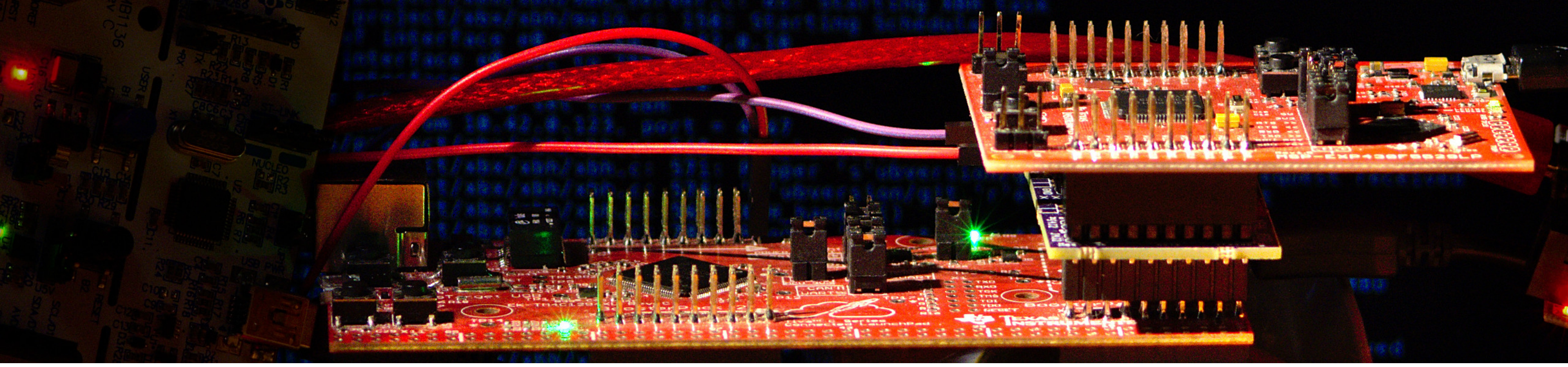

XXBX Power Shim – XBP

XBP User Guide v1.0

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Contents

Chapter 1

Introduction

The XXBX Power Shim (XBP) connects the Harness (XBH) to the Device under test (XBD). Figure 1.1 shows a typical XXBX setup with the XBP placed between the XBH and the XBD. All signals from the XBH to the XBD pass through the XBP. The main purpose of the XBP is to sense the current drawn by the XBD, amplify its value and pass it on to the XBH for measurement.

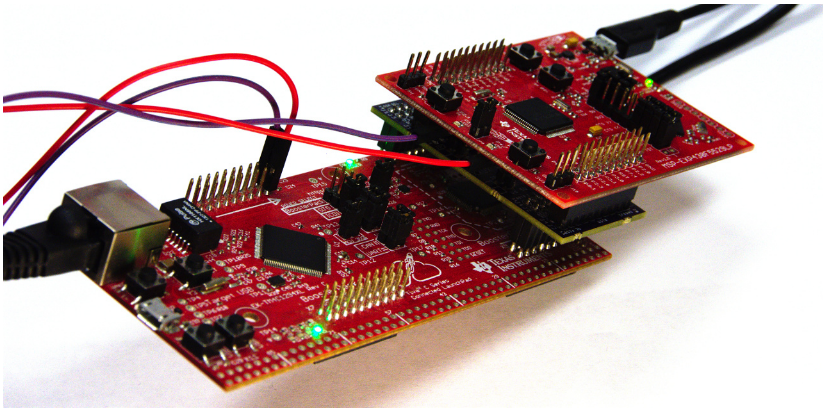

Figure 1.1: XXBX Setup with XBH on the bottom followed by XBP in the middle and XBD on top

1.1 XBP Current Sensing and Amplification

The power consumed by a device can be computed from the current I that it draws and its supply voltage $\mathrm{V_{CC}D}$ as $P = I \cdot V_{CC}D$. The energy it consumes for executing a particular task is the integral of P over the run time. As the voltage $V_{CC}D$ is fixed for a particular XBD we only have to measure the current.

The current is measured by sensing the voltage drop across a small shunt resistor R_S. The shunt resistor could be placed between the voltage source and the device or between the device and ground called high-side and low-side current sensing respectively. We opted for high-side current sensing (see Fig 1.2) as it eliminates the problems associated with multiple ground paths. The drawback of high-side sensing is the higher common-mode voltage which is the average voltage before and after the shunt.

The shunt resistor should be very small as to not have a large influence on the supply voltage of the XBD, however that means that voltage drop across the shunt will also be very small. Therefore, it has to be amplified before it can be measured by an analog to digital converter (ADC). Furthermore, the low input resistance of ADCs makes a direct measurement unfeasible. Hence, we use a current-shunt monitor (CSM), i.e. the INA225 from Texas Instruments. It has a programmable gain setting between 25 and 200, a buffered output so that it can drive an ADC input, a bandwidth of 125 kHz, and supports high common-mode voltages.

