

Keywords: InTune, digital power, power supplies, IOUT\_CAL\_GAIN, IOUT\_CAL\_OFFSET, load current measurement, calibrate, calibration, PMBus, point-of-load, PoL, buck converter

**APPLICATION NOTE 5601** 

# CURRENT CALIBRATION PROCEDURE FOR INTUNE DIGITAL POWER

By: Michael Day, Principal Member of Technical Staff

Abstract: This application note provides step-by-step instructions for calibrating the PMBus<sup>1</sup> parameters, IOUT\_CAL\_GAIN and IOUT\_CAL\_OFFSET, that are used by our InTune<sup>1</sup> MAX15301 and MAX15303 digital power supplies to report output current.

# Introduction

A major benefit of digital power solutions is the ability to read the actual load current in real time over the power management bus (PMBus). The load current measurement is possible with knowledge of the current-sense element's impedance. The current measurement's accuracy is a function of many parameters such as board parasitics, the measurement component's tolerance, and the IC's internal gains and offsets. If the variations in these parameters are not accounted for, the measured load current will not be as accurate as one might expect. Fortunately, the PMBus specification provides two calibration coefficients, IOUT\_CAL\_GAIN and IOUT\_CAL\_OFFSET (collectively referred to as IOUT\_CAL values), which allow the user to calibrate out the parameters that affect the current measurement's accuracy. Every InTune IC is shipped with default values for these coefficients. These values must be calibrated to provide accurate output current measurements.

# When is Calibration Needed?

An IC's IOUT\_CAL values should be calibrated at the initial board build and at any time when the currentsensing circuitry is changed. Maxim Integrated's digital power evaluation (EV) kits are shipped with IOUT\_CAL values that are specifically calibrated to each EV kit's inductor. This allows the user to experience accurate current measurement right out of the box. Our EV kits are designed to allow the user to easily modify the kits for their specific operating requirements. However, any modification to the output inductor, current measurement filter components, or the digital power IC require the user to recalibrate the IOUT\_CAL values to ensure that the design properly reports an accurate load current measurement. For instance, replacing the output inductor with another inductor that has the same part number does not necessarily require recalibration. The exact change in accuracy is a function of the change in the new inductor's actual inductance or resistance. However, replacing the output inductor with another inductor with a different part number always requires recalibration to ensure an accurate output-current measurement.

In this application note, Maxim provides an easy-to-follow procedure for calibrating new IOUT\_CAL\_GAIN and IOUT\_CAL\_OFFSET values that are optimized for your modified design.

# **Recommended Equipment**

- Maxim InTune EV Kit
- Maxim's MAXPOWERTOOL002# USB-to-PMBus interface kit
- 5V to 12V DC lab supply capable of supplying the current required by the EV kit
- Current meter
- Load (electronic or resistive)
- PC with Windows<sup>®</sup> operating system and available USB port
- PowerTool graphical user interface (GUI) installed on the computer. Visit the EV kit's tool folder for a link to the latest version of the GUI.
- Maxim's InTune Digital Power Current Calibration Worksheet (XLSX)

#### Precautions

- Verify that the lab supply is configured for a voltage within the InTune EV kit's absolute maximum limits before connecting and turning on the supply.
- Do not turn on any power supplies until all electrical connections have been completed.
- Do not exceed the current rating for the test leads used to connect  $V_{IN}$  and  $V_{OUT}$ .
- Do not exceed the current capability of the current meter.

# Setup

Refer to the InTune EV kit data sheet for detailed instructions on setting up the EV kit. This currentcalibration procedure requires an accurate load current measurement, which can be accomplished by using one of the following three methods:

- 1. If using an electronic load with a current reading, the current reading on the load can be used. Note that most labs do not use electronic loads with calibrated voltage and current readings. Ensure that the electronic load is properly calibrated.
- If using discrete load resistors, the load current can be calculated by measuring the voltage across the resistor and dividing by the resistor value. Typical resistor values used for these load currents are not very accurate and may have a large temperature coefficient that further affects the current measurement's accuracy.
- 3. Use a separate, calibrated current meter. This is the recommended technique and provides the most accurate measurements that result in the most accurate load current measurement by the InTune IC.

Figure 1 shows a typical measurement setup using a current meter.



Figure 1. Current-calibration test setup.

