Contents

1 Introduction

The ZSPM10X5A (ZSPM1025A / ZSPM1035A) is delivered without configuration or calibration, so the devices must be programmed prior to the first use. This is typically done using a programming fixture prior to soldering the components on the circuit board or during the end-of-line testing and calibration steps. Note that the devices will not power up their output voltage or react to the OPERATION command until the configuration has been written. This prevents any damage to the application caused by invalid configuration parameters.

The configuration is stored in a one-time-programmable memory (OTP) integrated in the ZSPM10x5A. Note that the ZSPM10x5A is only programmable once. Two different sets of parameters must be programmed: one for configuration and another for calibration. Configuration parameters are constant over all devices for a given application and can be programmed at any time during production. This includes parameters such as switching frequency and compensation.

Calibration data is specific to the ZSPM10X5A/board and must be programmed for each individual unit. It includes coefficients such as current sense offset, gain correction factors, and temperature offset correction. This application note details the end-of-line calibration functions of the ZSPM10x5A. The ZSPM10x5A supports calibration of the external temperature sense element and the current sense circuitry.

Refer to section 6 and also to the data sheet for the ZSPM1025 or ZSPM1035A regarding PMBus™ commands referenced in this document. Refer to the *Pink Power Designer™ Graphic User Interface (GUI)* if using the Pink Power Designer™ Graphical User Interface (GUI) to expedite configuration and calibration of the ZSPM10x5A.

2 Basic Access to OTP Data

As with the configuration data, calibration data is stored in the OTP of the ZSPM10x5A. Two basic subroutines allow access to the OTP.

2.1.1. Read Procedure

OTP data can be read from the device at any time during operation using the following steps:

1.) Set the OTP address pointer using the MFR_ADDRESS_POINTER command.

2.) Read the data using an MFR_OTP_READ_DATA command.

2.1.2. Write Procedure

OTP data can be written into the device using the following steps:

1.) Clear the OTP status register by writing 00000104_{HEX} using the MFR_OTP_STATUS command.

2.) Set the OTP address pointer using the MFR_ADDRESS_POINTER command.

3.) Write OTP data using the MFR_OTP_WRITE_DATA command.

4.) Finally check the OTP status to determine if the programming has been successful; i.e., read MFR_OTP_STATUS and check if bit 2 is zero.

Steps 2 and 3 can be repeated in a loop in order to write more than one data word. The status information is then accumulated over all write operations. Interrupting read operations, e.g. to verify the data, will not clear the status information.

2.1.3. Simple Tests

The OTP procedure can be tested using OTP cell $E4D_{HEX}$. Unconfigured parts should return 0004_{HEX}.

The OTP programming procedure can be tested using OTP spare cells at the end of the OTP configuration table. Table 2.1 provides the addresses.

Table 2.1 OTP Spare Cells per Device

Device Name	Address Range for Spare Cells
ZSPM10x5A	$EF8_{HEX}$ to EFE_{HEX}

3 Configuration Programming

Programming the configuration is the first step in production, prior to running any calibration routines. The Pink Power Designer™ GUI can be used to generate the configuration and store it in a ROM file. This is a plain text file that contains address and data values as detailed below. The contents of this ROM file can be downloaded into the part using the OTP write procedures detailed above or by using the Power Designer™ GUI.

Note that the configuration data is activated in the device only after a power cycle.

The configuration table's address range is given in Table 3.1. Recommendation: program the OTP starting from the highest address.

Table 3.1 OTP Configuration Table per Device

Device Name	Address Range for Configuration
ZSPM10x5A	$E4D_{HEX}$ to $EF7_{HEX}$

The comment header of the ROM file contains information about the part for which it has been created.

Recommendation: Compare the firmware (FW) version of the part to the FW version information stored in the ROM file to ensure proper operation. The FW version can be read using the MFR_REVISION command (see sections 6.1 and 6.2.8).

3.1. Format of the ROM File

The configuration of the device is available in a ROM file format and can be used to program the device in production. The file format of this ROM file is defined as follows:

Comment lines start with // and should be ignored.

