

## Introduction

This application note describes the current-sensing apparatus incorporated in the ZL2005 power management and conversion IC. The various modes of using the hardware, appropriate settings and limitations of these modes are explained.

## Overview

The ZL2005 delivers world-class power conversion along with flexible power management functions to point-of-load (PoL) regulator applications. The ZL2005 contains a mixed-signal controller for a synchronous buck power converter along with functional blocks for monitoring and reporting output voltage and current, input voltage, and both internal and external temperatures. Coordination among multiple ZL2005 controllers and a power system host is provided by communications on an integrated PMBus™ serial port. The resulting power system architecture is simple to manage, yet flexible in all aspects of power system performance.

## Circuit Connections

The current-protection function of the ZL2005 protects the power supply from damage if the output is shorted to ground (GND) or another power rail or if an overload condition is imposed on the output. The ZL2005 is designed to be used in all common current-sensing configurations for synchronous buck converters using N-channel MOSFETs. Figure 1 shows four of the common connections:

- Synchronous MOSFET  $R_{DS(ON)}$  sensing
- Ground referenced resistance sensing (LS sensing)
- Inline sensing of the inductor DC resistance (DCR) (HS inductor sensing)
- Inline (HS) resistor sensing

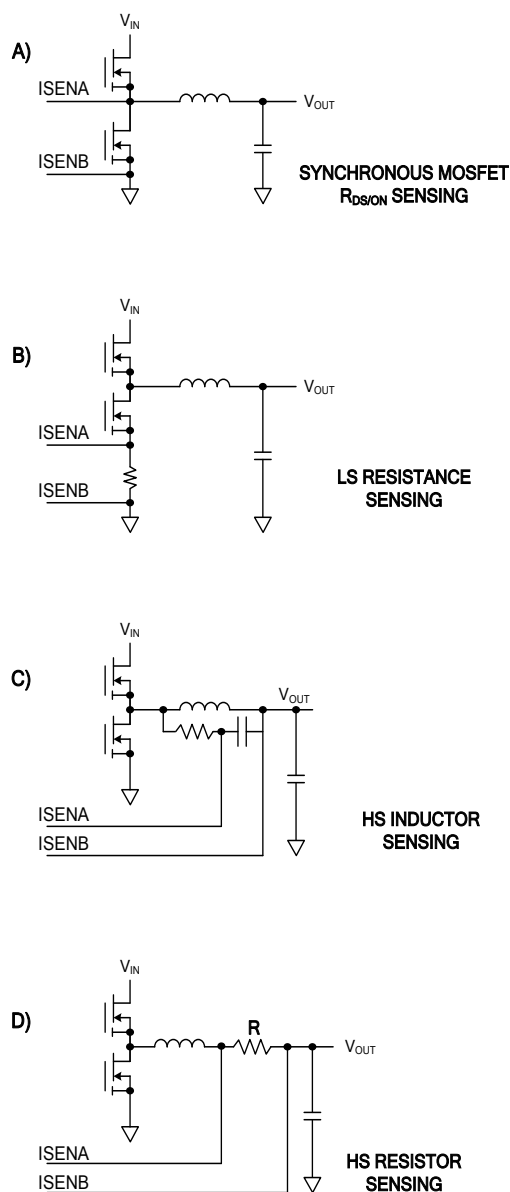


Figure 1. Current-Sensing Methods

In addition to these connections, a conventional current sense transformer, terminated with an appropriate burden resistor and reset circuit, can be substituted for either of the LS sensing methods.

The implementation of the current sensing apparatus in the ZL2005 is not intended to use the control MOSFET or a resistor in series with the control FET as a current sensing element. In many applications, the control FET is not ON for a long enough time to get a useful current signal on the control FET, so a more reliable signal is derived from the downslope waveform in the other current-sensing methods described above.

The circuit connections to the current-sensing apparatus are the current-sensing inputs ISENA and ISENB. These connections are designated without reference to polarity of the current signal because the polarity changes in the different circuit connections employed. Additionally, the ZL2005 is capable of sensing, reporting and protecting based on both positive output currents (sourcing) and negative output currents (sinking).

The design rating for the sense inputs is  $\pm 100$  mV representing 100% of rated output current. In actuality, the usable input range of ISENA–ISENB goes up to more than  $\pm 125$  mV, allowing some range for measuring currents greater than rated in overcurrent or protection modes.

