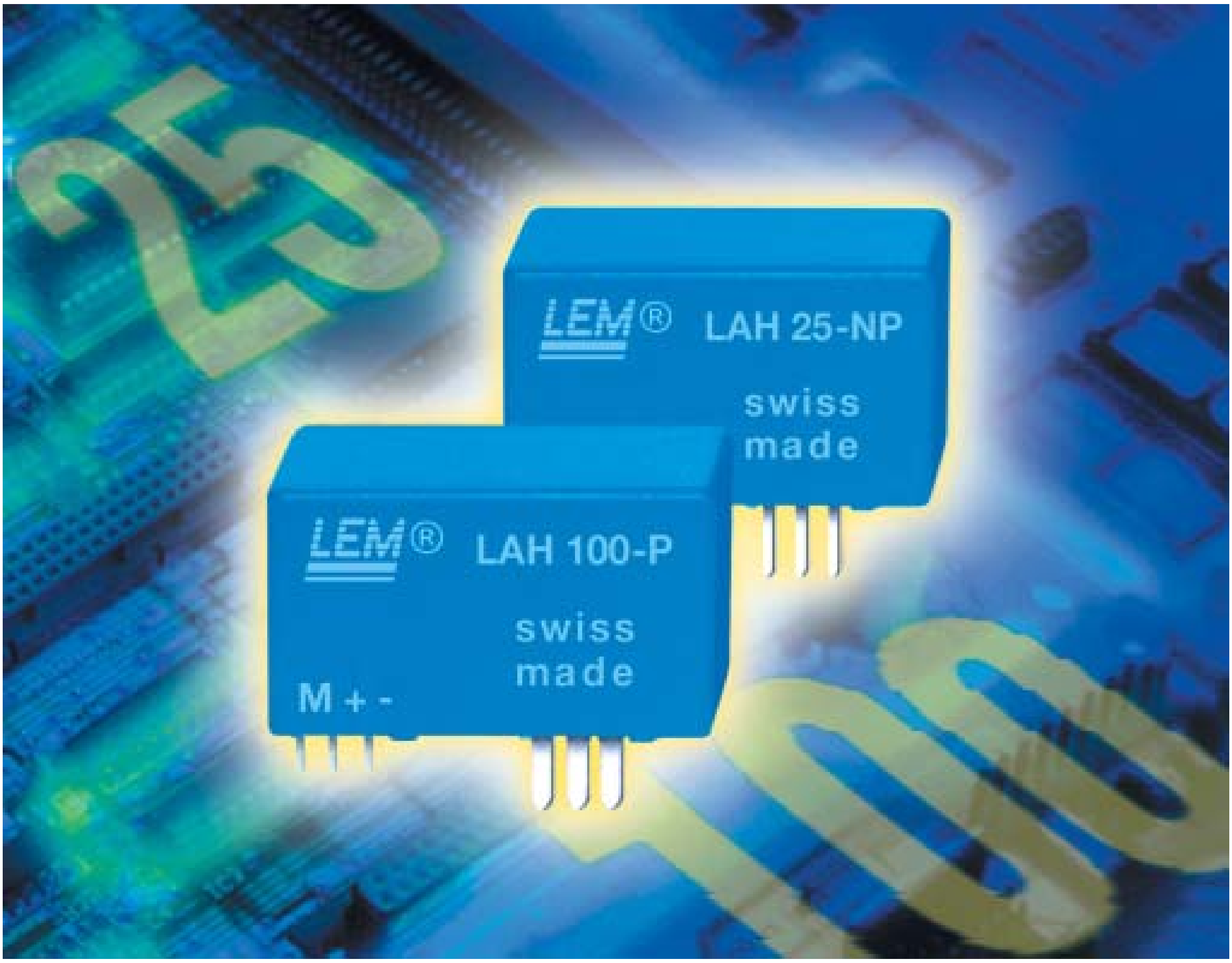
Technical
Information

Closed Loop Transducers
with small footprint
up to 100 A nominal

Electronic Components



The current transducers from LEM are considered as a key element linking power and the control circuitry. For a majority of application within the power electronics field such as: variable speed drives, servo-control elements, uninterruptible power supplies and switch mode power supplies. Due to their precise and isolated current measurements, the transducers contribute to the improvement of efficiency, reliability and safety of equipment, but very often, they are blamed for high functional costs and the volume they occupy in systems, which are continuously subjected to constraints of size and weight limitations, and price reductions in the market. With the LAH series, LEM meets these requirements and proposes a series of transducers characterised by six benefits.

- Thanks to the concept for vertical mounting, it has been possible to reduce the volume and, in particular, the footprint which is now fair below 5 cm^2. In order to facilitate the development of a product range at the customer's, all LAH types use the same housing thus occupying the same surface.

- A complete current range: the multiple-range primary circuit of the LAH 25-NP itself allows to obtain the three following turns ratios with a simple connection on the printed circuit board: I_{PN} = 8 A, 12 A and 25 A. This allows, for each range, to benefit from the maximum accuracy which is always expressed as a function of I_{PN}. Just like the LAH25-NP, the LAH 50-P and LAH 100-P are equipped with a three primary pins. Unlike the LAH-25-NP, the latter ones have a reinforced section and are internal interconnected, in order to facilitate the wiring and to ensure an optimum electrical connection between the primary circuit and the printed circuit board.