Data lines are defined as

@[OTP ADDRESS] ␣ ␣ [OTP DATA]

where OTP_ADDRESS represents the address of the OTP cell and OTP_DATA its contents. Both values are stored as a 16-bit word in hexadecimal format and must be separated by two spaces in the ROM file.

Example of an excerpt from a ROM file:

```
//
// Firmware version: "1.1.1" [MFR_REVISION=0x31313131]
//
@0E4D␣␣0027
@0E4E␣␣0018
@0E4D␣␣0007
@0E4E␣␣0018
@0E4F␣␣2662
@0E50␣␣0000
```

4 External Temperature Calibration

External temperature sensors vary in forward voltage, which requires a calibration of the 25°C reference voltage.

4.1. Requirements

- The device must be configured using OTP.
- The external sense element must be connected to the ZSPM10x5A.
- The actual ambient temperature must be known.
- The device must not have been temperature calibrated before; i.e., the OTP cell EED_{HEX} is empty.

4.2. Calibration Procedure

The actual calibration procedure is simple.

1.) Read the actual measurement value from the device using the READ_TEMPERATURE_1 command.

2.) Optional: Apply a correction procedure in case the ambient temperature is not 25°C (see section 4.3).

3.) Write the temperature offset value into OTP cell EED_{HEX} using the OTP data write procedure.

4.) Optional: Verify the procedure by reading via the READ_TEMPERATURE_1 command. This should now return the ambient temperature in degrees Celsius.

4.3. Correction Procedure for Ambient Temperatures Other than 25°C

The temperature sense offset value required by the device is designed for 25°C; therefore, if calibration is run at a different ambient temperature, the offset value read during step 1 of the calibration procedure must to be corrected prior to step 3 above.

This can be done by applying the following equation:

EXT_TEMP_REF_COR = EXT_TEMP_REF + (TEMP_AMBIENT- 25) / EXT_TEMP_SENSE

Where

EXT_TEMP_REF_COR is the corrected offset.
EXT_TEMP_REF is the offset value read from the device at the ambient temperature.
TEMP_AMBIENT is the ambient temperature value.
EXT_TEMP_SENSE is the sensitivity of the external temperature sensor as read from the device.

EXT_TEMP_SENSE can be calculated from the content of OTP cell EEE_{HEX} using the following equation:

EXT_TEMP_SENSE = (65536 - OTP[EEE_{HEX}]) / 2048.

4.4. Calculation Examples for Ambient Temperatures Other than 25°C

Setup 1: Ambient temperature correction is used.

Assume that the ambient temperature is 40°C; READ_TEMPERATURE_1 returns a value of 849_{DEC}; and the OTP cell EEE_{HEX} contains a value of $FD71_{HEX}$.

Calculate the corrected temperature offset:

EXT_TEMP_REF_COR = 849 + (40 – 25) / ((65536 – 64881)/2048) = 895 = $037F_{HEX}$

Write the results $037F_{HEX}$ into OTP cell EED_{HEX}.

Now use READ_TEMPERATURE_1 to verify the calibration. If the procedure was the successful, the result of the read will be 40°C, which is the temperature used for calibration.

Setup 2: Ambient temperature correction is NOT used.

Assume that the ambient temperature is 40°C and READ_TEMPERATURE_1 returns a value of 849_{DEC}.

As the ambient temperature connection is not used, write 849_{DEC} into OTP cell EEE_{HEX}.

Verifying the results via READ_TEMPERATURE_1 returns a value of 25°C even though the actual temperature is 40°C. This is expected as the part has been set up to accept the value of 40°C as its 25°C reference.

4.5. Additional Information for Temperature Calibration

Note that the absolute value of the temperature is only important for the monitoring the temperature. Temperature correction of the DCR could run from any temperature code, as long the current calibration procedure has been performed for the same temperature.

If the ambient temperature is unknown, the internal temperature sensor can be used as a reference for calibration.

5 Current Calibration Procedure

In order to improve the accuracy of the current sense circuitry of the device, a two-point current calibration procedure is recommended. This will calibrate the offset and gain error of the current sense circuitry and improve performance considerably.

