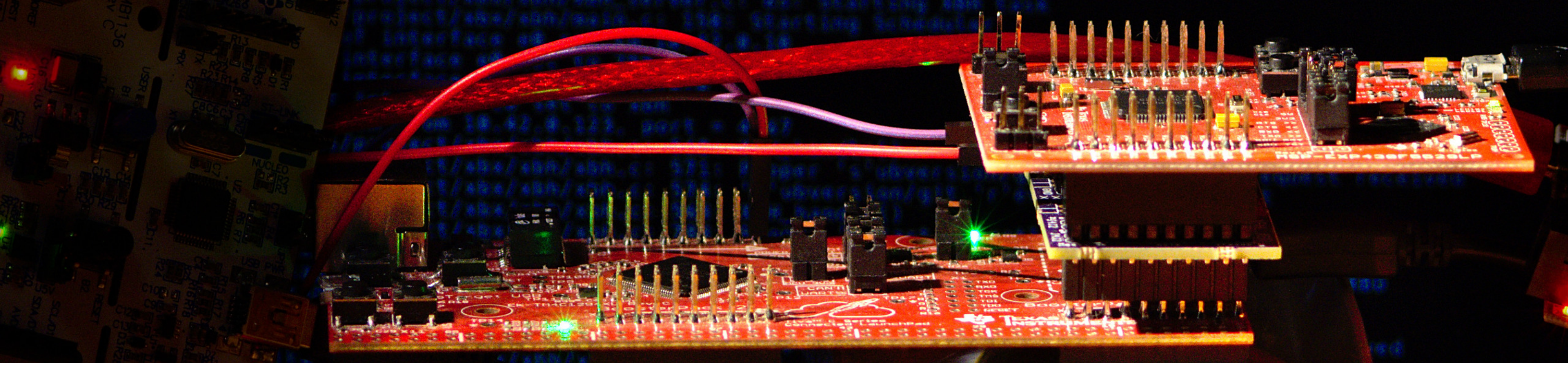


XXBX Power Shim – XBP

XBP User Guide v1.0

Jens-Peter Kaps
jkaps@gmu.edu

April 3, 2018
George Mason University
Fairfax, Virginia

cryptography.gmu.edu

www.gmu.edu

Cryptographic Engineering Research Group
Department of Electrical and Computer Engineering George Mason University
3100 Engineering Building, 4400 University Drive, Fairfax, VA 22030-4444, USA
Voice: (703) 993-1561, Fax: (703) 993-1601

Contents

1 Introduction **4**
- 1.1 XBP Current Sensing and Amplification 4
- 1.2 Voltage Level Shifter 5
- 1.3 Indicators 6
- 1.4 Optional Functionality 6
  - 1.4.1 I^2C Pull-Up Resistors 7
  - 1.4.2 Power Regulation 7

2 XBP Configuration **8**
- 2.1 Shunt Resistor Selection 8
- 2.2 Supply Voltages 8
  - 2.2.1 Powering the XBP 8
  - 2.2.2 Powering the XBD 9
- 2.3 I^2C Pull-Up Resistors 9
- 2.4 Usage without XBH 10

3 XXBX Devices under Test (XBD) **11**
- 3.1 Texas Instruments LaunchPads 11
  - 3.1.1 TI MSP430F5529 LaunchPad™ 11
  - 3.1.2 TI MSP430FR5994 LaunchPad™ 12
  - 3.1.3 TI MSP432P401R LaunchPad™ 13
  - 3.1.4 TI Stellaris® LM4F120 LaunchPad 13
  - 3.1.5 TI Tiva™ C Series TM4C123G LaunchPad 13
- 3.2 ST Microelectronics NUCLEO Boards 14

4 XBP Assembly **15**
- 4.1 Indicator LEDs 16
- 4.2 Current-Shunt Monitor 16
- 4.3 I^2C Pull-Up Resistors and Level Shifting 17
- 4.4 Through-Hole Components 17

A XBP Connections **19**

B Schematic **21**

C Board Layout **23**

D Parts List **24**

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.

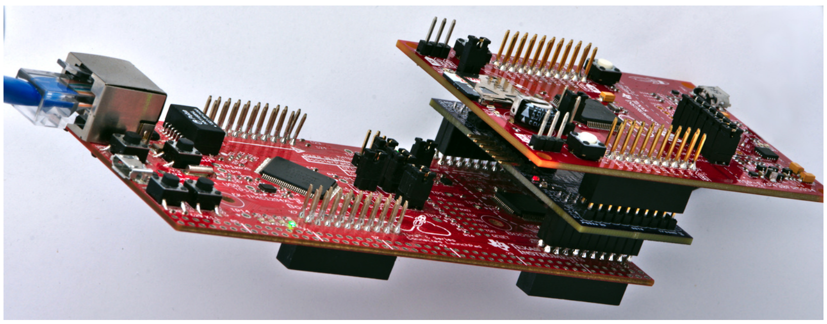


Figure 1.1: XXBX Setup with XBH on the bottom followed by XBP in the middle and XBD on top

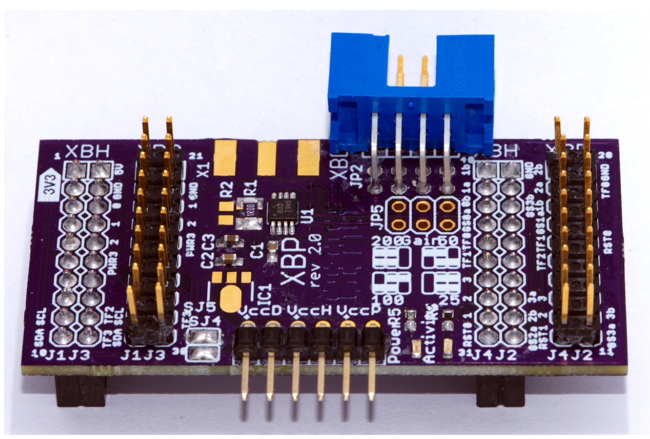


Figure 1.2: XBP

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 1.3) 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 formula for the resolution of the ADC is shown in (1.1). The maximum input voltage to the ADC (V_{CSMmax}) is 3.3V and its resolution is 12 bits.