# Procedure

This procedure assumes that the user has read the EV kit data sheet and has properly configured the EV kit jumpers, connected the test setup, applied power, has the PowerTool GUI software running, and turned on the EV kit so it is supplying a regulated output voltage. To obtain the most accurate results, the current measurements should span the expected range of load currents for the design. Although the procedure works with a minimum of two current measurements, additional measurements provide more accurate results. With the setup turned on and operating, follow the steps outlined below to recalibrate the InTune converter's current measurements:

1. In the accompanying InTune Digital Power Current Calibration Worksheet (XLSX), enter the Starting IOUT\_CAL\_GAIN and Starting IOUT\_CAL\_OFFSET values.

In the PowerTool GUI, these values can be found in two places. The first is on the **Configuration** tab (Figure 2) and the second is on the **PMBus Command** tab—**Configure** tab. The values on the **Configure** tab. The **PMBus Command** tab—**Configure** tab values are the values used internally by the IC. The two values may not be identical due to the accuracy limitations of the PMBus specification. For the recalibration procedure, use the values from the **PMBus Command** tab—**Configure** tab.

Dashboard 0x11 MAX1530	14402			Dashboard 0x11 MAX15301AA02			
Configuration   Monitor   Faults Sel	PMBus Command Permis			Configuration Monitor Faults Set PMBus Comman	nd Permissions		
PMBus Command	ForceHex	🔝 Use PEC	Manufacturer specific commands	Basic Settings		Device Status	
Configure Faults Monitor S	tore		MFR ID		Vout (V) 1.000		V) 1.000
VOUT_MODE	0x0020[7:0]	20 👙 1	MFR.JU MFR.MODEL	Vout Margin			
VOUT COMMAND	0x0021/1501	1.000244	MFR REVISION	Vout Margi			
VOUT TRIM	0x0022[15:0]	0	MFR LOCATION	Switching Frequency Set P			
VOUT CAL OFFSET	0x0023[15:0]	0.0	MFR DATE	Over Current			
VOUT MAX	0x0023[150]	1.100098	MFR_SERIAL	Power Go			
VOUT MARGIN HIGH	0x0024[150]	1.050049		Power Go	od Off (V) 0.849		
VOUT_MARGIN_LOW	0x0025[15:0]	0.950195	Firmware Revision 4328	Startup/Shutdown Times		Stat	us O
VOUT TRANSITION RATE	0x0027[15:0]	0.101685	Strap Disable dirty bits	On Delay T			
VOUT DROOP	0x0027[150]	0.101002		On Rise T		EXT_TEMP_CAL-m 1+	1.039
FREQUENCY_SWITCH	0x0028[15:0]	600	PMB_HDBM_VOUT_COMMAND	Off Delay T			-8.0
VIN ON			PM8_HD8M_VOUT_OV_FAULT_LIMIT	Off Fall T	Time (ms) 4.95 {	DUT CAL GAIN (mQ)	0.40
VIN_OFF	0x0035[15:0]	6.015625 🗢	PM8_HDBM_VOUT_OV_WARN_LIMIT PM8_HDBM_VOUT_UV_FAULT_LIMIT	Operation Mode		IOUT_CAL_GABN (ML)	0.00
INTERLEAVE	0x0030[150]	5.5 🗘	PM8_HD8M_VOUT_UV_WARN_LIMIT		in High, Act on Faults	ha	
OUT CAL GAIN		97 🗢	PMB_HDBM_POWER_GOOD_ON	Normal     Margin Low, Ignore Faults     Margir	n Low, Act on Faults	Advanced Configuration	
IOUT_CAL_OFFSET	0x0038[15:0]	0.399902	PM8_HDBM_POWER_GOOD_OFF	Soft Stop	te Stop	Advanced Configuration	
POWER COOD ON	0x0039[15:0]	0.00	PMB_HDBM_VOUT_MARGIN_LOW				
POWER GOOD OFF	0x005E[15:0]		PMB_HDBM_IOUT_OC_FAULT_LIMIT PMB_HDBM_FREQUENCY_SWITCH	Store User All Restore User All Restore	Maxim All Restore Default	All Save Configuration to File Load Configuration File to Device	
TON DELAY	0x005F[15:0]	0.849121	PM8_HDBM_PREQUENCT_SWITCH				
TON_RISE	0x0060[15:0]	4.984375 🗘	PM8_HD8M_VOUT_MAX				
TON_KEE TOFF_DELAY	0x0061[15:0]	4.945313 🗘	PM8_HDBM_COMP_MODEL PM8_HDBM_INTERLEAVE				
TOFF_DELAY	0x0064[15:0]	1.136719 🖨	T LUID LIDDW IN ICUTOANE				
ION_FALL	0x0065[15:0]	4.945313 🗘 .					

