TI High-voltage Seminar

Simplifying current sensing in high voltage systems while maximizing accuracy

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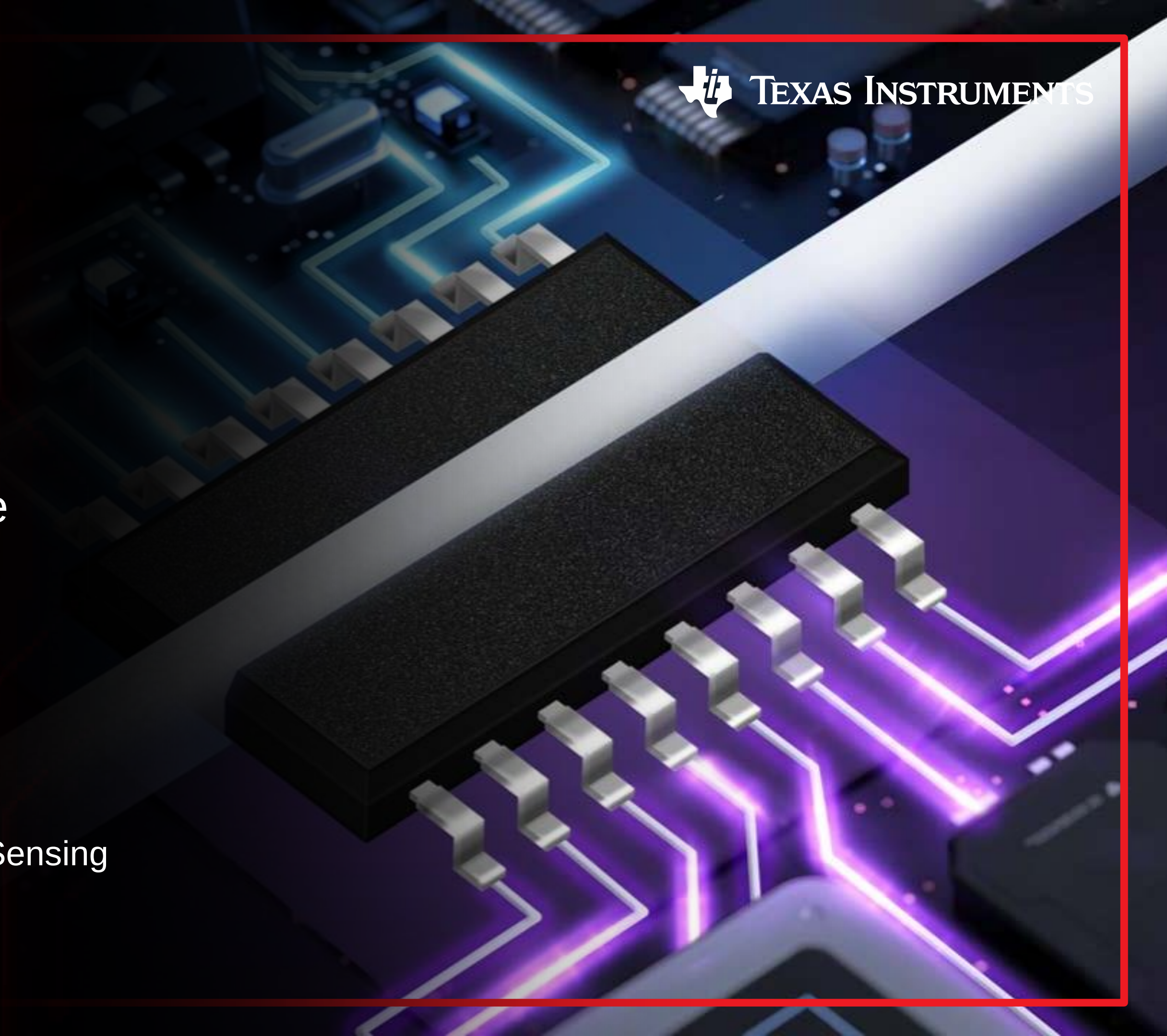
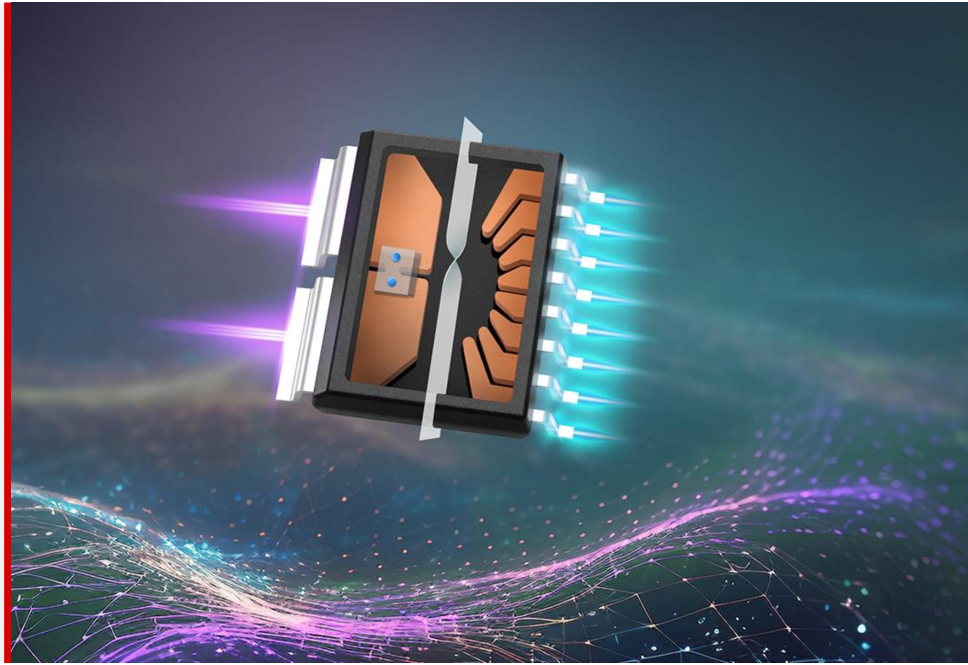
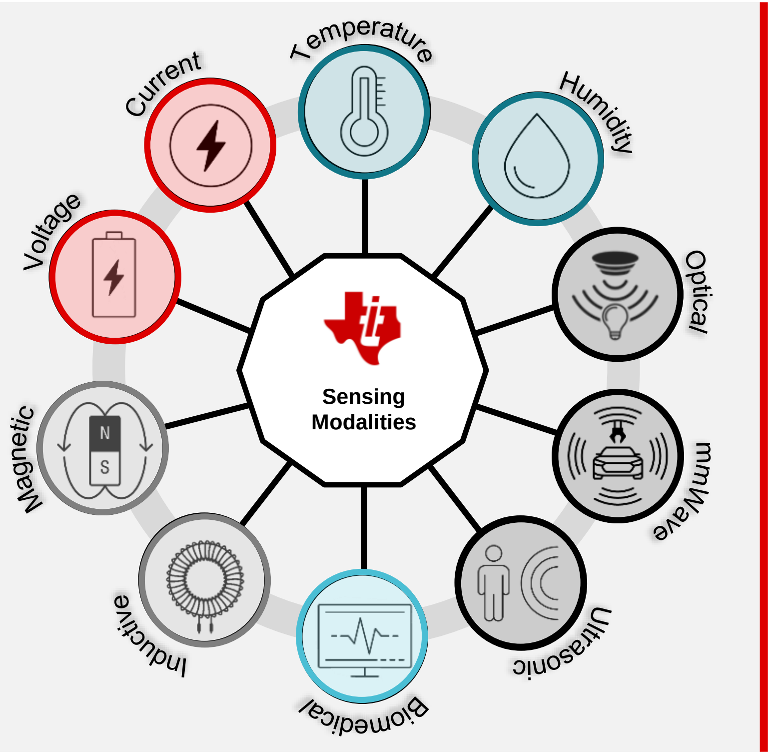


