Non-isolated Current Sensing in Low Voltage Battery Management System (BMS)

Key Considerations

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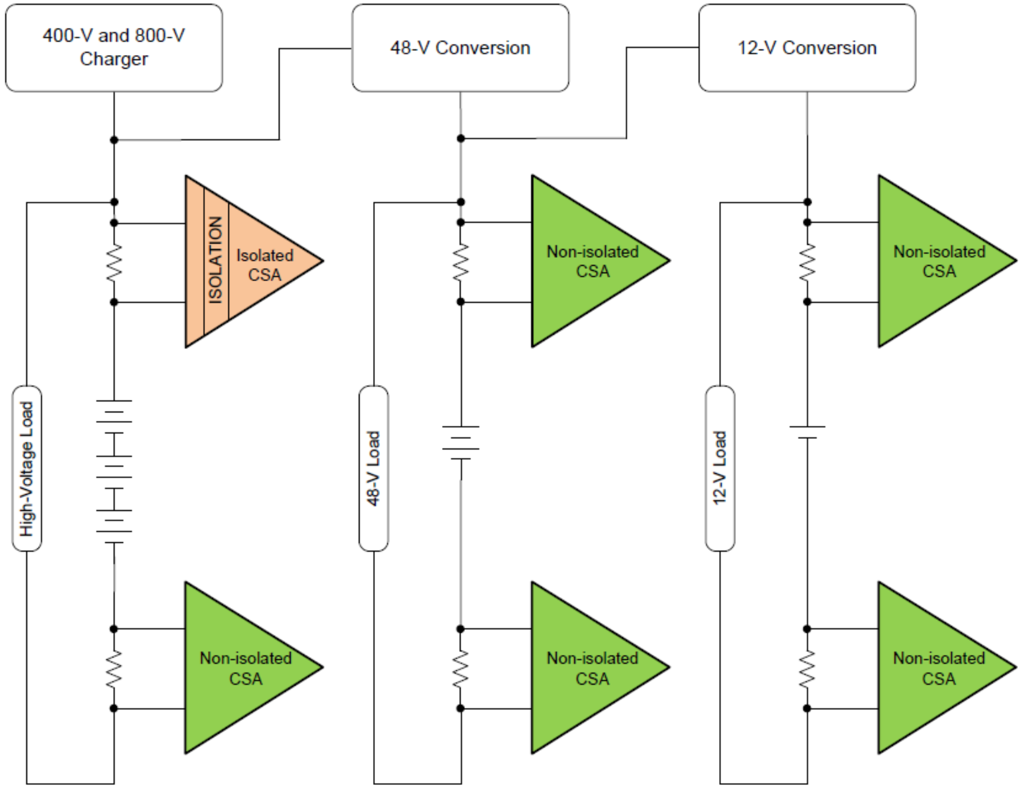
Topics

- Current sensing configuration in BMS
- Nonisolated shunt based current sensing in BMS and charging system
- How to size the shunt resistor
- Key specification of the CSA and how to choose the right CSA

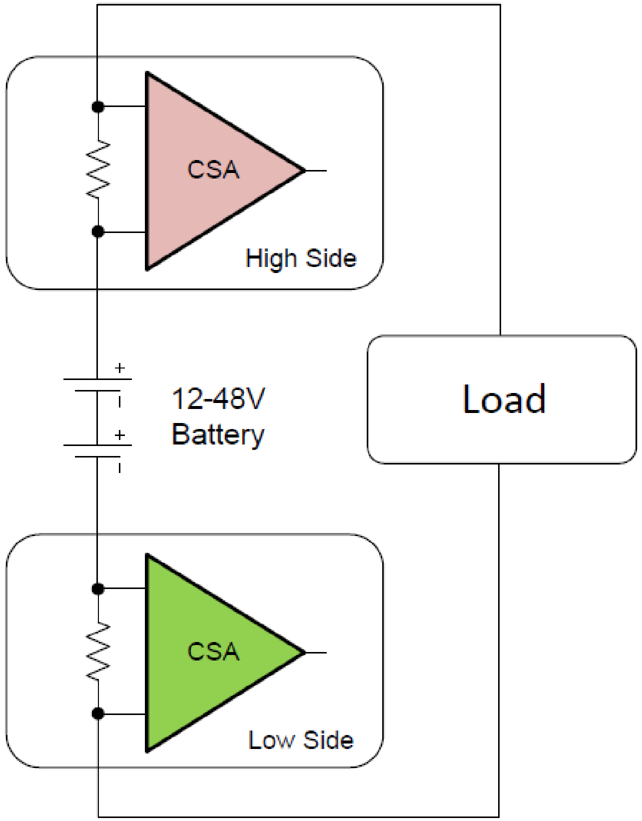
Overview of shunt based current sensing in EV BMS – Location Matters!

