Application note: Melexis IMC current sensor demonstrator based on U12

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Simon Houis (shu@melexis.com)

1 Scope

In this document, we describe the performances and share evaluation results of the **planar Melexis current sensing solution** based on U12 shield and MLX91208CAV sensor. The planar solution is based on a Melexis Hall Sensor with integrated magnetic concentrator (IMC). These results are referring to the single bus bar demonstrator based on U12 and to the 3-phase demonstrator.

The following performances are evaluated below:

- Output, linear current range and saturation
- Phase-shift
- Response time
- Noise

In this document, the phase shift, response time and the noise level of a 500A Bus bar demo designed with a U12 shield and a MLX91208CAV current sensor are evaluated.

2 Demonstrators based on U12 and MLX91208

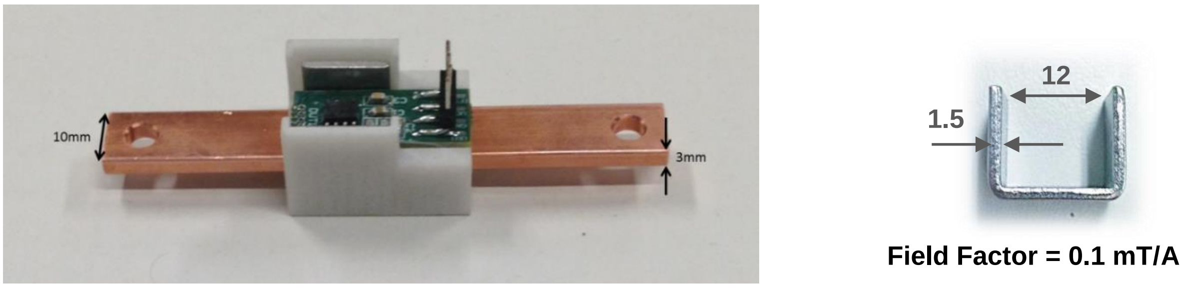

Figure1: *Assembled bus bar demonstrator and close-up on magnetic shield U12*

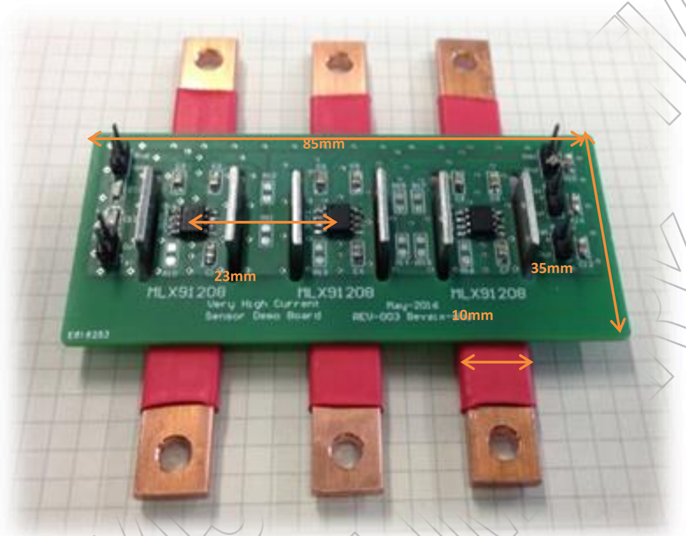

Figure 2: *3-phase demonstrator*

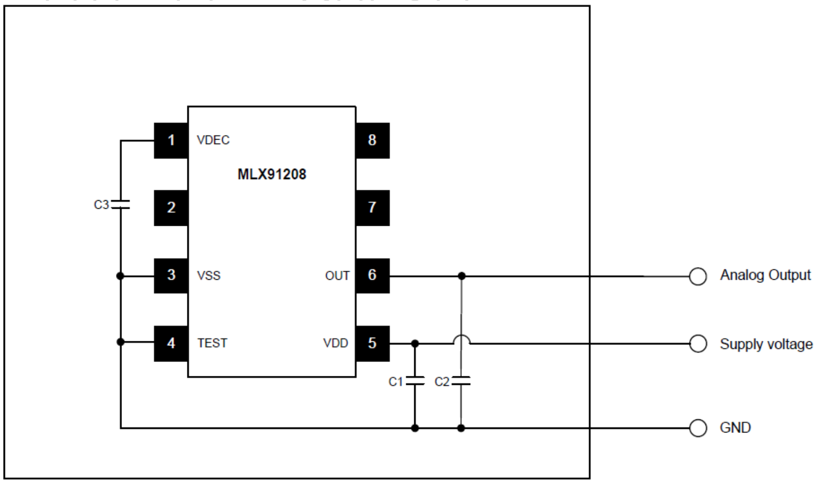

Figure 3: *Electric Scheme, C1=100nF C2=10nF C3=47nF*

3 Measurements Technics

3.1 Phase shift and Response Time