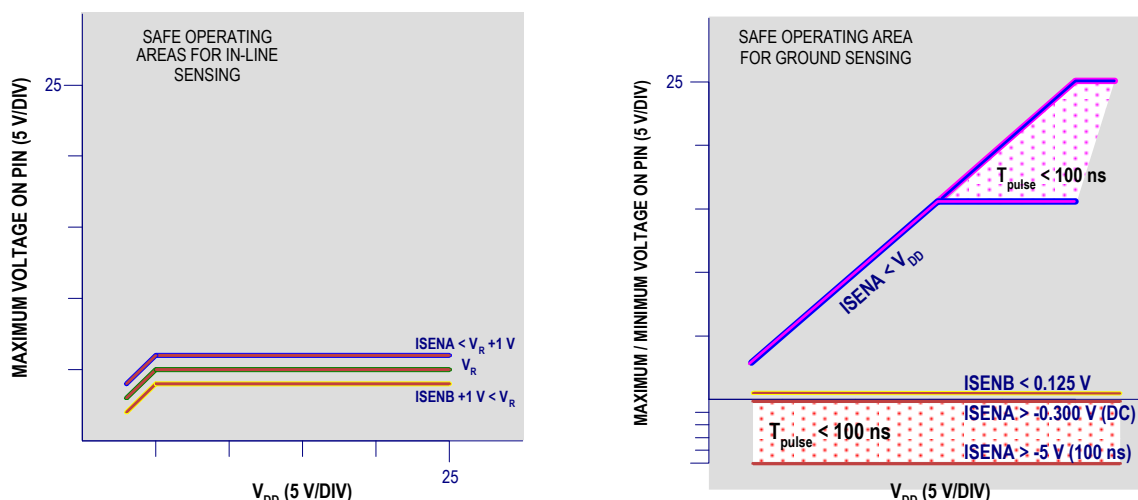
Since the ZL2005 allows sensing across the synchronous MOSFET, one sense terminal must be able to withstand the voltage at the power stage switching node (SW) over the full input voltage range. The ISENA terminal fulfills this role. It can withstand +25 V with respect to the signal ground (SGND) terminal, although in normal sensing, the voltage on ISENA will be in the range of -100 mV. The ISENB terminal is rated to only +5.5 V with respect to SGND and must also have a value 1 V less than the bias voltage, VR, to function. Applying any larger voltages to ISENB will permanently damage the part.

## General Current-Sensing Approach

The ZL2005 uses a mixed-signal implementation to sense the current signal presented to the ISENA and ISENB terminals, digitize it, and perform the reporting and protection functions on the resulting processed signal. In the intended context of a synchronous buck converter, the current waveform in the averaging inductor will normally be an upslope ramp during the control FET ON time (DTs) and a downslope ramp during the synchronous FET ON time (D'Ts), where Ts is the switching period. Depending on the ratio of output to input voltages, the duty ratio D may vary from around 5% to around 95%. The corresponding ON times for the FETs may be very short, especially at the maximum permissible frequency of 2 MHz for the ZL2005.

Because in different applications the ramp time can be very short and often corrupted with aberrations due to parasitic inductances and capacitances in the power circuit (resulting in waveforms dominated by sinusoidal ringing rather than the ideal ramp or trapezoidal current waveforms), the mode settings of the ZL2005 allow use of either the upslope ramp (where available) or the downslope ramp for current-sensing. Normally, the user chooses whichever ramp is longer for given nominal input and output voltages.

In conventional analog current-sensing implementations, the current signal is continuously compared to a fixed analog threshold and any crossing of the threshold is latched as a fault. In contrast, this part compares the current signal multiple times during the switching cycle to a threshold that is manipulated to provide different functions. This process can be thought of as sampling the current waveform, with each sample representing a binary “over setting” or “under setting” result. The actual value of the sample is not retained; rather, the relationship of the sample to the threshold is kept.



**Figure 2. SOA Voltage Graph for ISENA, ISENB**

The results of these sample comparisons of the current waveform are applied to a series of counters that determine the outcome of the detection process (see the section on Mode Settings and Sampling Rates on page 7). The settings on these counters can provide a filtering or time delay function to allow temporary deviations beyond the threshold for short-term surges such as during recovery from a transient or to mitigate the effects of the current waveform aberrations. The implementation also includes programmable blanking registers that can be used to ignore samples that occur when the current signal is known to be corrupted or when inadequate time has elapsed for the hardware to establish the comparison threshold accurately.

The threshold value used for determining the current comparison samples is multiplexed in time during successive switching cycles to derive multiple measurements from the current waveform. This threshold, which can represent either positive or negative currents, can be set near the peak of the current waveform for protection against overcurrents and surges sourced to the load, or it can be set near the

valley of the current waveform for protection against current absorbed from the load (negative output current). Another mode allows the threshold to be set near the median current during the ramp, which provides an approximation of the average output current of the power stage for load-line, current sharing, and current reporting purposes. Typically, the ramp peak and valley currents are sampled during one switch cycle and the median current is sampled during the next switch cycle.

The threshold values are programmable from internal registers accessible to the micro-controller embedded in the ZL2005. As a result, the controller can change the thresholds based on its temperature measurement capabilities to compensate for temperature variations in the current-sensing element (e.g., the FET  $R_{DS(ON)}$  value or the copper resistance of the averaging inductor). This capability improves the accuracy of the ZL2005 compared with fixed-threshold analog approaches. The resulting current protection thresholds can be nearly independent of temperature for all practical sensors.