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

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

$$V_{CSM} = V_S \cdot \delta_{CSM} = R_S \cdot I \cdot \delta_{CSM} \tag{1.2}$$

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

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

and can measure a current of at most

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

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

1.2 Voltage Level Shifter

Some XBDs might require a supply voltage $V_{CC}D$ which is higher than the $V_{CC}H = 3.3\,\mathrm{V}$ 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 1.4.

When SDA is not active or any side wants to transmit a logic ‘one’, the pull-up resistors on both sides pull the inputs 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

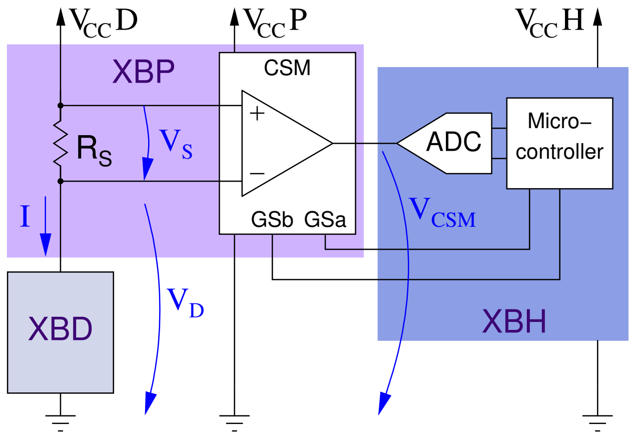


Figure 1.3: Block Diagram of the Power Measurement Setup

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 agnostic to whether the XBD side or the XBH side has a higher $V_C C$, i.e. it allows the use XBDs with higher as well as with lower supply voltages.

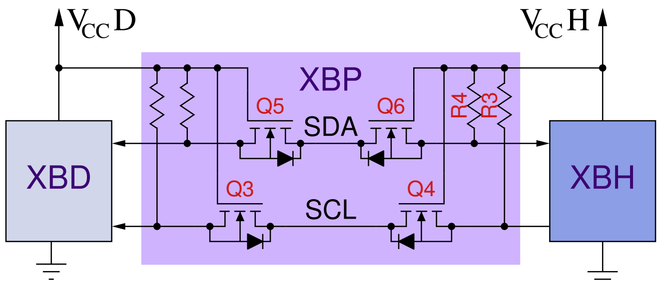


Figure 1.4: Voltage Level Shifter for I^{2}C

1.3 Indicators

The XBP has two LED indicators. A red LED “Power” lights up when the XBP is connected to $V_{CC}P$. A green LED “Activity” lights up when the XBD is performing a benchmark run. In order to not affect the power consumption of the XBD, the “Activity” LED is not directly tied to the timer flag (TF) signal of the XBD but driven by a field effect transistor.

1.4 Optional Functionality

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

1.4.1 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. They are marked in Fig 1.4 as R3 and R4.

1.4.2 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.

2 XBP Configuration

2.1 Shunt Resistor Selection

The shunt resistor R_S should be selected such that during maximum power draw of the XBD the output of the CSM V_{CSM}, i.e., the input to the ADC, is smaller but close to $V_{CSMmax} = 3.3\,\mathrm{V}$ at the lowest gain $\delta_{CSM} = 25$ in order to maximize the effective resolution of the ADC and minimize the amplification error of the CSM.

As shown in section 1.1, a shunt resistor R_S of $1\,\Omega$ allows us to use XBDs that draw a current I_max up to 132 mA. Using a higher gain the maximum can be dropped to 16.5 mA, however the CSM will introduce a slightly larger error.

The ideal value for the shunt resistor can be computed using (2.1).

$$R_S = \frac{V_{CSMmax}}{I_{max} \cdot \delta_{CSM}} = \frac{3.3\,\mathrm{V}}{I_{max} \cdot 25} \tag{2.1}$$

The XBP circuit board has two locations to place the shunt, labeled **R1** and **R2** and are of size 1210 and 0805 respectively. Try to use location **R1** if possible as its closer to the CSM (labeled **U1** on the board). Once a shunt resistor has been selected, the resolution and maximum supported current of the XBD can be recomputed using (2.2) and (2.3) respectively.

$$I_{res} = \frac{V_{res}}{R_S \cdot \delta_{CSM}} = \frac{0.8\,\mathrm{mV}}{R_S \cdot \delta_{CSM}} \tag{2.2}$$

$$I_{max} = \frac{V_{CSMmax}}{R_S \cdot \delta_{CSM}} = \frac{3.3\,\mathrm{V}}{R_S \cdot \delta_{CSM}} \tag{2.3}$$

2.2 Supply Voltages

The XBP uses three voltage supplies. The first supply, called $\mathrm{V_{CC}H}$ uses 3.3 V from the XBH and powers the $\mathrm{I^2C}$ pull-up resistors, the activity LED, and the level shifters. The second supply, called $\mathrm{V_{CC}P}$ uses 5 V and powers the current sense amplifier of the XBP and the power LED. The third supply is $\mathrm{V_{CC}D}$ which powers the XBD (see Fig 1.3).

2.2.1 Powering the XBP

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 $\mathrm{V_{CC}H}$ and $\mathrm{V_{CC}P}$. Please close solder jumper **SJ4** and solder jumper **SJ5** and do not connect the power connector's $\mathrm{V_{CC}H}$ and $\mathrm{V_{CC}P}$ 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**. $\mathrm{V_{CC}H}$ of 5 V and $\mathrm{V_{CC}P}$ 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.

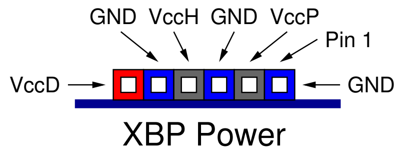


Figure 2.1: XBP Power Connector as Viewed from Front of PCB

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. When using such a voltage regulator please make sure hat $V_{CC}D$ pin on the power connector (see Fig 2.1) is not connected to any power source.

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). In either case, please check Chapter 3 of this guide for details on particular XBDs. When using a 3.3 V XBD, voltage level shifting is not required. You can close solder jumpers **SJ1**, **SJ2**, and **SJ3**. Then the FETs **Q3** through **Q8** and the resistors **R8** through **R11** should *not* be populated.