These measurements have been performed at 10 kHz for sine waves and square waves using a bus bar demo with a MLX91208CAL, noise filter OFF. MLX91208CAL (low field) and MLX91208 CAV (very high field) exhibit same phase shifts and same response times since these features do not depend on the sensitivity. However for a given input current, a MLX91208CAL sensor will exhibit a stronger signal and therefore a better S/N ratio, increasing the precision of our measurements. Consequently the following phase shift and response time results are consistent for both bus bar demos designed with a MLX91208CAV, or MLX91208CAH. The response time is defined as the period separated by the points 50%Ipk-pk and 50%Vpk-pk. The results are retrieved using the AC-mode of an oscilloscope *wave-surfer 3034*.

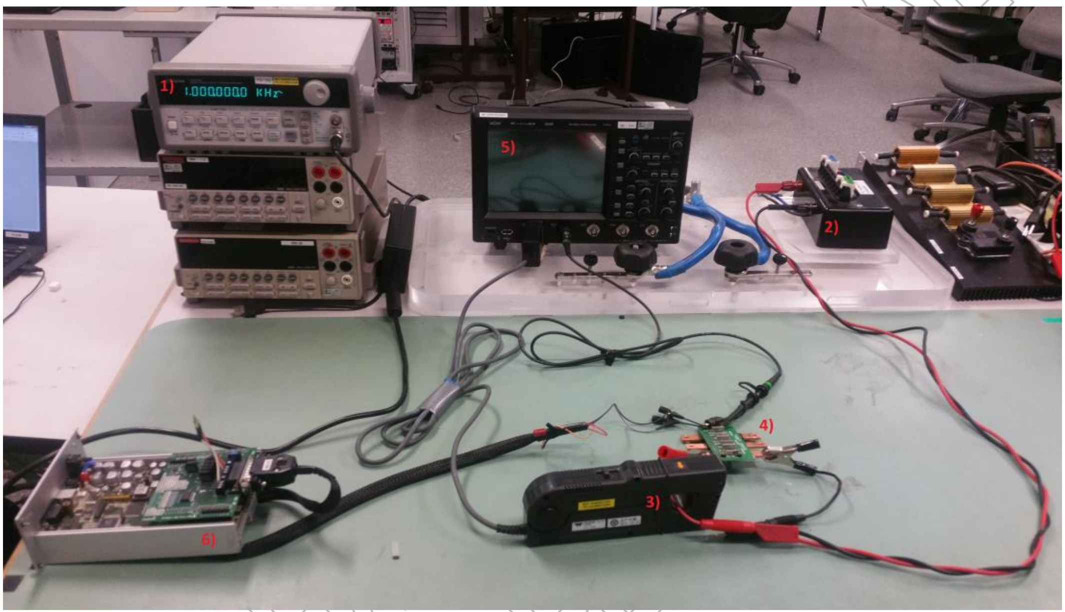

Figure 4: *Typical Phase shift and Phase delay measurement setup*

1) Input signal going to amplifier (not on picture)
2) Amplified current signal
3) Contactless current probe
4)DUT
5)Oscilloscope
6)PTC04 for VDD supply and device communication control

3.2 Noise Level

In contrary to the phase shift and the response time, the noise level depends on the sensitivity. That's why these measurements have been performed with a bus bar demo and a MLX91208CAV calibrated for 500A.

