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For up to date SW images and technical information refer to

All support for this board is provided via community support at
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To return a defective board for repair, please request an RMA at
http://beagleboard.org/support/rma

Please DO NOT return the board without approval from the RMA team first.
All boards received without RMA approval will not be worked on.
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1.0 Introduction

This document is the System Reference Manual for the BeagleBone Black and covers its use and design. The board will primarily be referred to in the remainder of this document simply as the board, although it may also be referred to as the BeagleBone Black as a reminder. There are also references to the original BeagleBone as well, and will be referenced as simply BeagleBone.

This design is subject to change without notice as we will work to keep improving the design as the product matures based on feedback and experience. Software updates will be frequent and will be independent of the hardware revisions and as such not result in a change in the revision number.

Make sure you check the support Wiki frequently for the most up to date information.


2.0 Change History

This section describes the change history of this document and board. Document changes are not always a result of a board change. But a board change will always result in a document change.

2.1 Document Change History

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<td>Preliminary</td>
<td>January 4, 2013</td>
<td>GC</td>
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<tr>
<td>A5</td>
<td>Production release</td>
<td>January 8, 2013</td>
<td>GC</td>
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<tr>
<td>A5.1</td>
<td>1. Added information on Power button and the battery access points. 2. Final production released version.</td>
<td>April 1, 2013</td>
<td>GC</td>
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<tr>
<td>A5.2</td>
<td>1. Edited version. 2. Added numerous pictures of the Rev A5A board.</td>
<td>April 23, 2013</td>
<td>GC</td>
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2.2 Board Changes

2.2.1 Rev A5B

This is the initial production release of the board. We will be tracking changes from this point forward.
3.0 Connecting Up Your BeagleBone Black

This section provides instructions on how to hook up your board. Two scenarios will be discussed:

1) Tethered to a PC and
2) As a standalone development platform in a desktop PC configuration.

3.1 What’s In the Box

In the box you will find three main items as shown in Figure 1.

- BeagleBone Black
- miniUSB to USB Type A Cable
- Instruction card

This is sufficient for the tethered scenario and creates an out of box experience where the board can be used immediately with no other equipment needed.

Figure 1. In The Box
3.2 Main Connection Scenarios

This section will describe how to connect the board for use. This section is basically a slightly more detailed description of the Quick Start Guide that came in the box. There is also a Quick Start Guide document on the board that should also be refereed. The intent here is that someone looking to purchase the board will be able to read this section and get a good idea as to what the initial set up will be like.

The board can be configured in several different ways, but we will discuss the two most common scenarios as described in the Quick Start Guide card that comes in the box.

- Tethered to a PC via the USB cable
  - Board is accessed as a storage drive
  - Or a RNDIS Ethernet connection.
- Standalone desktop
  - Display
  - Keyboard and mouse
  - External 5V power supply

Each of these configurations is discussed in general terms in the following sections.

For an up-to-date list of confirmed working accessories please go to http://circuitco.com/support/index.php?title=BeagleBone_Black_Accessories

3.3 Tethered To A PC

In this configuration, the board is powered by the PC via the provided USB cable--no other cables are required. The board is accessed either as a USB storage drive or via the browser on the PC. You need to use either Firefox or Chrome on the PC, IE will not work properly. Figure 2 shows this configuration.

![Figure 2. Tethered Configuration](image-url)
All the power for the board is provided by the PC via the USB cable. In some instances, the PC may not be able to supply sufficient power for the board. In that case, an external 5VDC power supply can be used, but this should rarely be necessary.

### 3.3.1 Connect the Cable to the Board

1. Connect the small connector on the USB cable to the board as shown in Figure 4. The connector is on the bottom side of the board.

![USB Connection to the Board](image)

2. Connect the large connector of the USB cable to your PC or laptop USB port.

3. The board will power on and the power LED will be on as shown in Figure 4 below.

![Board Power LED](image)
4. When the board starts to boot the LEDs will come on in sequence as shown in Figure 5 below. It will take a few seconds for the status LEDs to come on, so be patient. The LEDs will be flashing in an erratic manner as it boots the Linux kernel.

![Figure 5. Board Boot Status](image)

3.3.2 Accessing the Board as a Storage Drive

The board will appear around a USB Storage drive on your PC after the kernel has booted, which will take a round 10 seconds. The kernel on the board needs to boot before the port gets enumerated. Once the board appears as a storage drive, do the following:

1) Open the USB Drive folder.
2) Click on the file named **start.html**
3) The file will be opened by your browser on the PC and you should get a display showing the Quick Start Guide.
4) Your board is now operational! Follow the instructions on your PC screen.
3.4 Standalone w/Display and Keyboard/Mouse

In this configuration, the board works more like a PC, totally free from any connection to a PC as shown in Figure 6. It allows you to create your code to make the board do whatever you need it to do. It will however require certain common PC accessories. These accessories and instructions are described in the following section.

![Figure 6. Desktop Configuration](image)

Optionally an Ethernet cable can also be used for network access.

3.4.1 Required Accessories

In order to use the board in this configuration, you will need the following accessories:

- (1) 5VDC 1A power supply
- (1) HDMI monitor or a DVI-D monitor with an adapter. (NOTE: Only HDMI will give you audio capability).
- (1) Micro HDMI to HDMI cable
- (1) USB wireless keyboard and mouse combo.
- (1) USB HUB (OPTIONAL). The board has only one USB host port, so you may need to use a USB Hub if your keyboard and mouse requires two ports.
For an up-to-date list of confirmed working accessories please go to http://circuitco.com/support/index.php?title=BeagleBone_Black_Accessories

3.4.2 Connecting Up the Board

1. Connect the big end of the HDMI cable as shown in Figure 7 to your HDMI monitor. Refer to your monitor Owner’s Manual for the location of your HDMI port. If you have a DVI-D Monitor go to Step 3, otherwise proceed to Step 4.

![Figure 7. Connect microHDMI Cable to the Monitor](image)

**NOTE:** Do not plug in the cable to the board until after the board is powered up.

2. If you have a DVI-D monitor you must use a DVI-D to HDMI adapter in addition to your HDMI cable. An example is shown in Figure 8 below from two perspectives.

![Figure 8. DVI-D to HDMI Adapter](image)
3. If you have a single wireless keyboard and mouse combination such as seen in Figure 9 below, you need to plug the receiver in the USB host port of the board as shown in Figure 10.