Agenda

- Trends driving High Voltage current sensing
- In-Package Hall-Effect Current Sensing
- Key Applications
- TMCS1123 Family Performance Comparisons



Sensors to accurately measure the real world



Current/Voltage | Environmental | Proximity | Imaging | Position

Actively monitor current for

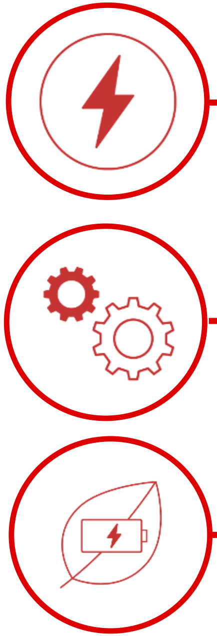
Real-time **overcurrent protection** (protection)

Current and power monitoring for system optimization (telemetry)

Current measurement for **closed-loop circuits** (feedback)

Trends driving sensing technology innovation

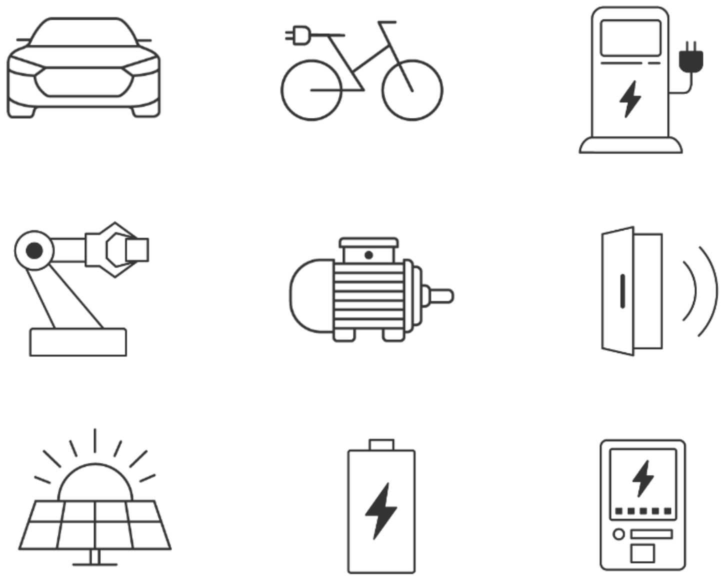
Isolated Current Sensing



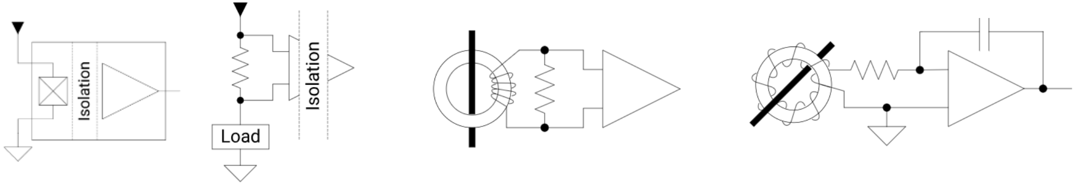
Widespread **electrification** requires precise control and management of power

Advancements in **automation** requires smart, real-time decision-making

Achieving sustainability goals requires efficient **renewable energy** capture, conversion and storage



High voltage current sensing solutions



	Hall-effect sensor	Shunt with isolation	Current transformer	Rogowski coil
DC capable	Yes	Yes	No	No
Current measured	A	mA to A	A to kA	A to MA
Output	Analog	Analog or digital	Analog: signal conditioning required (filter, gain)	Analog: signal conditioning required (integrator, filter, gain)
Bandwidth	Up to 1MHz	Up to 1MHz	Limited by sensor	1MHz and above
Propagation delay	<1μs	1μs to 3μs	>3μs	<1μs
Accuracy	0.9% to 2%	0.1% to 2%	0.1% to 1%	0.2% to 5%
Thermal drift	50ppm/K	25ppm/K to 300ppm/K	<100ppm/K	50ppm/K to 300ppm/K
Power loss	mW	mW to W	mW	mW
Solution size	Small	Medium	Large	Large

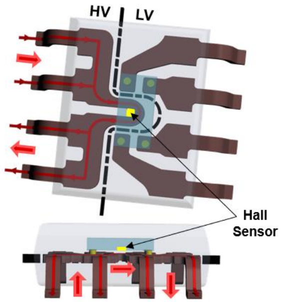
The challenges in accurate high-voltage current sensing

- Growing demand for high reliability and accuracy
- Typical high-accuracy solutions require multiple components and greater design expertise
- High cost-to-performance trade-off
- Hall-effect current sensors historically haven’t met accuracy needs

