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PUSHING HALL EFFECT TECHNOLOGY TO NEW LIMITS

Ground-breaking Transducers Improve Accuracy Over a Wide Temperature Range

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Introduction

Reducing energy consumption and improving efficiency are targeted outcomes for most power electronics applications, especially in motor control drives, uninterruptible and switch-mode power supplies, and in industrial uses such as welding. Outside of the industrial sphere, power generation plants using wind and solar energy also seek to operate more energy efficiently.

To meet these goals, it is necessary to improve insulation, use the most advanced materials, and to achieve better partial discharge levels to guarantee safety and immunity from external electrical, magnetic, and electromagnetic fields. In addition to providing EMC protection and lowering emissions, performance must be maintained over a wide temperature range.

Achieving all of this with power semiconductors means searching for characteristics such as low thermal drift, fast response times, low influence in common mode, large bandwidth, and low noise levels within the surrounding components. One company developing innovative transducer-based solutions for these challenges is LEM, and their latest products have gone beyond the preconceived limits of Hall effect technology.

Next Step Technology

Classic Hall effect technology has been used in the industrial market for many years. While the accuracy is quite good at 1% or 2%, its application has been challenged by poor performance over a wide temperature range. One solution is to use a fluxgate detector instead of the Hall effect chip, which improves stability over varying temperatures. The fluxgate detector is little more than a copper winding, but managing its performance can be costly.

Engineers at LEM set about finding a way to make Hall effect technology achieve the level of performance that fluxgate provides. The result is an Application Specific Integrated Circuit (ASIC) based on Hall effect technology for use in closed-loop mode. The secret behind the improvement is a patented spinning technique and specialist IC that also overcomes other drawbacks with fluxgate such as noise, starting up with primary current, and restarting without delay after an overload. ASIC is now at the heart of LEM's latest transducers and is the largest contributor to improved performance in areas such as offset and offset drift.

Such was the success of ASIC that LEM decided to renew its entire range of closed-loop Hall effect based current transducers for nominal current measurements from 200 to 2000A. The company has introduced four new series – the LF 210-S, LF 310-S, LF 510-S and, LF 1010-S – with a fifth, the LF 2010-S, coming in February 2015. (see Fig. 1).

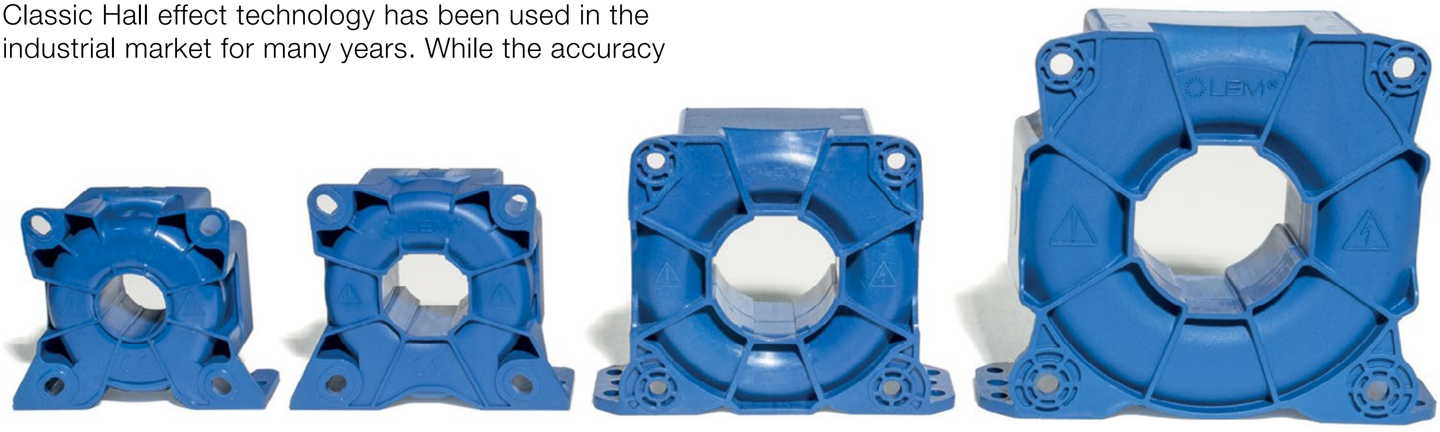

Fig. 1: New LF xx10 Current Transducers Range

An important advantage of the LF xx10 family is its low sensitivity to external AC and DC fields, allowing for a more compact design as it is not affected by fields created by other components that are close by. Because the transformer uses a magnetic core with a partial air gap, it creates a secondary current that is higher than the specified measuring range even with a low di/dt value, which should be of particular interest to R&D engineers in the industrial and rail transportation markets. The LF xx10 family can help measure inverter output current, particularly for static converters, and can be used in harsh environments. They are also fully compatible with the previous LEM LF xx05 range and fit in the same footprint, so they can be retrofitted into older installations.