![Wireless Keyboard and Mouse Combo](image)

**Figure 9. Wireless Keyboard and Mouse Combo**

![Connect Keyboard and Mouse Receiver to the Board](image)

**Figure 10. Connect Keyboard and Mouse Receiver to the Board**

If you have a wired USB keyboard requiring two USB ports, you will need a HUB similar to the ones shown in Figure 11. You may want to have more than one port for other devices. Note that the board can only supply up to 500mA, so if you plan to load it down, it will need to be externally powered.

![Keyboard and Mouse Hubs](image)

**Figure 11. Keyboard and Mouse Hubs**

4. Connect the Ethernet Cable
If you decide you want to connect to your local area network, an Ethernet cable can be used. Connect the Ethernet Cable to the Ethernet port as shown in Figure 12. Any standard 100M Ethernet cable should work.

![Figure 12. Ethernet Cable Connection](image)

5. Apply Power

The final step is to plug in the DC power supply to the DC power jack as shown in Figure 13 below.

![Figure 13. External DC Power](image)
6. The cable needed to connect to your display is a microHDMI to HDMI. Connect the microHDMI connector end to the board at this time. The connector is on the bottom side of the board as shown in Figure 14 below.

![Figure 14. Connect microHDMI Cable to the Board]

The connector is fairly robust, but we suggest that you not use the cable as a leash for your Beagle. Take proper care not to put too much stress on the connector or cable.

7. Booting the Board

As soon as the power is applied to the board, it will start the booting up process. When the board starts to boot the LEDs will come on in sequence as shown in Figure 15 below. It will take a few seconds for the status LEDs to come on, so be patient. The LEDs will be flashing in an erratic manner as it boots the Linux kernel.
Figure 15. Board Boot Status

While the four user LEDs can be overwritten and used as desired, they do have specific meanings in the image that is shipped with the board once the Linux kernel has booted.

- USER0 is the heartbeat indicator from the Linux kernel.
- USER1 turns on when the SD card is being accessed
- USER2 is an activity indicator. It turns on when the kernel is not in the idle loop.
- USER3 turns on when the onboard eMMC is being accessed.

8. A Booted System

1. The board will have a mouse pointer appear on the screen as it enters the Linux boot step. You may have to move the physical mouse to get the mouse pointer to appear. The system can come up in the suspend mode with the HDMI port in a sleep mode.
2. After a minute or two a login screen will appear. You do not have to do anything at this point.
3. After a minute or two the desktop will appear. It should be similar to the one shown in Figure 16. HOWEVER, it will change from one release to the next, so do not expect your system to look exactly like the one in the figure, but it will be very similar.
4. And at this point you are ready to go! Figure 16 shows the desktop after booting.
NOTE: At press time this is what the default screen looks like. If you see something different, do not be alarmed. It is intended. Once the final screen is finalized, this document will be updated and available for download.
4.0 BeagleBone Black Overview

The BeagleBone Black is the latest addition to the BeagleBoard.org family and like its predecessors, is designed to address the Open Source Community, early adopters, and anyone interested in a low cost ARM Cortex-A8 based processor.

It has been equipped with a minimum set of features to allow the user to experience the power of the processor and is not intended as a full development platform as many of the features and interfaces supplied by the processor are not accessible from the BeagleBone Black via onboard support of some interfaces. It is not a complete product designed to do any particular function. It is a foundation for experimentation and learning how to program the processor and to access the peripherals by the creation of your own software and hardware.

It also offers access to many of the interfaces and allows for the use of add-on boards called capes, to add many different combinations of features. A user may also develop their own board or add their own circuitry.

BeagleBone Black is manufactured and warranted by Circuitco LLC in Richardson Texas for the benefit of the community and its supporters. In addition, Circuitco provides the RMA support for the BeagleBone Black.

Jason Kridner of Texas Instruments handles the community promotions and is the spokesmen for BeagleBoard.org.

The board is designed by Gerald Coley, an employee of Texas Instruments and a charter member of the BeagleBoard.org community.

The PCB layout was done by Circuitco and Circuitco is the sole funder of its development and transition to production.

The Software is written and supported by the thousands of community members, including Jason Kridner, employees of Texas Instruments, DigiKey, and Circuitco.
4.1 BeagleBone Compatibility

The board is intended to be compatible with the original BeagleBone as much as possible. There are several areas where there are differences between the two designs. These differences are listed below, along with the reasons for the differences.

- Sitara XAM3359AZCZ100, 1GHz, processor.
  - Sorry, we just had to make it faster.
- 512MB DDR3L
  - Cost reduction
  - Performance boost
  - Memory size increase
  - Lower power
- No Serial port by default.
  - Cost reduction
  - Can be added by buying a TTL to USB Cable that is widely available
  - Single most cost reduction action taken
- No JTAG emulation over USB.
  - Cost reduction
  - JTAG header is not populated, but can easily be mounted.
- Onboard Managed NAND (eMMC)
  - 2GB
  - Cost reduction
  - Performance boost x8 vs. x4 bits
  - Performance boost due to deterministic properties vs. SD card
- GPMC bus may not be accessible from the expansion headers in some cases
  - Result of eMMC on the main board
  - Signals are still routed to the expansion connector
  - If eMMC is not used, signals can be used via expansion if eMMC is held in reset
- There may be 10 less GPIO pins available
  - Result of eMMC
  - If eMMC is not used, could still be used
- The power expansion header, for battery and backlight, has been removed
  - Cost reduction
  - Space reduction
  - Four pins were added to provide access to the battery charger function.
- HDMI interface onboard
  - Feature addition
  - Audio and video capable
  - Micro HDMI
- No three function USB cable
  - Cost reduction
4.2 **BeagleBone Black Features and Specification**

This section covers the specifications and features of the board and provides a high level description of the major components and interfaces that make up the board.

Table 2 provides a list of the features.