4 Typical Output, Saturation and Linearity

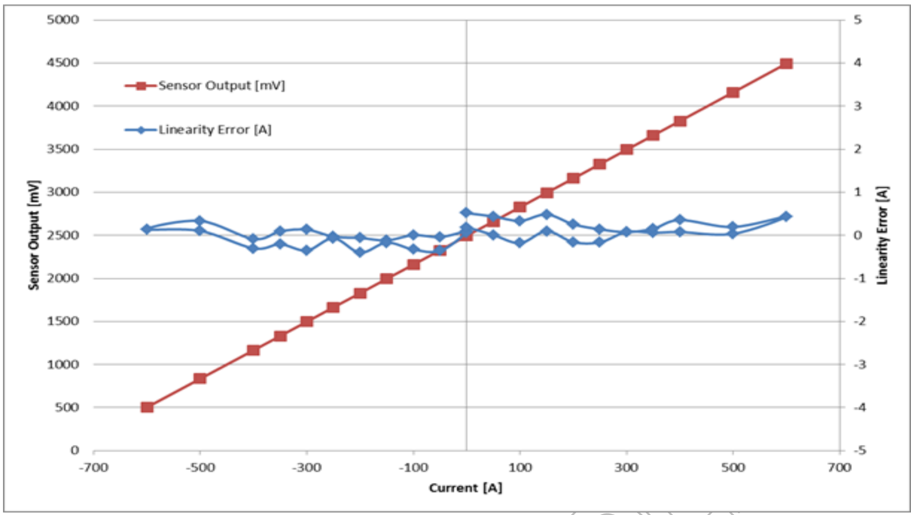

Figure 5*: Typical output and linearity range over [0; 600]A*

The demo is designed for 500/600A range, however it can be calibrated to cover larger current ranges. The IMC and the U-shield starts to saturate for currents higher than 600A leading to a non-linear output behavior. This behavior is stable and repeatable and can therefore be used to monitor higher currents. A wider U-shield can also be used to extend the linear range to higher currents. (fig.5)

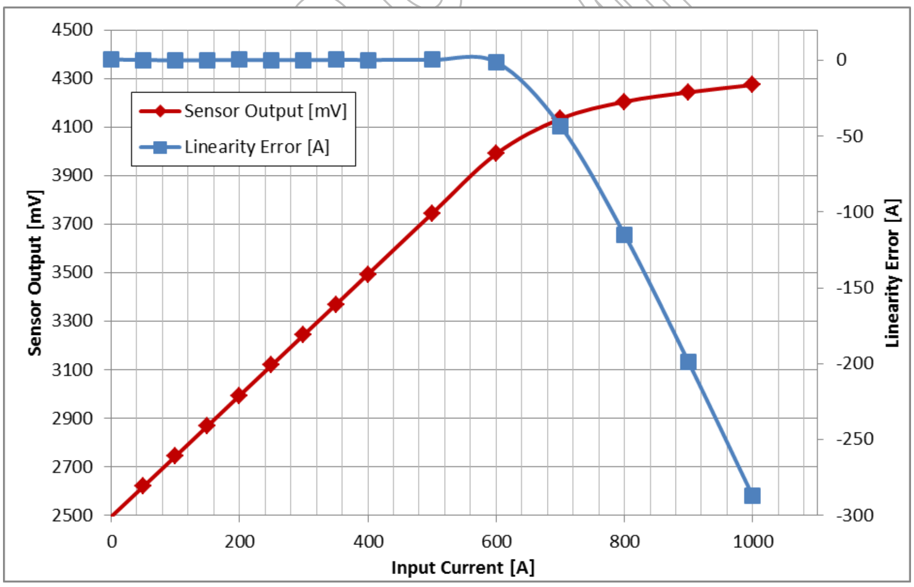

Figure 6*: Typical output and linearity error over [0;1000A]*

5 MLX91208 Timing specifications

A noise filter with the following specifications is implemented within the sensor. The noise filter is OFF by default.

