ACS37030/2 HIGH-BANDWIDTH 5 MHZ CURRENT SENSOR ENABLES HIGH-SPEED CONTROL AND PROTECTION IN POWER CONVERTER APPLICATIONS

Current Sensors System Engineering
Allegro MicroSystems

INTRODUCTION

SiC and GaN switches are enabling power conversion systems to switch at higher frequencies than standard MOSFET switches. To maximize the benefit from these new technologies, the control and sensing methodology needs to advance as well. The ACS37030/2 is the first integrated 5 MHz bandwidth current sensor, which enables these systems to extract more benefit from these faster and lower-loss switches.

The ACS37030/2 accomplishes this leap forward in sensing speed by integrating on-chip coils alongside the industry-leading Hall-effect sensing technology Allegro has developed. While low-frequency signal content is measured by the differential Hall path, on-chip coil transducers pick up the higher-frequency signal content. The low- and high-frequency signals are added together for a flat frequency response from DC all the way up to 5 MHz, all from one sensor.

The ACS37030/2 comes in the custom SOIC-6 LZ package (see Figure 1). This device has four signal pins, including VDD, GND, VOUT, and FAULT (ACS37032) or VREF (ACS37030). For the ACS37030/2 package pinout, refer to Figure 2.

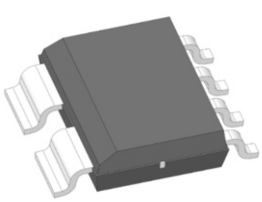

Figure 1 : 6-pin SOIC (Suffix LZ) Package

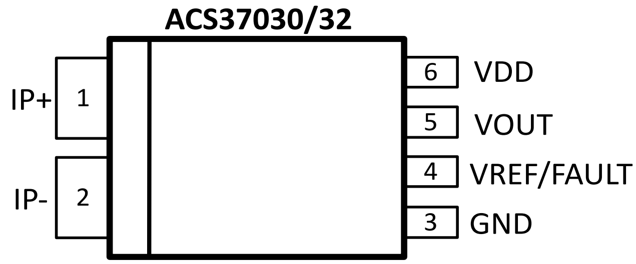

Figure 2: ACS37030/2 Pinout Diagram

The ACS37032 comes with pin 4 configured as an overcurrent FAULT detection circuit on chip, which reports high-current transients to the system within 150 µs. With high bandwidth and high-speed protection, system integrators can safely and efficiently use SiC and GaN switches to reduce system size and cost while increasing efficiency.

There are many benefits to integrated magnetic current sensing compared to the other high-speed current sensing methods. Resistive-based current sensing methods incur increased losses as current increases. Shunt solutions also must account for the inductance of the shunt changing the overall impedance across the frequency range of interest. Additionally, resistive-based methods must also trade off signal-to-noise ratio (SNR) for power loss by choosing the correct size resistor. Current transforms cannot capture DC content and saturate in the presence of DC current. Hall-effect sensors provide an elegant and lossless way to measure current in DC-DC converters while their small footprint allows the freedom to place the sensor anywhere in the system.

This document compares the bandwidth, isolation, and current capability of the ACS37030/2 current sensor to other sensing methods. Power converters have many design topologies; topics discussed in this application note can be applied to other power configurations more generally.

Table 1: System Operating Conditions and Sensing Methods Summary

Location	Current Shape	Voltage	Shunt	Current Transformer	Hall-Effect Sensor
1A	Positive Slope	Input Voltage	Isolation Required	AC Current	No Issue
1B	Positive Slope	Switching	Isolation Required	AC Current	No Issue
2A	Triangular	Switching	Isolation Required	DC Current	No Issue
2B	Triangular	Output Voltage	Isolation Required	DC Current	No Issue
3	Load Current	Output Voltage	Isolation Required	DC Current	No Issue
4	Negative Slope	Ground	Grounded	AC Current	No Issue

SENSING LOCATIONS

Depending on the control scheme employed by the system, different data about the current may be required to drive the current control feedback. The basic system architecture for a buck converter, including multiple possible current sensing locations, is shown in Figure 3. For descriptions of the signals at each node, refer to Table 1.