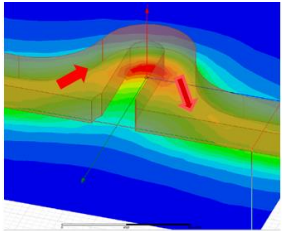
A complex high-voltage power design challenge

In-package MCS fundamentals of operation

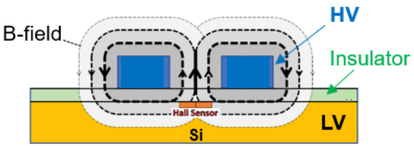
Current flows through lead frame, electrically isolated from die



Lead frame loop generates magnetic field proportional to current



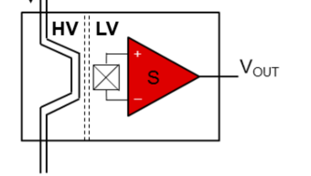
Precision Hall sensor converts magnetic field to voltage signal

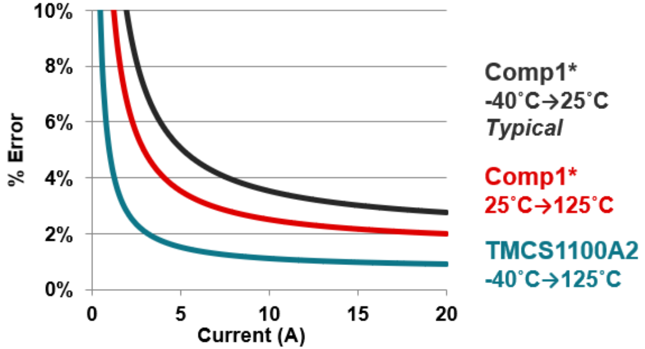


Cross sectional view showing **HV leadframe**, **insulator for increased isolation** capability, and **LV silicon**

Precision Hall sensor converts magnetic field to voltage signal

$$V_{OUT} = S \times I_{IN} + V_{OUT,0A}$$

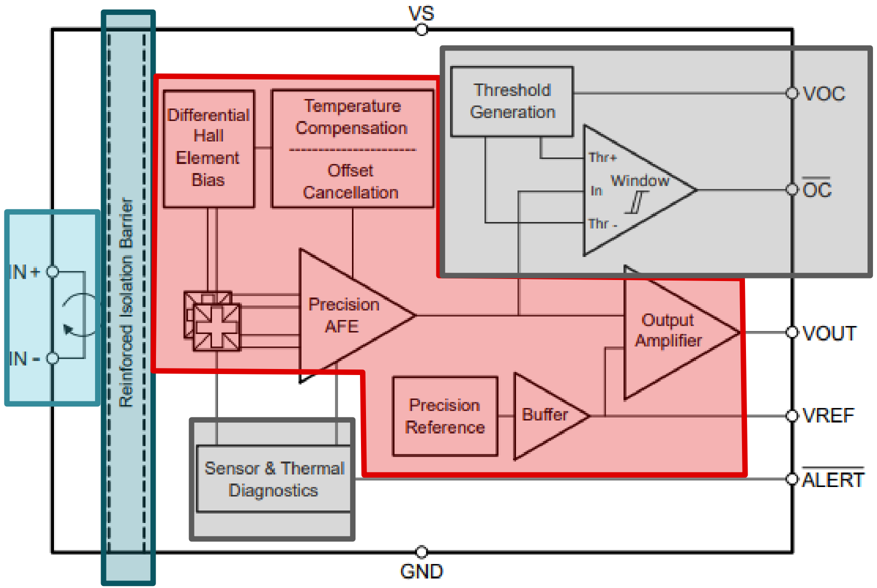




TI signal-chain enables stable measurement over time and temperature!

→ Reduce engineering time and efforts on calibration

TMCS1123: Achieve fast, accurate control in high-voltage systems with the lowest drift Hall-effect current sensor



Combines high accuracy and speed with the **simplicity of a Hall-effect current sensor**

- Highest accuracy Hall-effect current sensor with the **lowest total maximum sensitivity error** over lifetime and temperature (±1.40%)
  - ±0.4% sensitivity error
  - **50 ppm/°C temperature drift**
  - **±0.50% sensitivity lifetime drift**
- **Low propagation delay**: 110ns
- **High reinforced isolation** working voltage (1300 V_{DC})
- **80Arms** continuous current capability at 25C
- **Internal OCP** functionality
- Sensor and thermal **diagnostics**

TMCS new products

*all total errors are over temp (-40 to 125°C) and lifetime
**AFR = ambient field rejection

Existing | New Release

SOIC-8

- *1.8 mΩ Impedance*
- *±30 A_{RMS} @ 25°C*
- *80kHz bandwidth*
- *High Precision*
- *Basic Isolation*

TMCS1100
Total Sensitivity Error ≤ 1%
Sensitivity Drift < 50 ppm/°C
Offset Drift < 50 µV/°C
±600V Basic Isolation
External reference

TMCS1101
Total Sensitivity Error ≤ 1.5%
Sensitivity Drift < 50 ppm/°C
Offset Drift < 50 µV/°C
±600V Basic Isolation
Internal reference

Value-line
TMCS1107
Total Sensitivity Error ≤ 3%
Sensitivity Drift < 100 ppm/°C
Offset Drift < 100 µV/°C
±420V Basic Isolation
Internal reference

Value-line
TMCS1108
Total Sensitivity Error ≤ 3%
Sensitivity Drift < 100 ppm/°C
Offset Drift < 100 µV/°C
±100V Functional Iso
Internal reference

SOIC-16

- *670 µΩ Impedance*
- *±80 A_{RMS} @ 25°C*
- *High Precision*
- *Reinforced Isolation*
- *AFR***