<table>
<thead>
<tr>
<th>Feature</th>
<th>Specification</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Processor</strong></td>
<td>Sitara AM3359AZCZ100, 1GHz, 2000 MIPS</td>
</tr>
<tr>
<td><strong>Graphics Engine</strong></td>
<td>SGX530 3D, 20M Polygons/S</td>
</tr>
<tr>
<td><strong>SDRAM Memory</strong></td>
<td>512MB DDR3L 606MHz</td>
</tr>
<tr>
<td><strong>Onboard Flash</strong></td>
<td>2GB, 8bit Embedded MMC</td>
</tr>
<tr>
<td><strong>PMIC</strong></td>
<td>TPS65217C PMIC regulator and one additional LDO.</td>
</tr>
<tr>
<td><strong>Debug Support</strong></td>
<td>Optional Onboard 20-pin CTI JTAG, Serial Header</td>
</tr>
<tr>
<td><strong>Power Source</strong></td>
<td>miniUSB USB or DC Jack, 5VDC External Via Expansion Header</td>
</tr>
<tr>
<td><strong>PCB</strong></td>
<td>3.4” x 2.1”, 6 layers</td>
</tr>
<tr>
<td><strong>Indicators</strong></td>
<td>1-Power, 2-Ethernet, 4-User Controllable LEDs</td>
</tr>
<tr>
<td><strong>HS USB 2.0 Client Port</strong></td>
<td>Access to USB0, Client mode via miniUSB</td>
</tr>
<tr>
<td><strong>HS USB 2.0 Host Port</strong></td>
<td>Access to USB1, Type A Socket, 500mA LS/FS/HS</td>
</tr>
<tr>
<td><strong>Serial Port</strong></td>
<td>UART0 access via 6 pin 3.3V TTL Header. Header is populated</td>
</tr>
<tr>
<td><strong>Ethernet</strong></td>
<td>10/100, RJ45</td>
</tr>
<tr>
<td><strong>SD/MMC Connector</strong></td>
<td>microSD, 3.3V, Reset Button, Boot Button, Power Button</td>
</tr>
<tr>
<td><strong>User Input</strong></td>
<td>16b HDMI, 1280x1024 (MAX)</td>
</tr>
<tr>
<td><strong>Video Out</strong></td>
<td>1024x768, 1280x720, 1440x900 w/EDID Support</td>
</tr>
<tr>
<td><strong>Audio</strong></td>
<td>Via HDMI Interface, Stereo</td>
</tr>
<tr>
<td><strong>Expansion Connectors</strong></td>
<td>McASP0, SPI1, I2C, GPIO(65), LCD, GPMC, MMC1, MMC2, 7 AIN(1.8V MAX), 4 Timers, 3 Serial Ports, CAN0, EHRPWM(0,2), XDMA Interrupt, Power button, Expansion Board ID (Up to 4 can be stacked)</td>
</tr>
<tr>
<td><strong>Weight</strong></td>
<td>1.4 oz (39.68 grams)</td>
</tr>
<tr>
<td><strong>Power</strong></td>
<td>Refer to Section 6.1.7</td>
</tr>
</tbody>
</table>
4.3   Board Component Locations

This section describes the key components on the board. It provides information on their location and function. Familiarize yourself with the various components on the board.

4.3.1   Connectors, LEDs, and Switches

Figure 17 below shows the locations of the connectors, LEDs, and switches on the PCB layout of the board.

- **DC Power** is the main DC input that accepts 5V power.
- **Power Button** alerts the processor to initiate the power down sequence.
- **10/100 Ethernet** is the connection to the LAN.
- **Serial Debug** is the serial debug port.
- **USB Client** is a miniUSB connection to a PC that can also power the board.
- **BOOT switch** can be used to force a boot from the SD card.
- There are four blue **LEDs** that can be used by the user.
- **Reset Button** allows the user to reset the processor.
- **uSD slot** is where a uSD card can be installed.
- **microHDMI** connector is where the display is connected to.
- **USB Host** can be connected different USB interfaces such as Wi-Fi, BT, Keyboard, etc.
4.3.2 Key Components

Figure 18 below shows the locations of the key components on the PCB layout of the board.

- **Sitara AM3359AZCZ100** is the processor for the board.
- **Micron 512MB DDR3L** is the Dual Data Rate RAM memory.
- **TPS65217C PMIC** provides the power rails to the various components on the board.
- **SMSC Ethernet PHY** is the physical interface to the network.
- **Micron eMMC** is an onboard MMC chip that holds up to 2GB of data.
- **HDMI Framer** provides control for an HDMI or DVI-D display with an adapter.
5.0 BeagleBone Black High Level Specification

This section provides the high level specification of the BeagleBone Black.

5.1 Block Diagram

Figure 19 below is the high level block diagram of the BeagleBone Black.

![Figure 19. BeagleBone Black Key Components]
5.2 Processor

For the initial release, the board uses the Sitara XAM3359AZCZ processor in the 15x15 package. This is basically the same processor as used on the original BeagleBone. It does use the updated 2.0 revision with several fixes on this new processor as opposed to the original BeagleBone. A couple of important features from this new processor include:

- 1GHZ Operation
- RTC fix

Eventually the board will move to the Sitara AM3358BZCZ100 device once released and readily available from TI. At this time we do not have a date when this will happen. We do not expect any benefit from moving to this device and there should be no impact seen as a result of making this move.

5.3 Memory

Described in the following sections are the three memory devices found on the board.

5.3.1 512MB DDR3L

A single 256Mb x16 DDR3L 4Gb (512MB) memory device is used. The memory used is the MT41K512M16HA-125 from Micron. It will operate at a clock frequency of 303MHz yielding an effective rate of 606MHZ on the DDR3L bus allowing for 1.32GB/S of DDR3L memory bandwidth.

5.3.2 32KB EEPROM

A single 32KB EEPROM is provided on I2C0 that holds the board information. This information includes board name, serial number, and revision information. This will be the same as found on the original BeagleBone. It has a test point to allow the device to be programmed and otherwise to provide write protection when not grounded.

5.3.3 2GB Embedded MMC

A single 2GB embedded MMC (eMMC) device is on the board. The device connects to the MMC1 port of the processor, allowing for 8bit wide access. Default boot mode for the board will be MMC1 with an option to change it to MMC0 for SD card booting. MMC0 cannot be used in 8Bit mode because the lower data pins are located on the pins used by the Ethernet port. This does not interfere with SD card operation but it does make it unsuitable for use as an eMMC port if the 8 bit feature is needed.

5.3.4 MicroSD Connector

The board is equipped with a single microSD connector to act as the secondary boot source for the board and, if selected as such, can be the primary boot source. The
connector will support larger capacity SD cards. The SD card is not provided with the board. Booting from MMC0 will be used to flash the eMMC in the production environment or can be used by the user to update the SW as needed.

5.3.5 Boot Modes

As mentioned earlier, there are four boot modes:

- **eMMC Boot**…This is the default boot mode and will allow for the fastest boot time and will enable the board to boot out of the box using the pre-flashed OS image without having to purchase an SD card or an SD card writer.
- **SD Boot**…This mode will boot from the uSD slot. This mode can be used to override what is on the eMMC device and can be used to program the eMMC when used in the manufacturing process or for field updates.
- **Serial Boot**…This mode will use the serial port to allow downloading of the software direct. A separate USB to serial cable is required to use this port.
- **USB Boot**…This mode supports booting over the USB port.