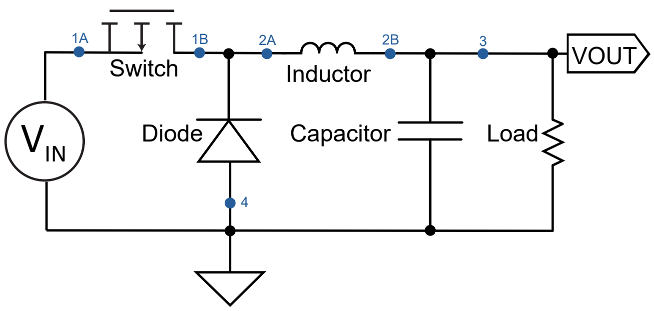

Figure 3: Basic Buck Converter Architecture

Sensors in location 1 (1A and 1B) can sense the positive slope current, sensors in location 2 (2A and 2B) can monitor the full triangular waveform, and sensors in location 4 can sense the negative slope current. The advantage of sensing in location 4 is that the voltage does not switch because that node is tied to ground. Locations 1B and 2A switch from ground to the input voltage, and 1A and 2B sit at the input and output voltages, respectively. Location 3 is held at the output voltage but does not measure the inductor current—only the output current draw. The construction of Allegro Hall-effect current sensors inherently offers galvanic isolation. This allows the output of the sensor to be routed directly to the microprocessor without the need for additional or external isolation when the primary side is at a high voltage relative to the device ground.

Other sensing techniques require extra consideration in some circuit locations. Use of a shunt resistor in any location other than location 4 requires an extra layer of isolation between the output signal and the controller. Current transformers cannot measure signals with DC content and have core saturation and output droop behaviors that must be designed around. If the current transformer measures switch current in locations 1A, 1B, or 4, the allowable duty cycle becomes restricted to allow the current transformer to reset properly.

COMPARING SENSING METHODS

Shunt-based solutions in high-power systems, especially on the low-voltage high-current side, incur resistive losses. To reduce the resistance and maintain an acceptable level of heating, high-power resistors become larger in size. This larger size comes with the drawback of increased inductance. When the shunt is inline with the switching current, the inductance causes voltage spikes at the switching events. The need for an amplifier between the shunt and the system controller further increases the total solution size and cost. Allegro current sensor ICs have internal, integrated conductors with resistances varying from 0.27 to 1.2 mΩ, and inductances ranging from 2 to 5 nH (for LZ package resistance and inductance, refer to Table 2). Because the magnetic field, not the voltage, is sensed, the Hall-effect sensing method is immune to the disturbances caused by the internal inductance.

Table 2: Primary Conductor Resistance and Inductance of Select Current Sensor Packages

Package	Resistance [mΩ]	Inductance [nH]
 6-Pin SOIC: LZ	0.68	2.4

The inherent isolation between the primary and secondary sides makes current transformers popular for sensing high levels of AC current. DC current can saturate current transformers. A larger core may have to be chosen to accommodate the DC current content and still resolve the AC ripple out of the current transformer. Current transformers also need to reset, and allotting time for this reset limits the maximum operating duty cycle of the system. Depending on the switching frequency, the size of current transformers can be considerably larger than an SOIC-8 package.

The ideal location for current sensing in the DC-DC converter is directly inline with the inductor current, allowing the sensor to capture the full current waveform. This allows the system designer to use any control technique in their design: peak, valley, average, etc. In location 2B, this waveform is captured in its entirety, and the voltage level should be stable due to the output filter capacitor.

The immunity of Allegro current sensors to the conditions on the primary side allows for their use in any of the locations in the DC-DC converter, and simplifies the bill of materials if multiple currents in the system need to be sensed.

Allegro current sensors also have the benefit of integrated features, such as reference voltages for differential trace routing and on-chip overcurrent fault detection. The operating conditions at different locations in the system shown in Figure 3 and comments on the performance of different sensing methods are shown in Table 1.

BANDWIDTH AND STEP RESPONSE

As switching losses decrease in power MOSFETs, the switching frequency can be increased while maintaining the same power efficiency. The major benefit of faster switching is achieving the same performance with smaller discrete components. Inductors, capacitors, and transformers are often the largest components in DC-DC converter systems. Decreasing the size of these components has a significant impact in decreasing the size of the overall system. Because the time between cycles is shorter, the passive components do not need to store as much energy between switching events, allowing their value, and therefore their size, to decrease.