- The LAH transducers, based on the closed-loop principle, offer exceptional electrical characteristics. The characteristics obtained are remarkable; bandwidth from 0 to 200 kHz, response time at 90 % less than 500 ns and accuracy better than 0.25 % [1)] for the LAH 50-P, LAH 100-P and 0.3 % [1)] for the LAH 25-NP.

- The reduced dimensions of the LAH transducers observe the prescribed distances between the primary and the secondary circuits, thus meeting the requirements of the standard EN 50178.

- Due to the uniformity of the different versions, their multi-purpose and the mass production, LEM can offer the LAH series with a remarkable price/performance ratio.

- An option on the LAH 25-NP and LAH 50-P ranges enables the measurement of differential current as well as the measurement of 3 phases with 2 transducers by means of a through hole aperture used for insertion of the second primary-circuit.

Evolution of the conditions for current measurement

The evolution of the requirements with regards to current measurements has been showing trends, which are mainly characterised by the standards, the evolution of the electronic power components, the permanent concern about improving the profitability of the proposed equipment, and the compactness of the measuring devices. So, the galvanic isolation is no longer only considered as an answer to a technological constraint, but also as an element of safety. Regarding the components, the new power switching devices used for electronic speed control, offer a reduction of the switching times and an increase of the operating voltages and currents. As far as profitability is concerned, the cost of ownership greatly depends on the efficiency curve of the equipment. If this equipment uses measured current values in its control circuits, then also the transducers contribute to the improvement.

When the latters use current measurements in its control circuits, their enhancement also comes through the transducers.

These recent innovations, and those to come, impose and will impose, on current measurements; the observance of the standard-related aspects, the high dynamic characteristics (response times and behaviour at high-amplitude current (di/dt) and voltage (dv/dt) changes) and a constant progress in accuracy and size reductions.

Preference for a measuring system

These conditions and trends give orientations as to the measuring methods to be used. The ideal is to combine experience and innovation at the same time. The experience must comprise both the theoretical and the technological aspects. The innovation must pursue two objectives, that of continuous improvements and that of technological progress. This approach allows to meet the actual requirements, but also to assure oneself of the level of evolution necessary for meeting the challenges of the future. The Hall effect transducer offers an extremely well-balanced solution to these needs. The principle is proven and the technological innovations are accompanied by the know-how of the engineers, thus allowing to offer transducers with regularly improved performances with a continuously increased price/performance ratio. Thanks to the measuring system offered by the transducer, the performances in dynamic operations are optimised once and for all.

Compared to a current measurement carried out with discrete elements, this relieves the design engineer of the difficult tasks related to EMC compatibility and of the development of the operating circuit scheme, which guarantees him the desired dynamic performance. Since the transducer is a precise element which does not cause

[1)] without electrical and magnetic offset any or few insertion losses, it actively participates in improving the efficiency of the equipment.

Closed-loop operating principle

The proven closed-loop operating principle, used by LEM when building its first current transducer more than 30 years ago, has served as a base for designing the LAH series. Since that time, this principle has been used with success for isolated measurements of currents and voltages.

Every conductor carrying a current Ip (Fig. 1) generates a magnetic field, which is concentrated in a magnetic circuit. This field can be measured in an air gap by using a Hall element. The latter has the property of converting the magnetic flux into a voltage, when it is supplied with a constant current I_C.

When applying the closed-loop principle, the Hall voltage is only used for balancing the primary and the secondary flux. The additional secondary coil, for example with 2,000 turns, carries a current Is which equals 1/2000 of the primary current, in order to exactly compensate for the field of the primary conductor. The total flux then equals zero.

The compensation circuit accepts DC and AC currents up to the limit frequency of the electronics. Above that value, the current transducer works as a normal transformer with a primary and a secondary winding. This allows electrically isolated measurements of currents up to several hundred kHz.

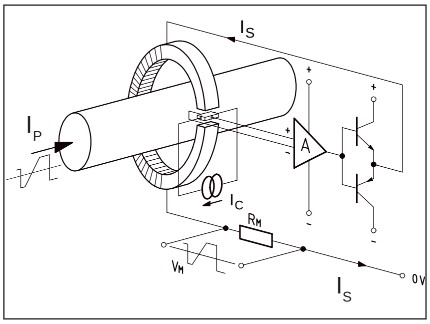


Figure 1. Operating principle of a closed-loop transducer.

The LAH series

The LAH series from LEM have been developed to offer a solution to the constraints of space, price, performance and weight. Their application areas are extremely varied: variable speed drives, servo-control elements, uninterruptible power supplies and switch mode power supplies.

Table 1 gives an overview of the main characteristics of the series LAH transducers.