*Software to support USB and serial boot modes is not provided by beagleboard.org.*

Please contact TI for support of this feature.

A switch is provided to allow switching between the modes.

- Holding the boot switch down during boot without a SD card inserted will force the boot source to be the USB port and if nothing is detected on the USB client port, it will go to the serial port for download.
- Without holding the switch, the board will boot from eMMC. If it is empty, then it will try booting from the uSD slot, followed by the serial port, and then the USB port.
- If you hold the boot switch down during boot, and you have a uSD card inserted with a bootable image, the board will boot form the uSD card.

5.4 Power Management

The **TPS65217C** power management device is used along with a separate LDO to provide power to the system. The **TPS65217C** version provides for the proper voltages required for the DDR3L. This is the same device as used on the original BeagleBone with the exception of the power rail configuration settings which will be changed in the internal EEPROM to the TPS65217 to support the new voltages.

DDR3L requires 1.5V instead of 1.8V on the DDR2 as is the case on the original BeagleBone. The 1.8V regulator setting has been changed to 1.5V for the DDR3L. The LDO3 3.3V rail has been changed to 1.8V to support those rails on the processor. LDO4 is still 3.3V for the 3.3V rails on the processor. An external **LDOTLV70233** provides the 3.3V rail for the rest of the board.
5.5 PC USB Interface

The board has a miniUSB connector that connects the USB0 port to the processor. This is the same connector as used on the original BeagleBone.

5.6 Serial Debug Port

Serial debug is provided via UART0 on the processor via a single 1x6 pin header. In order to use the interface a USB to TTL adapter will be required. The header is compatible with the one provided by FTDI and can be purchased for about $12 to $20 from various sources. Signals supported are TX and RX. None of the handshake signals are supported.

5.7 USB1 Host Port

On the board is a single USB Type A female connector with full LS/FS/HS Host support that connects to USB1 on the processor. The port can provide power on/off control and up to 500mA of current at 5V. Under USB power, the board will not be able to supply the full 500mA, but should be sufficient to supply enough current for a lower power USB device supplying power between 50 to 100mA.

You can use a wireless keyboard/mouse configuration or you can add a HUB for standard keyboard and mouse interfacing.

5.8 Power Sources

The board can be powered from four different sources:

- A USB port on a PC
- A 5VDC 1A power supply plugged into the DC connector.
- A power supply with a USB connector.
- Expansion connectors

The USB cable is shipped with each board. This port is limited to 500mA by the Power Management IC. It is possible to change the settings in the TPS65217C to increase this current, but only after the initial boot. And, at that point the PC most likely will complain, but you can also use a dual connector USB cable to the PC to get to 1A.

The power supply is not provided with the board but can be easily obtained from numerous sources. A 1A supply is sufficient to power the board, but if there is a cape plugged into the board or you have a power hungry device or hub plugged into the host port, then more current may needed from the DC supply.
Power routed to the board via the expansion header could be provided from power derived on a cape. The DC supply should be well regulated and 5V +/-0.25V.

5.9 Reset Button

When pressed and released, causes a reset of the board. The reset button used on the BeagleBone Black is a little larger than the one used on the original BeagleBone. It has also been moved out to the edge of the board so that it is more accessible.

5.10 Power Button

A power button is provided near the reset button close to the Ethernet connector. This button takes advantage of the input to the PMIC for power down features. While a lot of capes have a button, it was decided to add this feature to the board to insure everyone had access to some new features. These features include:

- Interrupt is sent to the processor to facilitate an orderly shutdown to save files and to un-mount drives.
- Provides ability to let processor put board into a sleep mode to save power.
- Can alert processor to wake up from sleep mode and restore state before sleep was entered.
- Allows board to enter the sleep mode, preserving the RTC clock

If you hold the button down longer than 8 seconds, the board will power off if you release the button when the power LED turns off. If you continue to hold it, the board will power back up completing a power cycle.

5.11 Indicators

There are a total of five blue LEDs on the board.

- One blue power LED indicates that power is applied and the power management IC is up. If this LED flashes when applying power, it means that an excess current flow was detected and the PMIC has shut down.
- Four blue LEDs that can be controlled via the SW by setting GPIO pins.

In addition, there are two LEDs on the RJ45 to provide Ethernet status indication. One is yellow (100M Link up if on) and the other is green (Indicating traffic when flashing).

5.12 CTI JTAG Header

A place for an optional 20 pin CTI JTAG header is provided on the board to facilitate the SW development and debugging of the board by using various JTAG emulators. This
header is not supplied standard on the board. To use this, a connector will need to be soldered onto the board.

5.13 HDMI Interface

A single HDMI interface is connected to the 16 bit LCD interface on the processor. The 16b interface was used to preserve as many expansion pins as possible to allow for use by the user. The NXP TDA19988BHN is used to convert the LCD interface to HDMI and convert the audio as well. The signals are still connected to the expansion headers to enable the use of LCD expansion boards or access to other functions on the board as needed.

The HDMI device does not support HDCP copy protection. Support is provided via EDID to allow the SW to identify the compatible resolutions. Currently the following resolutions are supported via the software:

- 1280 x 1024
- 1440 x 900
- 1024 x 768
- 1280 x 720

5.14 Cape Board Support

The BeagleBone Black has the ability to accept up to four expansion boards or capes that can be stacked onto the expansion headers. The word cape comes from the shape of the board as it is fitted around the Ethernet connector on the main board. This notch acts as a key to insure proper orientation of the cape.

The majority of capes designed for the original BeagleBone will work on the BeagleBone Black. The two main expansion headers will be populated on the board. There are a few exceptions where certain capabilities may not be present or are limited to the BeagleBone Black. These include:

- GPMC bus may NOT be available due to the use of those signals by the eMMC. If the eMMC is used for booting only and the file system is on the SD card, then these signals could be used.
- Another option is to use the SD or serial boot modes and not use the eMMC.
- The power expansion header is not on the BeagleBone Black so those functions are not supported.

For more information on cape support refer to Section 9.0.
6.0 Detailed Hardware Design

This section provides a detailed description of the Hardware design. This can be useful for interfacing, writing drivers, or using it to help modify specifics of your own design.

Figure 20 below is the high level block diagram of the board.