Parameter	Symbol	Test Conditions / Comments	Min	Typ	Max	Units
Refresh rate	Trr		0.8	1	2	µs
Step Response Time	Tresp	Delay between the input signal reaching 90% and the output signal reaching 90%, (2V step at the output, input rise time = 1µs) -Noise filter OFF -Noise filter ON	 3 5		 4 6	 µs µs
Bandwidth	BW	-Noise filter OFF -Noise filter ON	200 120	250 150	300 180	kHz kHz
Power on Delay	T_{POD}	Vout =100% of FS Pull-down resistor ≤100kOhm During the Power-on delay, the output will remain within the 10% fault band at all time.			1	ms
Ratiometry Cut-off Frequency	Fratio			250		Hz

***Figure 7:** MLX91208 Timing specifications*

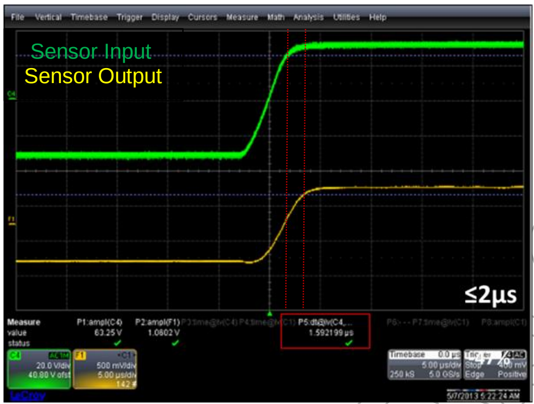

Figure 8: Sensor step response time with Noise filter OFF

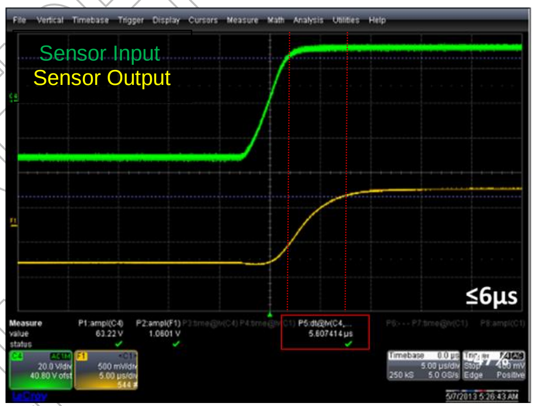

Figure 9: Sensor step response time with Noise filter ON

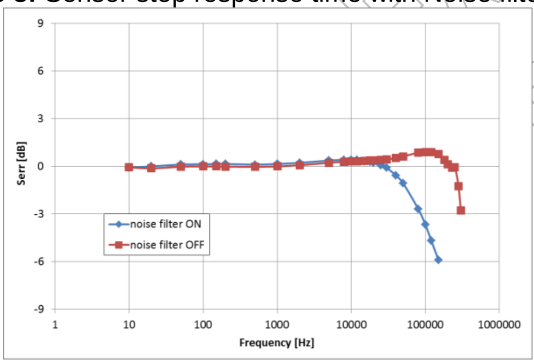

***Figure 10:** Typical frequency response*

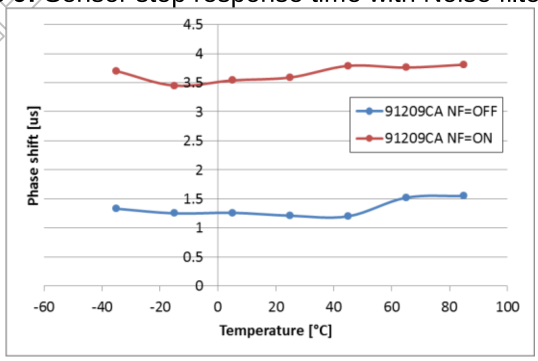

***Figure 11:** Phase shift over temperature at 20kHz*

6 Phase-shift

The total phase delay of a planar current sensor solution is based on sensor- and system design:

- The phase delay of the sensor is defined by the internal oscillator and filter setting => τ_{sensor} equals 2us, respective 6us if the integrated noise filter is turned on.