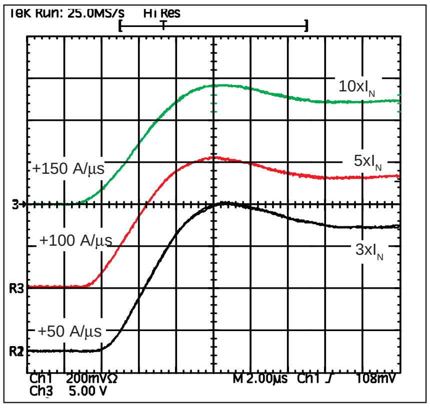


Figure 2. LAH 50-P: di/dt at overload

Table 1: The technical data are given for a supply voltage of ±15V (±5%)

Technical data	LAH 25-NP	LAH 50-P	LAH 100-P
Effective primary current I_{PN}	8/12/25 A	50 A	100 A
Measuring range at 85 °C at 70 °C	18/27/55 A -	110 A -	140 A 160 A
Accuracy	0.3 %	0.25 %	0.25 %
Supply voltage ±5 %	±12 V ... ±15 V		
Temperat. drift -25 °C...+85°C (typ.)	±0.1 mA	±0.1 mA	±0.1 mA
Response time	< 500 ns		
Bandwidth (-1dB)	0...200 kHz		
Test voltage, 50/60 Hz, 1 min	5 kV		
Standard	EN50178		
Surface on the printed circuit board	460 mm²		

Exact reproduction of the waveform at the transducer output

The protection of fast power switching devices such as IGBT's requires a very fast detection of overcurrents. At a current slope of 100 A/µs, there is practically (Fig. 2) no delay to be seen with regards to the primary current.

Behaviour at dv/dt noise

Each electrical component with a galvanic isolation between the primary and the secondary circuit has a capacitive coupling between the isolated potentials. At high switching frequencies, this leads to undesired EMI influences (EMI = **E**lectro-**M**agnetic **I**nterference). On the secondary side, i.e. at the output of the component, an interfering signal appears. The figures 3 et 4 show the behaviour at a voltage change of 1 and 6 kV/µs for an applied voltage of 1000V. Note the very short duration of the disturbance of less than 200 ns which can be easily filtered. This is very important for the use with digital regulating circuits using pulse width modulation (PWM). In this case, a small filter is sufficient for the attenuation, in order not to limit the dynamic characteristics.

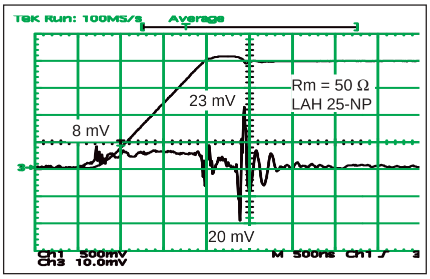


Figure 3. Behaviour at a voltage jump of 1 kV/µs, 1000 V

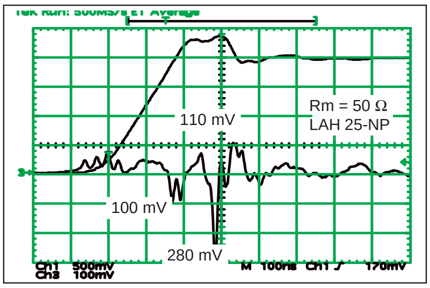


Figure 4. Behaviour at a voltage jump of 6 kV/µs, 1000 V

Wide frequency bandwidth

The excellent coupling characteristics between the primary circuit and the compensation coil are also reflected in the bandwidth. The LAH wide frequency range reaches a level which is rarely obtained with traditional Hall effect transducers.

Reduced mounting surface

With the LAH series, whether for measuring a current of 8 A or 100 A, the transducer only occupies 460 mm^2 on the printed circuit board, and its height is just 21 mm. Despite its compactness, the triple primary circuit is fully protected, and the distance obtained between the primary and secondary connections is 12 mm.

Primary circuits

The original constructive solution with three transversal U-shaped primary terminals offers technical advantages, which allow to reduce the development time and the number of transducers in stock. With the LAH 25-NP, you have three transducers in one; an 8 A nominal, a 12 A nominal and a 25 A nominal current type. It is important to note that in the three connection variants, the LAH 25-NP offers performances of a very high level and which are completely identical. Due to the amplitude of the measured currents and to the mounting on a printed circuit board, the LAH 50-P and LAH 100-P are equipped with a triple primary circuit which has a reinforced section and interconnected terminals.

Connection variants of the LAH 25-NP

In **variant 1**, the three primary circuits connected in parallel form one winding. The turns ratio is thus 1:1000. This allows to measure currents up to 55 A peak with a nominal current of 25 A.

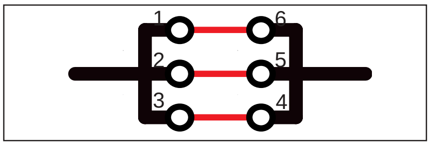


Fig. 6. Ratio 1:1000

In **variant 2**, two primary circuits connected in parallel are wired in series with the last primary circuit, thus forming two windings. The turns ratio is thus 2:1000. This allows to measure currents up to 27 A peak with a nominal current of 12 A.

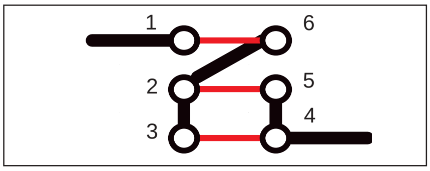


Fig. 7. Ratio 2:1000

In **variant 3**, the series-connected primary circuits form three windings. The turns ratio is thus 3 :1000. This allows to measure currents up to 18 A peak with a nominal current of 8 A.