![Figure 20. BeagleBone Black Block Diagram](image_url)
6.1 Power Section

Figure 21 is the high level block diagram of the power section of the board.

![Figure 21. High Level Power Block Diagram]

This section describes the power section of the design and all the functions performed by the TPS65217C.

6.1.1 TPS65217C PMIC

The main Power Management IC (PMIC) in the system is the TPS65217C which is a single chip power management IC consisting of a linear dual-input power path, three step-down converters, and four LDOs. The system is supplied by a USB port or DC adapter. Three high-efficiency 2.25MHz step-down converters are targeted at providing the core voltage, MPU, and memory voltage for the board.

The step-down converters enter a low power mode at light load for maximum efficiency across the widest possible range of load currents. For low-noise applications the devices can be forced into fixed frequency PWM using the I2C interface. The step-down converters allow the use of small inductors and capacitors to achieve a small footprint solution size.

LDO1 and LDO2 are intended to support system standby mode. In normal operation, they can support up to 100mA each. LDO3 and LDO4 can support up to 285mA each.

By default only LDO1 is always ON but any rail can be configured to remain up in SLEEP state. In particular the DCDC converters can remain up in a low-power PFM mode to support processor suspend mode. The TPS65217C offers flexible power-up and
power-down sequencing and several house-keeping functions such as power-good output, pushbutton monitor, hardware reset function and temperature sensor to protect the battery.

For more information on the TPS65217C, refer to http://www.ti.com/product/tps65217C.

**Figure 22** is the high level block diagram of the TPS65217C.
6.1.2 DC Input

Figure 23 below shows how the DC input is connected to the TPS65217C.

![Diagram of DC Input Connection]

Figure 23. TPS65217 DC Connection

A 5VDC supply can be used to provide power to the board. The power supply current depends on how many and what type of add-on boards are connected to the board. For typical use, a 5VDC supply rated at 1A should be sufficient. If heavier use of the expansion headers or USB host port is expected, then a higher current supply will be required.

The connector used is a 2.1MM center positive x 5.5mm outer barrel. The 5VDC rail is connected to the expansion header. It is possible to power the board via the expansion headers from an add-on card. The 5VDC is also available for use by the add-on cards when the power is supplied by the 5VDC jack on the board.
6.1.3 USB Power

The board can also be powered from the USB port. A typical USB port is limited to 500mA max. When powering from the USB port, the VDD_5V rail is not provided to the expansion header. So capes that require the 5V rail to supply the cape direct, bypassing the TPS65217C, will not have that rail available for use. The 5VDC supply from the USB port is provided on the SYS_5V, the one that comes from the TPS65217C, rail of the expansion header for use by a cape. Figure 24 is the connection of the USB power input on the PMIC.

![Figure 24. USB Power Connections](image)

6.1.4 Power Selection

The selection of either the 5VDC or the USB as the power source is handled internally to the TPS65217C and automatically switches to 5VDC power if both are connected. SW can change the power configuration via the I2C interface from the processor. In addition, the SW can read the TPS65217C and determine if the board is running on the 5VDC input or the USB input. This can be beneficial to know the capability of the board to supply current for things like operating frequency and expansion cards.

It is possible to power the board from the USB input and then connect the DC power supply. The board will switch over automatically to the DC input.
6.1.5 Power Button

A power button is connected to the input of the TPS65217C. This is a momentary switch, the same type of switch used for reset and boot selection on the board.

If you push the button the TPS65217C will send an interrupt to the processor. It is up to the processor to then pull the PMIC_EN pin low at the correct time to power down the board. At this point, the PMIC is still active, assuming that the power input was not removed. Pressing the power button will cause the board to power up again if the processor puts the board in the power off mode.

In power off mode, the RTC rail is still active, keeping the RTC powered and running off the main power input. If you remove that power, then the RTC will not be powered. You also have the option of using the battery holes on the board to connect a battery if desired as discussed in the next section.

If you push and hold the button for greater than 8 seconds, the PMIC will power down. But you must release the button when the power LED turns off. Holding the button past that point will cause the board to power cycle.

6.1.6 Battery Access Pads

Four pads are provided on the board to allow access to the battery pins on the TPS65217C. The pads can be loaded with a 4x4 header or you may just wire a battery into the pads. In addition they could provide access via a cape if desired. The four signals are listed below in Table 3.

<table>
<thead>
<tr>
<th>PIN</th>
<th>DESIGNATION</th>
<th>FUNCTION</th>
</tr>
</thead>
<tbody>
<tr>
<td>BAT</td>
<td>TP5</td>
<td>Battery connection point.</td>
</tr>
<tr>
<td>SENSE</td>
<td>TP6</td>
<td>Battery voltage sense input, connect to BAT directly at the battery terminal.</td>
</tr>
<tr>
<td>TS</td>
<td>TP7</td>
<td>Temperature sense input. Connect to NTC thermistor to sense battery temperature.</td>
</tr>
<tr>
<td>GND</td>
<td>TP8</td>
<td>System ground.</td>
</tr>
</tbody>
</table>

There is no fuel gauge function provide by the TPS65217C. That would need to be added if that function was required. Access to 1-wire SPI, or I2C interfaces required to use a fuel gauge will need to be accessed by using the expansion headers on the board.

**NOTE: Refer to the TPS65217C documentation before connecting anything to these pins.**
6.1.7 Power Consumption

The power consumption of the board varies based on power scenarios and the board boot processes. Measurements were taken with the board in the following configuration:

- DC powered and USB powered
- HDMI monitor connected
- USB HUB
- 4GB Thumbdrive
- Ethernet connected @ 100M
- Serial debug cable connected

Table 4 is an analysis of the power consumption of the board in these various scenarios.

<table>
<thead>
<tr>
<th>MODE</th>
<th>USB</th>
<th>DC</th>
<th>DC+USB</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reset</td>
<td>TBD</td>
<td>TBD</td>
<td>TBD</td>
</tr>
<tr>
<td>Idling @ UBoot</td>
<td>210</td>
<td>210</td>
<td>210</td>
</tr>
<tr>
<td>Kernel Booting (Peak)</td>
<td>460</td>
<td>460</td>
<td>460</td>
</tr>
<tr>
<td>Kernel Idling</td>
<td>350</td>
<td>350</td>
<td>350</td>
</tr>
<tr>
<td>Kernel Idling Display Blank</td>
<td>280</td>
<td>280</td>
<td>280</td>
</tr>
<tr>
<td>Loading a Webpage</td>
<td>430</td>
<td>430</td>
<td>430</td>
</tr>
</tbody>
</table>

The current will fluctuate as various activates occur, such as the LEDs on and uSD/eMMC accesses.

