Closed loop current transducers with excellent performance are also cost-effective.

Abstract

Isolated current transducers use many different magnetic technologies varying from simple open-loop devices based on Hall cells to complex closed-loop transducers using fluxgates as the magnetically sensitive element[1]. The higher accuracy of the more complicated types comes with an increased cost. Within each technology family the challenge of new developments is to attain the performance of transducers in the family above while maintaining the cost advantages inherent to its design. In this article we describe new closed-loop transducers using the Hall Effect in a custom ASIC for low currents from 1.5 A to 50 A nominal for PCB mounting. Their performance is similar to that of transducers using fluxgates. Advanced manufacturing techniques have also been introduced, and the new transducers achieve the highest levels of quality and traceability.

New transducer concept.

The simplest current transducers are open-loop devices in which the magnetic field from the primary current is sensed and amplified; they suffer from the drawbacks of any open-loop system, especially that of not having a stable feedback network to define their sensitivity.

Closed loop devices are more complex but they cancel the primary magnetic field with a secondary current in a coil of N turns and so have improved performance: the sensitivity is set by the value of N so it is precise and stable; above a few kiloHertz the transformer effect takes over from the feedback loop so the effective bandwidth is much higher than the noise bandwidth, and by always operating at zero magnetic field the linearity is intrinsically good. The response time, driven by the transformer effect, is very fast.

For convenience in the most recent sensor generations, the secondary current is converted back to a voltage V_{OUT} using a precise, stable measurement resistor followed by an amplifier referenced to a voltage V_{REF}.

The simplest closed loop transducers use Hall cells as the magnetically sensitive element: they have the advantages listed above but the Hall cells cause one weakness: the offset voltage ($V_{OUT} – V_{REF}$ with zero primary current), and its drift. Users requiring good offset performance tend to use transducers based on fluxgates – but fluxgate transducers have more components and are more costly.

This article describes a new family of LEM compact closed-loop current transducers in which the shortcoming of Hall cells has been addressed and most performance parameters equal those of small fluxgate transducers.

The heart of the new transducers is a custom designed and exclusively owned ASIC into which the Hall cells are integrated and whose features include:

- a new patented arrangement of multiple Hall cells in a very symmetrical layout merged with the first amplifier stages;
- use of sophisticated offset cancelling techniques in all of the electronics blocks in the control loop which generates the secondary current as well as in the amplifier which generates V_{OUT};

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[1] See http://www.lem.com/images/stories/files/Products/1-3_applications/CH24101.pdf for example.

- an on-chip memory so that during production of each transducer any residual offset – or other imperfection - can be measured and a correction stored.

The result is a family of transducers whose offset drift is in the range of 4 – 14 ppm/^{O}C, depending on the transducer sensitivity[2].

This is over four times smaller than the previous generation of closed-loop transducers based on Hall cells, and very similar to those using fluxgates.

In the new ASIC the opportunity was taken to add a very fast Over-Current Detection feature to give an indication that a measured current is exceeding its expected value or switch power off in the event of a short circuit.

<u>The transducer family.</u>

Table 1 gives a complete overview of the new family of LEM transducers.