## ZL2005 CURRENT SAMPLING STRATEGIES

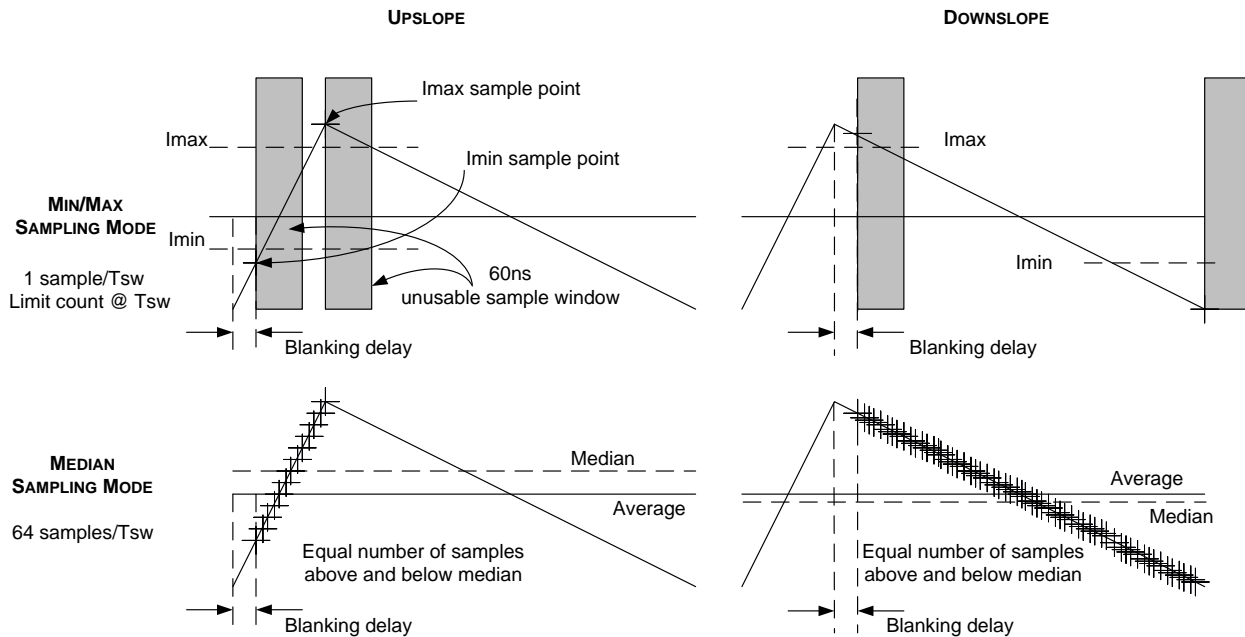


Figure 3. ZL2005 Current Sampling Strategies

In keeping with the PMBus fault response definitions, the ZL2005 can respond in one of three ways to a current protection fault:

1. The converter can continue operating despite the fault.
2. The converter can continue operating for the duration of a delay specified by the PMBus code and then shut down.
3. The converter can shut down and begin retries with a prescribed delay as specified in the PMBus code.

When a current protection fault has been detected, two events can occur. If the PMBus response is set for immediate shutdown, the current power switch ON time is terminated and an interrupt to the embedded microcontroller is also generated. The switch termination results in both switches being OFF;

therefore, any current in the output must freewheel through the corresponding body diode, ensuring that the current will always decrease in magnitude.

The interrupt to the microcontroller sets the appropriate current fault registers and schedules an orderly restart to the power converter according to the delay and ramp rules established in other control registers. In compliance with PMBus fault response protocol, the ZL2005 allows for setting zero, one through six, or continual retries before latching off after a fault. It also allows for continued operation during the fault, although this mode may pose some risk to the power stage.

Figure 4 summarizes the hardware implementation of the current-sensing function in the ZL2005.