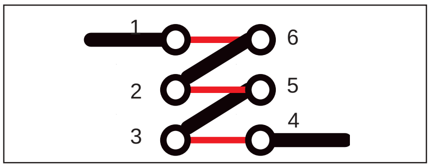


Fig. 8. Ratio 3:1000

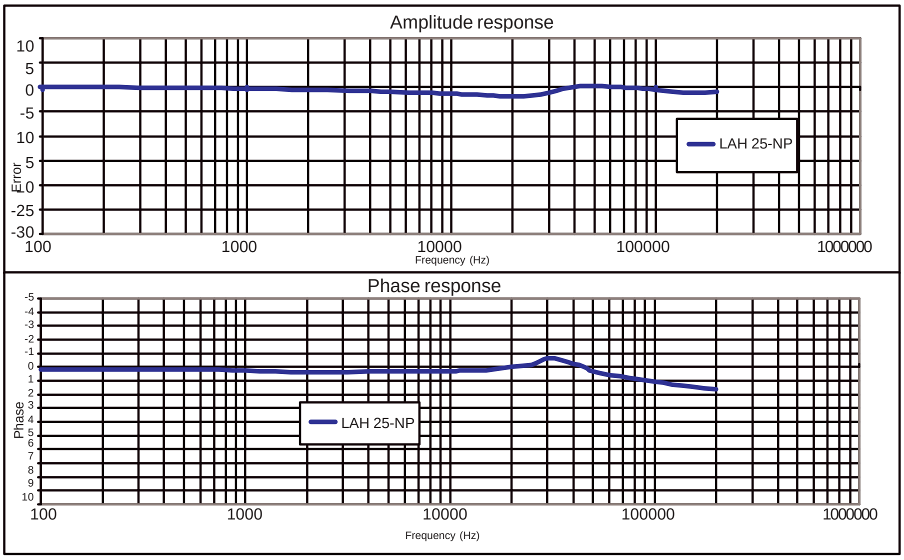


Fig. 5. Frequency Bandwidth

Applications and set-up

Measuring differential currents

LAH 25-NP and LAH 50-P are available in special versions with a through-hole (3.2 mm∅) which allows to measure differential currents. In this configuration, the magnetic fields generated by the currents circulating in the primary circuit and through the hole add or subtract dependant upon direction.

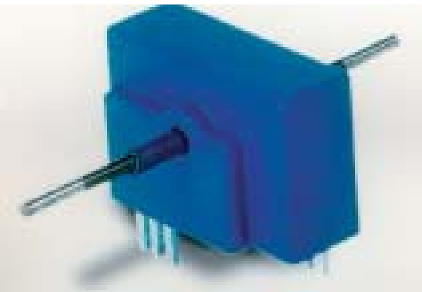


Fig. 9. Differential measurement

Measuring three phases with two transducers

A particularly interesting application for adding up currents is the measurement of two phases per transducer as shown in figure 10.

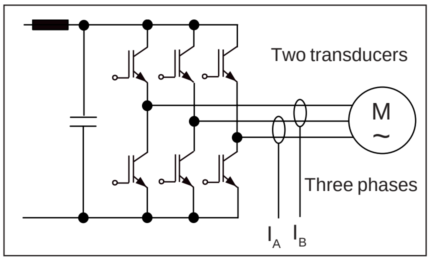


Fig. 10. Two transducers, three phases

Except in case of an earth fault, the sum of the currents in the three phases of a motor always equals zero. This makes it possible to easily reconstruct the three phase currents I_U, I_V, I_W from the measurements taken by the two transducers ($I_A = I_U + I_V$ and $I_B = I_V + I_W$, figure 11).

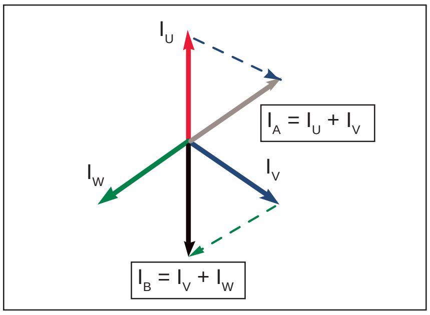


Fig. 11. Symetrical mode

It is important to note that this configuration allows an immediate detection (by exceeding a certain threshold for I_A and I_B) of all types of short circuits, even those to earth and this, without the need to reconstruct the three phases.

Example for a two-phase fault at V-W (Fig. 12): the threshold for I_A will detect the short circuit.

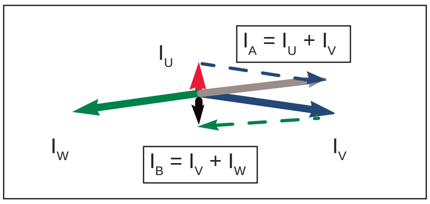


Figure 12. Short circuit between two phases

Example for a single-phase fault at V-N (Fig. 13): the thresholds for I_A and I_B can detect the short circuit.

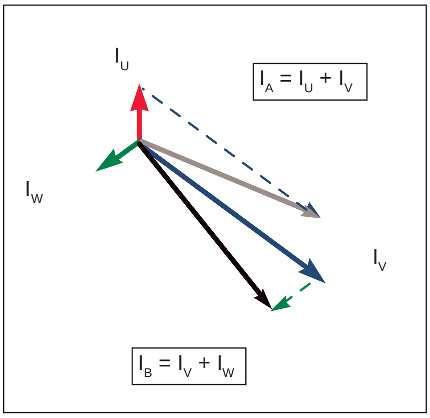


Figure 13. Earth leakage in the V phase

The detection of low-current earth faults can be carried out either with a transducer in the DC link of the inverter or with three transducers in phases.