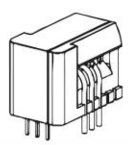
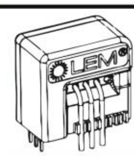
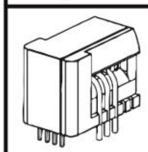
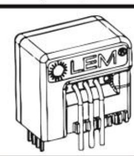
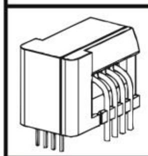
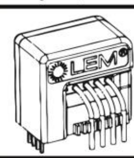
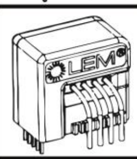
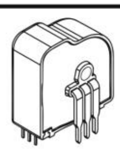
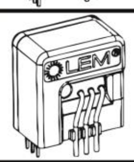
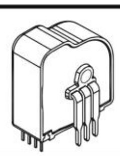
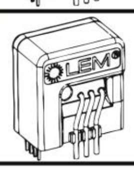
Old design	Old reference	New design	New reference	Secondary connection	Creepage Clearance (mm)	Temperature range
	CAS 6-NP		LES 6-NP	+5V GND V_{out}	dcl 7.7 dcp 7.7	-40 to 85°C
	CAS 15-NP		LES 15-NP			-40 to 85°C
	CAS 25-NP		LES 25-NP			-40 to 85°C
	CAS 50-NP		LES 50-NP			-40 to 85°C
	CASR 6-NP		LESR 6-NP	+5V GND V_{out} V_{ref}	dcl 7.55 dcp 7.55	-40 to 85°C
	CASR 15-NP		LESR 15-NP			-40 to 85°C
	CASR 25-NP		LESR 25-NP			-40 to 85°C
	CASR 50-NP		LESR 50-NP			-40 to 85°C
	CKSR 6-NP		LKSR 6-NP	+5V GND V_{out} V_{ref}	dcl 9.9 dcp 9.9	-40 to 105°C
	CKSR 15-NP		LKSR 15-NP			-40 to 105°C
	CKSR 25-NP		LKSR 25-NP			-40 to 105°C
	CKSR 50-NP		LKSR 50-NP			-40 to 105°C
	None		LPSR 6-NP	+5V GND V_{out} V_{ref} OCD	dcl 9.5 dcp 9.5	-40 to 105°C
	None		LPSR 15-NP			-40 to 105°C
	None		LPSR 25-NP			-40 to 105°C
	None		LPSR 50-NP			-40 to 105°C
	LTS 6-NP		LXS 6-NPS	+5V GND V_{out}	dcl 7.7 dcp 7.7	-40 to 85°C
	LTS 15-NP		LXS 15-NPS			-40 to 85°C
	LTS 25-NP		LXS 25-NPS			-40 to 85°C
	LTSR 6-NP		LXSR 6-NPS	+5V GND V_{out} V_{ref}	dcl 7.55 dcp 7.55	-40 to 85°C
	LTR 15-NP		LXSR 15-NPS			-40 to 85°C
	LTSR 25-NP		LXSR 25-NPS			-40 to 85°C

Table 1: Correlation of the new transducers' references with their equivalents from earlier families.

[2] In this article 'ppm' is referenced to 2.5 V, the center point of the measuring range with a 5 V supply.

Among the earlier references the CAS, CASR and CKSR families use fluxgates and the LTS(R) families use Hall cells. The new references all use Hall cells.

Table 2 summarizes electrical performance of 25 Amp sensors.

	LTSR 25-NP Earlier Hall	CKSR 25-NP Fluxgate	LKSR 25-NP New Hall
Sensitivity error (%)	± 0.6	± 0.7	± 0.2
Temperature coefficient of sensitivity [ppm/°C]	± 50	± 40	± 40
Electrical offset voltage (mV)	25.0	1.4	1.0
Magnetic offset current (mA) after overload 10x I_{PN} (Referred to primary)	80	100	90
Reference Voltage V_{REF} @ I_P=0	2.475 - 2.525	2.495 - 2.505	2.485 - 2.515
Temperature coefficient of V_{REF} @ I_P=0 (ppm/°C of 2.5 V)	± 100	± 50	± 100
Temperature coefficient of V_{OUT} - V_{REF} @ I_P=0 (ppm/°C of 2.5 V)	± 37.5	± 4	± 4
Linearity (%)	± 0.1	± 0.1	± 0.1
Reaction time @ 10% of I_{PN} (ns)	100	300	300
Response time to 90% of I_{PN} step (ns)	400	300	400
Overall accuracy (% of I_{PN}) @ 25°C	0.7	1	0.8
Overall accuracy @ T_A=85°C (% of I_{PN})	1.9	1.35	1.0
Overall accuracy @ T_A=105°C (% of I_{PN})	NA	1.45	1.2

Table 2: Electrical performance examples showing excellent performance of a new transducer (LKSR 25-NP model).[3] I_{PN} is the nominal current range of the transducer; 25 Amps in this example.

Table 2 clearly shows that the performance of the new LKSR 25-NP is similar to that of the fluxgate based CKSR 25-NP and considerably improved compared to LTSR 25-NP, the earlier Hall based design. The most impressive improvement is in the drift of $V_{OUT} – V_{REF}$ when I_P = 0 (the offset drift). For 25 Amp transducers the improvement is almost 10x.

Manufacturing.

From the outset the philosophy of manufacturing process of the new family was planned with full automotive qualification in mind. It has been designed to be autonomous, with an "Industry 4.0" approach.