Working Principle

For accurate measurement of DC currents, the technology compensates the current linkage Θ_P created by the current I_P to be measured by an opposing current linkage Θ_S created by a current I_S flowing through a known number of turns N_S (see Fig. 2) to obtain:

$\Theta_P - \Theta_S = 0$ or $N_p \cdot I_P - N_S \cdot I_s = 0$
with N_p the number of primary turns and N_S the number of secondary turns.

To obtain accurate measurement, it is necessary to have a highly accurate device to measure the condition $\Theta = 0$ precisely. This is accomplished by utilizing current transducers with the following characteristics:

- Excellent linearity
- Outstanding long-term stability
- Low residual noise
- Low thermal drifts
- High frequency response
- High reliability

To achieve accurate compensation of the two opposing current linkages (Θ_P and Θ_S), a detector capable of accurately measuring $\Theta = 0$ must be used, which means the detector must be very sensitive to small values of a residual magnetic flux Ψ (created by the current linkage Θ) to achieve the greatest possible detector output signal.

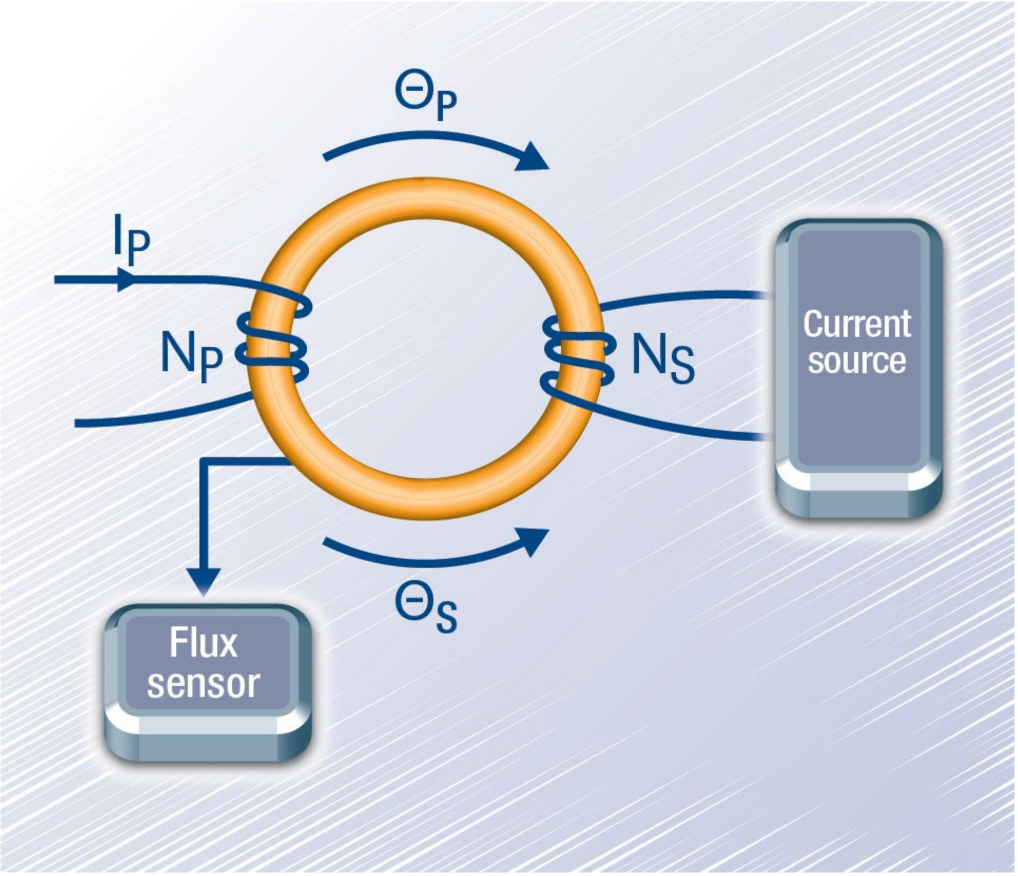

Fig. 2: Closed Loop Current Transducer Principle

Using this operating principle associated with the new LEM-designed patented Hall effect ASIC, the LF xx10 current transducers cover nominal current measurements from 200 to 2000A (4000A peak). To operate, they need only a standard DC power supply range of ±11.4 to ±25.2V.