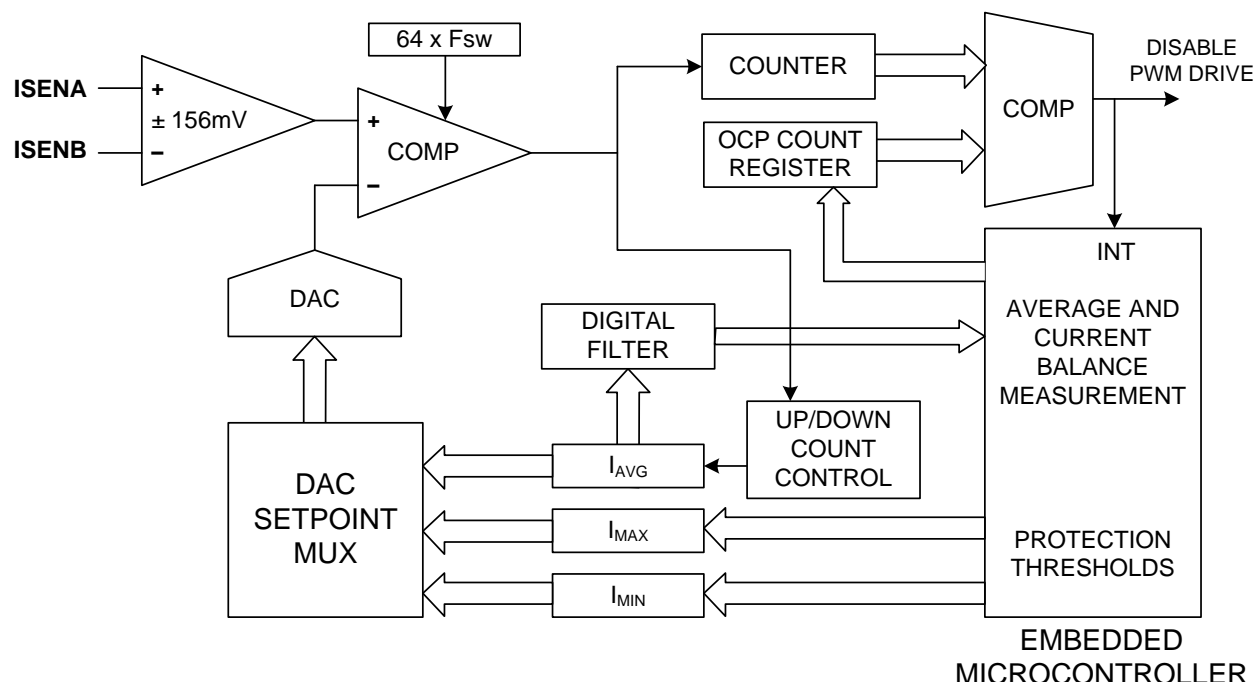


Figure 4. ZL2005 Current Sense Implementation

## Resolution and Accuracy

In a power controller, there are many sources of error in the signal path for current-sensing. The unique mixed-signal architecture of the ZL2005 current-sensing circuitry is designed to minimize the effects that contribute to errors in protection thresholds or reported currents.

The fundamental resolution of the current-sensing apparatus in the ZL2005 is 31 levels (each side of zero) full scale, or about 5 mV per level at the ISEN terminals. With a maximum input range of 156 mV, the resolution is then 5 mV/156 mV, or about 3%. This implies that the allowable settings of the current protection thresholds fall on values that are about 3% apart when the maximum value is 156 mV. However, if the sensor maximum value is much lower (e.g., 20 mV as measured on the parasitic conductor inductance [DCR] of an inductor), then the resolution is 5 mV/20 mV = 25%. Therefore, there is a tradeoff between the power lost in the sensor and the setting resolution for current protection. The effective resolution can be modified somewhat by the limit count settings described below.

For current reporting, the current samples are fed through a dedicated digital filter that extracts up to an additional 2 bits of resolution from the samples to give an effective resolution of 7 bits signed, or about 1.25 mV per least significant bit (LSB) at the current sense terminals.

The design goal of the ZL2005 is for a current reporting and threshold accuracy of  $\pm 10\%$  or better. With typical settings, the accuracy of protection thresholds can be better than 8%.

The accuracy of current measurements is determined by many factors:

### 1. Accuracy of the Current Sensor Value (including temperature variations)

Typically, for fixed resistors, this accuracy can be held to  $\pm 1\%$  with a small temperature coefficient on the order of 50–300 ppm/°C with little cost penalty. Many inductors now specify their DCR to  $\pm 5\%$  tolerance, but the copper still has a 30% variation over temperature. The channel resistance ( $R_{DS}$ ) value of a MOSFET is characterized generally no better than 10%, in addition to the large temperature coefficient variation of 55–65%

(see the section on Current Temperature Compensation on page 8).

## 2. Input Offset Errors in the Signal Amplifier

These are digitally calibrated out when the ZL2005 is tested, and an additional user calibration register (PMBus command IOUT\_CAL\_OFFSET (39h)) is provided for in-system nulling of these and other errors.

## 3. Gain Errors in the Signal Path

These are digitally calibrated out when the ZL2005 is tested, and an additional user calibration register (PMBus command IOUT\_SCALE (38h)) is provided for in-system nulling of these and other errors.

## 4. Errors Due to Bias Currents in the Signal Amplifier

For most sensors, the sensor output impedance is so small that the contribution of this error is negligible. With the DCR sensing method, however, the impedance level is arbitrary other than the bias current restriction. Bias current errors will remain small if the resistor value is less than about 5 kΩ. If the resistor values are too small, excessive dissipation in the resistor will result.