- The phase delay due to the magnetic system (magnetic circuit based on bus bar and shield geometry) is frequency depended. The magnetic field generated by the current (measured at the sensor position) is subjected to the eddy current effect (the higher the frequency, the higher the eddy currents).

$$\tau_{total} = \tau_{sensor} + \tau_{magnetic}$$

This delay $\tau_{magnetic}$ depends on frequency and temperature.

6.1 Eddy current, respective Skin effect

With increasing frequency, eddy currents in the bus bar force the current to flow on the surface of the conductor. This phenomenon is also called skin effect. Skin effect appears in the shield too. The following plot illustrates the change of current distribution as the frequency of the current changes.

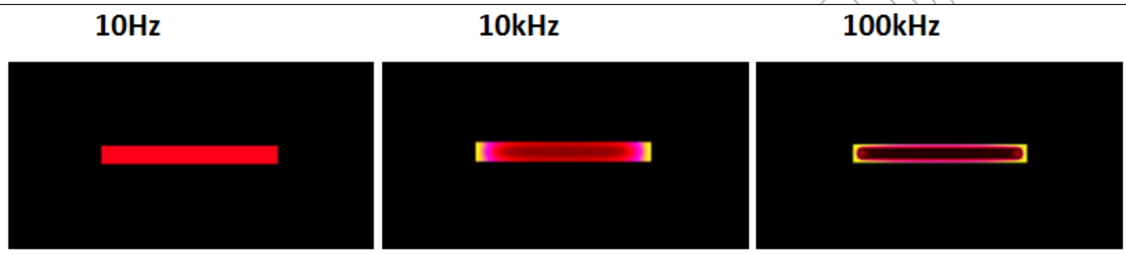

Figure 12 : Example - Current distribution in a copper bus bar (15mmx2mm)

A change of current density within the bus bar induces a variation of the magnetic field and phase delay at the sensor position.
The two following plots illustrate how the magnetic field and the phase delay changes with respect to position and frequency in the case of a bus bar conductor (without shield). This phenomenon exists as well if a shield is added to the system but the distribution is different.

6.2 Magnetic Field distribution and Phase-shift on a bus bar:

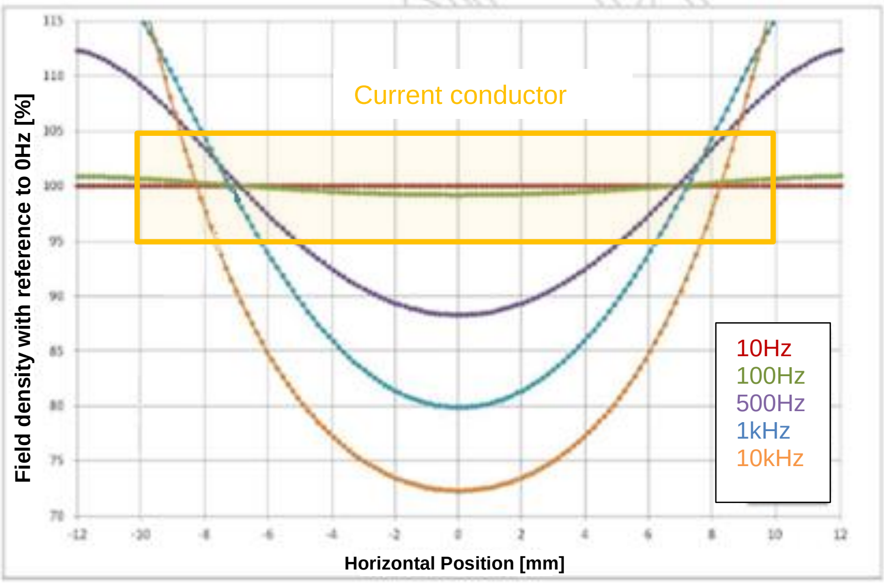

Figure 13: Simulation field density around sensor position for several frequencies, 20x3mm, no shield