Determination of the measuring resistor

The measuring voltage generated at the terminals of the measuring resistor depends on the amplitude of the primary current I_P, the turns ratio of the transducer K_N and the measuring resistor R_M. The nominal current I_{PN} determines the type of transducer and its turns ratio K_N. The voltage measured at a given primary peak current I_P is thus determined by the choice of the resistor R_M.

$$R_M = \frac{V_M}{I_P \bullet K_N}$$

With:
V_M = Measuring voltage
K_N = depending on the transducer and its wiring (see table 2)
I_P = Max. peak current to be measured

The LAH transducers have been developed with the concern for offering

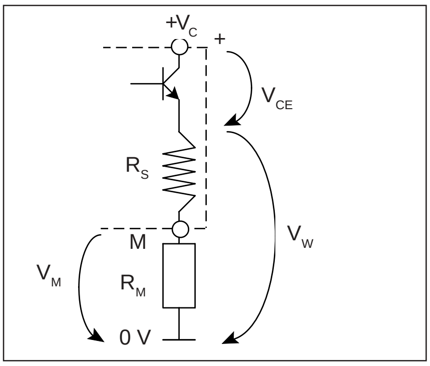


Fig. 14. Voltages V_{CE}, V_W, V_M

a great flexibility in the choice of the measuring resistor, in order to allow the user to adjust the measuring voltage to its optimum level. Of course, there is a lower and an upper limit for the choice of the resistors. For the user, these limits result in a measuring voltage range, within which he can adjust the desired voltage with the aid of the resistor.

The upper limit depends on the minimum supply voltage of the transducer (more precisely, the minimum voltage available for the coil and the resistance of V_W), the resistance of the coil (and its temperature) and the peak current that one desires to measure.

$$R_{M\ (max)} = \frac{V_W}{I_P \cdot K_N} - R_S\ @\ T_A$$

With:
V_W = 11.75 V ($V_{C(min)}$ -2.5 V = 15 • 0.95 -2,5*) or with a supply voltage of 12 V ±5 %: V_W= 12 • 0.95 -2,5= 8,9 V.
$R_S@T_A$ = coil resistance at the temperature T_A (see table 2)
*2,5 V (voltage V_{CE} minimum)

The lower limit depends on parameters some of which are intrinsic to the transducer, and others to the application. It is important to keep in mind that the nominal current of the customer's application is the parameter which has the greatest influence on the value of $R_{M(min)}$ and consequently on the lower limit of the measuring voltage range.

$$R_{M\ (min)} = \frac{V_{C\ (max)}}{I_{PNA} \cdot K_N} - \frac{P_{tr\ (max)}\ @\ T_A}{\left[I_{PNA} \cdot K_N\right]^2} - R_S@T_A$$

With:
$V_{C\ (max)}$ = 15,75 V at 15 V+ 5 % and 12,6 V at 12 V + 5 %
I_{PNA} = nominal current of the customer's application
$P_{tr}(max)@T_A$ = max. power of the transistors at the temperature T_A (see table 2)

Table 3. For different current measuring ranges, the required minimum RM must be indicated for an ambient temperature of 70°C or 85°C and a supply voltage of 15V.

Type	I_{PN} A	$R_{M\ (min)}$ T_A=70 °C Ω	T_A=85 °C Ω
LAH 25 NP	<21 <22 <23 <24 <25	0 18 38 54 67	0 23 42 57 70
LAH 50 P	<50	0	0
LAH 100 P	<60 <70 <80 <90 <100	0 0 0 13 20	0 27 42 45 45

Quick determination of $R_{M\ (min)}$

The minimum measuring resistor $R_{M\ (min)}$ as a function of the nominal current and the ambient temperature can also be rapidly determined with the help of table 3 (for V_{CC} = ± 15 V ± 5 %):

Example for calculating the measuring resistor R_M of an LAH 25-NP used in a variable speed drive.

Application data

a) An 11 kW variable speed drive draws a nominal current of 22 A_{RMS}.
b) It is required that the transducer can permanently withstand 1.1 times the nominal current, i.e. 24.2 A_{RMS}.
c) The overload currents of 1.7 times the nominal current during 3 seconds must be measurable. At the peak value of this current, the measuring voltage must be 4 V.
d) The ambient temperature can reach 70 °C. The transducer is supplied with 15 V (±5 %).

Table 2. R_S, $P_{tr(max)}$ and I_P as a function of the ambient temperature

	K_N	R_S @70 °C Ω	R_S @85 °C Ω	$P_{tr(max)}$ @70°C W	$P_{tr(max)}$ @85°C W	$I_{P(max)}$ 10 s A
LAH 25-NP (1Np)	1:1000	99	104	0,29	0,285	55
LAH 25-NP (2Np)	2:1000	99	104	0,29	0,285	27
LAH 25-NP (3Np)	3:1000	99	104	0,29	0,285	18
LAH 50-P	1:2000	135	142	0,4	0,305	110
LAH 100-P	1:2000	115	121	0,45	0,37	140 160@70°C

Calculations

1) For a nominal current of 24.2 A_{RMS}, one chooses an LAH 25-NP with one winding in the primary circuit.
This implies K_N = 1/1000 (s. table 2).

