Technical Paper

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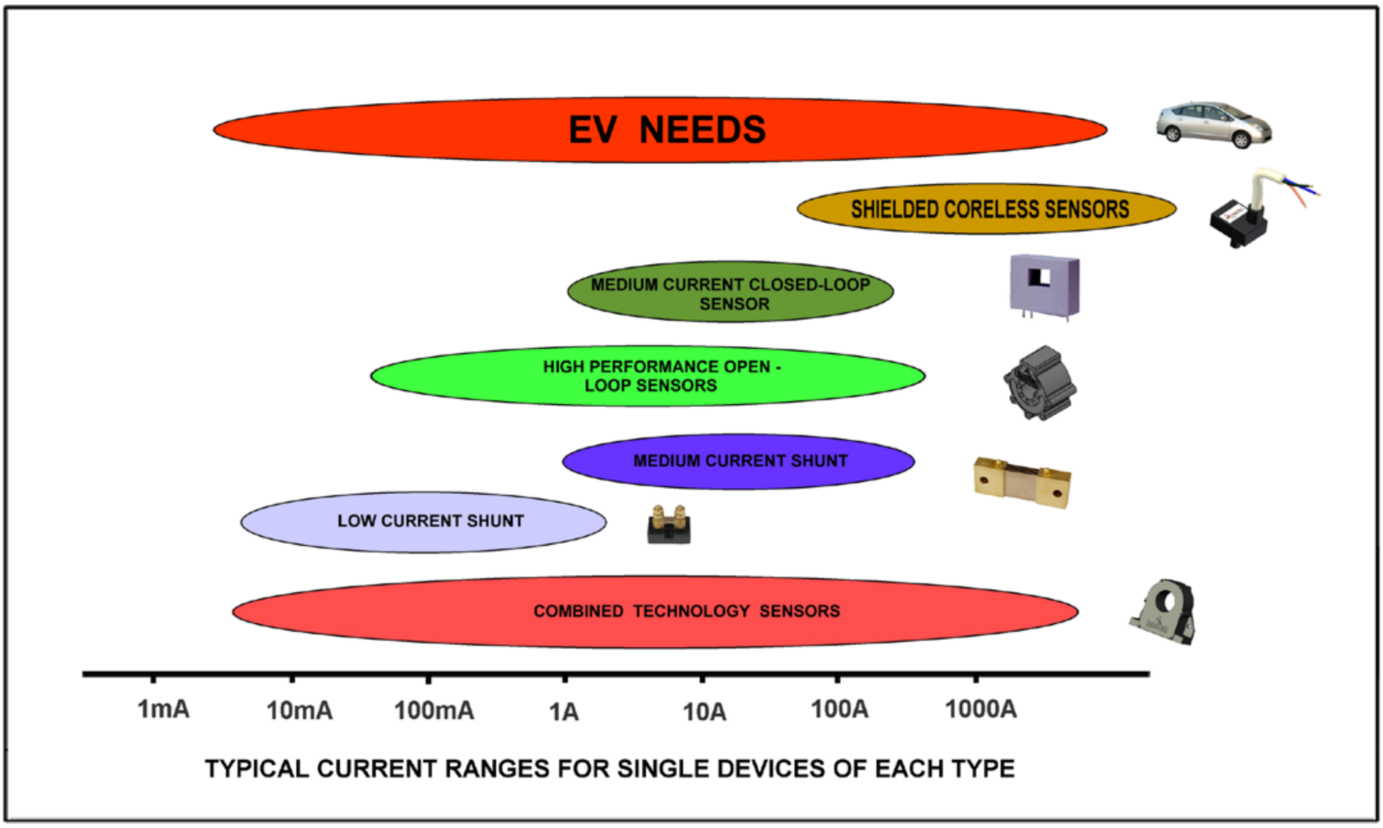
Current Sensing in an Automotive Environment

What qualities are needed for current sensors in an automotive environment?



