

of output. Very special material may be twice as good and leave 0.25% of remanent shift. Both open and closed-loop sensors are equally affected by remanence. Only an air circuit exhibits zero remanence.
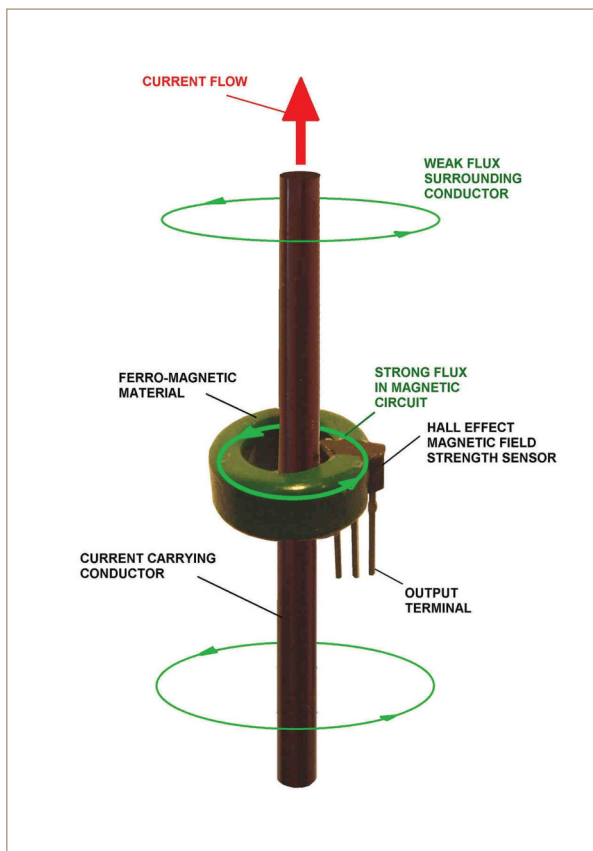
But sensors that don't use flux concentrators without suitable shielding are very vulnerable to stray magnetic fields. Even the earth's magnetic field can look like 0.4A. Shifts due to nearby solenoids can be very large, as will the influence of nearby current carrying conductors.

Shunts can exhibit variable offsets from thermo-electric effects due to temperature gradients in the shunt or its interfacing circuitry, which certainly includes its amplifier and A/D converter.

Dynamic range

The upper limit of a closed loop sensor is limited by the current rating of the compensating winding. This may have a high short-term rating, but thermal time constants are likely to be fast and the winding is a significant heat generator. The lower limit is set by remanent voltage.

Open loop sensor span may be limited by either core saturation or magnetic field sensor saturation. Ferrite cores have a lower saturation than iron based cores which limit their usefulness to about 180AT. Current rating is tailored by altering the magnetic circuit reluctance by altering the width of the magnetic sensor air gap. Materials with high saturation flux densities may be selected, but these tend to have high remanence. Additionally, iron cores exhibit considerable heating with high frequency (>20kHz) current flow. Ferrite is much superior in this regard. The lower practical limit again is set by remanence and possibly also by thermally induced null drift. A dynamic range of 200:1 is very practical for open and closed-loop sensors.

The upper current rating of shunts is set by their heating. Heating is proportional to the shunt resistance. But the signal to noise ratio and precision to a large extent is also proportional to the resistance. Therefore, the greater the required precision, the greater the heat generated. The lower limit is set by thermoelectric voltages, input offset drift and noise. A practical dynamic range for shunts would be 1000:1, but this is dependant on a number of factors.

This dynamic range can be matched by coreless open-loop high (~1500A) current sensors that incorporate magnetic screening. These devices are largely immune to remanence effects and offset drift can be managed down to low levels.

Also, in practice the dynamic range of a

Offset stability

The suitability of a sensor to measure small currents accurately (as well as high currents) is dependant on the stability of the offset voltage.