6.1.8 Processor Interfaces

The processor interacts with the TPS65217C via several different signals. Each of these signals is described below.

6.1.8.1 I2C0

I2C0 is the control interface between the processor and the TPS65217C. It allows the processor to control the registers inside the TPS65217C for such things as voltage scaling and switching of the input rails.

6.1.8.2 PMC_POWER_EN

On power up the VDD_RTC rail activates first. After the RTC circuitry in the processor has activated it instructs the TPS65217C to initiate a full power up cycle by activating the PMC_POWER_EN signal by taking it HI. When powering down, the processor can take this pin low to start the power down process.
6.1.8.3  LDO_GOOD

This signal connects to the RTC_PORZn signal, RTC power on reset. As the RTC circuitry comes up first, this signal indicates that the LDOs, the 1.8V VRTC rail, is up and stable. This starts the power up process.

6.1.8.4  PMIC_PGOOD

Once all the rails are up, the PMIC_PGOOD signal goes high. This releases the PORZn signal on the processor which was holding the processor reset.

6.1.8.5  WAKEUP

The WAKEUP signal from the TPS65217C is connected to the EXT_WAKEUP signal on the processor. This is used to wake up the processor when it is in a sleep mode. When an event is detected by the TPS65217C, such as the power button being pressed, it generates this signal.

6.1.8.6  PMIC_INT

The PMIC_INT signal is an interrupt signal to the processor. Pressing the power button will send an interrupt to the processor allowing it to implement a power down mode in an orderly fashion, go into sleep mode, or cause it to wake up from a sleep mode. All of these require SW support.
6.1.9 Power Rails

Figure 25 shows the connections of each of the rails from the TPS65217C.

6.1.9.1 VRTC Rail

The VRTC rail is a 1.8V rail that is the first rail to come up in the power sequencing. It provides power to the RTC domain on the processor and the I/O rail of the TPS65217C. It can deliver up to 250mA maximum.

6.1.9.2 VDD_3V3A Rail

The VDD_3V3A rail is supplied by the TPS65217C and provides the 3.3V for the processor rails and can provide up to 400mA.
6.1.9.3  VDD_3V3B Rail

The current supplied by the VDD_3V3A rail is not sufficient to power all of the 3.3V rails on the board. So a second LDO is supplied, U4, a TL5209A, which sources the VDD_3V3B rail. It is powered up just after the VDD_3V3A rail.

6.1.9.4  VDD_1V8 Rail

The VDD_1V8 rail can deliver up to 400mA and provides the power required for the 1.8V rails on the processor and the HDMI framer. This rail is not accessible for use anywhere else on the board.

6.1.9.5  VDD_CORE Rail

The VDD_CORE rail can deliver up to 1.2A at 1.1V. This rail is not accessible for use anywhere else on the board and only connects to the processor. This rail is fixed at 1.1V and is not scaled.

6.1.9.6  VDD_MPU Rail

The VDD_MPU rail can deliver up to 1.2A. This rail is not accessible for use anywhere else on the board and only connects to the processor. This rail defaults to 1.1V and can be scaled up to allow for higher frequency operation. Changing of the voltage is set via the I2C interface from the processor.

6.1.9.7  VDDS_DDR Rail

The VDDS_DDR rail defaults to 1.5V to support the DDR3L rails and can deliver up to 1.2A. It is possible to adjust this voltage rail down to 1.35V for lower power operation of the DDR3L device. Only DDR3L devices can support this voltage setting of 1.35V.
6.1.9.8  Power Sequencing

The power up process is made up of several stages and events. Figure 26 describes the events that make up the power up process for the processor.

![Power Rail Power Up Sequencing](image)

**Figure 26.** Power Rail Power Up Sequencing

**Figure 27** the voltage rail sequencing for the TPS65217C as it powers up and the voltages on each rail. The power sequencing starts at 15 and then goes to one. That is the way the TPS65217C is configured. You can refer to the TPS65217C datasheet for more information.

![TPS65217C Power Sequencing Timing](image)

**Figure 27.** TPS6517C Power Sequencing Timing
6.1.10 Power LED

The power LED is a blue LED that will turn on once the TPS65217C has finished the power up procedure. If you ever see the LED flash once, that means that the TPS65217C started the process and encountered an issue that caused it to shut down. The connection of the LED is shown in Figure 25.

6.1.11 TPS65217C Power Up Process

Figure 14 shows the interface between the TPS65217C and the processor.

![Figure 28. Power Processor Interfaces](image)

When voltage is applied, DC or USB, the TPS65217C connects the power to the SYS output pin which drives the switchers and LDOS in the TPS65217C.

At power up all switchers and LDOS are off except for the VRTC LDO (1.8V), which provides power to the VRTC rail and controls the RTC_PORZ input pin to the processor, which starts the power up process of the processor. Once the RTC rail powers up, the RTC_PORZ pin of the processor is released.

Once the RTC_PORZ reset is released, the processor starts the initialization process. After the RTC stabilizes, the processor launches the rest of the power up process by activating the PMIC_PWR_EN signal that is connected to the TPS65217C which starts the TPS65217C power up process.

The LDO_PGOOD signal is provided by the TPS65217C to the processor. As this signal is 1.8V from the TPS65217C by virtue of the TPS65217C VIO rail being set to 1.8V, and the RTC_PORZ signal on the processor is 3.3V, a voltage level shifter, U4, is used. Once the LDOs and switchers are up on the TPS65217C, this signal goes active releasing the processor. The LDOs on the TPS65217C are used to power the VRTC rail on the processor.
6.1.12 Processor Control Interface

Figure 11 above shows two interfaces between the processor and the TPS65217C used for control after the power up sequence has completed.

The first is the \texttt{I2C0} bus. This allows the processor to turn on and off rails and to set the voltage levels of each regulator to supports such things as voltage scaling.

The second is the interrupt signal. This allows the \texttt{TPS65217C} to alert the processor when there is an event, such as when the optional power button is pressed. The interrupt is an open drain output which makes it easy to interface to 3.3V of the processor.

6.1.13 Low Power Mode Support

This section covers three general power down modes that are available. These modes are only described from a Hardware perspective as it relates to the HW design.

\textbf{6.1.13.1 RTC Only}

In this mode all rails are turned off except the \texttt{VDD_RTC}. The processor will need to turn off all the rails to enter this mode. The \texttt{VDD_RTC} staying on will keep the RTC active and provide for the wakeup interfaces to be active to respond to a wake up event.