The concern with increasing the switching speed is that the system controller must still be able to adequately regulate the output voltage. To meet these fast-switching needs, Allegro has developed the ACS37030/2 to be 5 MHz capable. While control can be accomplished with the average inductor current, using the peak current level offers

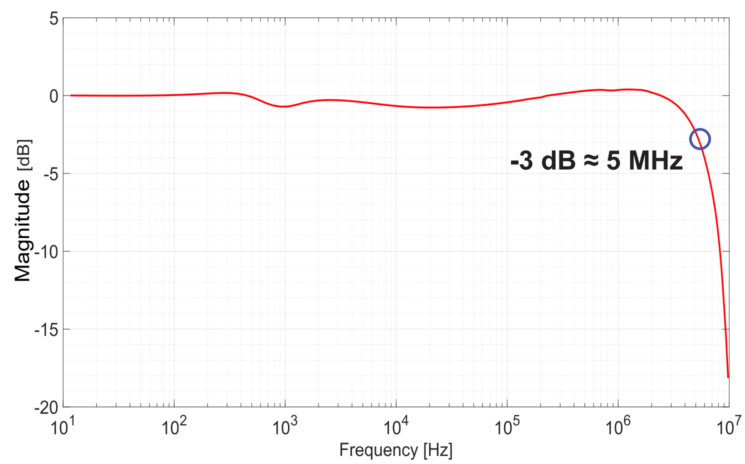

Figure 4: ACS37030/2 Bandwidth

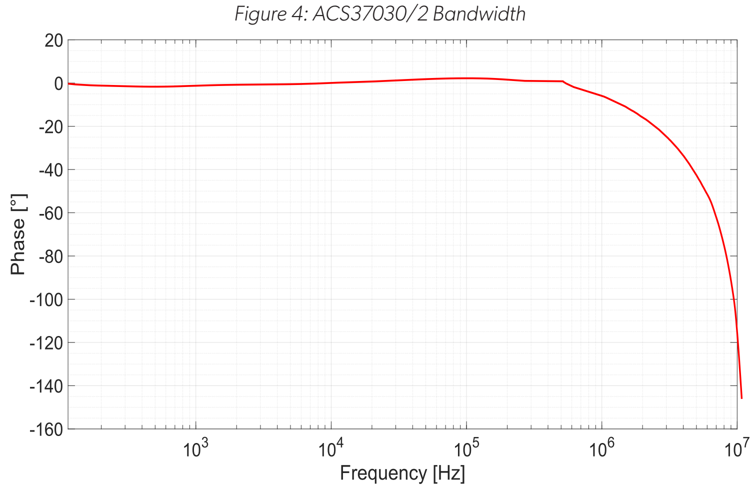

Figure 5: ACS37030/2 Phase

the advantage of cycle-by-cycle protection of overcurrent events. The ACS37032 version of the device replaces the reference voltage function with an overcurrent FAULT set to trip when 100% of the full-scale sensing range is surpassed. If the current exceeds the overcurrent detection level set by the ACS37032, the fault pin pulls low within 150 µs, signaling the system to react.

The magnitude frequency response of the ACS37030/2 is plotted in Figure 4. The –3dB point of the ACS37030 is just above 5 MHz. The general rule is to leave a decade between the bandwidth of the sensor and the maximum operating frequency. Using this rule, the ACS37030 enables switching speeds up to 500 kHz. This is 5 times higher than the previous fastest Allegro current sensor, which had a bandwidth of 1 MHz (ACS732/ACS733). [1] The phase response plot of the ACS37030/2 matches the performance expected of a 5 MHz bandwidth senor at –45°C at 5 MHz, as shown in Figure 5.

[1] https://www.allegromicro.com/en/products/sense/current-sensor-ics/zero-to-fifty-amp-integrated-conductor-sensor-ics/acs732-3

ISOLATION

Allegro integrated current sensors have inherent galvanic isolation because the coupling from the primary conductor to the die is through magnetic field; applied current flowing through the copper conduction path generates a magnetic field that is sensed by the IC and converted to a proportional voltage. The ACS37030/2 is provided in the custom 6-pin SOIC LZ package with a material group 1 overmold material. This allows the package to achieve a 1118 V_{PK} basic and a 594 V_{PK} reinforced isolation. For more information about the isolation characteristics of the LZ package, see Table 3 and Table 4.

DV/DT

Allegro current sensors are robust against switching transients due to the isolated nature of the sensing element. Allegro has the capability to generate a fast dV/dt in order to mimic a switching transient in a converter system. A voltage step with a slew rate of 50 kV/µs was pulsed onto the primary side leadframe of an ACS37030/2.

The high speed of the ACS37030/2 signal paths allows it to quickly recover after the short disturbance during the switching event. The response of ACS37030/2 to the dV/dt transient is shown in Figure 4.