As mentioned above, temperature shift, but a significant contributor is shifts due to remanence effects in the magnetic circuit of the sensor. Reasonably good material can cause a 0.5% shift of output after a significant current excursion. The greater the excursion, the greater the shift
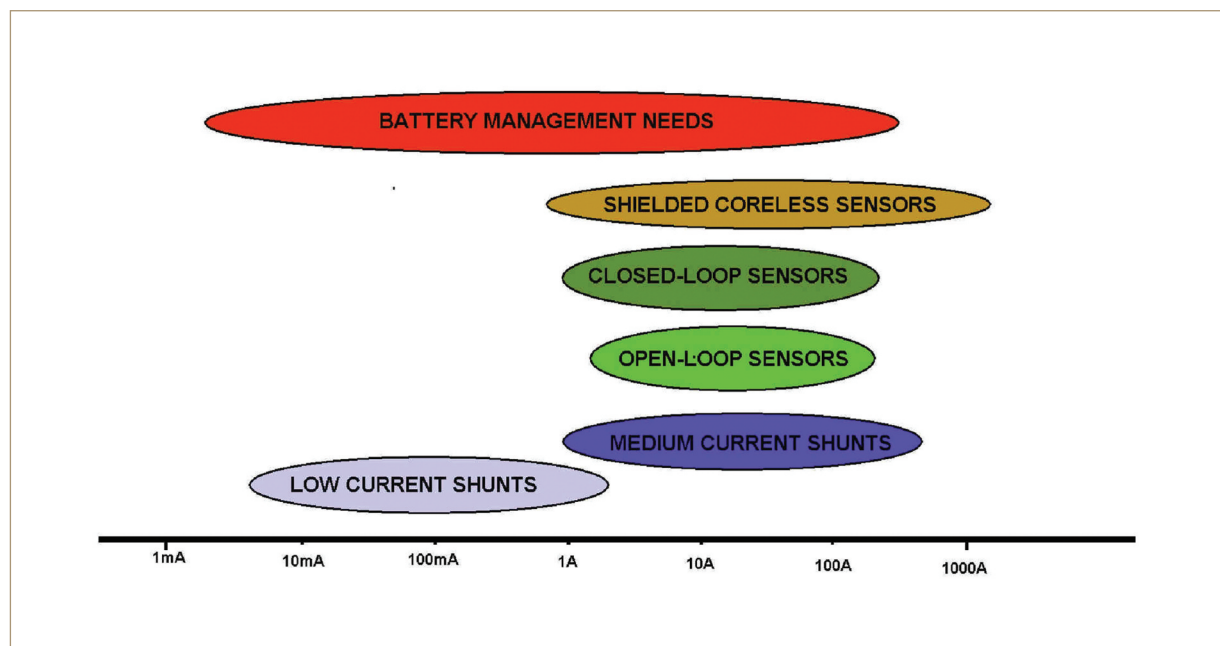
Figure 5: Typical current ranges for single devices of each current sensing technology

sensor is governed by the signal to noise ratio. This is especially true in high frequency circuits where noise filtering could kill the frequency response. For example, if a 10,000:1 dynamic range was required and the maximum voltage swing was 2V, 0.2mV must be sensed reliably. This could well be a challenge in a practical environment where noise levels could be in the order of hundreds of millivolts.

The author of this article has recognised the need for a practically priced sensor with a wide dynamic current range and will describe a solution in a following article. Such devices are particularly relevant to accurate and reliable battery management.

Frequency response

The frequency response of open loop sensors has been traditionally limited to about 20kHz, but this does not have to be the case. It is possible to manufacture sensors that respond to frequencies to 350kHz. The limitation is normally the hall element buffer amplifier. It is relatively easy to achieve good (~100kHz) frequency response from closed loop sensors by incorporating their inherent current transformer. The closed loop sensor is effectively a CT with the DC offset voltage added.

The frequency response of a shunt is dependant on its inductance; this being proportional to its length. High frequency currents induce Ldi/dt effects which can easily swamp the I x R voltage. If this noise is filtered, the frequency response could well be compromised.

Just as shunts are vulnerable to di/dt effects, open and closed-loop sensors are vulnerable to dv/dt effects. Unless carefully designed and electrostatic screening is implemented, switching noise can swamp sensor output – particularly if switching voltages are high.

These problems can be alleviated somewhat with digital systems. The D/A conversion can be implemented away (in time) from the power bridge switching point.

Destructive overload capability

Open loop current sensors excel with this quality. The rating is purely the rating of the conductor passing through the device. The provision of adequate apertures is not a significant design challenge.

Closed loop sensors are not quite as good, as they absorb significant quiescent current when the primary current is high. This generates appreciable self-heating, but they are immune to short duration high current transients.

High (fault) currents can easily damage shunts. They are constructed like a fuse. Also, a thermal transient could alter their calibration.

Size

For currents above about 50A, open-loop sensors become smaller than shunts. Often the size is defined by creepage requirements for the particular voltage rating. Closed-loop sensors are always a little larger due to the bulk of the included compensating winding.

Price

The stand-alone cost of a shunt is

generally less than other DC capable sensing technologies. However, if we take into account the cost of interfacing devices and components necessary to give necessary common-mode rejection or galvanic isolation, then shunts may well not be the cheapest option. Open and closed loop sensors can generally 'talk' directly to an A/D or analogue circuitry. Some closed loop sensors do require a ballast resistor. Due to the cost of the compensating winding and its driver, closed-loop sensors will always be more expensive than open-loop for the same size.

Conclusion

As illustrated by Figure 5, there is at present no one technology that is suitable for accurately providing the wide range required by particularly demanding applications such as high power battery management… but with recent developments, all of that is about to change. It is often not easy to decide the most appropriate technology. It may be necessary to do trial designs incorporating each technology before a conclusive decision can be made. Hopefully, this article can help a little with the process. It may be that none of the technology is appropriate. In this case, it may be best to approach a specialist supplier. They may well be able to help with a custom solution.

Literature

Selecting the Most Effective Technology, Power Electronics Europe 8/2007, pages 27 – 31.