## 5. Accuracy of Threshold Compensation for Temperature

In the ZL2005, the register settings for temperature coefficients are structured in a 7-bit binary format with the least significant bit representing a +100 ppm/°C temperature coefficient. The equation implementing the temperature compensation is  $R_{sen} = R_{25} * (1 + TC * (T - 25))$ , where  $R_{sen}$  is the effective value of the current sense resistor at temperature  $T$  and  $R_{25}$  is the value of the current sense resistor at  $T = 25^{\circ}\text{C}$ . Typical values are  $TC = 300 \text{ ppm/}^{\circ}\text{C}$  for thick film resistors,  $TC = 3930 \text{ ppm/}^{\circ}\text{C}$  for copper, and  $TC = 4800 \text{ ppm/}^{\circ}\text{C}$  for typical trench MOSFETs. Another source of error is usually the fact that the sensor value is not strictly linear with temperature.

## 6. Variations Due to Inductor Ripple Current Amplitude Over Various Input and Output Voltage Combinations

If the thresholds are set to intercept the peak or valley of the current waveform, the average current output will be a function of the amplitude of current ripple, which in turn is a function of the duty ratio or output/input voltage ratio. For large ripple currents, this effect will introduce a significant variation in the overcurrent protection thresholds with input voltage.

## 7. Aberrations in the Measured Waveform Due to Circuit Parasitics

Although the ZL2005 can be set to sample the most ideal portions of the sensed waveform, some ripple or disturbances in the low amplitude signals may deviate from the ideal current signal. These effects can be minimized by proper Kelvin connection to the sensor, running the ISENA and ISENB signals as a balanced differential pair from the sensor to the controller IC and avoiding magnetic or capacitive coupling to the sense lines (please refer to Zilker Labs Application Note AN2010).

## 8. Non-idealities in the Measurement Blanking or Sampling Times

If the blanking or sampling intervals result in sampling a portion of the waveform that includes an aberration, the resulting current protection threshold will be inaccurate. Since the aberrations are usually greatest just after a switch transition and tend to die out as the cycle progresses, the earlier samples will have more error than the later samples.

## 9. Counter Settings and Sampling Modes

Because the current waveform has a predominant ramp characteristic, the settings of the limit counters will modify the effective threshold. A larger count setting generally requires a greater excess of current above or below the threshold before a fault is generated.

## 10. Errors Due to Location of the Kelvin Connections to the Current Sensor

These errors can arise especially if there are other power circuits in the system that draw currents with the same frequency but a different phase, such as in a multiphase group. Currents drawn by another phase can cause an error to appear in this phase if the sensor connections are not correct.



## 11. Non-linear Inductance Effects

If the power averaging inductor has a characteristic that the inductance varies strongly with the instantaneous current or is designed to be very near magnetic saturation, the measured current will not accurately reflect the average output current.

The ZL2005 current protection thresholds specify the average output current that generates a fault as  $\pm 10\%$  of the threshold setting, including all the above errors except those relating to the external current sensor and the inductor ripple current.

## Mode Settings and Sampling Rates

The current-sensing apparatus in the ZL2005 has many different operating modes:

### 1. Upslope Sampling

The ZL2005 can be set to sample either the rising or falling inductor current waveform, usually set to whichever is of longer duration with the PMBus command MFR\_CONFIG (D0h). With control bits 5 and 4 set to 1 and 0, respectively, the current is sampled during the upslope.

### 2. Downslope Sampling

The ZL2005 also can be set to sample the falling inductor current waveform with the PMBus command MFR\_CONFIG (D0h). With control bits 5 and 4 set to 0 and 0, respectively, the current is sampled during the downslope on a low-side sensor (see Figure 1a or Figure 1b). Since most point-of-load converters operate with a large stepdown in voltage and the corresponding large  $D'$ , this mode is the default in the ZL2005. With control bits 5 and 4 set to 0 and 1, respectively, the current is sampled during the downslope on an inline sensor (see Figure 1c or Figure 1d).

### 3. Min/Max Detection

The threshold generator can be set for a threshold intended for current protection on a positive (sourcing) output current, current protection on a negative (sinking) output current, or a median value used to represent the average output current for reporting purposes. In min/max mode, this threshold generator alternates between the minimum (most negative) threshold value and maximum (most positive) value. When in upslope mode, the minimum threshold sample is made first, then the maximum threshold sample just before the switch transition. When in downslope mode, the maximum threshold sample is taken before the

minimum threshold sample. In min/max mode, only one sample for each threshold setting is taken during the switching cycle.

### 4. Median Detection

Another mode for the current-sensing apparatus is used to extract an approximation of the average output current from the current waveform. Since the target applications tend to use high frequency converters and small power components, which result in large current ripple in the averaging inductor, neither the peak nor valley currents are representative of the average output current. The median detection mode seeks the measurement that has an equal number of samples higher and lower than the threshold. This measurement is then digitally filtered, which results in additional resolution to the median current reading. In the median sampling mode, the current samples are taken at intervals of  $T_{sw}/64$ .