More detailed image Figure 2. Location of the IOUT\_CAL\_GAIN and IOUT\_CAL\_OFFSET values.

 In the Faults Set tab, disable IOUT OC FAULT (A) by selecting Ignore to eliminate the possibility of overcurrent faults due to incorrect IOUT\_CAL values (Figure 3). Be sure to stay within the current capability of the design.

💿 Maxim PowerTool™ (1.08.02)	)			
	<11 AX15301AA0	2		
		Bus Command	Permissions	
	Status 🧹	Limit -	Response	Status - Other Faults
Power Good ON	•			Vout Max Clamp Warn 🔘
Power Good ON	•	0.901 🚔		CML: Invalid/Unsupported Cmd 🔘
Power Good OFF		0.849 💂		CML: Invalid/Unsupported Data 🔘
Vout Over Voltage Fault (V)	•	1.148 🌲	80 (Hex) ShutdownAndRetry   NoRetries  MinDelay	CML: Invalid PEC 🔘
			00 (Hex) Ignore V NoRetries V MinDelay V	CML: Memory Fault 🔘
Vout Under Voltage Fault (V)	•	0.849 💌	00 (Hex) Ignore	CML: Processor Fault
Vin Over Voltage Fault (V)	•	14.016 💂	C0 (Hex) ShutdownAndMonitor V NoRetries V MinDelay V	CML: Other Comm fault O CML: Other Memory Logic fault O
Vin Under Voltage Fault (V)	•	4.180 🔺	C0 (Hex) ShutdownAndMonitor • NoRetries • MinDelay •	civit, other memory togic rault
Iout Over Current Fault (A)	•	19.563 🚔	BF (Hey, ShutdownAndRetry Continuous_Retry   ) Delay7x100ms  Ignore	
Over Temperature Fault (°C)	•	115 🖍	C0 Hex) DelayAndRetry ShutdownAndRetry N Retries MinDelay •	
Adaptive Mode Fault Response	:		00 (Htt) Ignore VoRetries MinDelay -	
Over Temperature Warn (°C)	•	95 🔺		
				Clear Fault/Warning
<u>الــــــــــــــــــــــــــــــــــــ</u>				•
Selected PowerTool: MXXGP2T	N (v15) 🔘 D	evice Firmware Ve	sion: 4328	

Figure 3. Disabling the overcurrent fault.

3. Adjust the load in the lab equipment to the lowest desired load current.

- 4. Enter the load current value, as measured by the current meter in the Excel spreadsheet's **Actual IOUT (A)** measurement column.
- 5. Enter the load current value displayed in the GUI in the Excel spreadsheet's **Monitored IOUT (A)** measurement column.

The current value is displayed in two places in the GUI (Figure 4). The first is the **Output Current (A)** on the **Dashboard** tab and the second is the **Read IOUT (A)** on the **Monitor** tab. These values are identical. Note that the monitored output current constantly changes due to both differences in load currents and noise introduced into the measurement. Try to enter an averaged value of the load current.



Figure 4. Location of monitored IOUT.

- 6. Increase the load current and enter the actual and monitored output currents in the spreadsheet for a total of up to eight data points.
- 7. The spreadsheet now provides **New IOUT\_CAL\_GAIN** and **New IOUT\_CAL\_OFFSET** values that must be programmed into the InTune IC.

Enter the new values in the GUI on the **Configuration** tab. At this point, the GUI's reported load current should match the actual load current.

Note: The InTune digital supply is currently using the New IOUT\_CAL\_GAIN and New IOUT\_CAL\_OFFSET values, but these values are not permanently stored in the IC. Power cycling the input voltage to the IC erases the New IOUT\_CAL\_GAIN and New IOUT\_CAL\_OFFSET values. As a result, the IC reverts to previously stored values.

Significant changes to the IOUT\_CAL values may cause the IC's internal circuitry to switch between different gain ranges. Rerunning the calibration procedure a second time ensures proper calibration.