The transducers maintain all the advantages of the previous range while bringing improvements in accuracy, external field sensitivity, measuring range, common mode and EMC.

Characteristics

Overall accuracy is within ±0.3% of I_{PN} at room temperature but just as important it is better than ±0.6 % of I_{PN} over its entire operating temperature range from -40 to +85˚C (see Fig. 3a).

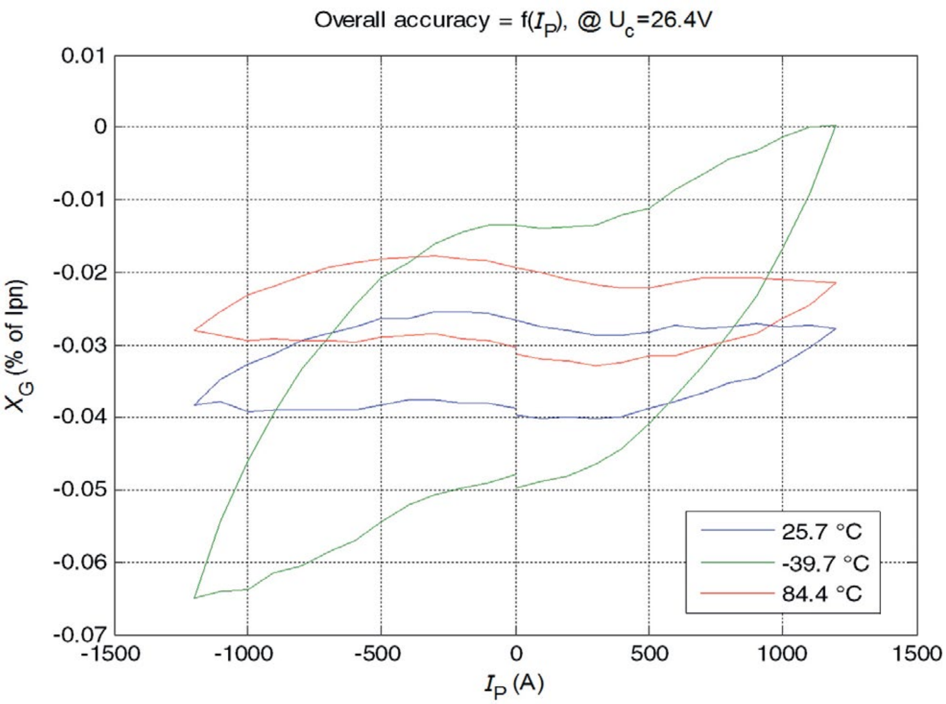

Fig. 3a: Typical Overall Accuracy of LF 1010 Model Over -40 to +85ºC

For the LF 1010 family, the initial offset at +25˚C is ±1A.turn with a maximum possible drift of ±1A. turn over the operating temperature range. Sensitivity error at +25˚C is ±0.1% and linearity is only ±0.1%.

Measuring range has been improved to reach higher peak currents than with the LF xx5 series. With a 5000 turns ratio, the LF 1010 can measure up to 2500A peak whereas the LF 1005 was limited to 1800A peak (see Fig. 3b).

Thanks to the partial air gap of the magnetic core (see Fig. 4), the LF 510, 1010 and 2010 models have a very low sensitivity to external AC and DC fields. This allows for a more compact design as there is practically no sensitivity to high current conductors near to the transducer.