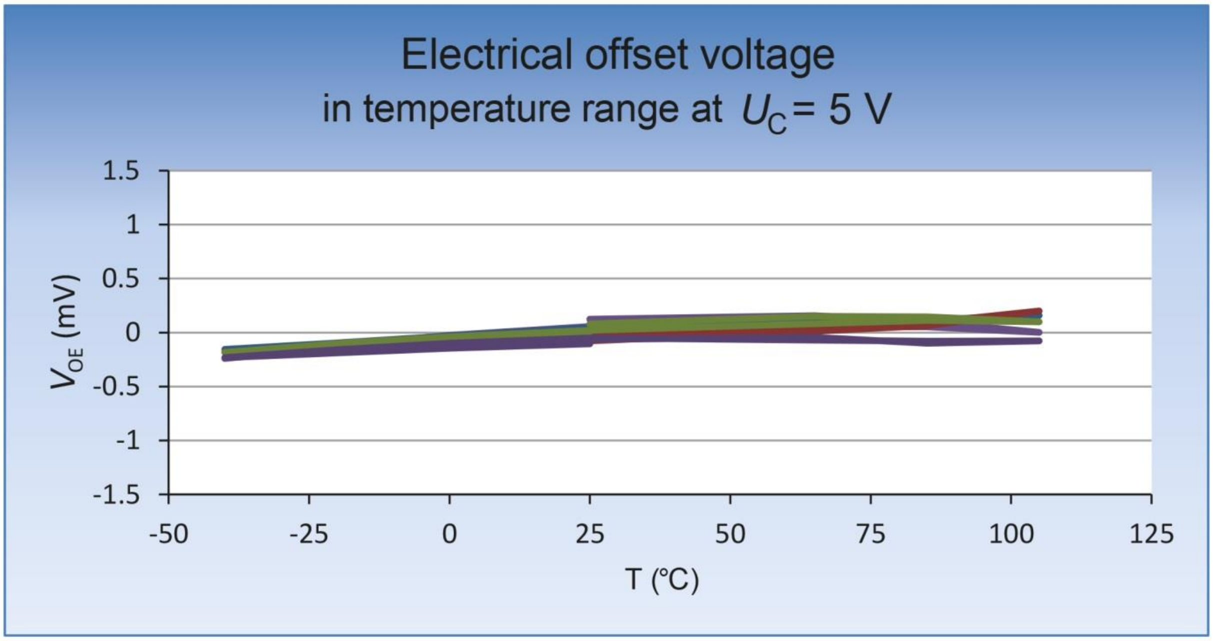
As an example of the design for quality: two secondary coils wound in series are used to give best high frequency performance: a special winding technique, economical in production time, is used to avoid any soldered connections between them. Equally there are no soldered joints between the coil and the internal PCB; only press-fit connections.

Each transducer is individually calibrated and sensitive adjustments are stored in a One-Time-Programmable memory in the ASIC. Also a unique ID number is written in the memory: each individual ASIC and its history can be individually traced. The passive components are traceable at the lot level.

Characterization.

[3] Latest results are shown: the characterization of the new transducers is finishing at the time of writing.

Full characterization of the new transducer family has been carried out over all the extremes of operating conditions. As an example, in figure 1 the characterization of offset voltage over temperature for a LKSR 25-NP transducer is shown. The offset drift is calculated as is less than 4 $\mu V/^{O}C$, equivalent to less than 1.6 $ppm/^{O}C$ for these transducers (the specification limit is 4 $ppm/^{O}C$).