### 5. Interleave of Min/Max and Median Modes

This is the normal default operation of the current sense apparatus. On one switching cycle, the current signal is compared against the min and max thresholds for fault limits; on the next switching cycle, the current samples are equated above and below the median value. This pattern of alternating switching cycles is repeated without end.

In each of the above sampling modes, there are delay settings that can determine when the first usable sample is taken after the switching transition. These delays are set using bits 11-15 of the PMBus command MFR\_CONFIG (D0h). The delay settings are in units of 32 ns for any switching frequency. The range of delays is 0–31 of the 32 ns intervals. These delays can be used to avoid sampling the current signal during a parasitic ring or other aberration in the waveform. In ground sensing mode, the minimum leading edge delay should be set to at least 180 ns to allow for recovery of the current sense amplifier after the large-signal overload that occurs during DTs.

When the power FETs are driven directly by the ZL2005, the trailing edge delay should be set to zero so that the sample is taken just before the switching transition. If an external driver with significant propagation delay is used, this trailing edge delay may need to be set longer to compensate for the propagation delay.

When the duty ratio becomes too small or too large for samples to be taken with the prescribed delays, the sample is abandoned during the current switching cycle

and regular sampling resumes when the duty ratio allows the required delays.

## Limit Counters and Fault Response Time

The result of crossing the maximum or minimum drain ( $I_{MAX}$  or  $I_{MIN}$ ) threshold depends on a counter (the “*limit counter*”). The settings for this counter are chosen with bits 8-10 of the PMBus command MFR\_CONFIG (D0h). Allowable values are 1, 3, 7,..., 15 counts of the threshold crossing before a fault is declared.

For example, if an overcurrent (greater than the  $I_{MAX}$  threshold) occurs during switching cycle  $T_0$ , which is a median sampling cycle, then the first limit count would occur during cycle  $T_1$  when the max limit check is done. If the limit count is set at the maximum value of 15, then the fault must persist throughout cycles  $T_1$  through  $T_{31}$  (16 odd numbered cycles of limit check and 15 even numbered cycles of median check). Any  $I_{MAX}$  sample in this interval that is not above the threshold resets the limit counter, requiring the count to start again from 1. If the fault persists through cycle  $T_{31}$  at the end of the  $I_{MAX}$  sampling time, the fault is latched and the microcontroller is interrupted to handle this fault.

The limit count can be used to screen the samples to reject spurious or transient disturbances in the current signal. Short limit counts give very fast responses to a current fault situation, but also exposure to false faults due to transient signal disturbances or momentary overcurrents during a converter response to a step load. Long limit counts are good for rejecting false faults and riding through step load transients without issuing a fault, but do not provide as much protection for the power FETs in shorted output cases.

Once the limit count criterion for issuing a fault has been satisfied, the handling of the fault is determined by the PMBus command IOUT\_OC\_FAULT\_RESPONSE (E5h) or IOUT\_UC\_FAULT\_RESPONSE (E6h).

These commands allow one of the following courses of action:

1. Continue operating throughout the fault.
2. Continue operating throughout the delay time, which can be 1–6 increments of 10 ms, and then shut down.
3. Initiate an immediate shutdown.
4. Initiate a shutdown and restart for 1–6 tries with a delay between tries specified in multiples of 8 ms.
5. Initiate a shutdown and restart indefinitely with a delay between tries of multiples of 8 ms. The default behavior is this response with the maximum 64 ms delay.

## NLR Actions and Current-sensing

One of the advanced features of the ZL2005 is its ability to bypass the response characteristic of the linear PID regulation loop with a time-based Non-Linear Response (NLR) loop. This NLR function has the ability to override the normal pulse width modulation for up to two switching cycles. The settings of the current protection and the NLR response must be carefully coordinated, because a fault can cause both an NLR response and a current protection response, and the nature of the two responses is to oppose each other. The ZL2005 firmware calculates the minimum blanking time for NLR required to allow a current sample to be taken and enforces this time allowance so that current sampling is always possible.

The operation of current-sensing during NLR activity is just like pulse width modulator (PWM) operation, except that the switching transitions can occur at times other than those prescribed by the usual PWM generation. The sampling windows and delays are determined by the drive output signals, so the timing relationships during NLR activity will be the same as during normal PWM activity.

## Current Temperature Compensation

A MOSFET's  $R_{DS(ON)}$  increases significantly with temperature increases.

A MOSFET with an  $R_{DS(ON)}$  specified at a junction temperature of 25°C can expect  $R_{DS(ON)}$  to increase by 30% at a junction temperature of 125°C. To avoid premature current limit during normal operation, specific attention should be used to select a suitable current limit threshold.



Figure 5 shows a typical trench FET curve of  $R_{DS(ON)}$  vs. temperature.