2) For this transducer, at 70 °C:
R_S = 99 Ω, and P_{tr}(max.) = 0.29 W (see table 2)

3) Peak current to be measured during 3 seconds:
$22 \cdot 1.7 \cdot \sqrt{2} = 52.89\ \hat{A}$

The amplitude and the duration are well below the specifications in the data sheet (55 A during 10 s). Depending on the application, these values can be exceeded (please contact LEM).

4) Calculation of $R_{M\ (max.)}$

$$R_{M\ (max)} = \frac{11.75}{52.89 \cdot \frac{1}{1000}} - 99 = 123.16\ \Omega$$

hence

$$V_{M\ (max)} = 123.16 \cdot 52.89 \cdot \frac{1}{1000} = 6.51\ \text{V}$$

5) Calculation of $R_{M\ (min.)}$

$$R_{M\ (min)} = \frac{15{,}75}{\frac{24{,}2 \cdot 1}{1000}} - \frac{0{,}29}{\left[\frac{24{,}2 \cdot 1}{1000}\right]^2} - 99\ = 56{,}6\Omega$$

hence

$$V_{M\ (min)} = 56.6 \cdot 52.89 \cdot \frac{1}{1000} = 2.996\ \text{V}$$

6) Calculation of R_M for a measuring voltage of 4 V (V_M) at 52.89 Â.

$$R_M = \frac{4}{52.89 \cdot \frac{1}{1000}} = 75.6\ \Omega$$

7) Check that R_M(min.) < R_M < R_M(max.)
56.6 Ω < 75.6 Ω < 123.16 Ω

8) With a 75 Ω resistor of the E24 series, one obtains an output voltage of 3.97 V at 52.89 A.

$$V_M = 75 \bullet 52.89 \bullet \frac{1}{1000} = 3.97 \text{ V}$$

Reminders and advice

It is possible that the desired measuring voltage is outside the calculated measuring voltage range (this could have been the case above). If the desired measuring voltage is below the lower limit of the calculated voltage range, one can..

- either realise R_M with the aid of two resistors forming a voltage divider,
- or slightly reduce the supply voltage of the transducer (reduction of the thermal losses in the amplifier), in order to be able to decrease the value of $R_{M\ (min.)}$ and consequently the value of the minimum measuring voltage,
- or try it with another current range of the LAH series. In the example above (at +85 °C), with an LAH 50-P instead of the LAH 25-NP, the lower limit of the measuring voltage range decreases by 3.18 V to 0 V.

If the desired measuring voltage is greater than the upper limit of the calculated measuring voltage range, one must..

- try it with a another current range of the LAH series. In the example above (at +85 °C), with an LAH 50-P instead of the LAH 25-NP, the upper limit of the measuring voltage range increases to 6.25 V at 8 V.
- and, of course, check that one has neither underestimated the minimum value of the supply voltage of the transducer for the calculation of $R_{M\ (max.)}$, nor over-estimated the ambient temperature for the value of R_S (coil resistance)

Standards

During the design of the LAH series, the regulations of the EN 50 178 standard have been taken into consideration. All transducers offer a safe insulation up to a voltage of 600 V in symmetrical networks. This value is valid for mains-circuits with pollution degree 2 and overvoltage category III.

All materials are UL-listed
(UL = Underwriter’s Laboratories).
The marking with the CE mark testifies the conformity with the European EMC Directive 89/336/EEC and the Low Voltage Directive 72/23/EEC.

ELECTRICAL DATA

	UNITS	LAH 25-NP		LAH 50-P		LAH 100-P	
I_{PN}: Primary, permanent DC or rms current	At	25		50		100	
I_P: Primary current measuring range (10s) max	± At	0 to 55		0 to 110		0 to 160	
R_M: Measuring resistor with ± 15V (±5%)		Min	Max	Min	Max	Min	Max
1) T_A= 70°C at I_{PN} [± At_{DC}]	Ω	67	371	0	335	20	120
at I_{PN} [At_{RMS}] (note 1)	Ω	67	236	0	195	20	51
2) T_A= 85°C at I_{PN} [± At_{DC}]	Ω	70	366	0	327	45	114
at I_{PN} [At_{RMS}] (note 1)	Ω	70	231	0	188	45	45
I_{SN}: Secondary nominal DC or rms current	mA	25				50	
K_N: Conversion ratio		1-2-3/1000		1/2000			
V_C: Supply voltage (± 5%)	V	±12...15					
I_C: Current consumption	mA	10 + I_S					
V_d: rms voltage for AC isolation test 50/60 Hz 1 min	kV	5					
V_b: rms rated voltage (see note 2)	V	600					

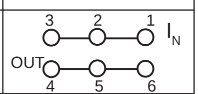
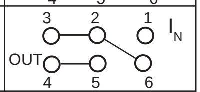
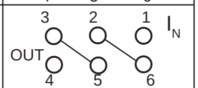
ACCURACY - DYNAMIC PERFORMANCES DATA