The resolution of the ADC is shown in (1.1). The maximum input voltage to the ADC is 3.3V and its resolution is 12 bits.

$$V_{res} = \frac{V_{CSM}}{2^{ADCbits}} = \frac{3.3\,\text{V}}{2^{12}\,\text{bits}} = 0.8\,\text{mV} \tag{1.1}$$

The voltage applied to the ADC depends on the voltage drop across the shunt resistor R_S and the gain of the CSM δ_{CSM}. This relationship is expressed in (1.2).

$$V_{CSM} = 3.3\,\text{V} = V_S \cdot \delta_{CSM} = R_S \cdot I \cdot \delta_{CSM} \tag{1.2}$$

When using a $1\,\Omega$ resistor for R_S we achieve for a gain factor of 25 a resolution of

$$I_{res} = \frac{V_{res}}{R_S \cdot \delta_{CSM}} = \frac{0.8\,\text{mV}}{1\,\Omega \cdot 25} = 32\,\mu\text{A}$$

and can measure a current of at most

$$I_{max} = \frac{V_{res}}{R_S \cdot \delta_{CSM}} = \frac{3.3\,\text{V}}{1\,\Omega \cdot 25} = 132\,\text{mA}.$$

At the maximum gain of 200 the resolution is $4.0\,\mu$A and the maximum current is 16.5 mA.

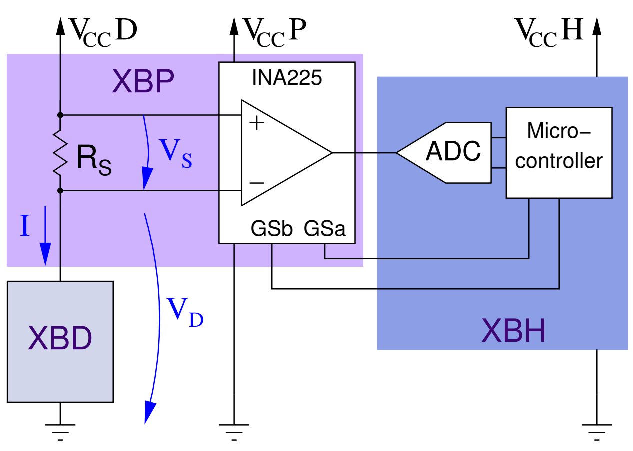

Figure 1.2: Block Diagram of the Power Measurement Setup

1.2 Voltage Level Shifter

Some XBDs might require a supply voltage $V_{CC}D$ which is higher than the $V_{CC}P = 3.3\,\text{V}$ or lower. As all control signals for the XBD pass through the XBP, we added circuitry for voltage level shifting. The circuit used on the XBP is shown in fig 1.3.

When SDA is not active or any side want to transmit a logic 'one', the pull-up resistors on both sides pull the input on the XBD and the XBH to their voltage levels. When the XBH pulls down SCL, the source input of the transistor Q6 becomes low, while the gate stays high. V_{GS} rises above the threshold and the transistor conducts. This pulls down the the drain input of Q5. Now the drain-substrate diode of Q5 is pulled down until V_GS passes the threshold and the transistor conducts, hence SDA on the XBD is low. Due to symmetry, XBD can pull down SDA in a similar fashion which results in SDA on XBH going low. While single transistor solutions exist that can accomplish the same functionality, only this 2 transistor circuit is agnositc to whether the XBD side or the XBH side has a higer V_CC, i.e. it allows the use XBDs with higher as well as with lower supply voltage.

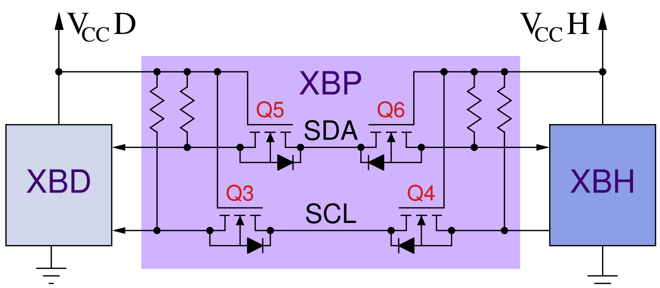

Figure 1.3: Voltage Level Shifter for I^{2}C

1.3 Optional Functionality

Because of its location in an XXBX setup, we were able to integrate additional functionality which leads to a cleaner setup.

1.3.1 I^{2}C Pull-Up Resistors

The I^{2}C bus requires pull-up resistors. The XBH does not have pull-up resistors on its I^{2}C pins. Only some XBDs either have these pull-up resistors or can be configured to use internal pull-up resistors. We therefore decided to provide a place for pull-up resistors on the XBP. They can be put on the board depending on the users needs.