- Top of stack
  - High voltage battery system –
    - Isolated current sensing device, including magnetic.
    - Floating supply - With the help of special circuit techniques and isolation devices, a low voltage CSA can sometimes be adapted for high voltage applications see the next couple of slides
  - Low voltage battery system –
    - 12V to 48V
    - Possible to use CSA directly
- Bottom of stack
  - The common mode voltage requirement is less stringent
  - Much wider selection of CSA
- Challenges of current sensing BMS
  - Wide current range
  - Accuracy requirement at both the high and low end of the current range.



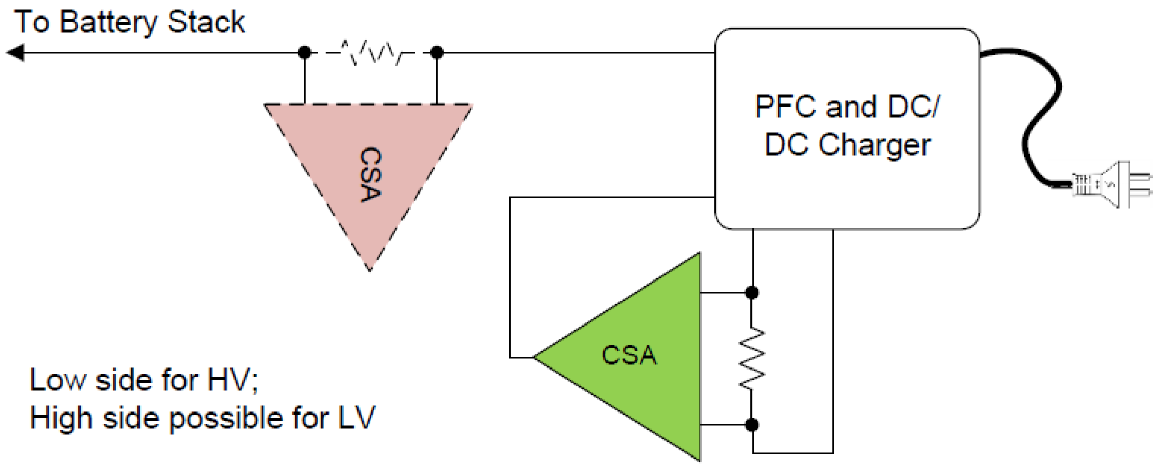
Non-Isolated CSA for BMS

- Compared to isolated CSA, non-isolated CSA has the following advantages
  - Simple to implement
  - low cost
  - excellent linearity,
  - Accuracy
- However it has the following drawbacks
  - Invasive
  - Shunt resistor dissipates power in the form of heat
  - Common mode input range may limit CSM to low side configuration



Non-Isolated CSA in Vehicle Charger

- Types of battery technology
  - Li-Ion
  - Lead acid
  - Other Less common but actively researched
- Why is current sensing required in chargers
  - Maintain a specific charging profile
  - Safety
- Challenges
  - Large current range
  - Common mode voltage



How to size the shunt resistor for BMS application

- Shunt resistor is determined by:
  - Upper bound – power dissipation
  - Lower bound – minimum detectable current
- An example
  - Max current 100A; min current 1A
  - With max Rshunt=1mΩ, $P = I^2R = (100A)^2 \times 1\text{m}\Omega = 10\mathcal{W}!$
  - What about 100uΩshunt? $P = I^2R = (100A)^2 \times 100u\Omega = 1\mathcal{W}$
  - At lowest current, $V_{sense} = IR = (1A) \times 100u\Omega = 100\mu V$
- The final Rshunt also depends on the accuracy requirement and which CSA to choose
  - If $V_{os} = \pm 100\mu V$, effective total input to the ideal CSA is $V_{in} = 100\mu V \pm 100\mu V = 0\mu V\ to\ 200\mu V$. Then $100u\Omega$ is probably too small
  - If $V_{os} = \pm 10\mu V$, then the effective total input to the ideal CSA is $V_{in} = 100\mu V \pm 10\mu V = 90\mu V\ to\ 110\mu V$.