Table 3: LZ Package Isolation Characteristics

Characteristic	Symbol	Notes	Value	Units
Dielectric Strength [1][2]	V_{ISO}	Agency rated for 60 seconds per UL 62368 Edition 3	3500	V_{RMS}
Impulse Withstand	$V_{IMPULSE}$	Tested ±5 pulses at 2/minute in compliance to IEC 61000-4-5,1.2 µs (rise)/50 µs (width)	5000	V_{PK}
Working Voltage for Basic Isolation [2]	V_{WVBI}	Maximum approved working voltage for basic (single) isolation according to UL 62368 Edition 3	1188	V_{PK} or V_{DC}
			840	V_{RMS}
Working Voltage for Reinforced Isolation [2]	V_{WVRI}	Maximum approved working voltage for reinforced isolation according to UL 62368 Edition 3	594	V_{PK} or V_{DC}
			420	V_{RMS}
Clearance	D_{CL}	Minimum distance through air from IP leads to signal leads	4.2	mm
Creepage	D_{CR}	Minimum distance along package body from IP leads to signal leads	4.2	mm
Distance Through Insulation	DTI	Minimum internal distance through insulation	54	µm
Comparative Tracking Index	CTI	Material Group I	>600	V

[1] Production tested for 1 second in accordance with UL62368.
[2] Certification pending.

Table 4: LZ Package Characteristics

Characteristic	Symbol	Notes	Min.	Typ.	Max.	Unit
Internal Conductor Resistance	R_{IC}	T_A = 25°C	–	0.68	–	mΩ
Internal Conductor Inductance	L_{IC}	T_A = 25°C	–	2.4	–	nH
Moisture Sensitivity Level	MSL	Per IPC/JEDEC J-STD-020	–	2	–	–

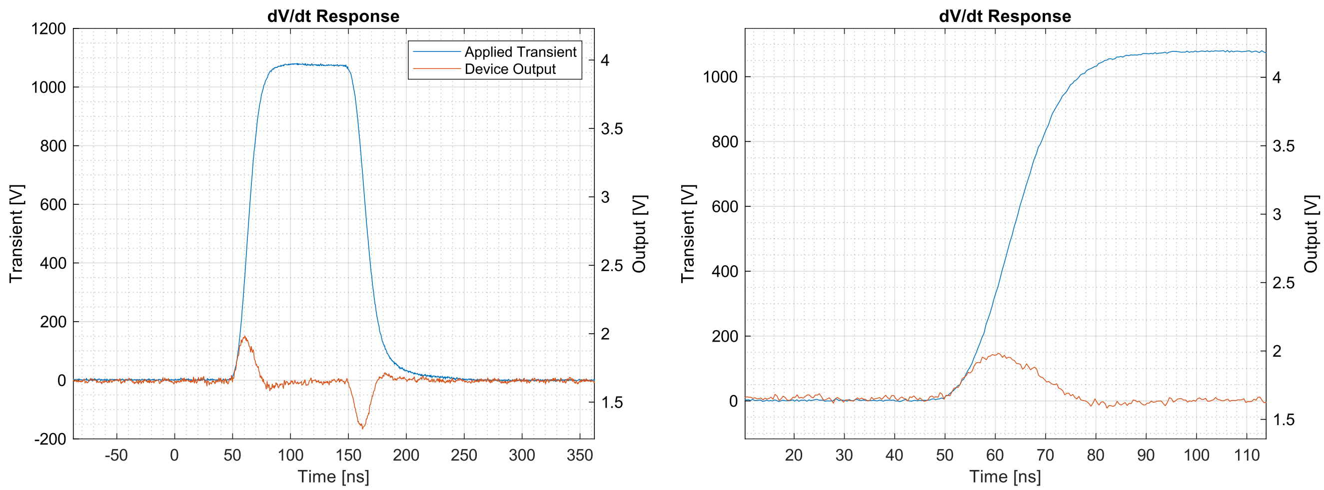

Figure 6: ACS37030/2 dV/dt Response

CONCLUSION

The key parameters for DC-DC system design, including bandwidth, isolation, and dV/dt transient response, have been discussed in this application note. Each Allegro current sensor has a different set of capabilities that make it useful for the system controller in different ways. In addition to the current sensing output, the built-in overcurrent fault detection of the ACS37030/2 can be used to remove the need for a system controller to monitor the analog output for an out-of-range signal. With the high 5 MHz bandwidth and high-speed protection 150 µs overcurrent detection, systems can safely and efficiently use SiC and GaN switches to reduce system size and cost while increasing efficiency. The SOIC-8 footprint of the ACS37030/2 makes it a space-efficient sensor for use in DC-DC converters and power-factor-correction (PFC) circuits. The high working voltage of 1188 V_{PK} of the device makes the ACS37030/2 a great fit in 12 and 48 V power conversion systems, all the way up to 800 V high-voltage battery systems.

For more information about Allegro Hall-effect integrated current sensors, visit the Allegro Microsystems website and refer to device datasheets.

Revision History

Number	Date	Description
–	March 25, 2024	Initial release

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