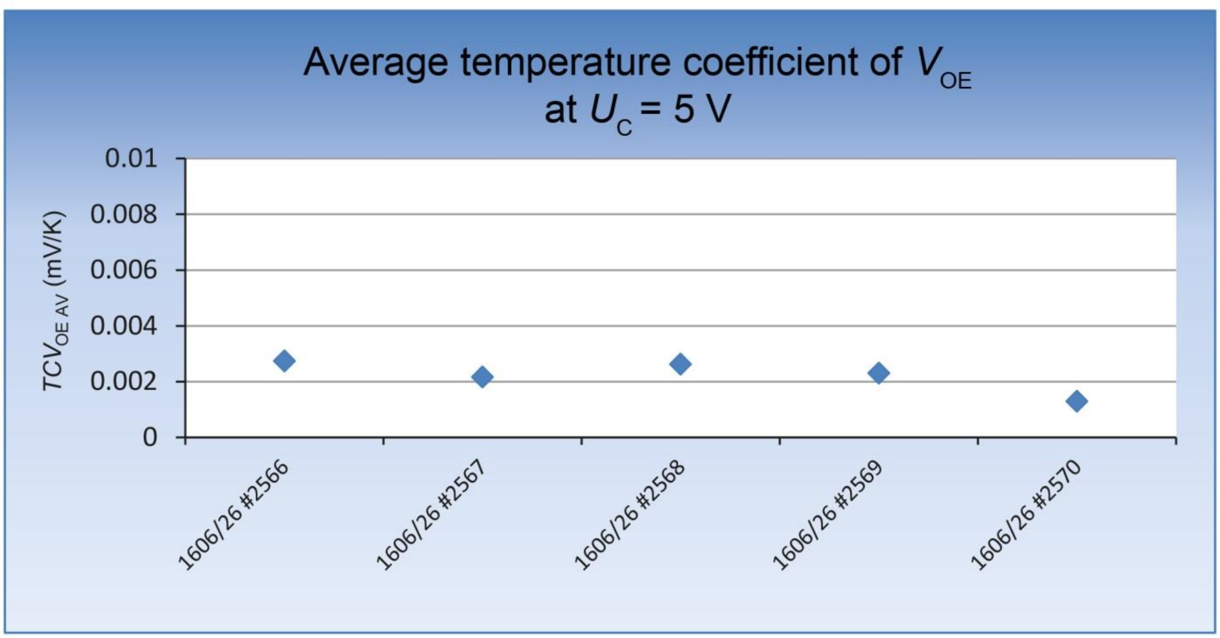


Figure 1: Characterization example: offset drift - LKSR 25-NP model.

<u>Over-Current Detection system.</u>

The OCD system monitors the transducer secondary current. This allows a faster response time than at the transducer output and, since the control loop which generates the secondary current is not limited by the 5V supply voltage, it allows the OCD trigger level to be set outside the transducer measurement range. The OCD threshold can be set between 1.25x and 5x I_{PN}. It is triggered by both positive and negative over-currents. The default value is 4.1x I_{PN}.
Figure 2 shows the OCD timing.

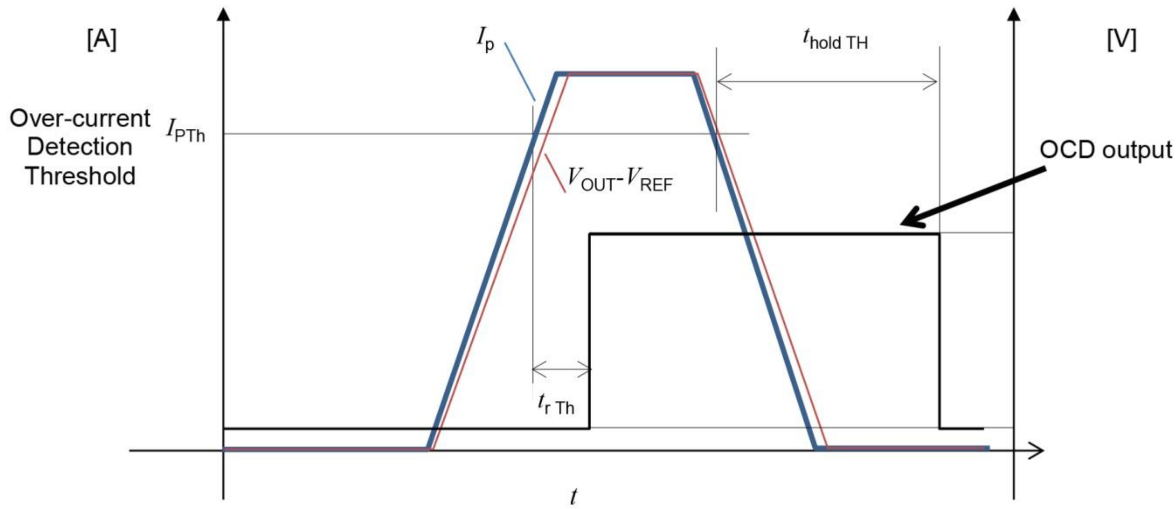


Figure 2: The OCD response time t_r is 2.2 µs maximum and the hold time t_{hold} is 1 ms.

Figure 3 shows a photograph of examples of the new transducers.

Figure 3: Different transducers from the new families: LES, LESR, LXS, LXSR, LKSR, LPSR series

Conclusion:

This article has introduced new closed-loop Hall cell transducers which give the extra performance of fluxgate transducers without the extra cost. They will be particularly well suited to applications where low offset drift is important such as in the AC output of solar power installations where standards require a very low DC component in the output current. Low offset drift also opens up more servo drive applications. The strong performance of these transducers comes from an ASIC which was specifically designed for them combined with an advanced high quality manufacturing process.