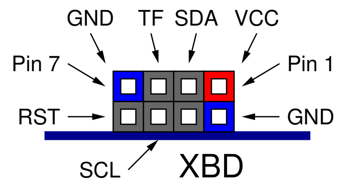


Figure 2.2: XBD Connector as Viewed from Back of PCB

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 **R8** 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.

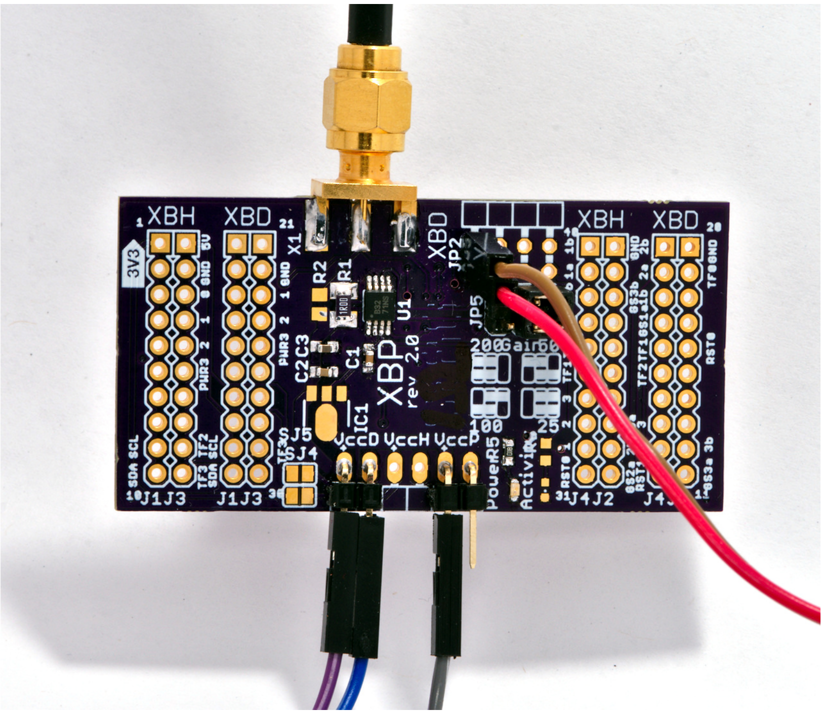


Figure 2.3: XBP Connections without XBH

3 XXBX Devices under Test (XBD)

XXBX supports several microcontroller boards as XBD. Table 3.1 describes briefly the features of each supported board. The sections below contain instructions on how to modify the boards if necessary for use as XBDs.

Table 3.1: Devices for Benchmarking (XBD) Supported by XXBX

Board	Manuf.	CPU	ISA	Bus	f	HW	ROM	RAM	Price
MSP-EXP430F5529LP	TI	MSP430F	MSP430X	16-bit	25 MHz		128kB	10kB	$12.99
MSP-EXP430FR5994	TI	MSP430FR	MSP430X	16-bit	16 MHz	AES, LEA	256kB	8kB	$15.99
MSP-EXP432P401R	TI	ARM Cortex M4F	ARMv7E-M	32-bit	48 MHz	AES	256kB	64kB	$12.99
EK-TM4C123GXL	TI	ARM Cortex M4F	ARMv7E-M	32-bit	80 MHz		256kB	32kB	$12.99
EK-TM4C129EXL	TI	ARM Cortex M4F	ARMv7E-M	32-bit	120 MHz	AES	1024kB	256kB	$24.99
NUCLEO-F091RC	STM	ARM Cortex M0	ARMv6-M	32-bit	48 MHz		256kB	32kB	$10.33
NUCLEO-F103RB	STM	ARM Cortex M3	ARMv7-M	32-bit	72 MHz		128kB	20kB	$10.33

3.1 Texas Instruments LaunchPads

3.1.1 TI MSP430F5529 LaunchPad™

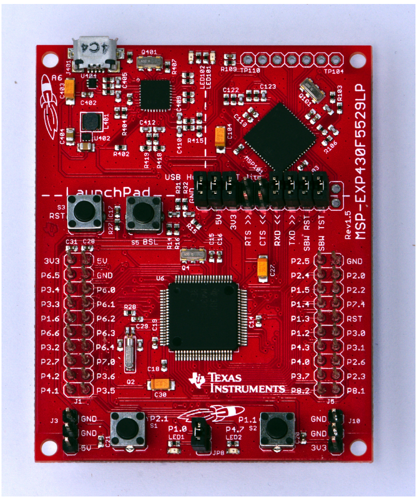


Figure 3.1: TI MSP-EXP430F5529LP

The supply voltage $V_{CC}D$ is 3.3 V and provided through the BoosterPack header from the XBP. For precise current measurements remove all jumpers from the isolation jumper block between the programmer and the target MSP with the exception of the ground (GND) jumper. The device specific code makes sure there are no floating I/Os. Ports P4.1 (SDA), P4.2 (SCL), P2.0 (TF) are used for communicating with the XBH. The following Ports are used by XBH when more XBPs are used, hence they can't be outputs on XBD and have to be configured as inputs (default): P1.5, P1.4, P1.3, P1.2, P2.5, P2.4, P2.3, P3.7, P3.6, P4.0, P6.2, P6.1, P6.0, P8.2, P8.1. XBH will assign logic values to these ports. All other ports should be outputs driving a logic 0. Furthermore the USB LDO has to be disabled. Below is the code to initialize the ports and USB device accordingly. This code is part of the device specific bootloader code.

```
// Port Configuration
P1OUT = 0x00; P2OUT = 0x00; P3OUT = 0x00; P4OUT = 0x00; P5OUT = 0x00;
P6OUT = 0x00; P7OUT = 0x00; P8OUT = 0x00; PJOUT = 0x00;
P1DIR = 0xC3; P2DIR = 0xC7; P3DIR = 0x3F; P4DIR = 0xFE; P5DIR = 0xFF;
P6DIR = 0xF8; P7DIR = 0xFF; P8DIR = 0xF9; PJDIR = 0xFF;
// Disable VUSB LDO and SLDO
USBKEYPID   = 0x9628;              // enable access to USB config
USBPWRCTL &= ~(SLDOEN+VUSBEN);    // disable the VUSB LDO and the SLDO
USBKEYPID   = 0x9600;              // disable access to USB config
```