		LAH 25-NP		LAH 50-P		LAH 100-P	
X: Accuracy at I_{PN}, T_A = 25°C (see note 3)	$\%I_{PN}$	0.3		0.25			
ε_L: Linearity	$\%I_{PN}$	<0.2		<0.15			
I_O: Zero offset current at T_A = 25°C max	mA	±0.15		±0.15			
		Typ	Max	Typ	Max	Typ	Max
I_{OM}: Residual current at zero I_P after an overload of $5xI_{PN}$	mA	±0.20	±0.25	±0.10	±0.15	±0.10	±0.15
I_{OT}: Thermal drift of offset current I_O 0...+70°C	mA	±0.10	±0.60	±0.10	±0.30	±0.10	±0.40
-25°C...+85°C	mA	±0.10	±0.70	±0.10	±0.40	±0.10	±0.50
t_{ra}: Reaction time at 10% pf I_{PN}	ns	<200					
t_r: Response time at 90% of I_{PN} (with di/dt of 100 A/µs)	ns	<500					
di/dt: di/dt accurately followed	A/µs	>200					
f: Frequency bandwidth (-1dB)	kHz	DC-200					

GENERAL DATA

		T_A 70°C	T_A 85°C	T_A 70°C	T_A 85°C	T_A 70°C	T_A 85°C
R_S: Secondary coil resistance	Ω	99	104	135	142	115	121
m: Weight	g	20		22		24	
T_A: Operating temperature	°C	-25...+85					
T_S: Storage temperature	°C	-40...+90					

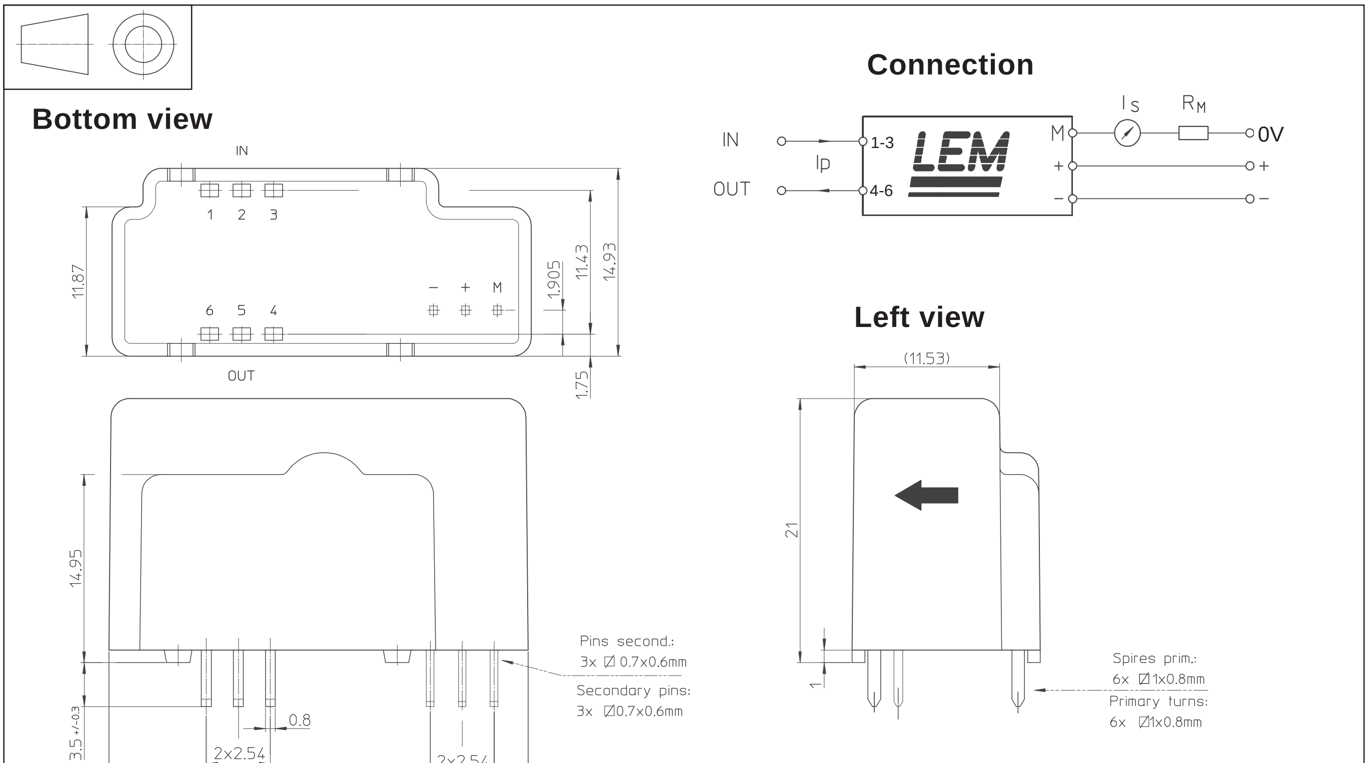
PRIMARY BUSES CHARACTERISTICS

	Number of primary turns	Primary permanent DC or rms current I_{PN} [A]	Conversion ratio K_N	Output current at I_{PN} I_{SN} [mA]	Primary resistance max at I_{PN} and T_A 85°C R_P [mΩ]	Primary insertion inductance L_P [µH]	Recommended PCB connections
LAH 25-NP	1	25	1/1000	25	0.18	0.012	
	2	12	2/1000	24	0.81	0.054	
	3	8	3/1000	24	1.62	0.11	
LAH 50-P	1	50	1/2000	25	0.12	0.008	
LAH 100-P	1	100	1/2000	50	0.08	0.007	

Note 1: Sinusoidal 50 Hz Note 2: Pollution class 2, cat. III Note 3: Without I_O and I_{OM}