\textbf{6.1.13.2 RTC Plus DDR}

In this mode all rails are turned off except the \texttt{VDD_RTC} and the \texttt{VDDS_DDR}, which powers the DDR3L memory. The processor will need to turn off all the rails to enter this mode. The \texttt{VDD_RTC} staying on will keep the RTC active and provide for the wakeup interfaces to be active to respond to a wake up event.

The \texttt{VDDS_DDR} rail to the DDR3L is provided by the 1.5V rail of the \texttt{TPS65217C} and with \texttt{VDDS_DDR} active, the DDR3L can be placed in a self refresh mode by the processor prior to power down which allows the memory data to be saved.

Currently, this feature is not included in the standard software release. The plan is to include it in future releases.

\textbf{6.1.13.3 Voltage Scaling}

For a mode where the lowest power is possible without going to sleep, this mode allows the voltage on the ARM processor to be lowered along with slowing the processor frequency down. The I2C0 bus is used to control the voltage scaling function in the \texttt{TPS65217C}.
6.2 Sitara XAM3359AZCZ100 Processor

The board is designed to use either the Sitara AM3358AZCZ100 or XAM3358BZCZ100 processor in the 15 x 15 package. The initial units built will use the XAM3359AZCZ100 processor from TI. This is the same processor as used on the original BeagleBone except for a different revision. Later, we will switch to the AM3358BZCZ100 device when released.

6.2.1 Description

Figure 29 is a high level block diagram of the processor. For more information on the processor, go to [http://www.ti.com/product/am3359](http://www.ti.com/product/am3359).

![Figure 29. Sitara XAM3359AZCZ Block Diagram](image-url)
NOTE: Figure 29 is an older block diagram and the higher frequency is not reflected. As soon an updated picture is available, this will be changed. You can also refer to the updated datasheet for the XAM3359 processor.

6.2.2 High Level Features

Table 5 below shows a few of the high level features of the Sitara processor.

<table>
<thead>
<tr>
<th>Operating Systems</th>
<th>Linux, Android, Windows Embedded CE, QNX, ThreadX</th>
<th>MMC/SD</th>
</tr>
</thead>
<tbody>
<tr>
<td>Standby Power</td>
<td>7 mW</td>
<td>CAN</td>
</tr>
<tr>
<td>ARM CPU</td>
<td>1 ARM Cortex-A8</td>
<td>UART (SCI)</td>
</tr>
<tr>
<td>ARM MHz (Max.)</td>
<td>275,500,600,800,1000</td>
<td>ADC</td>
</tr>
<tr>
<td>ARM MIPS (Max.)</td>
<td>1000,1200,2000</td>
<td>PWM (Ch)</td>
</tr>
<tr>
<td>Graphics Acceleration</td>
<td>1 3D</td>
<td>eCAP</td>
</tr>
<tr>
<td>Other Hardware Acceleration</td>
<td>2 PRU-ICSS, Crypto Accelerator</td>
<td>eQEP</td>
</tr>
<tr>
<td>On-Chip L1 Cache</td>
<td>64 KB (ARM Cortex-A8)</td>
<td>RTC</td>
</tr>
<tr>
<td>On-Chip L2 Cache</td>
<td>256 KB (ARM Cortex-A8)</td>
<td>I2C</td>
</tr>
<tr>
<td>Other On-Chip Memory</td>
<td>128 KB</td>
<td>MeASP</td>
</tr>
<tr>
<td>Display Options</td>
<td>LCD</td>
<td>SPI</td>
</tr>
<tr>
<td>General Purpose Memory</td>
<td>1 16-bit (GPMC, NAND flash, NOR Flash, SRAM)</td>
<td>DMA (Ch)</td>
</tr>
<tr>
<td>DRAM</td>
<td>1 16-bit (LPDDR-400, DDR2-532, DDR3-606)</td>
<td>IO Supply (V)</td>
</tr>
<tr>
<td>USB Ports</td>
<td>2</td>
<td>Operating Temperature Range (C)</td>
</tr>
</tbody>
</table>

6.2.3 Documentation

Full documentation for the processor can be found on the TI website at http://www.ti.com/product/am3359 for the current processor used on the board. Make sure that you always use the latest datasheets and Technical Reference Manuals (TRM).
6.3 DDR3L Memory

The BeagleBone Black uses a single MT41K256M16HA-125 512MB DDR3L device from Micron that interfaces to the processor over 16 data lines, 16 address lines, and 14 control lines. The following sections provide more details on the design.

6.3.1 Memory Device

The design will support standard DDR3 and DDR3L x16 devices. A single x16 device is used on the board and there is no support for two x8 devices. The DDR3 devices work at 1.5V and the DDR3L devices can work down to 1.35V to achieve lower power. The specific Micron device used is the MT41K256M16HA-125. It comes in a 96-BALL FBGA package with 0.8 mil pitch. Other standard DDR3 devices can also be supported, but the DDR3L is the lower power device and was chosen for its ability to work at 1.5V or 1.35V. The standard frequency that the DDR3L is run at on the board is 303MHZ.

6.3.2 DDR3L Memory Design

Figure 30 is the schematic for the DDR3L memory device. Each of the groups of signals is described in the following lines.

**Address Lines:** Provide the row address for ACTIVATE commands, and the column address and auto pre-charge bit (A10) for READ/WRITE commands, to select one location out of the memory array in the respective bank. A10 sampled during a PRECHARGE command determines whether the PRECHARGE applies to one bank (A10 LOW, bank selected by BA[2:0]) or all banks (A10 HIGH). The address inputs also provide the op-code during a LOAD MODE command. Address inputs are referenced to VREFCA. A12/BC#: When enabled in the mode register (MR), A12 is sampled during READ and WRITE commands to determine whether burst chop (on-the-fly) will be performed (HIGH = BL8 or no burst chop, LOW = BC4 burst chop).

**Bank Address Lines:** BA[2:0] define the bank to which an ACTIVATE, READ, WRITE, or PRECHARGE command is being applied. BA[2:0] define which mode register (MR0, MR1, MR2, or MR3) is loaded during the LOAD MODE command. BA[2:0] are referenced to VREFCA.

**CK and CK# Lines:** are differential clock inputs. All address and control input signals are sampled on the crossing of the positive edge of CK and the negative edge of CK#. Output data strobe (DQS, DQS#) is referenced to the crossings of CK and CK#.