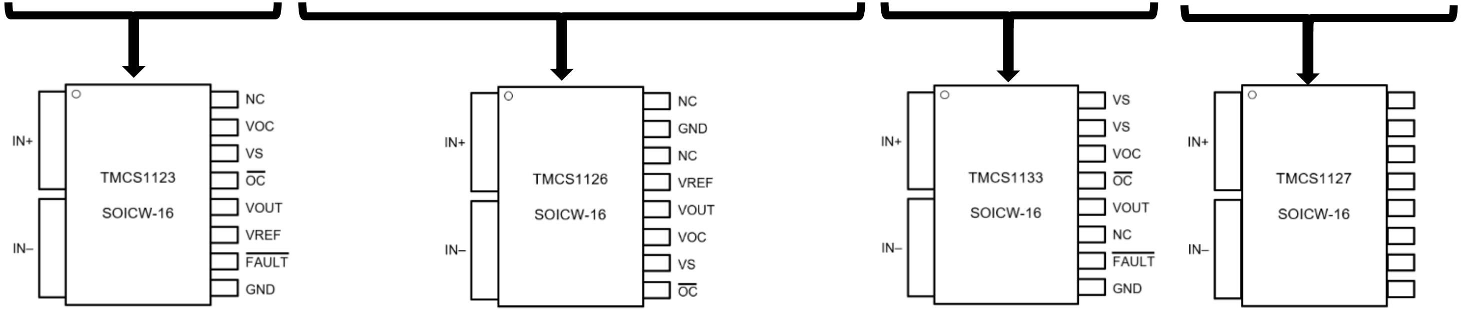
TMCS1123
Total Error ≤ 1.40%
Sensitivity Drift < 50 ppm/°C
Offset Drift < 10 µV/°C
250kHz Bandwidth
< 250 ns OCP comparator

TMCS1126xxA
Total Error ≤ 1.45%
Sensitivity Drift < 50 ppm/°C
Offset Drift < 10 µV/°C
500kHz Bandwidth
< 250 ns OCP comparator

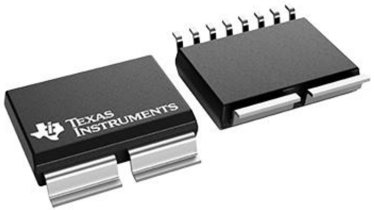
Value-line
TMCS1126xxB
Total Error ≤ 2.5%
Sensitivity Drift < 100 ppm/°C
Offset Drift < 30 µV/°C
500kHz Bandwidth
< 250 ns OCP comparator

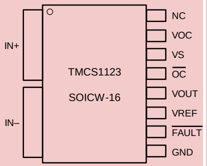
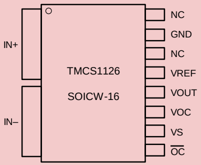
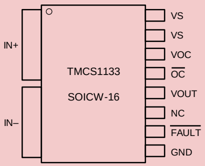
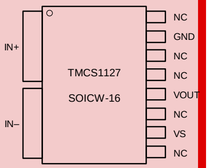
TMCS1133
Total Error ≤ 1.75%
Sensitivity Drift < 50 ppm/°C
Offset Drift < 50 µV/°C
1MHz Bandwidth
< 250 ns OCP comparator

Value-line
TMCS1127
- Total Error ≤ 4%
- Sensitivity Drift < 150 ppm/°C
- Offset Drift < 100 µV/°C
- *250kHz Bandwidth*

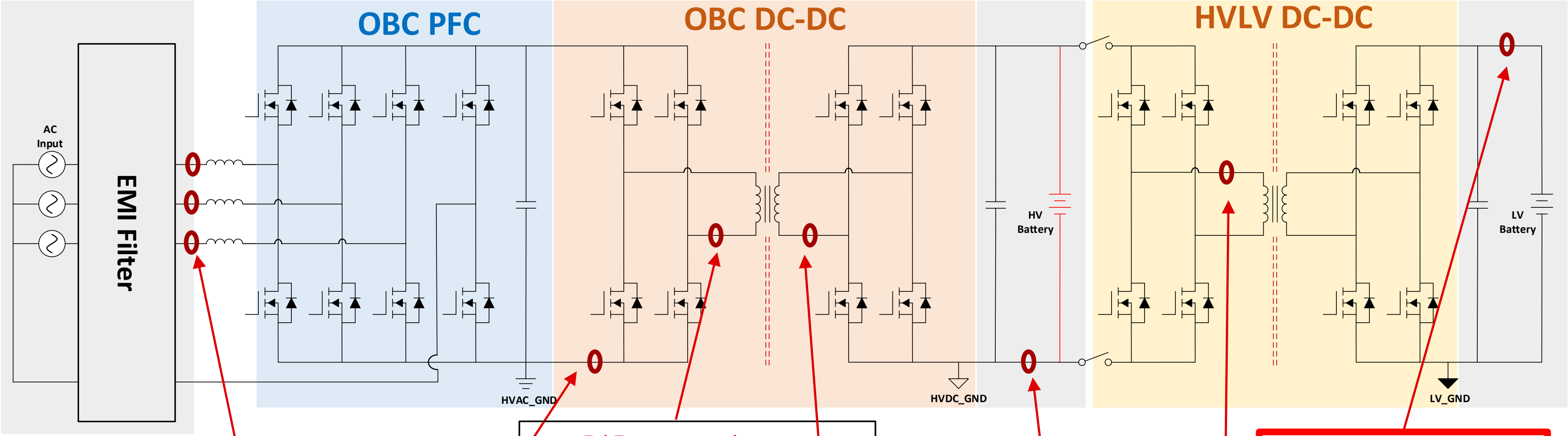


TMCS112x/3x family compatibility



	TMCS1123	TMCS1126	TMCS1133	TMCS1127
Description	High featured, precision	Mid-BW, featured	High BW, precision, featured	Low cost, spec de-rate
Bandwidth	250 kHz	500 kHz	1 MHz	250 kHz
Total Error	≤ 2.5 %	≤ 2.75 %	≤ 3 %	≤ 3.5 %
Internal OCP	Yes	Yes	Yes	No
VREF Output	Yes	Yes	No	No
FAULT Output	Yes	No	Yes	No
Pinout				
Key Market(s)	Motor Drives, Solar	HEV/EV OBC, Solar	Inverter & Motor Control, OBC, UPS	Solar, Telecom & Server Power

Current sensing in 3-ohase OBC (PFC + DCDC) & HVLV DCDC



HV AC current Sensing
- PFC current control loop
- OCP and monitoring

Pri Resonant tank current
- SR using ZCD in reverse direction
- Needed in bidirectional
- Protection

HV DC current Sensing
- **Isolated/Non-isolated***
- Return current of Sec DCDC
- Battery current control loop

LV sec current Sensing
- **Non-isolated**
- Battery current control loop
- Protection