The linearized expression for this curve is:

$$\frac{R_{DS}(T)}{R_{DS}(25)} = 1 + \left( \frac{0.6}{125} \right) \times (T - 25) \quad \text{Eq. [1]}$$

This should be fairly representative of available devices. Some parts exhibit a multiplier in the range of 1.55–1.65 at 150°C, depending on the MOSFET technology.

## Example Calculations

### Synchronous MOSFET $R_{DS(ON)}$ Sensing

With this sensing method, the ZL2005 blanks the current-sensing circuit while the top MOSFET is ON and during the switching transition between the top and bottom MOSFET when the current sense signal is not accurate. During normal operation, the current to be sensed will flow from ground into the inductor. ISENB, the low voltage sense pin, should be connected to the source terminal of the synchronous MOSFET. The current sense circuitry can sense negative voltages. Should a fault be encountered where current flows in the negative (sinking) direction in the bottom MOSFET, the current protection will occur at a separate current threshold value  $I_{MIN}$ . The default assignment is that  $I_{MIN} = -I_{MAX}$ , unless configured separately by the user. The current limit threshold is determined by the bottom MOSFET's  $R_{DS(ON)}$ .

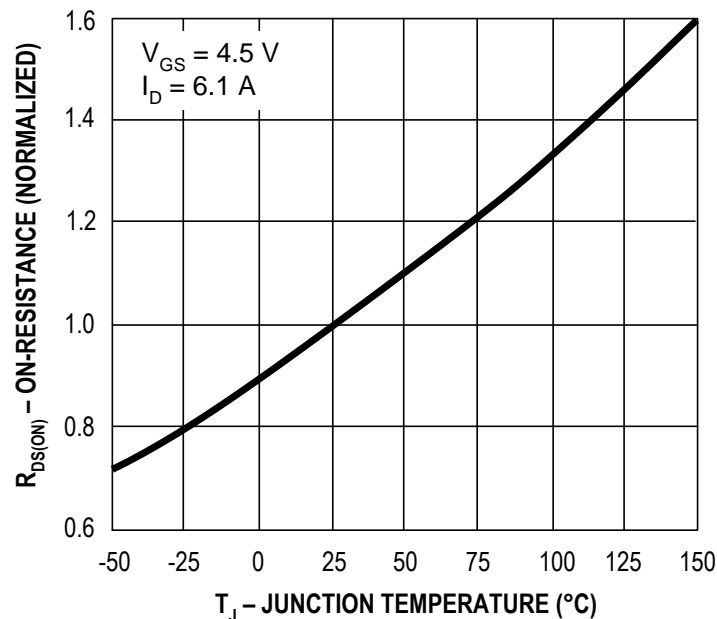


Figure 5. On-Resistance vs. Junction Temperature (Si3434DV)

1. Calculate the maximum peak inductor current:

$$I_{Lpk} = I_o + \frac{1}{2} \times \left( 1 - \left( \frac{V_o}{V_{in}} \right) \right) \times V_o \times \left( \frac{T_s}{L} \right)$$

**Eq. [2]**

In this example, a rated average output current of  $I_o = 20$  A and voltages  $V_o = 1.2$  V and  $V_{in} = 12$  V are used. Assume  $T_s = 1/390$  kHz =  $2.56$   $\mu$ s and  $L = 390$  nH. Then  $I_{Lpk} = 25.2$  A.

This threshold value is entered for  $I_{MAX}$  with the PMBus command `IOUT_OC_FAULT_LIMIT` (46h). The 25.2 A value is entered as DB25h.

2. Find the  $R_{DS(ON)}$  of the selected MOSFET at 25°C. A typical MOSFET for this use would have an  $R_{DS(ON)}$  of about 3 m $\Omega$  at 25°C.

This value is entered with the PMBus command `IOUT_SCALE` (38h). The value of 3 m $\Omega$  is entered as C300h.

3. Calculate the minimum current protection threshold voltage:

$$V_{th} = I_{Lpk} \times R_{DS(ON)} = 75.5 \text{ mV} \quad \text{Eq. [3]}$$

This value is automatically calculated if the current threshold and scale values are entered by PMBus commands. The nearest quantized level (about 75.6 mV) would be used for the threshold. If the current limit settings are done by pin-straps (see below), the nearest value accessible would be 80 mV.

4. Add margin or delay for a transient response. To achieve a fast response to an output current transient, the current in the power stage will overshoot the desired final value to replenish the charge in the output capacitors. This transient current overshoot can be masked with the limit count as described above.

For this example, the threshold is left at the value calculated above, and the limit count is set with PMBus command `MFR_CONFIG` (D0) to 15 counts ([10:8]=111). This will give a time of  $\sim 2 \times 15 \times T_s = 77$   $\mu$ s to ride through a transient current before issuing a fault.