Current Sensing Key Considerations

- **Configuration**
  - High side; Low side
- **Directionality**
  - Uni-directional swing; Bi-directional swing
- **Output**
  - Analog (voltage/current); Digital
  - Integrated shunt
- **Speed**
  - System bandwidth
- **DC error sources**
  - Vos; Gain error; CMRR; PSRR; IB;
- **Noise**
- **Temperature drift**

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INA240

SBOS662B – JULY 2016 – REVISED FEBRUARY 2018

INA240 High- and Low-Side, Bidirectional, Zero-Drift, Current-Sense Amplifier With Enhanced PWM Rejection

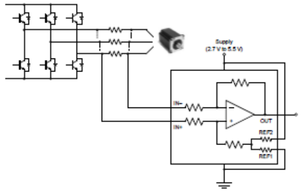
1 Features

- Enhanced PWM Rejection
- Excellent CMRR:
  - 132-dB DC CMRR
  - 93-dB AC CMRR at 50 kHz
- Wide Common-Mode Range: –4 V to 80 V
- Accuracy:
  - Gain:
    - Gain Error: 0.20% (Maximum)
    - Gain Drift: 2.5 ppm/°C (Maximum)
  - Offset:
    - Offset Voltage: ±25 µV (Maximum)
    - Offset Drift: 250 nV/°C (Maximum)
- Available Gains:
  - INA240A1: 20 V/V
  - INA240A2: 50 V/V
  - INA240A3: 100 V/V
  - INA240A4: 200 V/V
- Quiescent Current: 2.4 mA (Maximum)

2 Applications

- Motor Controls
- Solenoid and Valve Controls
- Power Management
- Actuator Controls
- Pressure Regulators
- Telecom Equipment

Typical Application



3 Description

The INA240 device is a voltage-output, current-sense amplifier with enhanced PWM rejection that can sense drops across shunt resistors over a wide common-mode voltage range from –4 V to 80 V, independent of the supply voltage. The negative common-mode voltage allows the device to operate below ground, accommodating the flyback period of typical solenoid applications. Enhanced PWM rejection provides high levels of suppression for large common-mode transients (ΔV/Δt) in systems that use pulse width modulation (PWM) signals (such as motor drives and solenoid control systems). This feature allows for accurate current measurements without large transients and associated recovery ripple on the output voltage.

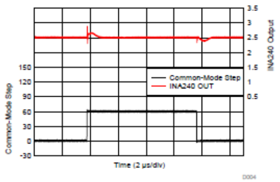
This device operates from a single 2.7-V to 5.5-V power supply, drawing a maximum of 2.4 mA of supply current. Four fixed gains are available: 20 V/V, 50 V/V, 100 V/V, and 200 V/V. The low offset of the zero-drift architecture enables current sensing with maximum drops across the shunt as low as 10-mV full-scale. All versions are specified over the extended operating temperature range (–40°C to +125°C), and are offered in an 8-pin TSSOP and 8-pin SOIC packages.

Device Information(1)

PART NUMBER	PACKAGE	BODY SIZE (NOM)
INA240	TSSOP (8)	3.00 mm × 4.40 mm
	SOIC (8)	4.00 mm × 3.91 mm

(1) For all available packages, see the orderable addendum at the end of the data sheet.

Enhanced PWM Rejection



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7.5 Electrical Characteristics

at T_A = 25 °C, VS = 5 V, $V_{SENSE} = V_{IN+} – V_{IN–}$, V_{CM} = 12 V, and $V_{REF1} = V_{REF2} = V_S / 2$ (unless otherwise noted)