5.1. Requirements

- The device must be configured using OTP.
- The external temperature sense element must have been calibrated if DCR temperature compensation is used with the external temperature sensor.
- The device has not been current calibrated before; i.e., OTP cells $E52_{HEX}$ and $E53_{HEX}$ are empty.
- The user must be able to draw two known currents from the power converter; e.g., an electronic load has been connected to the output voltage.

5.2. Calibration Procedure

1.) The over-current protection of the device must be disabled so that the calibration currents do not trigger an over-current event. This is done by sending the following PMBus™ command sequence:

Table 5.1 Command Sequence for Disabling Over-Current Protection

CMD Code	Data Bytes (lowest byte first)	Transaction Type
$F9_{HEX}$	01_{HEX}, 00_{HEX}	Write word
$F8_{HEX}$	80_{HEX}, $3e_{HEX}$	Write word
FA_{HEX}	00_{HEX}, 00_{HEX}	Write word

2.) Apply a known load current I_{OUT1}.

3.) Measure the output current reported from the device using the READ_IOUT command (I_{OUT1_MEAS} in section 5.3).
Optional: Measure the temperature for I_{OUT1} using the READ_TEMPERATURE_x command.

4.) Apply a known load current I_{OUT2}.

5.) Measure the output current reported from the device using the READ_IOUT command (I_{OUT2_MEAS} in section 5.3).
Optional: Measure the temperature for I_{OUT2} using the READ_TEMPERATURE_x command.

6.) Optional: Enable the over-current protection again.

Table 5.2 Command Sequence for Re-enabling Over-Current Protection

CMD Code	Data Bytes (lowest byte first)	Transaction Type
$F9_{HEX}$	01_{HEX}, 00_{HEX}	Write word
$F8_{HEX}$	80_{HEX}, $3e_{HEX}$	Write word
FA_{HEX}	80_{HEX}, 00_{HEX}	Write word

7.) Compute the gain and offset correction factors according to the equations listed in the next section.

8.) Write gain and offset correction factors in the ZSPM10x5A. The gain factor is written into OTP cell $E52_{HEX}$; the offset value is written into OTP cell $E53_{HEX}$.

5.3. Computation of Current Sense Correction Factors

The gain and offset correction factors can be computed from the nominal and measured current values using the following equations:

Gain correction factor: IOUT_CAL_GAIN_CORR = $(I_{OUT2} - I_{OUT1}) / (I_{OUT2\_MEAS} - I_{OUT1\_MEAS})$

Offset correction factor: IOUT_CAL_OFFSET = $I_{OUT1} - (I_{OUT1\_MEAS}$ * ICOUT_CAL_GAIN_CORR)

Both values must be scaled prior to writing them into their respective OTP cells:

IOUT_CAL_GAIN_CORR_OTP = IOUT_CAL_GAIN_CORR * 128

IOUT_CAL_OFFSET_OTP = IOUT_CAL_OFFSET * IOUT_READ_FACTOR

IOUT_READ_FACTOR can be calculated from the content of OTP cell $EF1_{HEX}$ using the following equation:

IOUT_READ_FACTOR = OTP[$EF1_{HEX}$] / 32.

Prior to writing the values into the OTP, the calibration values should be checked for correctness, as the values are constrained by the following limits:

Table 5.3 Limits for Calibration Values

Value	Data Format	Lower Limit	Upper Limit
IOUT_CAL_GAIN_CORR_OTP	Unsigned Q1.7	0.5 (0040_{HEX})	1.5 ($00C0_{HEX}$)
IOUT_CAL_OFFSET_OTP	Signed Q0.7, 16-bit signed extended	-0.75 ($FFA0_{HEX}$)	0.75 (0060_{HEX})

5.4. DCR Temperature Correction during Calibration

If output current sensing is required with high accuracy or the temperature during calibration is significantly higher than 25°C, a correction of the DCR temperature rise is recommended during calibration. This is due to the fact that gain and offset of the current sense circuitry are defined for 25°C.

This temperature correction can be easily done by scaling the measured currents with the DCR temperature correction values.

