Open-Loop Transducers with near Closed-Loop Performance

LEM added three HO series of Hall-effect current transducers which extend nominal current measurement up to 250 A and offer a range of mounting options. Open-loop transducers using Silicon Hall-effect sensors are based on a simple design concept and are inexpensive to manufacture, but their simplicity gives rise to some performance limitations. These limitations may be overcome by using a closed-loop architecture for some current ranges, but with the penalty of a more costly and physically larger design. LEM's new open-loop transducers using a dedicated ASIC bridge the performance gap between today's open-loop and closed-loop transducers. **David Jobling, LEM Switzerland SA, Geneva**

The principle of operation of open- and closed-loop current transducers using the magnetic field of the current measured is shown in Figure 1. Both may use a Hall cell integrated in the ASIC as the magnetically sensitive element; both have the advantages of isolation from the measured current and a wide frequency range including DC.

In the open-loop transducer the Hall cell voltage output is amplified to output a copy of the measured current. However any variation in the Hall cell sensitivity, for example with temperature, gives an error. The electrical signal at the Hall cell is very low, so the desire for a fast response time tends to give a noisy output because the signal bandwidth must be wide. Typically the ASIC signal bandwidth must be larger than that of the current to be measured because in order to overcome the offset and 1/f noise of the Hall cell its output must be modulated to a high frequency by biasing the cell successively in the 4 orthogonal directions and then demodulated after amplification.

In the closed-loop architecture the magnetic field induced by the measured (primary) current is exactly cancelled by a secondary current whose value is smaller by the primary:secondary turns ratio and is easily measured at the precise resistance R_M. The exact sensitivity of the Hall cell is

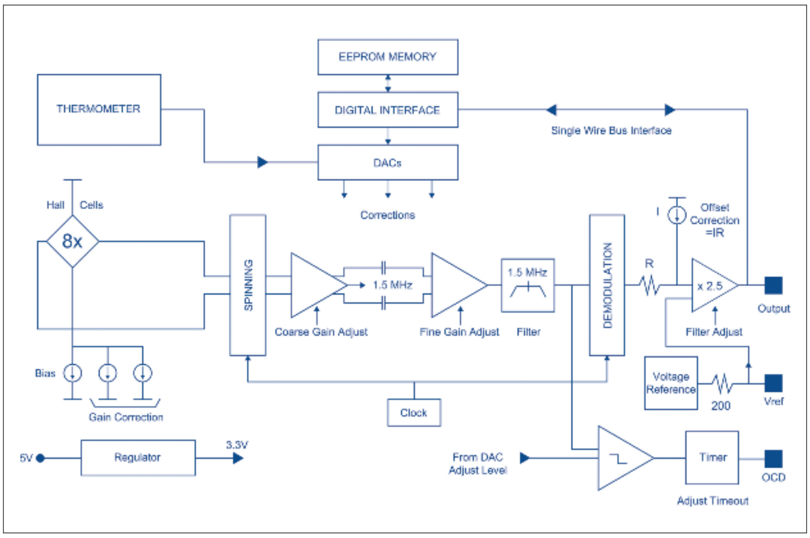

Figure 2: Block Diagram of the ASIC used in the new open-loop transducer

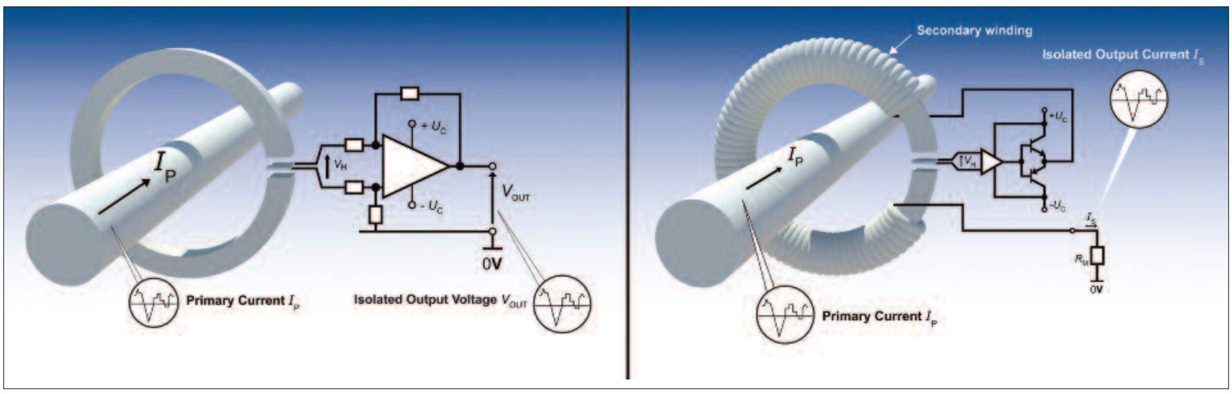

Figure 1: Open-loop (left) and closed-loop transducers

no longer of importance. Furthermore, the bandwidth of the signal from the Hall cell and hence its noise may be kept low since at frequencies above a few kHz the current in R_M comes directly from the primary:secondary transformer effect. These improvements, however, need a transducer construction which is more costly and which limits how small it can be made. Furthermore the maximum measureable primary current is limited by practical limits to the secondary current and the number of turns of the secondary winding.