3.1.2 TI MSP430FR5994 LaunchPad™

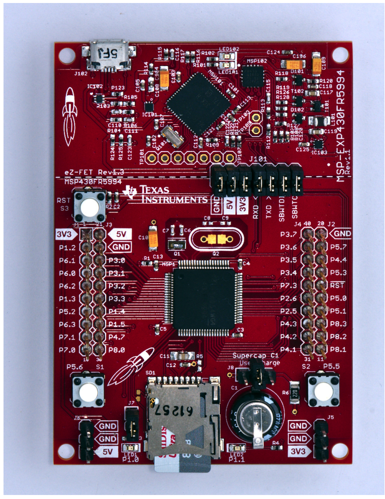


Figure 3.2: TI MSP-EXP430FR5994

The supply voltage $V_{CC}D$ is 3.3 V and provided through the BoosterPack header from the XBP. For precise current measurements disconnect the Super Cap by removing jumper J8, make sure that no microSD memory card is inserted and remove all jumpers from the isolation jumper block between the programmer and the target MSP with the exception of the ground (GND) jumper. The device specific code makes sure there are no floating I/Os. Ports P7.0 (SDA), P7.1 (SCL), P5.7 (TF) are used for communicating with the XBH. The following Ports are used by XBH when more XBPs are used, hence they can't be outputs on XBD and have to be configured as inputs (default): P2.6, P3.7, P3.6, P3.5, P3.4, 3.2, P3.1, P3.0, P4.7, P4.3, P4.2, P4.1, P7.3, P8.2, P8.1, XBH will assign logic values to these ports. All other ports should be outputs driving a logic 0. Below is the code to initialize the ports and USB device accordingly. This code is part of the device specific bootloader code.

```
// Port Configuration --- to be verified
```

```
P1OUT = 0x00; P2OUT = 0x00; P3OUT = 0x00; P4OUT = 0x00; P5OUT = 0x00;
P6OUT = 0x00; P7OUT = 0x00; P8OUT = 0x00; PJOUT = 0x00;
P1DIR = 0xFF; P2DIR = 0xBF; P3DIR = 0x04; P4DIR = 0x71; P5DIR = 0xFF;
P6DIR = 0xFF; P7DIR = 0xF7; P8DIR = 0xF9; PJDIR = 0xFF;
```

3.1.3 TI MSP432P401R LaunchPad™

DUMMY TEXT 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.

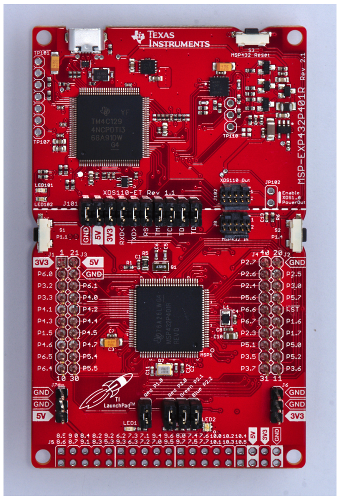


Figure 3.3: TI MSP-EXP432P401R

3.1.4 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.

3.1.5 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.

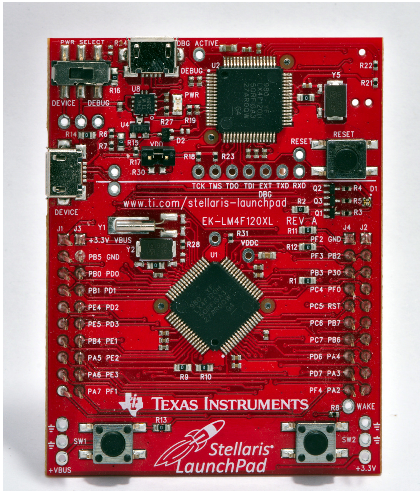


Figure 3.4: TI Stellaris EK-LM4F120XL

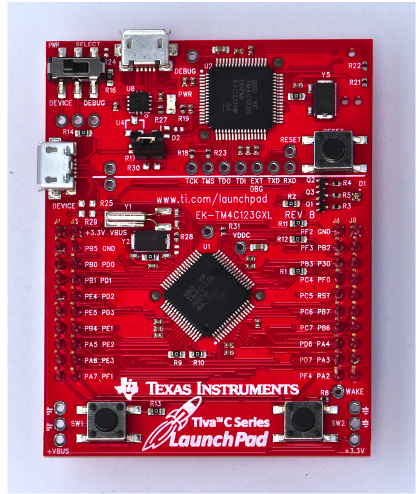


Figure 3.5: TI TIVA EK-TM4C123GXL

3.2 ST Microelectronics NUCLEO Boards

DUMMY TEXT 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.

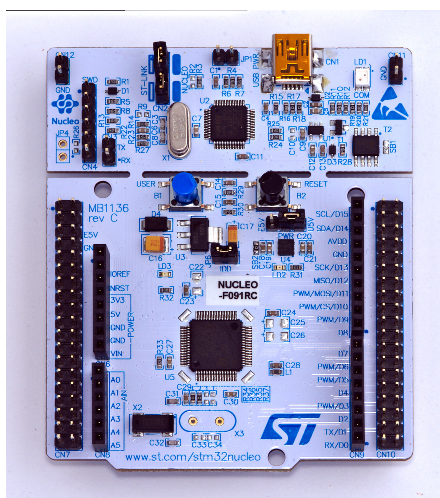


Figure 3.6: ST Microelectronics Nucleo F091RC

4 XBP Assembly

This chapter shows the assembly of the XBP. Please follow it step by step.