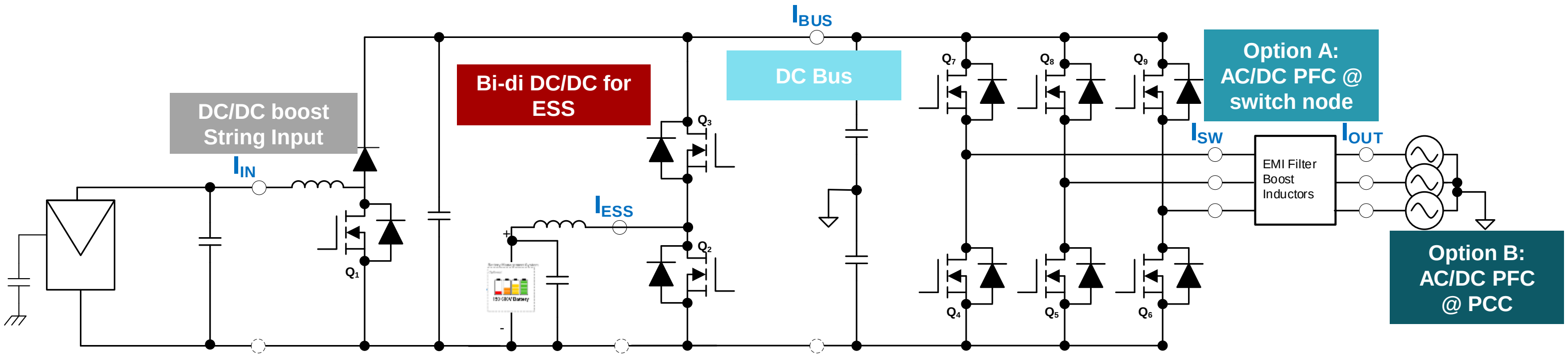
DC-link current Sensing
- Return current of Pri DCDC
- OCP and monitoring

Sec Resonant tank current
- SR using ZCD in forward direction
- Protection

HV Pri current Sensing
- Peak current control loop
- OCP and monitoring

*depends on MCU Architecture

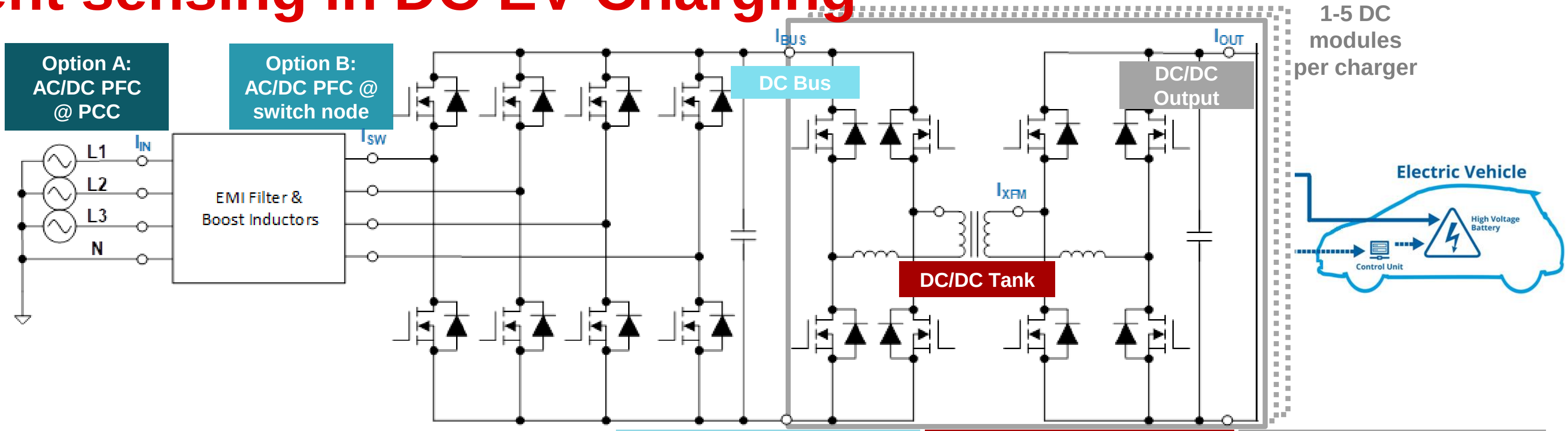
Control loop current sensing – Solar inverter (hybrid/ESS)



		DC/DC boost String Input	Bi-di DC/DC for ESS	DC Bus	A: AC/DC PFC @ switch node	B: AC/DC PFC @ PCC
Current characteristics		I_{IN} 12A x # string $I_{IN(max)}$ 15A x # string 100's kHz inductor current	I_{ESS} 15 - 30A, $I_{ESS(max)}$ 2.5 x I_{ESS} 100's kHz inductor current	$I_{BUS\ 10\text{-}20A}$ $I_{BUS(max)}$ 1.5 x I_{BUS} PFC SW freq ripple (~100kHz) Low freq ripple 6 x line frequency	I_{SW} 16A@11kW, $I_{SW(max)}$ 1.5 x I_{SW} 50/60Hz (7 harm.) line frequency <100kHz switching	I_{OUT} 16A@11kW , $I_{OUT(max)}$ 1.5 x I_{OUT} 50/60Hz (7 harm.) line freq
Sensor specs	**Type**	In-package hall sensor	In-package hall sensor	In-package hall sensor	Shunt-based, In-package hall sensor	Shunt-based (iso power) Toroid-based hall, Fluxgate
	Current range	<25A	<50A	<50A	25A @ 11kW (current scales with power)	25A @ 11kW (current scales with power)
	Bandwidth	300kHz (control)	300kHz (control)	200kHz (control)	200kHz (control)	20kHz (control)
	Latency	< 1us (protection)	< 1us (protection)	< 1us (protection)	1us – 3us (protection)[1]	< 2-3us (control)[2]
	Accuracy	< 2% over temp & current range	< 2% over temp & current range	< 2% over temp & current range	< 1% over temp & current range	< 1% over temp & current range

[1] Gate driver without DESAT and OC protection needs lower latency (~1us). [2] Current sensor in PCC require DESAT and OC protection in gate driver