Parameters	Models							
	LF 1005-S	LF 1010-S	LF 505-S	LF 510-S	LF 305-S	LF 310-S	LF 205-S	LF 210-S
I_{PN} Primary nominal current [A]	1000	1000	500	500	300	300	200	200
I_{PM} Primary measuring range [A]	1800	2500	800	1500	500	500	420	420
Turns ratio	1/5000	1/5000	1/5000	1/5000	1/2000	1/2000	1/2000	1/2000
Supply voltage (±5%) [V]	± 15 … 24	± 15 … 24	± 15 … 24	± 15 … 24	± 12 … 20	± 12 … 20	± 12 … 15	± 12 … 15
ε_L Linearity	< 0.1%	< 0.1%	< 0.1%	< 0.1%	< 0.1%	< 0.1%	< 0.1%	< 0.1%
Offset drift	< ± 0.4% of I_{PN}	< ± 0.1% of I_{PN}	< ± 0.4% of I_{PN}	< ± 0.1% of I_{PN}	< ± 0.5% of I_{PN}	< ± 0.1% of I_{PN}	< ± 0.4% of I_{PN}	< ± 0.1% of I_{PN}
Overall accuracy @ I_{PN}, T_A =25°C	< ± 0.5% of I_{PN}	< ± 0.3% of I_{PN}	< ± 0.7% of I_{PN}	< ± 0.3% of I_{PN}	< ± 0.5% of I_{PN}	< ± 0.3% of I_{PN}	< ± 0.5% of I_{PN}	< ± 0.3% of I_{PN}
Overall accuracy @ I_{PN}, over temperature range	< ± 0.9% of I_{PN}	< ± 0.4% of I_{PN}	< ± 1.1% of I_{PN}	< ± 0.6% of I_{PN}	< ± 1% of I_{PN}	< ± 0.2 % of I_{PN}	< ± 0.9% of I_{PN}	< ± 0.2 % of I_{PN}
t_r: Response time at 90% of I_{PN} step (di/dt 100 A/us) [us]	< 1	< 0.5	< 1	< 0.5	< 1	< 0.5	< 1	< 0.5
Technology	Hall cell traditional	Hall ASIC	Hall cell traditional	Hall ASIC	Hall cell traditional	Hall ASIC	Hall cell traditional	Hall ASIC
Dimensions (L x W x H) [mm]	90 x 34 x 95 / hole 38	94 x 34 x 95 / hole 40	70 x 31 x 70 / hole 30	70 x 31 x 70 / hole 30	54 x 27 x 57 / hole 20	54 x 27 x 57 / hole 20	49 x 26 x 52 / hole 15	49 x 26 x 52 / hole 15
Operating temperature range [°C]	-40…+85	-40…+85	-40…+70	-40…+85	-40…+85	-40…+85	-40…+85	-40…+85

Fig. 3b: Performance Comparison Between LF xx10 Series and the Previous Generation of Transducers

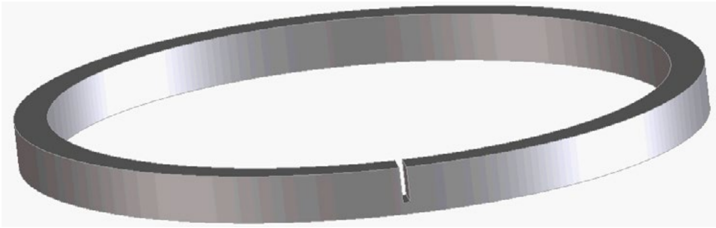

Fig. 4: Partial Air Gap on Magnetic Core

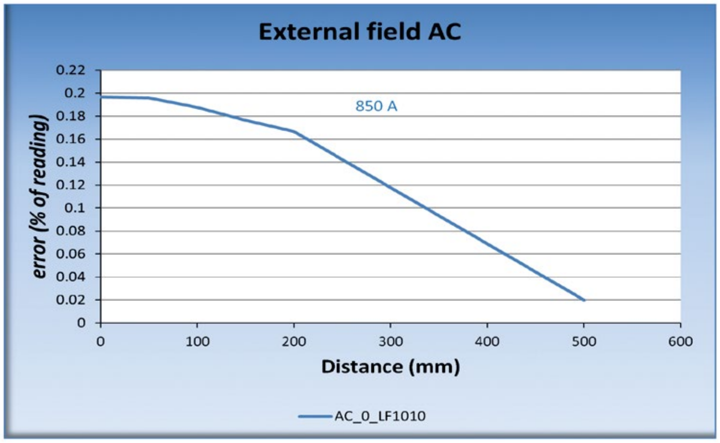

Fig. 5a: Error Created by a Busbar Close to the LF 1010 in Front of the Air Gap (850A_{RMS} 50Hz)