1.3.2 Power Regulation

The operating voltage for an XBD ($V_{CC}D$) has to pass through the XBP to measure the current consumption. As $V_{CC}D$ depends on the particular XBD, it makes sense to provide a place on the XBP for a voltage regulator. This enables the user to supply all XBP's with 5 V and have the voltage regulator on the XBP produce the voltage required for each individual XBD.

Chapter 2

XBP Configuration

2.1 Shunt Resistor Selection

R_S

2.2 Supply Voltages

The XBP uses three voltage supplies. The first supply, called V_{CC}H uses 3.3 V from the XBH and powers the I^2C pull-up resistors, the activity LED, and the level shifters. The second supply, called V_{CC}P uses 5 V and powers the current sense amplifier of the XBP and the power LED. The third supply is V_{CC}D which powers the XBD.

2.2.1 Powering the XBP

In this section we only discuss how to supply V_{CC}H and V_{CC}P. There are two options to power the XBP. Option one is to power the XBP from the XBH using the LaunchPad connector. This only works if the XBP is directly plugged into the LaunchPad connector on the XBH, we call this an XBP0. Then the XBH can supply V_{CC}H and V_{CC}P. Please close solder jumper **SJ4** and solder jumper **SJ5** and do not connect the power connector's V_{CC}H and V_{CC}P pins to the XBH. They can be used to power another XBP though.

The other option is to power the XBP through the power connector on the front (see Fig. 2.1). This works for XBP0 through XBP3. Please make sure that the solder jumper **SJ4** and solder jumper **SJ5** are **open**. V_{CC}H of 5 V and V_{CC}P of 3.3 V can be wired to the corresponding pins on the XBH or the power connector of the XBP0 if the XBP0 is supplied directly from the XBH through the LaunchPad connectors.

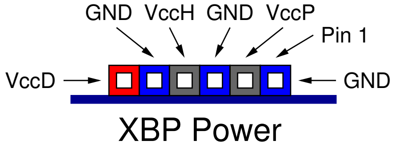

Figure 2.1: XBP Power Connector as Viewed from Front of PCB

2.2.2 Powering the XBD

Power for the XBD can be provided through the power connector's $V_{CC}D$ pin. Optionally $V_{CC}D$ can be generated on the XBP from the 5 V $V_{CC}P$. If this is desired, please populate **IC1** with an LDO voltage regulator in a SOT-89-3 package. An example is the Microchip MCP1702T-3302E/MB 3.3 V regulator.

Using XBDs with $V_{CC} = 3.3$ V

If your XBD uses a $V_{CC} = 3.3$ V and has a LaunchPad connector, you can plug it directly on top of the XBP. Otherwise you can use the XBD connector on the back of the XBP (see Fig. 2.2) and close solder jumpers **SJ1**, **SJ2**, and **SJ3** as you don't need voltage level shifting. In either case, please check Section 3 in this guide for details on particular XBDs.

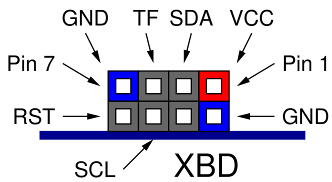

Figure 2.2: XBD Connector as Viewed from Back of PCB

Using XBDs with $V_{CC} \neq 3.3$ V

Such XBDs can only be connected through the XBD connector on the back (Fig 2.2). The FETs Q3 through Q8 and the resistors R9 through R11 have to be populated. Please make sure that solder jumpers **SJ1**, **SJ2**, and **SJ3** are open. $V_{CC}D$ can be higher or lower than 3.3 V.

2.3 I^2C Pull-Up Resistors

The XBP can provide the pull-up resistors for I^2C. These are needed only once on an I^2C bus. We suggest that you populate **R3** and **R4** using 10 kOhm resistors (size: 0604) on the first XBP (XBP0).

2.4 Usage without XBH

The XBP can be used also without an XBH as an experimenter's board for the INA225 current-shunt monitor. The XBH requires $V_{CC}P$ of 5 V to be supplied through its power connector (see Fig. 2.1. The power for the device under test can be supplied as described in section 2.2.2. The amplified voltage drop over the shunt can be measured by through the SMA connector **X1**. The gain of the amplifier can be set through jumper JP5. The jumper settings required for the different gains are printed on the circuit board. The device under test will get its power from the XBD connector (see Fig. 2.2). Only pins 1 and 2, V_{CC} and GND respectively, have to be used.

Chapter 3

XBX Devices under Test (XBD)

3.1 TI Stellaris® LM4F120 LaunchPad

Neither the Debug, nor the Device USB should be connected for power measurements. The *+3.3V* line on pin J1.1 of the boosterpack connector is connected directly to the In-Circuit Debugger. Therefore, it is recommended to select on the XBP to power the XBD via the external XBD connector and not via the boosterpack connector. On the TI Stellaris Launchpad, the VDD jumper has to be pulled and the external 3.3V has to be supplied to the right pin. The green power LED on the Launchpad lights up when the 3.3V are supplied to the left (wrong) pin. The *PWR Select* switch can be in any position and won't affect the measurements.