Current sensing in DC EV Charging

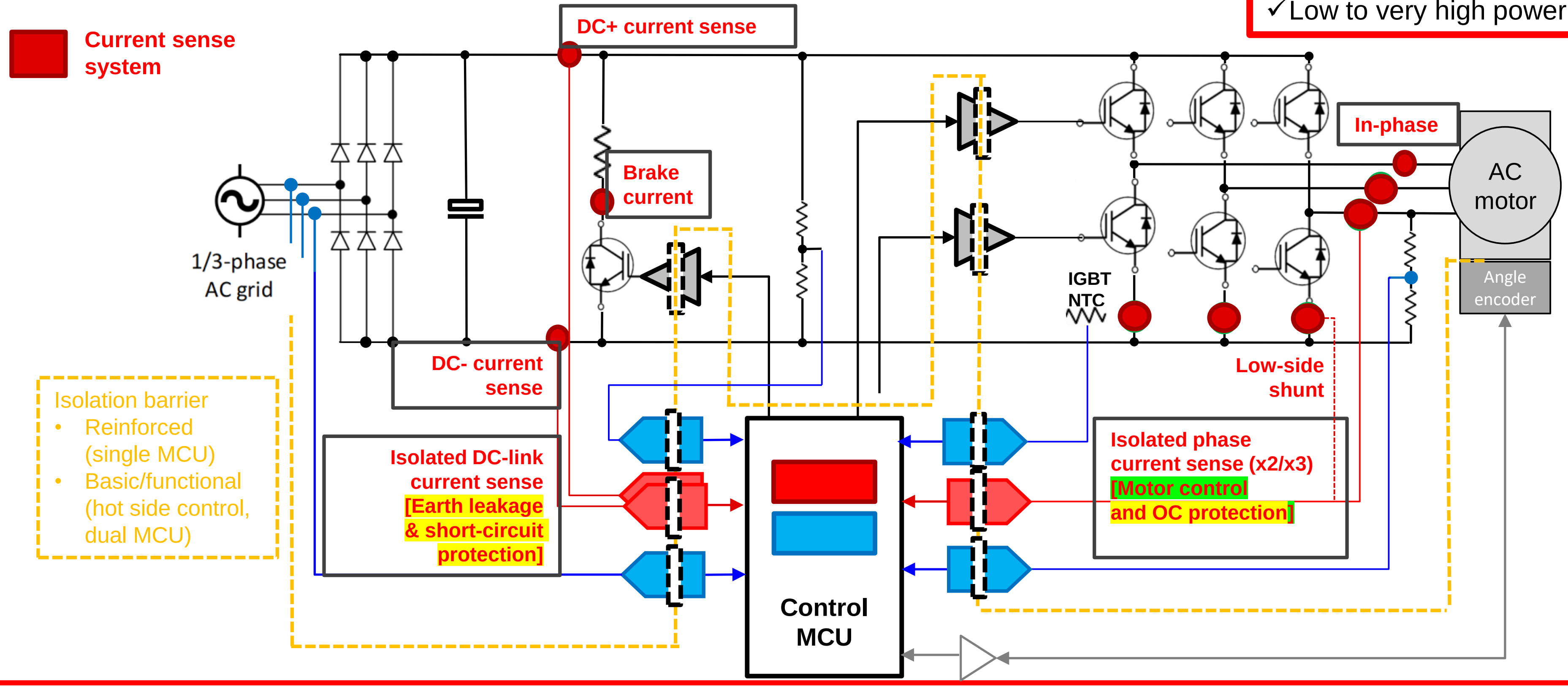


		AC/DC PFC				
		Option A: @ PCC	**Option B: @ SW node**	**DC Bus**	**DC/DC Tank**	**DC/DC Output**
Current characteristics		I_{In}: 100's kHz inductor current, 50/60Hz (7 harm.) line freq & control	I_{SW}: 100's kHz inductor current, 50/60Hz (7 harm.) line freq protection & control	I_{BUS}: PFC SW freq ripple (~100kHz) Low freq ripple 6 x line frequency for protection	I_{XFM}: SR(ZCD) for CLLLC topology. Flux balancing for multi-phase shifts like in DAB topology	I_{OUT}: DC/DC SW freq ripple (~100kHz for phase-shifted, ~500 kHz for CLLLC); protection & metering
# of Sockets		2-4 (phase dependent)	2-4 (phase dependent)	1-3 (depending on modules)	1-2 per module	1 per module
Sensor specs	**Type**	**In-package hall sensor**, Shunt-based (iso power), Fluxgate, CT	**In-package hall sensor**, Shunt-based	In-package hall sensor	**CT**, In-package hall Sensor	**In-package hall Sensor**, Shunt-based, Fluxgate
	Current	<150 A (300 A pk)	<150A (300Apeak)	<250 A (450 A pk)	<125A (e.g. 50kW module)	<125A (e.g. 50kW module)
	Bandwidth	>10 kHz (e.g. 20 kHz)	>200 kHz (e.g. 200 kHz)	>10 kHz (e.g. 50 kHz)	>1Mhz	>10 kHz
	Latency	< 1us (control)[1]	< 1us (protection), < 1us (control)[1]	< 1us (protection)	< 100 ns (control)[1] CLLLC < 1 us (control)[1] DAB	< 1us (protection)
	Accuracy	< 1% over temp & current range	< 3% over temp & current range	< 1% over temp & current range	< 2% over temp & current range	< 1% over temp & current range

[1] Latency requirements varies based on analog front end and filtering. Latency requirement may be shorter to simplify calibration