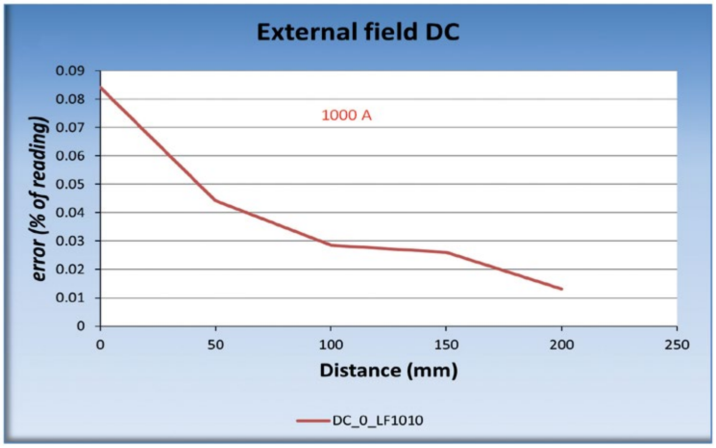

Fig. 5b: Error Created by a Busbar Close to the LF 1010 in Front of the Air Gap (1000A DC)

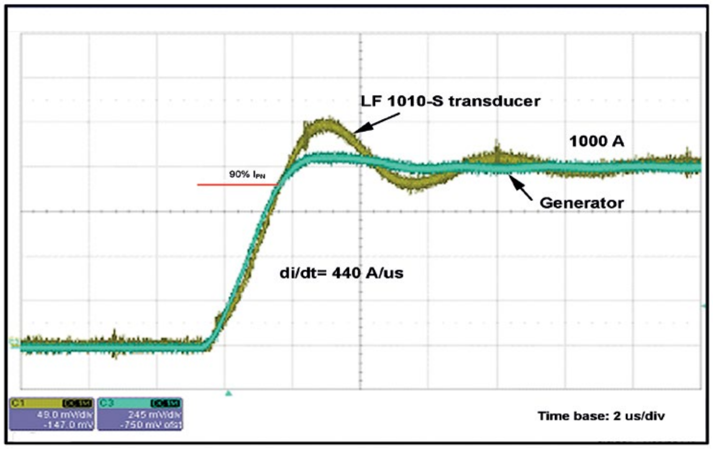

Fig. 6: LF 1010 Response Time at 90% of I_{PN}

To simulate external fields, the best test is to place a busbar with nominal current closely around the transducer at different positions. The added error due to the field created by this bar can then be measured. This is also a way to simulate a return busbar and its effect on the accuracy of the transducer.

For example, the sensitivity against AC or DC fields (worst case) with the LF 1010-S model is five times better than with the LF 1005-S (former generation). The typical error with a LF 1010-S is 2% of I_{PN} compared with 10% with an LF 1005-S when submitted to the same conditions caused by AC or DC perturbating fields (see Fig. 5a, 5b).

On response time (see Fig. 6), the LF xx10 transducers have a typical delay (defined at 90% of I_{PN}) against a current step at I_{PN} of less than 0.5µs. The magnetic core with a partial air gap improves the magnetic coupling, and improves the response against di/dt.

The bandwidth is only limited by the resonance frequency of the secondary winding to roughly100 kHz. This resonance is due to the leakage inductance and the parasitic capacitors between winding layers and between turns.

Signal-to-noise ratio (SNR) compares the level of a desired signal to the level of background noise. It is defined as the ratio of signal power to the noise power, often expressed in decibels. When a measurement is digitized, the number of bits used to represent the measurement determines the maximum possible signal-to-noise ratio. Thanks to the very good SNR, the LF xx10 models have more than 14bit resolution (see Fig. 7).

Various connections are available for the secondary side, such as connectors, cables, terminals, and threaded studs according to the customer's specifications, and a mounting kit for the primary bar will be available on LF 2010 models.

As semiconductor commutations are faster, a higher dv/dt between primary (high potential) and secondary (low potential) sides of the transducers is seen. The secondary side is generally connected to ground for safety reasons. The primary side is under some differential voltages, but the voltage can float. The potential can then change on the primary side to cause some perturbations at the secondary (output) of the transducer. This cannot be filtered because it would degrade the response time and frequency performances, so the parasitic capacitance between the primary and secondary sides of the transducer had to be reduced during its design to the lowest possible. Having a low parasitic capacitance between primary conductor and secondary side of the transducer is a way to reduce the effect of dynamic common mode. If this is not enough, an electro-static screen can be added to cancel common mode perturbations.