The current information read with the READ_IOUT command is converted into the temperature-corrected current IOUT_TC_COR using

IOUT_TC_COR = READ_IOUT / (1.0 + TC_DCR * (T - 25))

Where

TC_DCR is the temperature coefficient of the DCR.
T is the actual temperature during the measurement of the output current.

The temperature corrected currents are then substituted into the equations in section 5.3 instead of the actual uncorrected readings.

Recommendation: Read the temperature of the sensor configured for the DCR temperature correction algorithm in the device; i.e., READ_TEMPERATURE_1 if the external sensor is used and READ_TEMPERATURE_2 if the internal sensor is used.

The temperature coefficient of the DCR is set to 3900ppm/°C by default. Alternatively, it can be extracted from the device using the following equations:

If the external temperature sensor is used: TC_DCR = OTP[$EF2_{HEX}$] / 16.0 / OTP[EEE_{HEX}]

If the internal temperature sensor is used: TC_DCR = OTP[$EF2_{HEX}$] / 16.0 / OTP[$E47_{HEX}$]

Note that the OTP cells $EF2_{HEX}$, EEE_{HEX} and $E47_{HEX}$ are all in 16-bit signed data format.

5.5. Calculation Examples

Scenario 1:

Assume this is a calibration of a power converter with a nominal current of I_{OUT1} = 5.0A and I_{OUT2} = 25A; the OTP[$EF1_{HEX}$] = $19B_{HEX}$; and I_{OUT1_MEAS} has been measured as 2.8A and I_{OUT2_MEAS} as 19.7A.

Calculate the correction coefficients:

IOUT_CAL_GAIN_CORR = (25.0 – 5.0) / (19.7 – 2.8) = 1.18
IOUT_CAL_OFFSET = 5 – (2.8 * 1.18) = 1.70.

Convert this into OTP format as follows:

IOUT_CAL_GAIN_CORR_OTP = 1.18 * 128 = 151 = 0097_{HEX}

IOUT_CAL_OFFSET_OTP = 1.70 * (411 / 32) = 22 = 0016_{HEX}

Both values lie within the allowed limits of the ZSPM10x5A and hence can be written into the IC.

Scenario 2:

Assume this is a calibration of a power converter with nominal current of I_{OUT1} = 5.0A and I_{OUT2} = 15A; the OTP[$EF1_{HEX}$] = $19B_{HEX}$; and I_{OUT1_MEAS} has been measured as 4.79 A and I_{OUT2_MEAS} as 13.66 A.

Calculate the correction coefficients:

IOUT_CAL_GAIN_CORR = (15.0 – 5.0) / (13.66 – 4.79) = 1.128
IOUT_CAL_OFFSET = 5 – (4.79 * 1.128) = -0.402.

Convert this into OTP format as follows:

IOUT_CAL_GAIN_CORR_OTP = 1.128 * 128 = 144 = 0090_{HEX}

IOUT_CAL_OFFSET_OTP = -0.402 * (411 / 32) = -5 = $FFFB_{HEX}$

Both values lie within the allowed limits of the ZSPM10x5A and hence can be written into the IC.

Scenario 3:

Assume this is a calibration of a power converter with nominal current of I_{OUT1} = 5.0A and I_{OUT2} = 20A; I_{OUT1_MEAS} has been measured as 4.96 A at 31.0°C and I_{OUT2_MEAS} as 18.24 A at 31.0°C. The OTP contains these values: OTP[EEE_{HEX}] = $FD70_{HEX}$, OTP[$EF1_{HEX}$] = $019B_{HEX}$ and OTP[$EF2_{HEX}$] = $FFD2_{HEX}$. The external temperature sensor is used for DCR compensation.

The DCR temperature coefficients is calculated as

TC_DCR = -41 / 16.0 / -655 = 0.0039

Next the current measurements are temperature corrected:

IOUT1_TC_COR = 4.96 / (1.0 + 0.0039 * (31.0 – 25.0)) = 4.84

IOUT1_TC_COR = 18.24 / (1.0 + 0.0039 * (31.0 – 25.0)) = 17.82

Substituting these values into the equations gives

IOUT_CAL_GAIN_CORR = (20.0 – 5.0) / (17.82 – 4.84) = 1.156
IOUT_CAL_OFFSET = 5 – (4.84 * 1.156) = -0.600.