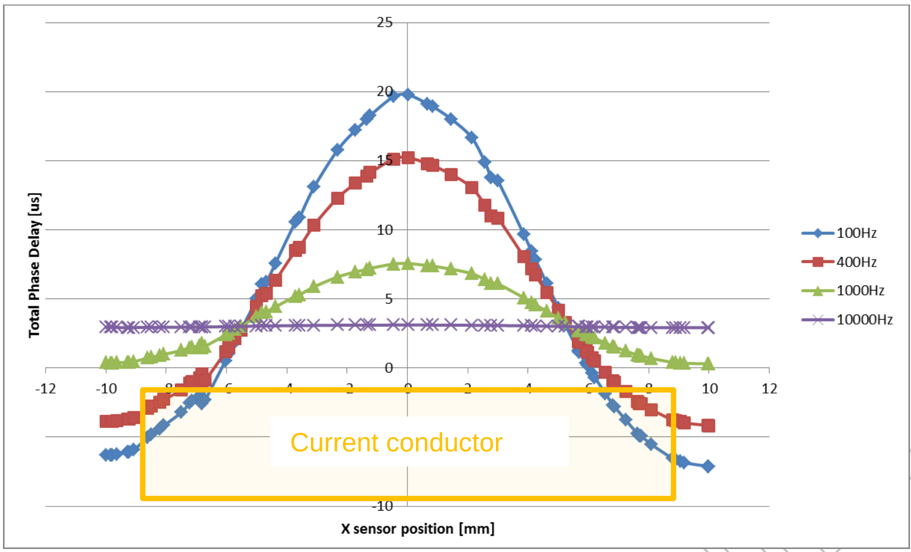

Figure 14: Simulation Total phase delay depending on sensor position for several frequencies, BB18x3mm, no shield

Measurements

Since the skin effect depends on frequency, the phase-shift at the sensor position is also subjected to frequency variations. Nevertheless, this behaviour is repeatable and stable, which means it can be compensated once it has been evaluated for a certain design.

Figure 15: *Phase shift results at 10 kHz, MLX91208CAL,* Iin_{pk-pk}*=14.3A,* $Vout_{pk-pk}$*=1.33V,* ***2.4us ↔8.6º*** *(note: The vertical resolution on the close-up plot has been tuned to increase accuracy).*

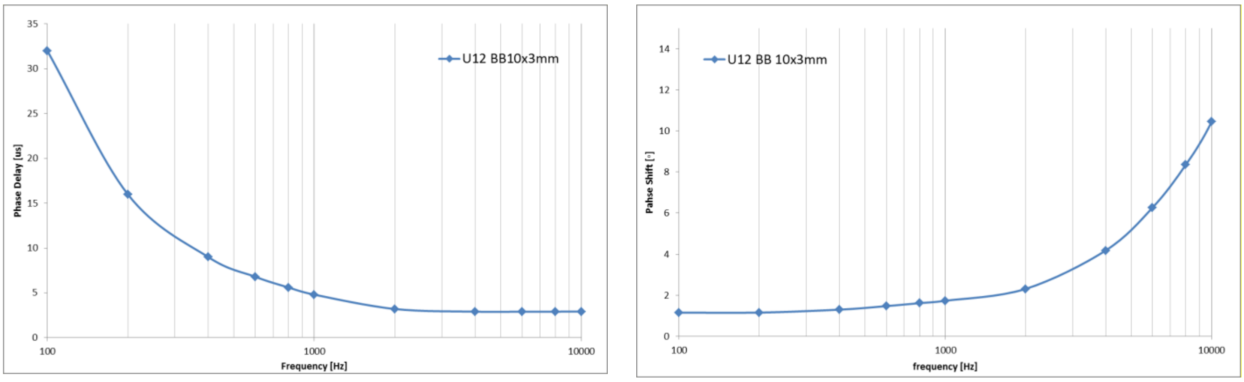

Figure 16: *Total Phase delay and corresponding total phase shift for U12 solution as function of frequency*

7 Response time

7.1 Measurements

The response time is defined as the time delay separating the points 50%I_{pk-pk} and 50%V_{pk-pk}.