An specifically designed ASIC (Figure 2) allows performance near to that of closed-loop transducer, thus the design complexity is in the ASIC, not in the transducer. Once designed, this ASIC may be used in a range of inexpensive open-loop transducers with different features.

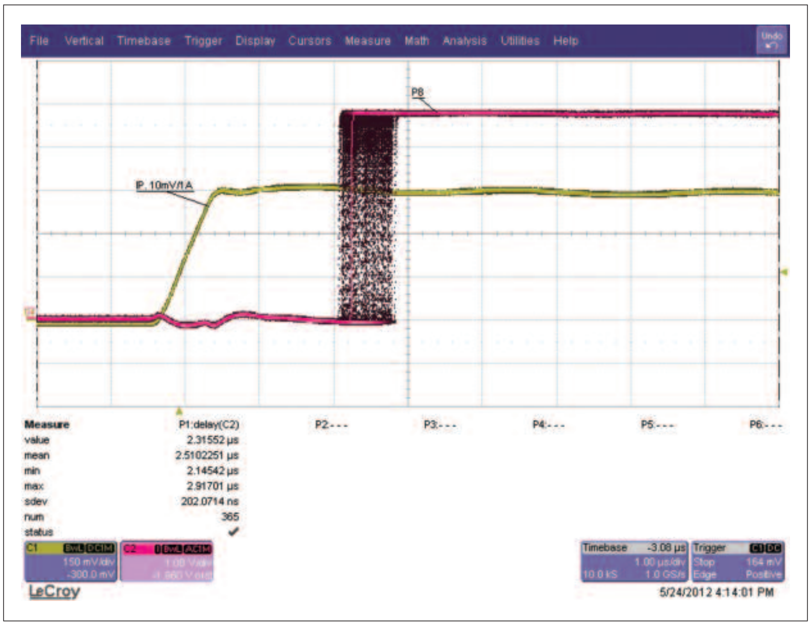

Figure 3: Envelope of OCD response

Hall-effect ASIC functionality

Eight Halls cells are used to mitigate the poor signal-to-noise ratio at the start of the signal path by a factor of $\sqrt{8}$ and spinning at 1.5 MHz eliminates the Hall cell offset. Where the signal levels are low a differential architecture is used to give immunity from external dv/dt interference. After the signal is converted from differential to single-ended to economize die area some selective screening is applied to critical nodes without using additional metal layers to maintain dv/dt immunity. A bandpass filter at the spinning frequency keeps the overall noise level low by limiting the noise bandwidth to that required for the response time and by stopping aliasing of high frequency noise components into the signal frequency range.

Quality standards in the automotive and increasingly in the industrial markets require that the ASIC be fully tested after packaging at 2 or preferably 3 temperatures – in order to measure errors inherent in the open-loop architecture and to store corrections in the on-chip EEPROM. The Hall cell temperature dependence and the offset of the amplifiers after demodulation are corrected in this way.

The EEPROM memory also means that transducers can be configured according to user's preferences - for example, different reference voltages may be chosen and the output filter may be made narrow to reduce noise or wider to reduce response time.

A new feature of this ASIC is the provision of a digital over-current detect (OCD) output from an intermediate point in the signal chain. The threshold level may therefore be above the level which saturates the conventional analogue output. Again, the exact threshold level may be chosen and stored in EEPROM according to different application needs.

Communication with the EEPROM is by a single wire bus to the ASIC output pin, this may be convenient even in the end user's final application since this pin is likely to be connected in any case to a microprocessor for signal processing.

Figure 3 shows the digital OCD response to a current step on the transducer input. The response time of about 2 µs is due partly to the delay of the transducer magnetic circuit and partly due to a circuit that validates the presence of the over-current for at least 1 µs, to avoid triggering the OCD on short spikes. The envelope of the response is about 600 ns wide since the current step is not synchronized with the internal 1.5 MHz clock of the ASIC.