System overview: Current sensing subsystems in AC inverters / servo drives

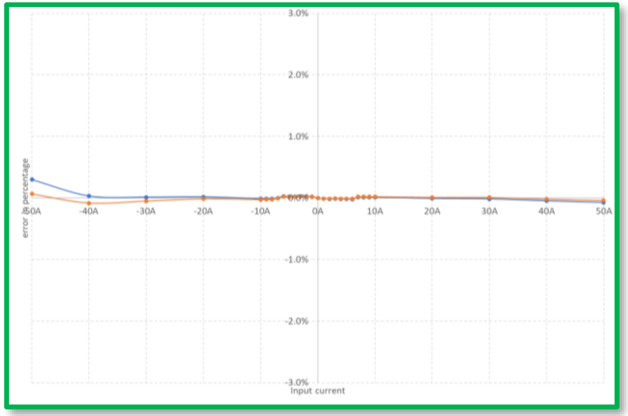
✓Variable speed
✓Low to very high power



Comparisons versus competition

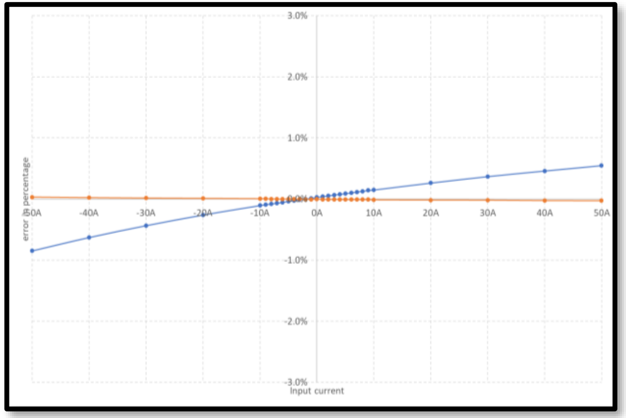
Accuracy – DC Measurement

TMCS1123: error vs input current



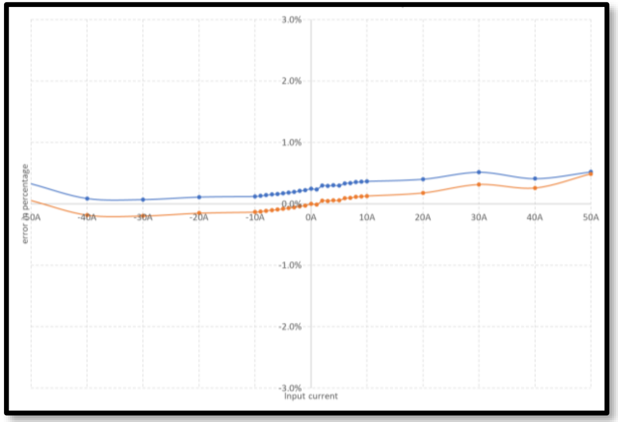
<0.5% error before calibration and <<1% after calibration
(Proto-units have been trimmed only at one Temp)

Competitor module: error vs input current



<0.8% error before calibration and <<1% after calibration
(gain error predominantly)

Competitor in-package hall: error vs input current



<<1% error before and after calibration

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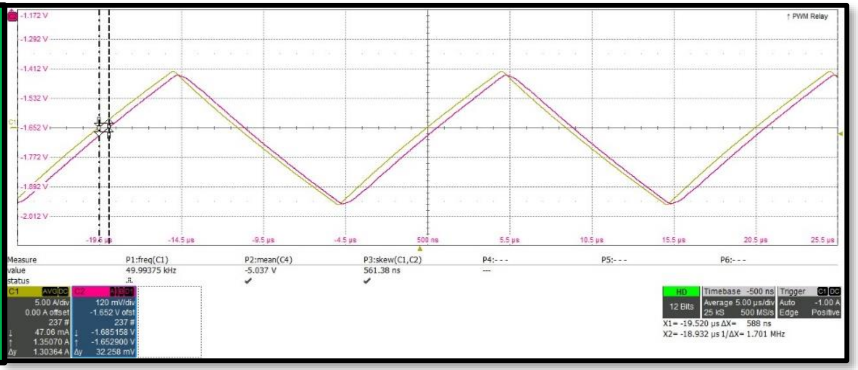
Comparisons versus competition

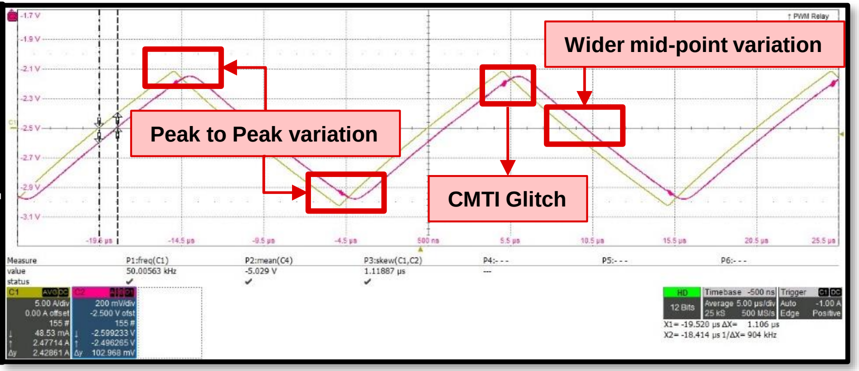
Propagation Delay – transient measurements (+10A /- 12A at 50kHz)

TMCS1123



TMCS1123:
BW ~250kHz not limiting, t_{PROP} ~0.6us

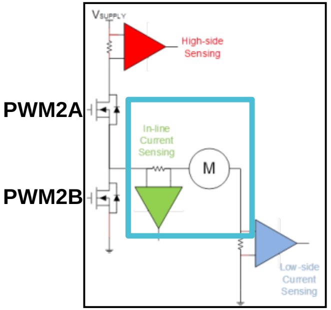
Competitor



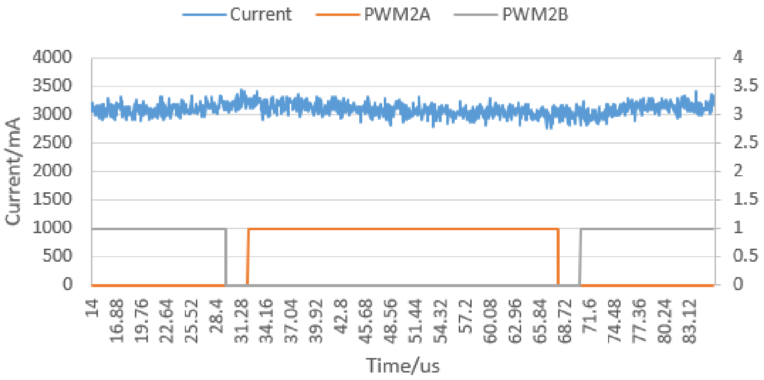
Competitive In-Package Hall-Effect Current Sensor:
BW ~400kHz limiting, no distortion, t_{PROP} ~1.1us