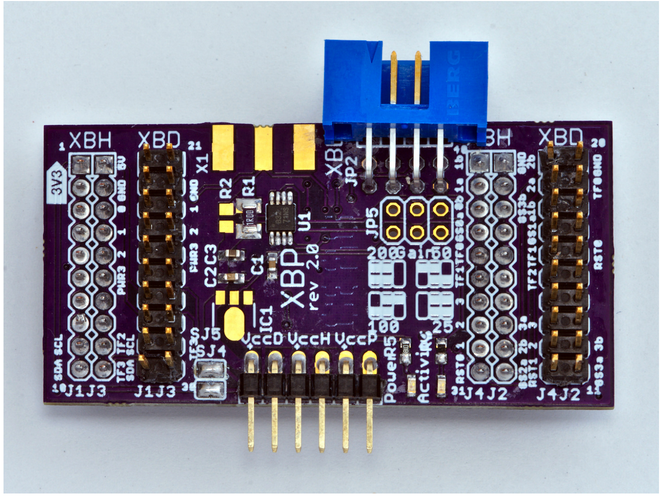


Figure 4.1: Top of Fully Populated XBP

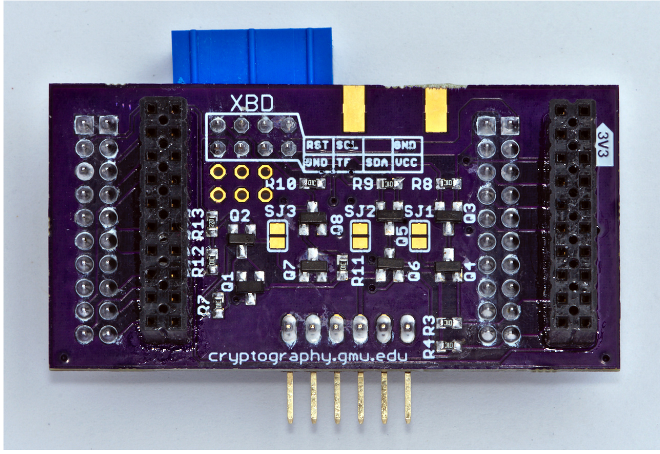


Figure 4.2: Bottom of Fully Populated XBP

4.1 Indicator LEDs

The first thing to assemble are the LEDs **LED1** for “Power” and **LED2** “Activity” and the associated resistors **R5** and **R6**. The cathode of the LEDs is pointing toward the bottom of the board. The orientation of the diode is indicated on the bottom of the LED with a triangle pointing toward the cathode. Then solder on the power connector **JP4**.

Test: Test the LEDs by applying GND to any GND pin on the power connector and touching the side of the resistors that does not point toward the LEDs with a wire connected to a 3.3 V power supply. The “Power” LED should light up dimly and the “Activity” LED should light up brightly.

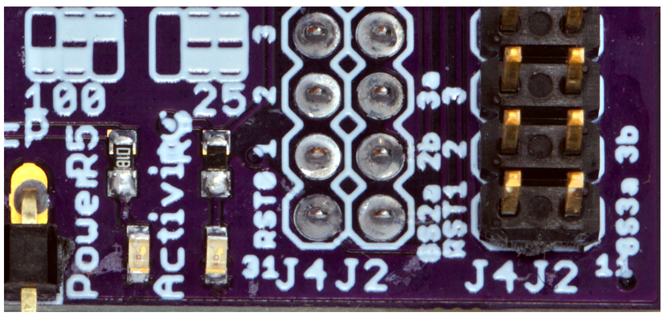


Figure 4.3: Location of LEDs, R5 and R6 on the top of the PCB

> **Note: XBP without XBH**
>
> When using the XBP without XBH, you don’t have to assemble the “Activity” LED **LED2** or **R6** as they won’t be used. Also skip the steps for mounting **Q1**, **Q2**, **R7**, **R12**, and **R13**.

Next solder the circuitry to drive the “Activity” LED which is located on the bottom of the PCB. Start with the FETs **Q1** and **Q2** and continue with **R7**, **R12**, and **R13**.

4.2 Current-Shunt Monitor

First solder the CSM **U1**. An arrow on the PCB indicates the location of pin 1. Pin 1 on the device is marked by a dot. Make sure that there are no solder bridges between the pins. Then solder the current shunt in either the **R1** or the **R2** location. If the shunt fits into the **R1** location, use it. Next, solder the capacitors **C1** and **C3**.

> **Note: Generate $V_{CC}D$ on the XBP**
>
> Only if you want to have the XBP generate $V_{CC}D$ for the XBP, solder **IC1**.

Next, solder **C2**.

Test: Apply 5 V to $V_{CC}P$ on the power connector. The “Power” LED should light up brightly. The current consumption should not exceed 10 mA. If you mounted **IC1**, check with a Voltmeter that the top side of **R1** has the desired voltage.

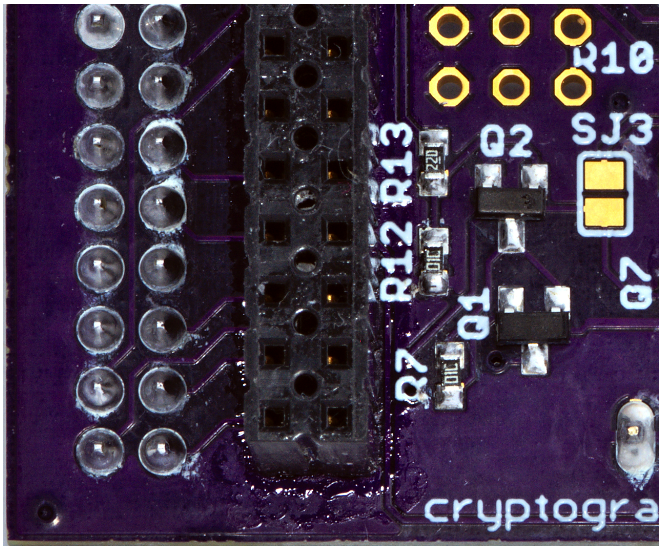


Figure 4.4: Location of LED circuit: Q1, Q2, R7, R12, and R13 on the bottom of the PCB

4.3 I^{2}C Pull-Up Resistors and Level Shifting

If you want the XBP to pull-up the I^{2}C bus solder **R3** and **R4** as discussed in section 2.3.

If you want to use an XBD whose $V_{CC}D \neq 3.3\,\mathrm{V}$ solder first the FETs **Q3**, **Q4**, **Q5**, **Q6**, **Q7**, and **Q8** followed by the resistors **R8**, **R9**, **R10**, and **R11**.