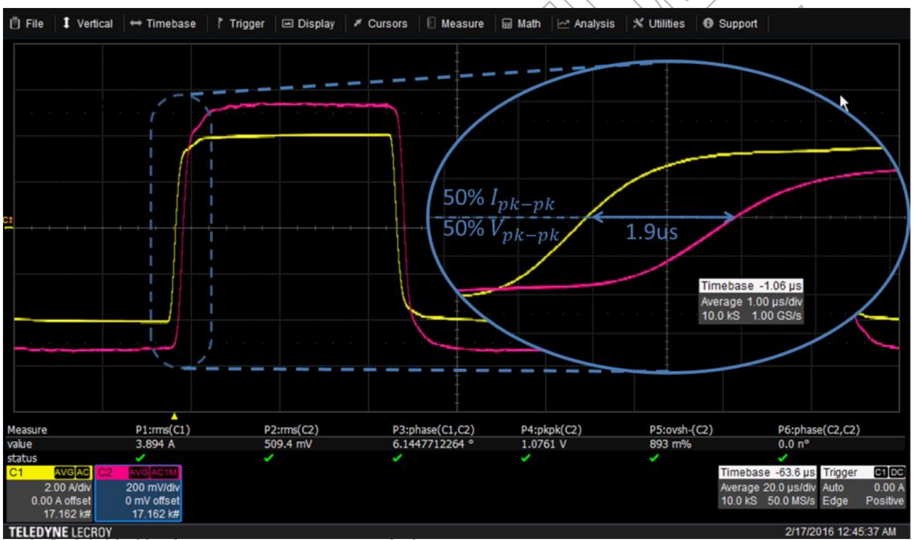

Figure17: Response time at 10kHz, MLX91208CAL, Iin_{pk-pk}=7.8A, $Vout_{pk-pk}$=1.08V, **1.9us**.
(note: The vertical resolution on the close-up plot has been tuned to increase accuracy)

8 Noise level

The noise level is dependent on the calibrated sensitivity of the sensor and is defined in the datasheet for the following standard sensitivities.

RMS Output noise	N_{rms}	S=40mV/mT (xxV version)				
		S=100mV/mT (xxH version)				
		S=250mV/mT (xxL version)				
		-Noise filter OFF			0.2	%Vdd
		-Noise filter ON			0.12	%Vdd