3.2 TI Tiva™ C Series TM4C123G LaunchPad

The circuit connections are the same as on the TI Stellaris LaunchPad. Please follow those instructions. Supply voltage is 3.3V with a maximum current of 300 mA.

3.3 TI MSP430F5529 LaunchPad™

For precise current measurements remove all jumpers from the isolation jumper block with the exception of the ground (GND) jumper.

3.4 TI MSP430FR6989 LaunchPad™

For precise current measurements remove all jumpers from the isolation jumper block with the exception of the ground (GND) jumper. Supply voltage is 3.3V with a maximum current of 2.7 mA not including LEDs or external circuitry.

Chapter 4

XBP Assembly

4.1 XBP Connections

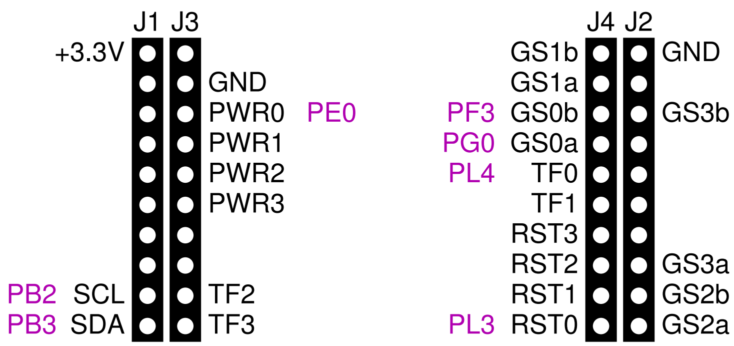

Figure 4.1: Boosterpack Connector XBH as Viewed from Top of PCB

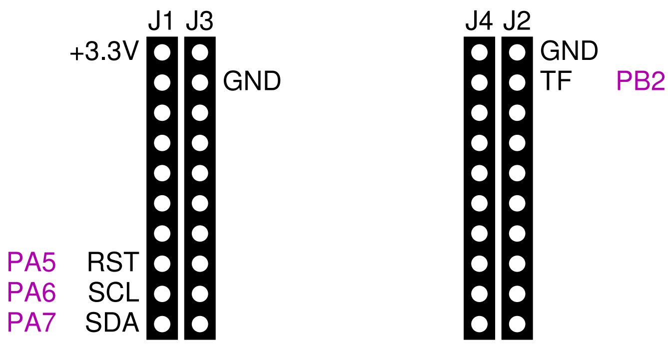

Figure 4.2: Boosterpack Connector XBD as Viewed from Top of PCB

Table 4.1: Pin Configuration of Boosterpack Connector for XBH

Connector	Pin	Net	Comment
J1	1	+3V3	Supply Voltage V_{CC}H from XBH for I^2C pull-up resistors on XBP0
J1	9	SCL	I^2C Serial Clock
J1	10	SDA	I^2C Serial Data
J3	21	+5V	Supply Voltage V_{CC}P from XBH for the XBP0
J3	23	PWR0	Analog signal of current consumption of XBD0 from XBP0
J4	37/38	GS0a/GS0b	Gain select for current monitor of XBD0 on XBP0
J4	36	TF0	Timer Flag from XBD0
J4	31	RST0	Reset of XBD0
J3	24	PWR1	Analog signal of current consumption of XBD1 from XBP1
J4	39/40	GS1a/GS1b	Gain select for current monitor of XBD1 on XBP1
J4	35	TF1	Timer Flag from XBD1
J4	32	RST1	Reset of XBD1
J3	25	PWR2	Analog signal of current consumption of XBD2 from XBP2
J2	11/12	GS2a/GS2b	Gain select for current monitor of XBD2 on XBP2
J3	29	TF2	Timer Flag from XBD2
J4	33	RST2	Reset of XBD2
J3	26	PWR3	Analog signal of current consumption of XBD3 from XBP3
J2	13/18	GS3a/GS3b	Gain select for current monitor of XBD3 on XBP3
J3	30	TF3	Timer Flag from XBD3
J4	34	RST3	Reset of XBD3
J2	20	GND	
J3	22	GND	

Table 4.2: Pin Configuration of Boosterpack Connector for XBD

Connector	Pin	Net	Comment
J1	1	+3V3	Supply Voltage, current is measured by XBP
J1	9	SCL	I^2C Serial Clock
J1	10	SDA	I^2C Serial Data
J2	16	RST	Reset of XBD
J2	19	TF	Timer Flag to start/stop execution timer on XBH
J2	20	GND	
J3	22	GND	