Note: XBP without XBH

When using the XBP without XBH, you can ignore this section.

4.4 Through-Hole Components

First, solder the connections to the XBD (pin header) so that the pins are pointing to the top. Then, from the bottom of the board put in the connectors for the XBH and solder them from the top. The last connector is **JP5** which you only have to mount if you plan on connecting an external XBD.

Note: XBP without XBH

When using the XBP without XBH, you don't have to mount the launchpad connectors. Instead of mounting a complete XBD connector on **J2** a simple 2-pin connector on pins 1 and 2 of **J2** will be sufficient. Solder the gain select **JP5** and the SMA connector **X1**.

Test: bla

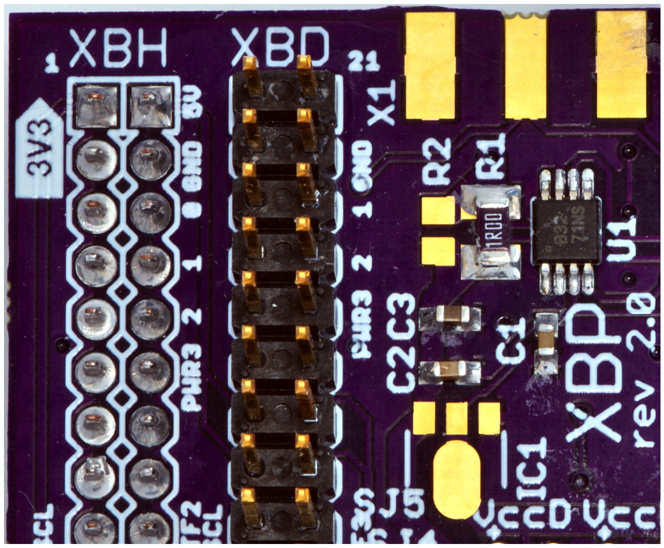


Figure 4.5: Location of the CSM circuit: U1, IC1, R1, R2, C1, C2, and C3 on the top of the PCB

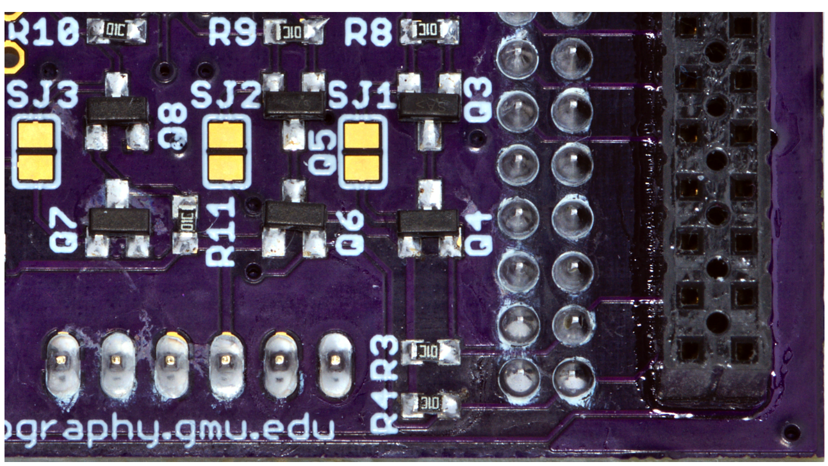


Figure 4.6: Location of the I^2C pull-up: R3, R4 and level shifter: Q3–Q8 and R8–R11 on the bottom of the PCB