Modern expectations are very different from what they were even 5 years ago. As complexity grows, performance and reliability must be disproportionally increased because of the challenge of repair and service in the field. This is particularly true in the electric vehicle market where many current sensors are now required to allow the management of routine (and not so routine) operations. It is just not practical to train vast numbers of service technicians. It is far better not to have failures so repair and service is not required.

Another relentless expectation is cost reduction. The old adage that you could have quality or low cost has long been blown out of the water for automotive. Our customers demand both and this does create challenges.

On a more technical front we will now list some of the important performance parameters many of which are related to cost minimization.

Supply Voltage:

Low voltage 5V supplies are really the only option although now with 3.3V micros, 3.3V supply voltage are now being demanded to save the customer the cost of dual supply voltages. Low quiescent power is also necessary to reduce power supply cost and bulk. This virtually eliminates power hungry closed-loop current sensors which carry a cost premium anyway. In some environments, sensors need immunity to large supply transients which significantly complicates sensor power supply design.

Operating Temperature Range:

Commonly -40C to 125C is demanded. For this temperature range, careful selection of materials and components is required. Magnetic field sensors must remain stable and the magnetic circuit must also have stable characteristics over its operating flux range. Again closed-loop current sensors that have significant self-heating are virtually eliminated.

Mechanical Configuration:

In many applications, sensors are mounted in free air outside of any electronic enclosure. For these cases, sensors need to be water proof probably to an IP65 rating as well as mechanically robust. Many times customer specific mounting is required along with automotive style water proof connection. Significant tooling and product design is therefore required so that all interested parties are best satisfied.

Mounting:

Time is money! Also the cost of any additional components or space must be considered and included into the cost of current sensing. Non-intrusive mounting is always preferred, especially for externally mounted sensors. Clips are preferred to screws. Screw heads, if used, must be readily accessible. The final installation must comply with shock and vibration requirements. Cables must be routed so as to protect from snagging, vibration, excessive heat and corrosive fluids.

Size / Weight:

Under-bonnet space is always a premium so size is an important quality, likewise weight. Energy efficiency is steadily increasing in importance with each rise in the price of oil. Weight is doubly important for EVs as this reflects in the size and cost of the battery. Energy consumption is very much related to weight so even small components are counted. Where high currents are involved it is a real challenge to develop light-weight components.

Operating Current Range:

Where it is necessary to measure battery current, system designers often need to know both the peak discharge current which may be many hundreds of amps as well as the current at charge completion which could be a fraction of an amp. No one (economical) sensor technology can perform over this span, so a hybrid of sensor types is required. This generally necessitates having a low current sensor which is not corrupted by high currents in combination with an economical high current sensor which has good low current performance.

Apart from the challenge of measuring current over such a wide dynamic range, is the challenge of measuring the sensor output over that range. Measuring milliamps to hundreds of amps has a span of say 100,000:1. If this signal was to be read by an A/D, 17 bit resolution would be required. This is obviously not practical, so again we see the need to split the range into two or 3 sub-ranges.

Performance Stability:

Since the sensors very likely will have to operate over a very wide temperature range, their gain and offset will need to be very stable. It is necessary to assess the effect of system performance with calculated drifts. Can the drifts be positive or negative? i.e. will it cause system failure or lack of performance? What is the statistical spread of drifts? What is the long-term stability?

Another important parameter if low DC currents are to be sensed is the sensors residual offset after a high DC load (core remanence). This offset is generally in the order of 0.5A so accuracy below 1A will be very poor. There are very special low remanence core materials available or degaussing may be an option but this adds cost.

Frequency of Response:

In instances where cycle by cycle current control is incorporated, the current sensor frequency response needs to be greater than 4X the fundamental frequency of a switching control system. Where the current sensor is to protect against overloads or short-circuits, its reaction speed needs to be matched against the likely rate of rise of current and the circuit tolerance to short-term overload. Fortunately, currents don't rise instantaneously as there is always some parasitic inductance.
$di/dt = V/L$ As a rule of thumb, a conductor has ~1nH/mm (less for a bus bar, more for a PCB trace)

Voltage Ratings:

Voltages in HEV is creeping up so the isolating rating of the sensor must be assessed, and a proper safety margin applied. Associated with voltage ratings are creepage and clearances. These are assessed according to the application and the environment. Standards specify requirements.