Common mode transient immunity

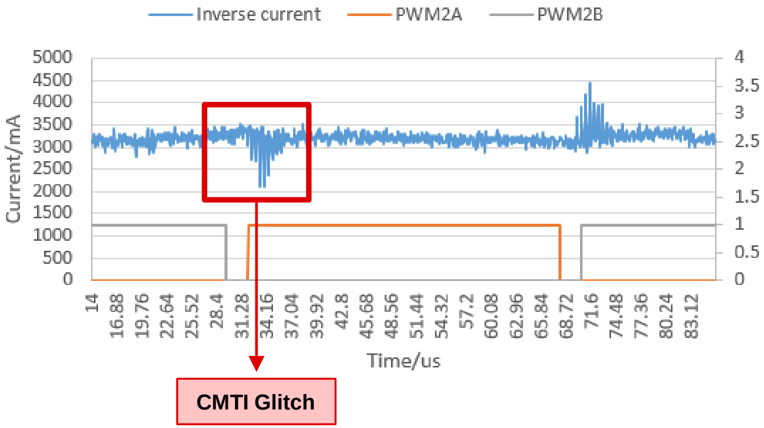
Square Wave – 300VDC in, 3A out



TMCS1123

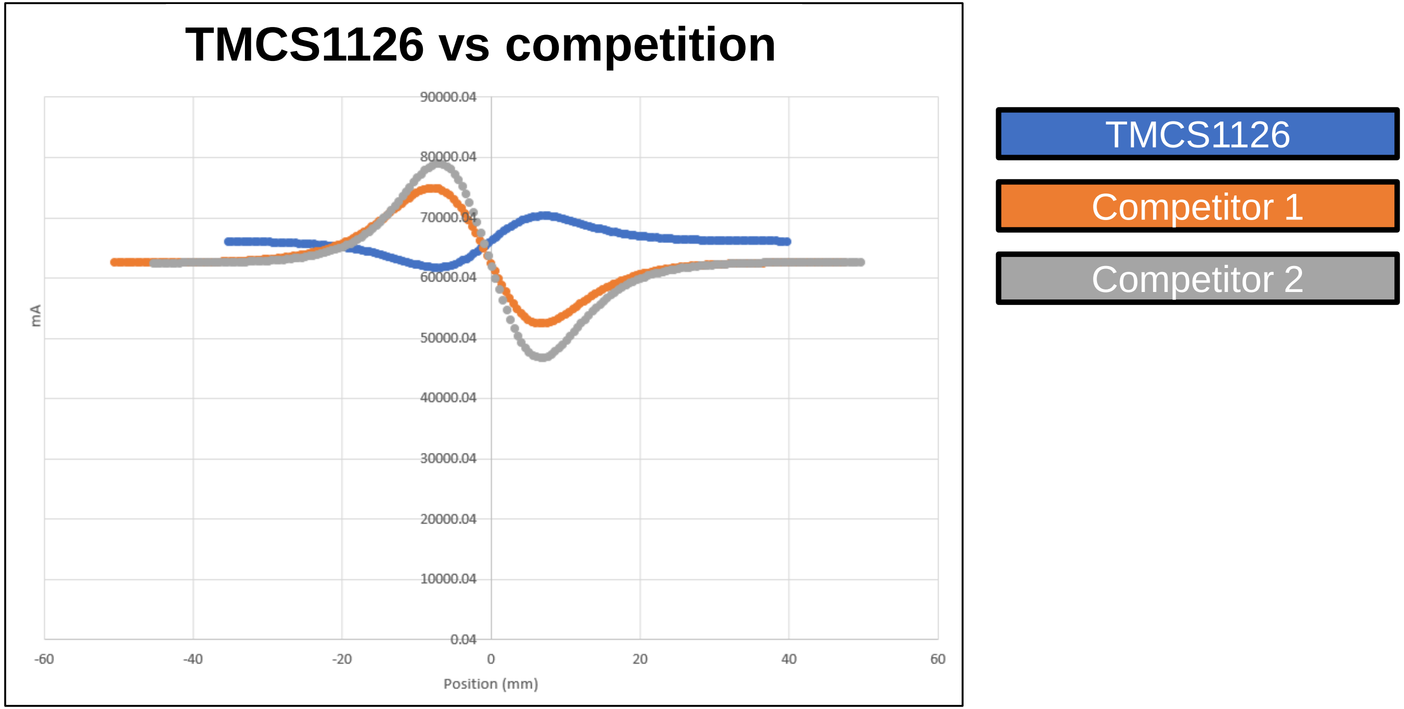


Competitive In-Package Hall Effect Current Sensor



Ambient field rejection

Rejection of stray magnetic fields



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Thermal management

Data taken on TMCS1126xEVM (650uW)

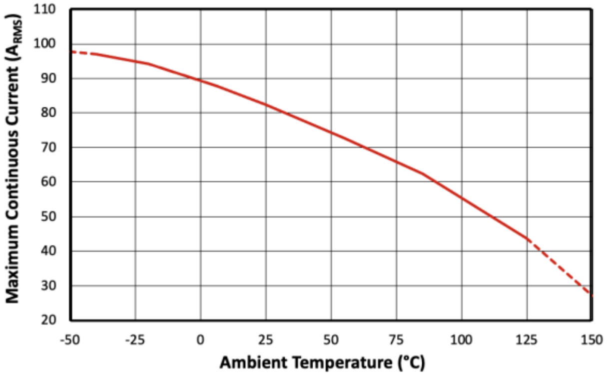

Figure 7-4. Maximum Continuous RMS Current vs Ambient Temperature

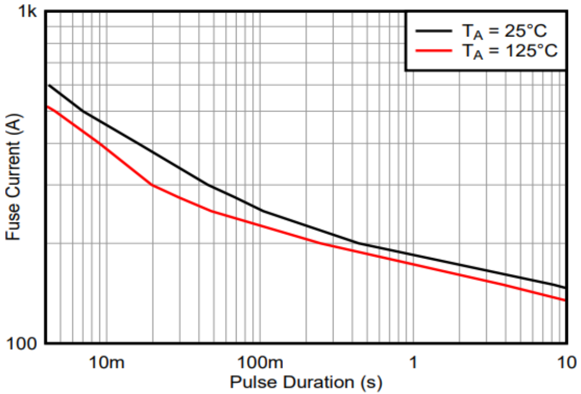

Figure 7-9. Single-Pulse Leadframe Capability

Thank You

Learn more at TI.com/CurrentSensing for more information.