PARAMETER		TEST CONDITIONS	MIN	TYP	MAX	UNIT
INPUT						
V_{CM}	Common-mode input range	V_{IN+} = –4 V to 80 V, V_{SENSE} = 0 mV; T_A = – 40°C to 125°C	–4		80	V
CMRR	Common-mode rejection ratio	V_{IN+} = –4 V to 80 V, V_{SENSE} = 0 mV; T_A = –40°C to 125°C	120	132		dB
		f = 50 kHz		93		
V_{OS}	Offset voltage, input-referred	V_{SENSE} = 0 mV		±5	±25	µV
dV_{OS}/dT	Offset voltage drift	V_{SENSE} = 0 mV, T_A = –40°C to 125°C		±50	±250	nV/°C
PSRR	Power-supply rejection ratio	V_S = 2.7 V to 5.5 V, V_{SENSE} = 0 mV; T_A = –40°C to 125°C		±1	±10	µV/V
I_B	Input bias current	I_{B+}, $I_{B–}$, V_{SENSE} = 0 mV		90		µA
	Reference input range		0		V_S	V
OUTPUT						
G	Gain	INA240A1		20		V/V
		INA240A2		50		
		INA240A3		100		
		INA240A4		200		
	Gain error	GND + 50 mV ≤ V_{OUT} ≤ V_S – 200 mV		±0.05%	±0.20%	
		T_A = –40°C to 125°C		±0.5	±2.5	ppm/°C
	Non-linearity error	GND + 10 mV ≤ V_{OUT} ≤ V_S – 200 mV		±0.01%		
	Reference divider accuracy	V_{OUT} = | (V_{REF1} – V_{REF2}) | / 2 at V_{SENSE} = 0 mV, T_A = –40°C to 125°C		0.02%	0.1%	
RVRR	Reference voltage rejection ratio (input-referred)	INA240A1		20		µV/V
		INA240A3		5		
		INA240A2, INA240A4		2		
	Maximum capacitive load	No sustained oscillation		1		nF
VOLTAGE OUTPUT(1)						
	Swing to V_S power-supply rail	R_L = 10 kΩ to GND; T_A = –40°C to 125°C		V_S – 0.05	V_S – 0.2	V
	Swing to GND	R_L = 10 kΩ to GND, V_{SENSE} = 0 mV; V_{REF1} = V_{REF2} = 0 V, T_A = –40°C to 125°C		V_{GND} + 1	V_{GND} + 10	mV
FREQUENCY RESPONSE						
BW	Bandwidth	All gains, –3-dB bandwidth		400		kHz
		All gains, 2% THD+N(2)		100		
	Settling time - output settles to 0.5% of final value	INA240A1		9.6		µs
		INA240A4		9.8		
SR	Slew rate			2		V/µs
NOISE (INPUT REFERRED)						
	Voltage noise density			40		nV/√Hz
POWER SUPPLY						
V_S	Operating voltage range	T_A = –40°C to 125°C	2.7		5.5	V
I_Q	Quiescent current	V_{SENSE} = 0 mV		1.8	2.4	mA
		I_Q vs temperature, T_A = –40°C to 125°C			2.6	
TEMPERATURE RANGE						
	Specified range		–40		125	°C

(1) See Figure 13.
(2) See the *Input Signal Bandwidth* section for more details.

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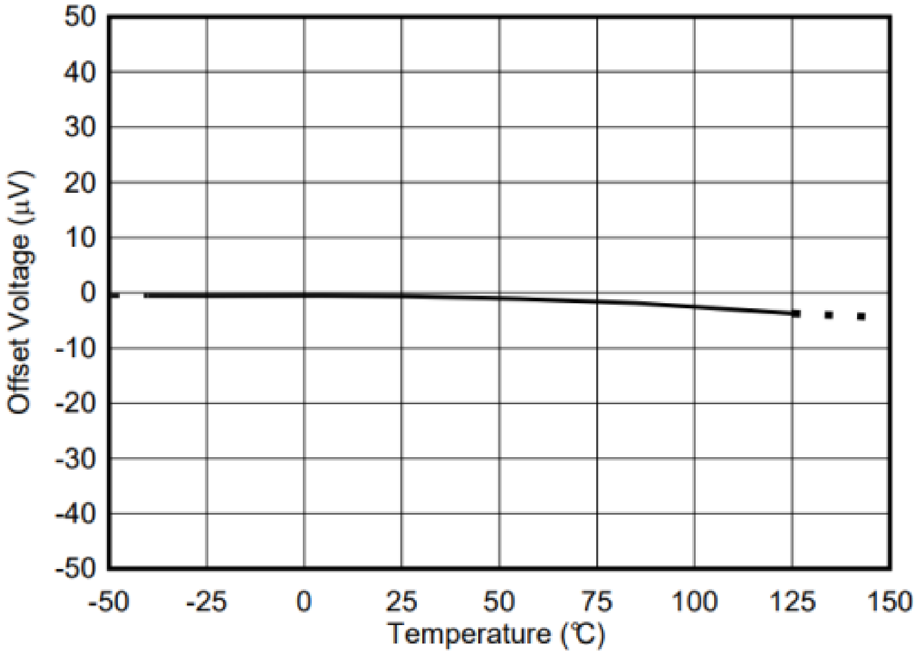
CSA Specification – Temperature Drift Example

- The best
  - Room temp Vos 25uV; Drift: 250nV/ºC;
- At 105ºC
  - Vos<= 25+0.25*80= 45uV
- A good, but not the best:
  - Identical room temp spec; Drift: 1uV/ºC
  - Vos<= 25+1*80= 105uV



For more info ***www.ti.com/currentsense***