5. Find the  $R_{DS(ON)}$  temperature compensation. Using the example from Figure 5, the temperature coefficient of  $R_{DS}$  is  $(0.6/125) = 4.8E-3$ , or 4800 ppm/°C. Because the ZL2005 temperature coefficient correction is in units of 100 ppm/°C, a value of 48d or 30h would be entered with the PMBus command `TEMPCO_CONFIG` (DCh), assuming the ZL2005 controller temperature is a good representation of the power FET temperature. If an external temperature sensor mounted next to the power FET is used, the `TEMPCO_CONFIG` value is B0h.

### Ground Referenced Resistor Sensing

The calculations for a ground referenced resistor (in series with the synchronous MOSFET source terminal) follow the same pattern as above, with the resistance and temperature of the discrete resistor replacing the corresponding values for the MOSFET.

### Output Resistor Sensing

The calculations for an inline resistor (in series with the averaging inductor) follow the same pattern as above, with the resistance and temperature of the discrete resistor replacing the corresponding values for the MOSFET.

In addition to setting the sensor values, the current-sensing mode must be changed from the default ground-sensing mode to the inline sensing mode using the PMBus command `MFR_CONFIG` (D0h). For downslope inline sensing, the code sent could be [5:4] = 01, for example.

### Inline Sensing on the Inductor DC Resistance (DCR)

This method of sensing current uses the parasitic conductor resistance ( $R_L$ , also known as DCR) of the averaging inductor to provide a small differential voltage proportional to the inductor current. Because the inductor in normal operation has a large-amplitude rectangular waveform across it, an equivalent averaging function must be provided to remove the large waveform. This is typically accomplished with a small-signal resistor-capacitor filter. While the average current will be extracted with a wide range of filter

time constants, the exact inductor current is represented only when

$$\tau_F = \tau_L \quad \text{Eq. [4]}$$

where

$$\tau_F = R \times C \text{ is the filter time constant,}$$

$$\text{and } \tau_L = L/R_L$$

The impedance of the filter is still a free parameter. It must be high enough that the resistor has negligible power dissipation, yet low enough that any bias currents in the current sense amplifier introduce negligible error. For the ZL2005, the best compromise would place the resistor value in the range of 500–5000  $\Omega$ .

For the DCR method, a resistor in series with ISENA that is 5-10 times the averaging resistance calculated above is recommended. This resistor prevents noise spikes on the power leads from rectifying on the ESD protection clamps of the IC and depositing a charge on the averaging capacitor.

Just as with the inline resistor sensing method, the sensing mode must be set with the MFR\_CONFIG command.

Since the inductor winding is usually formed out of copper, the temperature coefficient is near 3930 ppm/°C. This is entered in the TEMPCO\_CONFIG register with a code of 27h or A7h.

### Setting the Current Protection Threshold Using Pin-strap Method

If the desired current protection threshold is one of the fixed values listed in Table 1, ILIM0 and ILIM1 are connected as indicated.

The current threshold value in amperes will depend on the current-sensing method used and the value of the sensing element resistance.

**Table 1. Current Protection Threshold Setting Using Pin-strap Method**

		ILIM0		
		LOW	OPEN	HIGH
ILIM1	LOW	0 mV	30 mV	40 mV
	OPEN	50 mV	60 mV	70 mV
	HIGH	80 mV	90 mV	100 mV

### Setting the Current Protection Threshold Using Resistor Method

The current protection threshold voltage can be set between 10 mV and 100 mV by connecting a resistor  $R_{ILIM}$  between ILIM0 and GND according to Eq. [5]. This is the default method when the ILIM0 pin is connected to GND through a resistance with a value between 10 k $\Omega$  and 110 k $\Omega$ . ILIM1 may be left open.

$$R_{ILIM} = V(\text{volts}) \times 1 \text{ M}\Omega \quad \text{Eq. [5]}$$

### Setting the Current Protection Threshold Using PMBus Method

The current protection threshold can be set between 10 mV and 156 mV using PMBus. See Application Note AN2013 [2] for details on setting current protection using the PMBus.

## Conclusion

The ZL2005 provides unprecedented flexibility in choosing current measurement and protection methods. With modes and settings appropriate for most applications, the ZL2005 can significantly improve the accuracy of current protection thresholds over traditional approaches to current protection.

## References

- [1] AN2010 – *ZL2005 Thermal and Layout Guidelines*, Zilker Labs, Inc., 2005.
- [2] AN2013 – *ZL2005 PMBus™ Commands*, Zilker Labs, Inc., 2005.

## Revision History

Date	Rev. #	
October 2, 2005	09	Initial Release
July 12, 2006	10	Removed SenseFET method. Changed ISENA max voltage, mode setting bits, removed fast max mode and min/max only mode, changed delay settings, limit count settings, NLR comments, added comment on ISENA resistor
May 01, 2009	AN2015.0	Assigned file number AN2015 to app note as this will be the first release with an Intersil file number. Replaced header and footer with Intersil header and footer. Updated disclaimer information to read "Intersil and it's subsidiaries including Zilker Labs, Inc." No changes to application note content.

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