Figure 4 shows the immunity of the new transducer to dv/dt interference compared with an older design where external screening or grounding of the magnetic circuit would be needed to obtain an equivalent performance. The slope of the dv/dt signal is 5 kV/µs, its amplitude is 1 kV. The delay between the

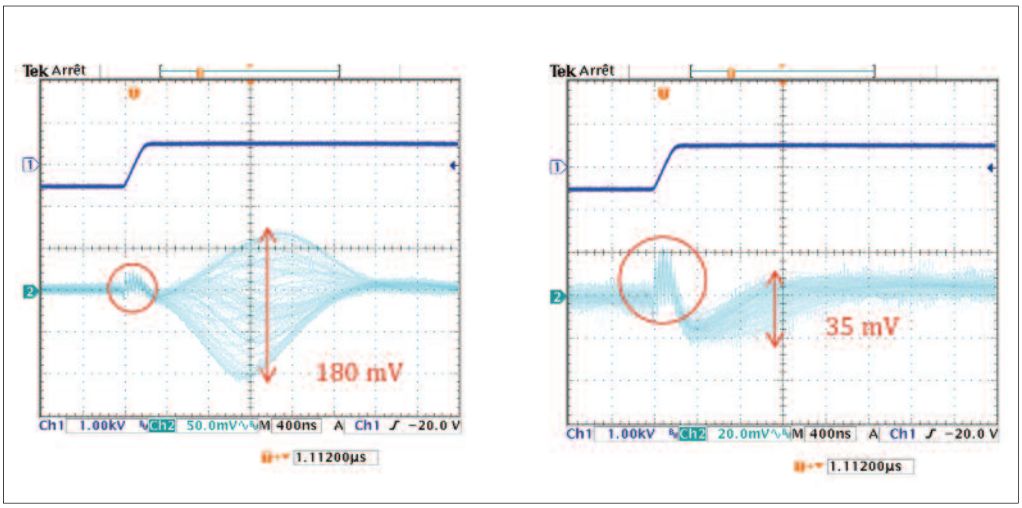

Figure 4: Envelope of the dv/dt response of older open-loop transducer (left) and the new transducer

dv/dt signal and its effect on the output is due to internal sample and hold functions and filter blocks. Figure 5 shows the step response of the new transducer to a primary current step: the response time is below 2 µs. However the bandwidth of the 2nd order output filter may be reduced to down to 1/6th of its largest value which increases the response time but gives a corresponding reduction in output noise.

Figure 6 shows examples of two different current transducers using the described ASIC. No electrical components other than the ASIC are needed so their physical volume is very small. The magnetic circuit which concentrates the magnetic field at the ASIC is made of a low-cost ferrite which may be left floating due to the dv/dt immunity inherent in the ASIC design. The same ASIC is used in the two transducers whose performances may be quite different due to the configurations defined by the EEPROM and due to the primary and magnetic circuit arrangements.

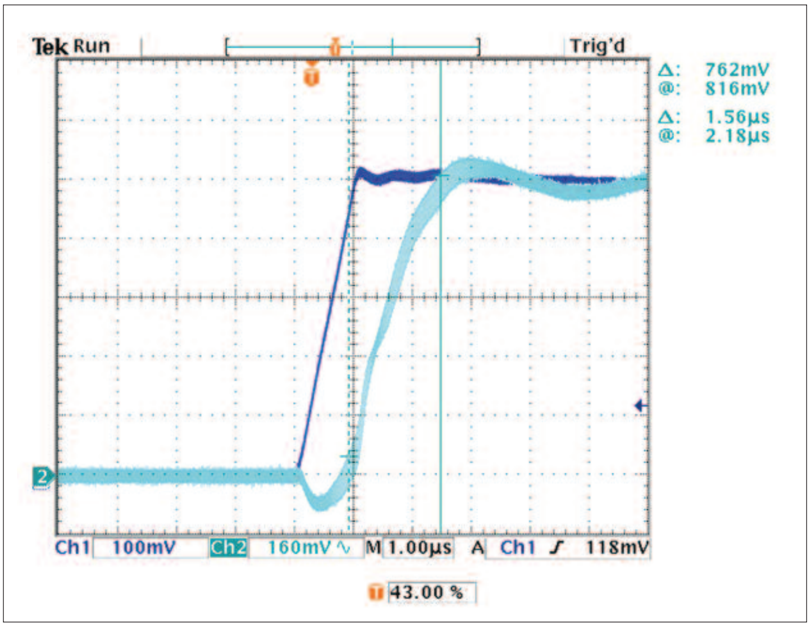

Figure 5: Response to a di/dt input

Conclusions

New open-loop current transducers have been presented whose performance approaches that of closed loop transducers. The key to the good performance is an ASIC which was specifically developed to target these improvements. Measured performance is at the level expected and increases the range of applications which may be addressed by open-loop transducers instead of more complex solutions. The range of options offered by HO transducers makes them suitable for a wide selection of applications where high performance and mounting flexibility are required. These applications include solar combiner boxes and solar-power inverters, as well as small smart meters, variable speed drives, uninterruptible and switch-mode power supplies, air conditioning, home appliances, static converters for DC motor drives, and robotics. The wide operating temperature range of -40 to +105°C also makes the HO series suitable for use in any industrial applications.

Literature

Jobling D., "New Open-Loop Current Transducers with near Closed-Loop Performance", PCIM Europe 2014 Proceedings, pp. 222-226 (http://www.mesago.de/en/PCIM/home.htm).

Figure 6: Examples of two different current transducers using the described ASIC