A XBP Connections

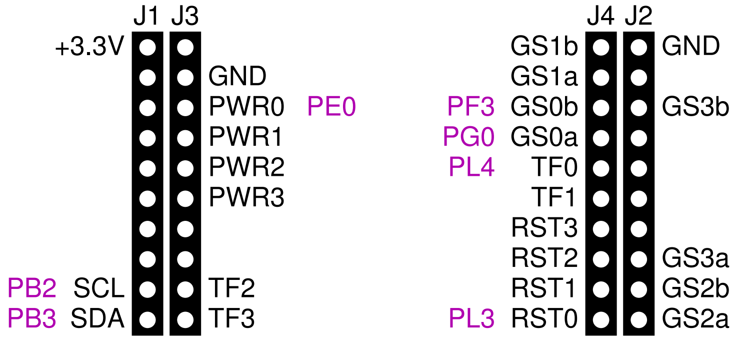


Figure A.1: Boosterpack Connector XBH as Viewed from Top of PCB

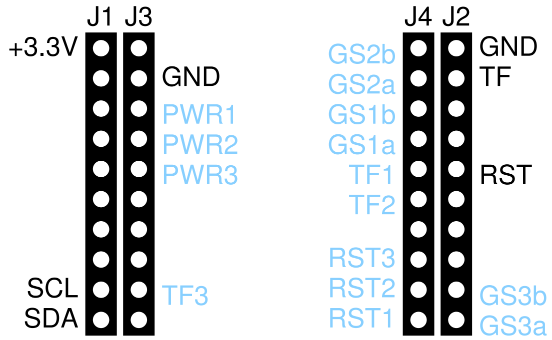


Figure A.2: Boosterpack Connector XBD as Viewed from Top of PCB

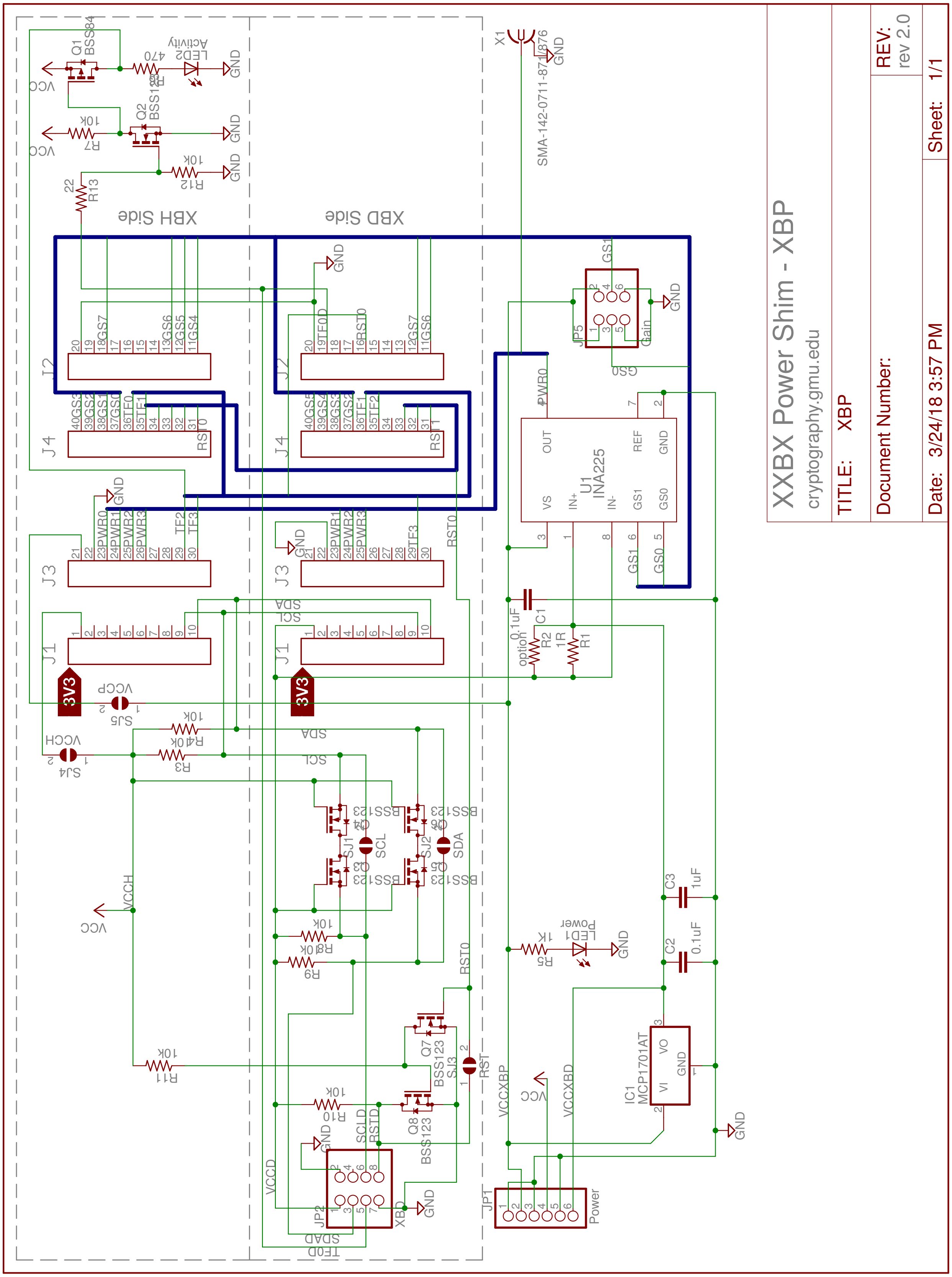
Table A.1: Pin Configuration of Boosterpack Connector for XBH

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 A.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	

B Schematic


XXBX Power Shim - XBP
cryptography.gmu.edu
TITLE: XBP
Document Number:
REV: rev 2.0
Date: 3/24/18 3:57 PM
Sheet: 1/1
XBH Side
XBD Side
U1 INA225
IC1 MCP1701AT
SMA-142-0711-871/876
JP1 Power