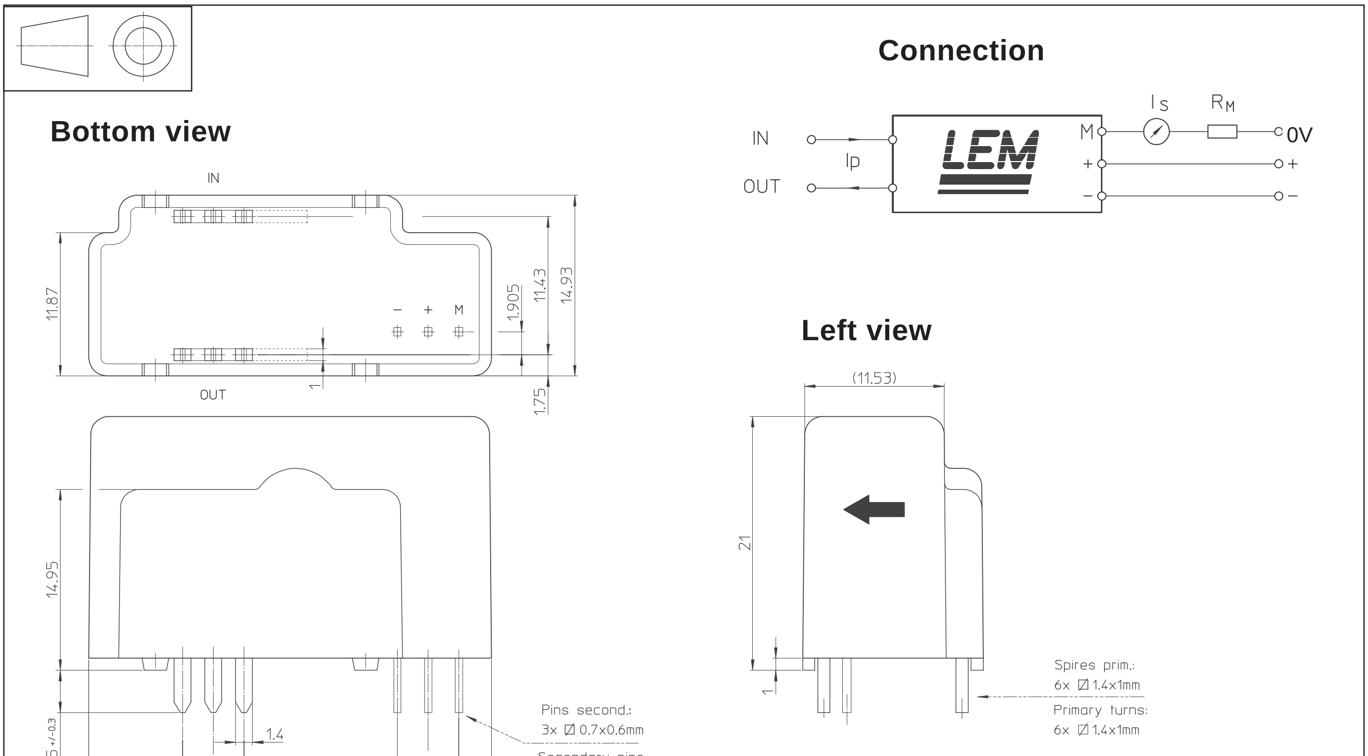
LEM reserves the right to carry out modifications on its transducers, in order to improve them, without previous notice.

Dimensions LAH 25-NP (in mm, 1 mm = 0.0394 inch)



Secondary Terminals:
Terminal M : Measure
Terminal + : Supply Voltage +12...+15V
Terminal - : Supply Voltage -12...-15 V

Dimensions LAH 50-P, LAH 100-P (in mm, 1 mm = 0.0394 inch)



Secondary Terminals:
Terminal M : Measure
Terminal + : Supply Voltage +12... +15V
Terminal - : Supply Voltage -12... -15V

Notes

Technical Information "Closed Loop Transducers with small footprint up to 100 A nominal"

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5 Years Warranty
on LEM Transducers

LEM designs and manufactures high quality and
high reliability products for its customers over the entire world.

Since 1972, we have delivered several million current and voltage transducers which are, for most of them, still in operation on traction vehicles, industrial motor drives, UPS systems and many other applications requiring high quality standards.

Our 5 years warranty applies on all LEM transducers delivered from the 1st. of January 1996 and is valid in addition to the legal warranty. The warranty granted on our Transducers is for a period of 5 years (60 months) from the date of their delivery.

During this period we shall replace or repair at our cost all defective parts (provided the defect is due to defective material or workmanship).

Further claims as well as claims for the compensation of damages, which do not occur on the delivered material itself, are not covered by this warranty.

All defects must be notified to us immediately and faulty material must be returned to the factory along with a description of the defect.

Warranty repairs and or replacements are carried out at our discretion. The customer bears the transport costs. An extension of the warranty period following repairs undertaken under warranty cannot be granted.

The warranty will be invalidated if the buyer has modified or repaired, or has had repaired by a third party the material without LEM's written consent.

The warranty does not cover any damage caused by incorrect conditions of use and cases of force majeure.
No responsibility will apply except legal requirements regarding product liability.

The warranty explicitly excludes all claims exceeding the above conditions.

LEM, Geneva, January 1. 2001
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Paul Van Iseghem
President of LEM Components

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