The LF xx10 models have been designed and tested according to the latest recognized worldwide standards for industry and traction applications. These include EN 50178 for electronic equipment used in power installations in industrial applications, and EN 50155 for electronic equipment used on rolling stock in railway applications. These standards guarantee the overall performance of products in industry and railway environments. The LF xx10 transducers are UL recognized and CE marked as a guarantee of compliance to the European EMC directive 2004/108/EEC and low voltage directive 2006/95/EEC. They also comply with the derived local EMC regulations and with the most recently updated EN 50121-3-2 standard (railway EMC standard), which features EMC constraints higher than that of the typical industrial application standards.

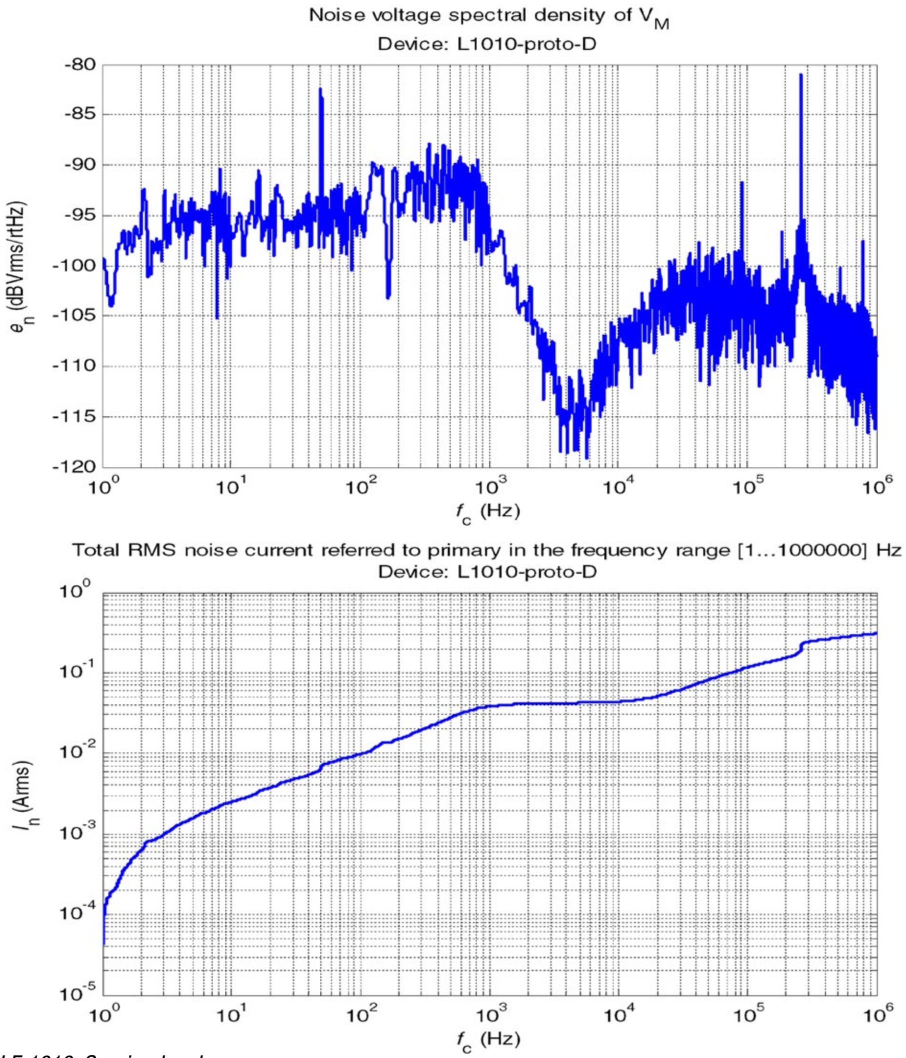

Fig. 7: LF 1010-S noise level

Conclusion

Systems integrate more and more sensors due to the high levels of automation that improve productivity and energy efficiency. Whatever kinds of sensors, current transducers can be used to make the link between different systems for monitoring and control. In the search for the best efficiency, these systems can benefit from the performance of the new LF xx10 series. These transducers are suitable for any kind of rugged environment where good performance in terms of accuracy, gain, linearity, low initial offset, and low thermal drift is required. Featuring high immunity to external interferences generated by adjacent currents or external perturbations, the LF xx10 transducers provide excellent reliability.

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