8. Permanently store the New IOUT\_CAL\_GAIN and New IOUT\_CAL\_OFFSET values in the IC by clicking on the Store User All button in the GUI (Figure 5). Note that clicking on Store User All writes all the changed PMBus commands on the Configuration tab to the IC. If you wish to store the IOUT\_CAL values but not disturb the rest of the settings, be sure not to change any other settings between the time that power is applied to the IC and the Store User All button is clicked.

Maxim PowerTool™ (1.08.02)					- • •
Dashboard 0x11 MAX15301A	402				
	PMBus Command Permis	sions			
Basic Settings			Device Status		
basic settings	Vout (V)	1.000	Device Status	Output Voltage (V)	1.000
	Vout Margin High (V)	1.050		Input Voltage (V)	11.953
	5 5			1 3.1	
	Vout Margin Low (V)	0.950 🝨		Output Current (A)	3.87
Switching	Frequency Set Point (kHz)	600 🚔		Switching Frequency (kHz)	601
	Over Current Limit (A)	19.563 🚔		Internal Temperature (°C)	23
	Power Good On (V)	0.901 🚔		External Temperature (°C)	35
	Power Good Off (V)	0.849 🜩		Duty Cycle (%)	7.80
Startup/Shutdown Times				Status	0
	On Delay Time (ms)	4.98 🗬	User Calibration -		
	On Rise Time (ms)	4.95 🍨		EXT_TEMP_CAL-m 1+	1.0391 🚔
	Off Delay Time (ma)	114 🔺		EXT TEMP CAL-b	-8.00 🌧
	Off Fall Time (ms)		ds, from when the output starts to	rise until the voltage has entered the reg	julation band
	Off fair fine (ins)	4.95		IOUT_CAL_GAIN (mΩ)	0.400 🚔
Operation Mode				IOUT_CAL_OFFSET (A)	0.000 🖨
Margin High, Ignore Faults	🔘 Margin High, Act	on Faults			
<ul> <li>Normal</li> <li>Margin Low, Ignore Faults</li> </ul>	Margin Low, Act of	on Faults	Advanced Configuration		
Soft Stop	Tristate Stop		E E	Advanced Configuration	
Store User All Restore User A	All Restore Maxim All	Restore Default All	Save Configuration to File	ad Configuration File to Device	
<					•
Selected PowerTool: MXXGP2TN (v15)	Device Firmware Version: 432	28			

Figure 5. Enter the IOUT\_CAL\_GAIN and IOUT\_CAL\_OFFSET values.

# Setting IOUT\_CAL\_GAIN and IOUT\_CAL\_OFFSET Values During Production

The ideal situation for a production environment is to set common IOUT\_CAL\_GAIN and IOUT\_CAL\_OFFSET values in each power supply. This can be achieved by characterizing the inductor on 10 or 20 individual power-supply boards and then using the averaged IOUT\_CAL\_GAIN and IOUT\_CAL\_OFFSET values on the production builds. The advantage of using averaged IOUT\_CAL values is reduced production test time. The disadvantage is that the current measurement's accuracy is degraded by the variation in inductor-to-inductor DCR.

# Conclusion

The procedure outlined in this application note explains how to recalibrate an InTune digital power IC's IOUT\_CAL\_GAIN and IOUT\_CAL\_OFFSET parameters to ensure an accurate load current measurement. Recalibration is recommended any time the output inductor, current-measurement filter components, or the digital power IC components are changed.

InTune is a trademark of Maxim Integrated Products, Inc. Microsoft is a registered trademark and registered service mark of Microsoft Corporation. PMBus is a trademark of SMIF, Inc. Windows is a registered trademark and registered service mark of Microsoft Corporation.

Related Parts		
MAX15301	InTune Automatically Compensated Digital PoL Controller with Driver and PMBus Telemetry	
MAX15303	6A Digital PoL DC-DC Converter with InTune Automatic Compensation	Free Samples
MAXPOWERTOOL002	USB-to-PMBus Interface Dongle for Power Products	Free Samples

More Information

For Technical Support: http://www.maximintegrated.com/en/support For Samples: http://www.maximintegrated.com/en/samples Other Questions and Comments: http://www.maximintegrated.com/en/contact

Application Note 5601: http://www.maximintegrated.com/en/an5601 APPLICATION NOTE 5601, AN5601, AN 5601, APP5601, Appnote5601, Appnote 5601 © 2014 Maxim Integrated Products, Inc. The content on this webpage is protected by copyright laws of the United States and of foreign countries. For requests to copy this content, contact us. Additional Legal Notices: http://www.maximintegrated.com/en/legal