Figure 18: *MLX91208 ouput noise specifications*

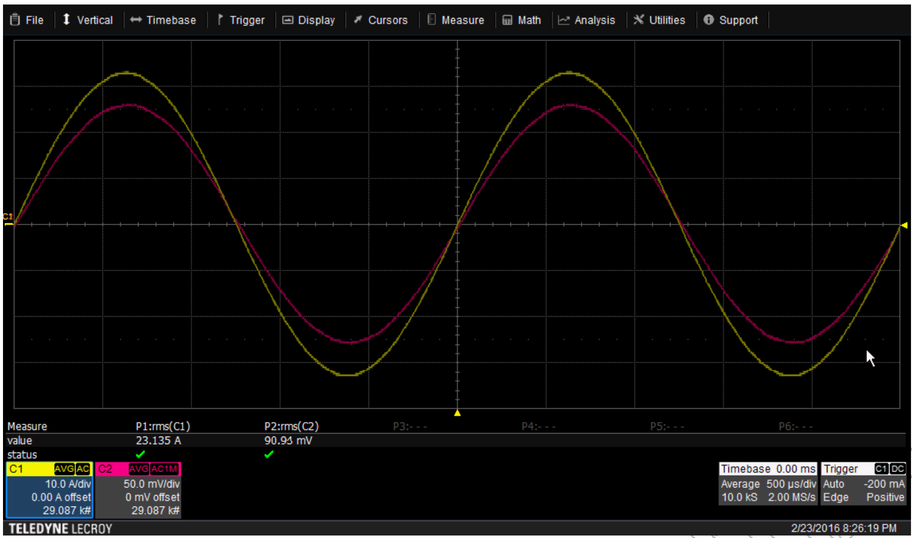

Figure19: Input and Output Swing, *MLX91208CAV, Iin = 23.14Arms, Vout=90.96mV →*
Sensitivity = 90.96/23.15 = 3.9 mV/A

Sens.	3.9mV/A	→	**Expected Noise Level**
Field Factor	0.1mT/A	→	Noise Filter OFF : 0.2%Vdd = **10mVrms**
Magn. Sens.	3.9/0.1 = 39 mV/mT		Noise Filter ON : 0.12%Vdd = **6mVrms**

Table1: *Magnetic Sensitivity and Related Noise Level based on MLX91208 Datasheet Specifications*

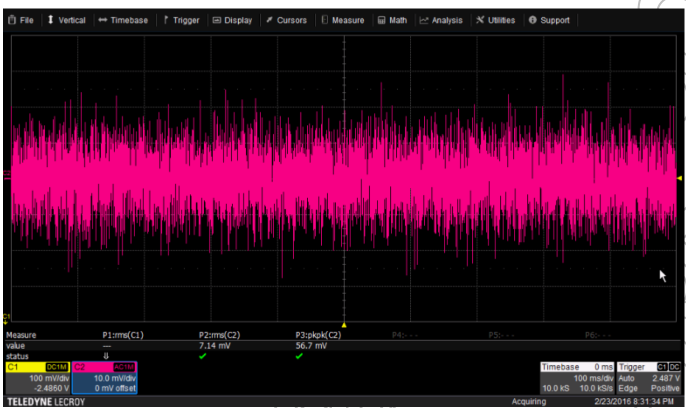

Figure 20: *Noise measurement @ 0A with Noise Filter OFF, MLX91208CAV, **7.14 mVrms***

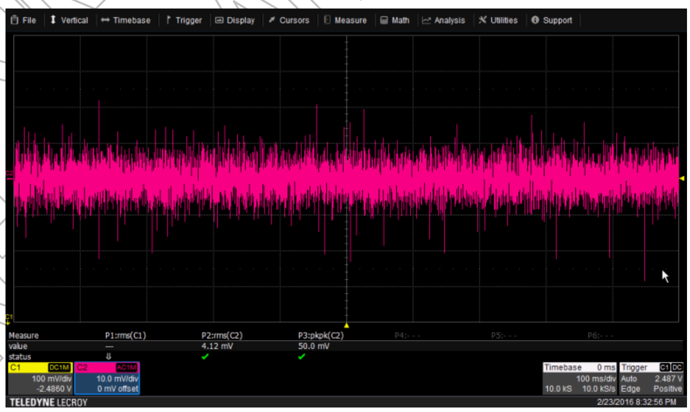

Figure 21: *Noise Measurement @ 0A for Noise Filter ON, MLX91208CAV, **4.12mVrms***

9 Conclusion

U12 (with 1.5mm thickness) based demos feature:

- a good linearity over the range [0 ; 600A] : <1%
- a highly repeatable behavior over the saturation range [600 ; 1000A]
- very fast frequency responses
- small size and low weight
- easy to assemble
- and a good signal to noise level

	Phase Shift (@10kHz)	Response Time (@10kHz)	Noise Level (@0A)
Noise Filter OFF	2.4 us (8.6º)	1.9 us	7.14mVrms < 0.2%Vdd
Noise Filter ON	4.4 us (15.8º)	3.9 us	4.12mVrms < 0.12%Vdd