Immunity to the Environment:

The automotive environment can be pretty nasty! Extremes of temperature, possible 100% humidity, water-blasting, aggressive fluids, high vibration and shock, large electrostatic fields, large magnetic fields, high radiated electromagnetic fields …… There are standards that define all of these environments so a specification must be agreed upon with the customer for all details. This is tedious but must be completed if a totally satisfactory product is to be supplied.

Sensor Technologies

We will now look briefly at what different sensing technologies that are available and compare qualities.

Shunts:

Where galvanic isolation is not required shunts become an option. For low currents they are attractive but as currents get above 100A or so, their bulk and cost grows exponentially. Larger shunts are also problematical for measuring high frequencies as their inductance causes inductive kicks of considerable magnitude.

Low current coreless open-loop hall-effect sensors:

These can be manufactured as an IC so can be low cost and do have their place for some applications generally in the 20A to 50A current range. The lack of core means lack of shielding against stray magnetic fields. Immunity can be improved by using a pair of hall sensors and doing differential measurement. However, lack of a magnetic circuit to amplify flux strength does mean field strengths are low so sensitivities need to be set high making the whole vulnerable to drifts.

Open-loop hall-effect sensors:

These devices have good all around performance. Components such as core material and hall sensor can be selected to optimize performance for a particular application. Improvements in hall sensing technology now allow these sensors to perform similar to closed-loop technologies.

Closed-loop hall-effect sensors:

The necessary compensating coil and its driving electronics add bulk and cost but does allow excellent gain stability and speed of operation. Because of their inherent short-comings however, these sensors are not commonly used in an automotive environment.

FET on resistance:

This can be an option where current sensing precision is unimportant but low cost is a premium. It is software intensive and needs a capable micro for signal processing. Thermal drifts are a menace and in-process calibration is essential but the end result is near free.

Shielded air core open-loop high current sensors:

Significant improvements in hall-effect magnetic field sensors has opened the way for precise direct differential sensing of current generated magnetic fields. Immunity to common mode fields is provided by differential field sensing. Immunity to primary generated electrostatic fields is implemented by screening. Hybrid techniques are used to improve frequency response. The significant benefits of this technology is its ease and flexibility of mounting and its small size. The sum of qualities very much align this technology to automotive needs.

TECHNOLOGY	OFFSET STABILITY	GAIN STABILITY	SPAN	LINEAR-ITY	HYSTERESIS ERROR	STRAY FLUX IMMUNITY	QUIESCENT CURRENT	H.F. PERFORM-ANCE	AMBIENT TEMP RANGE	OVERLOAD CAPABILITY	SIZE	PRICE
Core-less open-loop	P	M	G	G	Ex	P	VG	G	VG	M	Ex	Ex
Ferrite core open-loop	P to G	M	G	M	G	M	VG	G	VG	Ex	Ex	VG
Iron core open-loop	P to G	M	VG	G	VG	G	VG	G	Ex	Ex	VG	G
Closed-loop	VG	Ex	VG	Ex	VG	VG	P	VG	M	G	M	M
Low current shunt	Ex	Ex	VG	Ex	Ex	Ex	Ex	Ex	Ex	G	G	Ex
High current shunt	VG	Ex	VG	Ex	Ex	Ex	Ex	VG	VG	M	M	G
FET on resistance	VG	P	P	P	Ex	Ex	Ex	VG	G	M	Ex	Ex
Shielded air-core open-loop	G	G	Ex	VG	Ex	VG	VG	Ex	Ex	Ex	Ex	Ex

NOTE 1: Grading is relative to competing technology and assumes mass-produced but quality devices.
NOTE 2: Shunted performance is recorded assuming no galvanic isolation. The inclusion of galvanic isolation would alter the table ratings.

GRADING	
Excellent	Ex
Very Good	VG
Good	G
Modest	M
Poor	P