C Board Layout

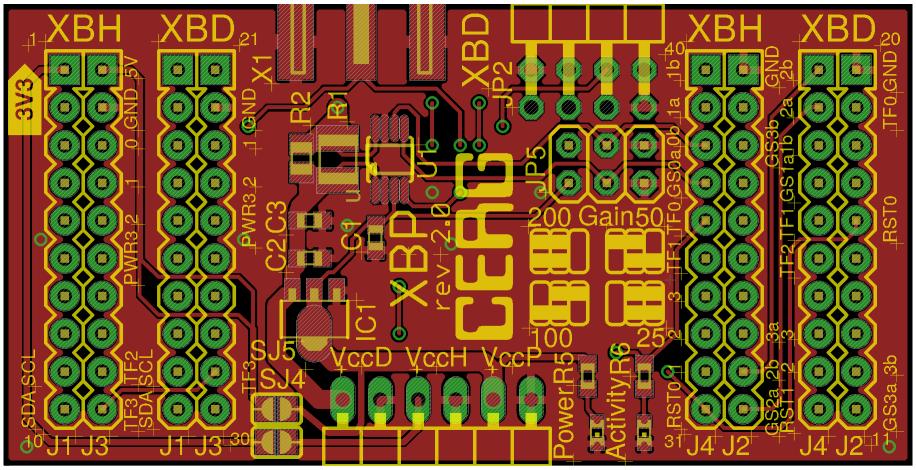


Figure C.1: Top of the Circuit Board

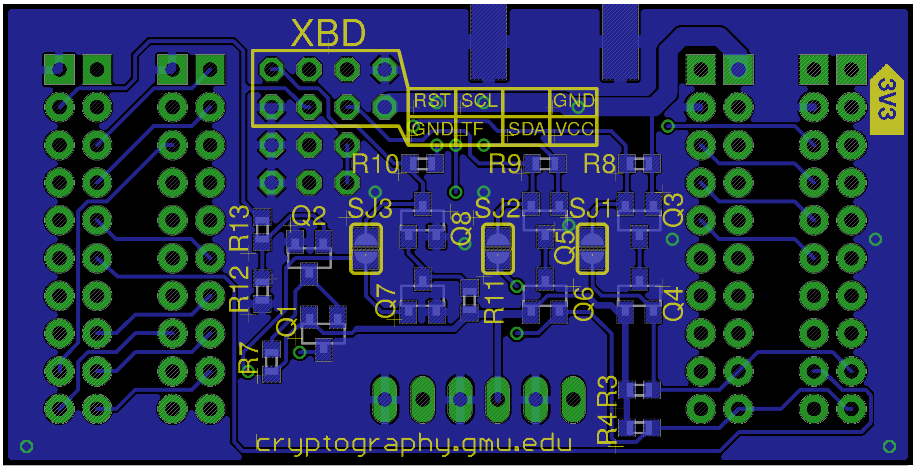


Figure C.2: Bottom of the Circuit Board

D Parts List

Table D.1: XBP Bill of Materials

	Option[1]								
Part	**1**	**2**	**3**	**Value**	**Package**	**Device**	**Mfr.#**	**Manufacturer**	**Description**
A1	X	X		XBHCon	2* 2x10	Pin Strip	929852-01-10-RB	3M	Headers & Wire Housings 20/2R/BM SKT/.100 STR/.125/30AVE/ROHS
A2	X	X		XBDCon	2* 2x10	Pin Header	67997-272HLF	FCI / Amphenol	Headers & Wire Housings Breakaway Header 72
C1	X	X	X	0.1uF	C0603	Capacitor	GRM155R61A104JA01D	Murata Electronics	Multilayer Ceramic Capacitors
C2	X	X	X	0.1uF	C0603	Capacitor	GRM155R61A104JA01D	Murata Electronics	Multilayer Ceramic Capacitors
C3	X	X	X	1uF	C0603	Capacitor	TMK107B7105KA-T	Taiyo Yuden	Multilayer Ceramic Capacitors 25V X7R +/-10%
IC1				3.3V 250mA	SOT89	LDO Regulator	MCP1702T-3302E/MB	Microchip Technology	LDO Voltage Regulators LDO w/ Low Quiescent
JP1	X	X	X	Power	1X06/90	Pin Header	61303611021	Wurth Electronics	Headers & Wire Housings WR-PHD 2.54mm Hdr 36P Single RA Gold
JP2	X	X		XBD	2X04/90	Pin Header	75867-132LF	FCI / Amphenol	Headers & Wire Housings 8P DR R/S SHRD HDR 30 microinch gold
JP5			X	Gain	2X03	Pin Header	67997-272HLF	FCI / Amphenol	Headers & Wire Housings Breakaway Header 72
LED1	X	X	X	Power	0603	LED, red	APT1608EC	Kingbright	Standard LEDs - SMD HI EFF RED WTR CLR
LED2	X	X		Activity	0603	LED, green	AP1608SGC	Kingbright	Standard LEDs - SMD GREEN WATER CLEAR
Q1	X	X		BSS84	SOT23	P-Channel FET	BSS84P H6327	Infineon	MOSFET P-Ch -60V -170mA SOT-23-3
Q2	X	X		BSS123	SOT23	N-Channel FET	BSS123LT1G	ON Semiconductor	MOSFET 100V 170mA N-Channel
Q3	X			BSS123	SOT23	N-Channel FET	BSS123LT1G	ON Semiconductor	MOSFET 100V 170mA N-Channel
Q4	X			BSS123	SOT23	N-Channel FET	BSS123LT1G	ON Semiconductor	MOSFET 100V 170mA N-Channel
Q5	X			BSS123	SOT23	N-Channel FET	BSS123LT1G	ON Semiconductor	MOSFET 100V 170mA N-Channel
Q6	X			BSS123	SOT23	N-Channel FET	BSS123LT1G	ON Semiconductor	MOSFET 100V 170mA N-Channel
Q7	X			BSS123	SOT23	N-Channel FET	BSS123LT1G	ON Semiconductor	MOSFET 100V 170mA N-Channel
Q8	X			BSS123	SOT23	N-Channel FET	BSS123LT1G	ON Semiconductor	MOSFET 100V 170mA N-Channel
R1	X	X		1R	R1210	Resistor	SR732BTTD1R00D	KOA Speer	Current Sense Resistors - SMD 1 OHM .5%
R2				option	R0805	Resistor			
R3	X	X		10k	R0603	Resistor	RC0603FR-0710KL	Yageo	Thick Film Resistors - SMD 10K OHM 1%
R4	X	X		10k	R0603	Resistor	RC0603FR-0710KL	Yageo	Thick Film Resistors - SMD 10K OHM 1%
R5	X	X	X	1K	R0603	Resistor	RC0603FR-071KL	Yageo	Thick Film Resistors - SMD 1K OHM 1%
R6	X	X		470	R0603	Resistor	RC0603FR-07470RL	Yaego	Thick Film Resistors - SMD 470 OHM 1%
R7	X	X		10k	R0603	Resistor	RC0603FR-0710KL	Yageo	Thick Film Resistors - SMD 10K OHM 1%
R8	X			10k	R0603	Resistor	RC0603FR-0710KL	Yageo	Thick Film Resistors - SMD 10K OHM 1%
R9	X			10k	R0603	Resistor	RC0603FR-0710KL	Yageo	Thick Film Resistors - SMD 10K OHM 1%
R10	X			10k	R0603	Resistor	RC0603FR-0710KL	Yageo	Thick Film Resistors - SMD 10K OHM 1%
R11	X			10k	R0603	Resistor	RC0603FR-0710KL	Yageo	Thick Film Resistors - SMD 10K OHM 1%
R12	X	X		10k	R0603	Resistor	RC0603FR-0710KL	Yageo	Thick Film Resistors - SMD 10K OHM 1%
R13	X	X		22	R0603	Resistor	RC0603FR-0722RL	Yaego	Thick Film Resistors - SMD 22 OHM 1%
U1	X	X	X	INA225	VSSOP-8	CSM	INA225AIDGKT	Texas Instruments	Current Sense Amplifiers 36V Bidir 0-Drift
X1			X	SMA	End Launch	SMA 50 Ohm Jack	142-0701-801	Johnson / Cinch Connectivity Solutions	RF Connectors / Coaxial Connectors PC END MT JCK GLD .062 BOARD THICK
A3				XBDCab	2* 2x 4P	RCPL	71600-008LF	FCI / Amphenol	Headers & Wire Housings 2X4P SNGL BEAM RCPL 30 microinch gold
1				1ft	10 Cond	Ribbon	3365/10-CUT-LENGTH	3M	Flat Cables .050 10 COND. 28AWG ROUND 1PC=1FT

[1] Option 1: Supports XBD using any $V_{CC}D$, Option 2: Supports only XBD with $V_{CC}D = 3.3\,\mathrm{V}$, Option 3: no XBH