Convert this into OTP format as follows:

IOUT_CAL_GAIN_CORR_OTP = 1.156 * 128 = 148 = 0094_{HEX}

IOUT_CAL_OFFSET_OTP = -0.600 * (411 / 32) = -8 = $FFF8_{HEX}$

Both values lie within the allowed limits of the ZSPM10x5A and hence can be written into the IC.

6 PMBus™ Command Reference

6.1. Overview about PMBus™ Commands

Table 6.1 PMBus™ Command Overview

PMBus™ Command	Description	Transaction Type	Command Byte (hex)	Data Length (bytes)
READ_IOUT	Output current	Read word	$8C_{HEX}$	2
READ_TEMPERATURE_1	External temperature	Read word	$8D_{HEX}$	2
READ_TEMPERATURE_2	Internal temperature	Read word	$8E_{HEX}$	2
MFR_REVISION	Device FW revision [1.)]	Block read	$9D_{HEX}$	(4)
MFR_ADDRESS_POINTER	Address pointer for OTP operation	Read word Write word	$F8_{HEX}$	2
MFR_OTP_READ_DATA	Read data from OTP	Read word	$F1_{HEX}$	2
MFR_OTP_WRITE_DATA	Write data to OTP	Write Word	$F0_{HEX}$	2
MFR_OTP_STATUS	OTP status information	Read word Write word	EF_{HEX}	4
1.) This is a block command; i.e., the length of the data is transmitted as the first byte of the message.				

6.2. PMBus™ Command Definitions

6.2.1. READ_IOUT

READ_IOUT (read only)		
Bits	**Name**	**Description**
[15:0]	IOUT	Output current in A (linear data format).

6.2.2. READ_TEMPERATURE_1

READ_TEMPERATURE_1 (read only)		
Bits	**Name**	**Description**
[15:0]	TEMP1	External temperature in °C (linear data format). RAW data format if device is not temperature calibrated.

6.2.3. READ_TEMPERATURE_2

READ_TEMPERATURE_2 (read only)		
Bits	**Name**	**Description**
[15:0]	TEMP2	Internal temperature in °C (linear data format).

6.2.4. MFR_ADDRESS_POINTER

MFR_ADDRESS_POINTER (read / write)		
Bits	**Name**	**Description**
[0]	RESERVED	
[15:1]	ADDRESS	Address of OTP data access

6.2.5. MFR_OTP_READ_DATA

READ_OTP_READ_DATA (read only)		
Bits	**Name**	**Description**
[15:0]	DATA	Data read from OTP at the address set by MFR_ADDRESS_POINTER

6.2.6. MFR_OTP_WRITE_DATA

MFR_OTP_WRITE_DATA (write only)		
Bits	**Name**	**Description**
[15:0]	DATA	Data to be written into OTP at address set by MFR_ADDRESS_POINTER

6.2.7. MFR_OTP_STATUS

MFR_OTP_STATUS (read / write)		
Bits	**Name**	**Description**
[1:0]	Reserved	
[2]	FAILED	OTP Programming has failed. Write a one to clear this bit.
[7:3]	Reserved	
[8]	CLEAR	Clear OTP faults by writing 1 to this bit.
[31:9]	Reserved	

6.2.8. MFR_REVISION

MFR_REVISION (read)		
Bits	**Name**	**Description**
[31:0]	REVISION	FW Revision in ISO/IEC 8859-1 format.

7 Related Documents

Document
ZSPM1025A Data Sheet
ZSPM1035A Data Sheet
ZSPM8025-KIT Evaluation Kit Description
ZSPM8035-KIT Evaluation Kit Description
Pink Power Designer™ Graphic User Interface (GUI)

Visit www.IDT.com/ZSPM1025A, www.IDT.com/ZSPM1035A, www.IDT.com/ZSPM8025-KIT, www.IDT.com/ZSPM8035-KIT or contact your nearest sales office for the latest version of these documents.

8 Document Revision History

Revision	Date	Description
1.00	October 22, 2013	First release.
	April 7, 2016	Changed to IDT branding.

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