**Clock Enable Line:** CKE enables (registered HIGH) and disables (registered LOW) internal circuitry and clocks on the DRAM. The specific circuitry that is enabled/disabled is dependent upon the DDR3 SDRAM configuration and operating mode. Taking CKE LOW provides PRECHARGE power-down and SELF REFRESH operations (all banks idle) or active power-down (row active in any bank). CKE is synchronous for power-down entry and exit and for self refresh entry. CKE is asynchronous for self refresh exit.
Input buffers (excluding CK, CK#, CKE, RESET#, and ODT) are disabled during power-down. Input buffers (excluding CKE and RESET#) are disabled during SELF REFRESH. CKE is referenced to VREFCA.

**Figure 30. DDR3L Memory Design**

**Chip Select Line:** CS# enables (registered LOW) and disables (registered HIGH) the command decoder. All commands are masked when CS# is registered HIGH. CS# provides for external rank selection on systems with multiple ranks. CS# is considered part of the command code. CS# is referenced to VREFCA.
**Input Data Mask Line:** DM is an input mask signal for write data. Input data is masked when DM is sampled HIGH along with the input data during a write access. Although the DM ball is input-only, the DM loading is designed to match that of the DQ and DQS balls. DM is referenced to VREFDQ.

**On-die Termination Line:** ODT enables (registered HIGH) and disables (registered LOW) termination resistance internal to the DDR3L SDRAM. When enabled in normal operation, ODT is only applied to each of the following balls: DQ[7:0], DQS, DQS#, and DM for the x8; DQ[3:0], DQS, DQS#, and DM for the x4. The ODT input is ignored if disabled via the LOAD MODE command. ODT is referenced to VREFCA.

### 6.3.3 Power Rails

The DDR3L memory device and the DDR3 rails on the processor are supplied by the TPS65217C. Default voltage is 1.5V but can be scaled down to 1.35V if desired.

### 6.3.4 VREF

The VREF signal is generated from a voltage divider on the VDDS_DDR rail that powers the processor DDR rail and the DDR3L device itself. **Figure 31** below shows the configuration of this signal and the connection to the DDR3L memory device and the processor.

![Figure 31. DDR3L VREF Design](image-url)
6.4 2GB eMMC Memory

The eMMC is a communication and mass data storage device that includes a Multi-MediaCard (MMC) interface, a NAND Flash component, and a controller on an advanced 11-signal bus, which is compliant with the MMC system specification. The nonvolatile eMMC draws no power to maintain stored data, delivers high performance across a wide range of operating temperatures, and resists shock and vibration disruption.

One of the issues faced with SD cards is that across the different brands and even within the same brand, performance can vary. Cards use different controllers and different memories, all of which can have bad locations that the controller handles. But the controllers may be optimized for reads or writes. You never know what you will be getting. This can lead to varying rates of performance. The eMMC card is a known controller and when coupled with the 8bit mode, 8 bits of data instead of 4, you get double the performance which should result in quicker boot times.

The following sections describe the design and device that is used on the board to implement this interface.

6.4.1 eMMC Device

The device used in a Micron MTFC2GMTEA-0F_WT 2GB eMMC device. This is a new device and so for documentation and support, you will need to contact your local Micron representative.

The package is a 153 ball WFBGA device. The footprint on the BeagleBone Black for this device supports 4GB and 8GB devices. As this is a JEDEC standard, there are other suppliers that may work in this design as well. The only device that has been tested is the MTFC2GMTEA-0F_WT.
6.4.2 eMMC Circuit Design

Figure 32 is the design of the eMMC circuitry. The eMMC device is connected to the MMC1 port on the processor. MMC0 is still used for the uSD card as is currently done on the original BeagleBone.

The device runs at 3.3V both internally and the external I/O rails. The VCCI is an internal voltage rail to the device. The manufacturer recommends that a 1uf capacitor be attached to this rail, but a 2.2uF was chosen to provide a little margin.

Pullup resistors are used to increase the rise time on the signals to compensate for any capacitance on the board.

![Diagram of eMMC circuit design]

Figure 32. eMMC Memory Design

The pins used by the eMMC1 in the boot mode are listed below in Table 6.

<table>
<thead>
<tr>
<th>Signal Name</th>
<th>Pin Used in Device</th>
</tr>
</thead>
<tbody>
<tr>
<td>clk</td>
<td>gpmc_cen1</td>
</tr>
<tr>
<td>cmd</td>
<td>gpmc_cen2</td>
</tr>
<tr>
<td>dat0</td>
<td>gpmc_ad0</td>
</tr>
<tr>
<td>dat1</td>
<td>gpmc_ad1</td>
</tr>
<tr>
<td>dat2</td>
<td>gpmc_ad2</td>
</tr>
<tr>
<td>dat3</td>
<td>gpmc_ad3</td>
</tr>
</tbody>
</table>

For eMMC devices the ROM will only support raw mode. The ROM Code reads out raw sectors from image or the booting file within the file system and boots from it. In raw mode the booting image can be located at one of the four consecutive locations in the main area: offset 0x0 / 0x20000 (128 KB) / 0x40000 (256 KB) / 0x60000 (384 KB). For this reason, a booting image shall not exceed 128KB in size. However it is possible to
flash a device with an image greater than 128KB starting at one of the aforementioned locations. Therefore the ROM Code does not check the image size. The only drawback is that the image will cross the subsequent image boundary. The raw mode is detected by reading sectors #0, #256, #512, #768. The content of these sectors is then verified for presence of a TOC structure. In the case of a **GP Device**, a Configuration Header (CH) **must** be located in the first sector followed by a **GP header**. The CH might be void (only containing a CHSETTINGS item for which the Valid field is zero).

The ROM only supports the 4-bit mode. After the initial boot, the switch can be made to 8-bit mode for increasing the overall performance of the eMMC interface.

### 6.5 Micro Secure Digital

The uSD connector on the board will support a uSD card that can be used for booting or file storage on the BeagleBone Black.

#### 6.5.1 uSD Design

**Figure 33** below is the design of the uSD interface on the board.

![Figure 33. uSD Design](image)

The signals **MMC0-3** are the data lines for the transfer of data between the processor and the uSD connector.

The **MMC0_CLK** signal clocks the data in and out of the uSD card.

The **MMC0_CMD** signal indicates that a command versus data is being sent.

There is no separate card detect pin in the uSD specification. It uses **MMC0_DAT3** for that function. However, most uSD connectors still supply a CD function on the
connectors. In the BeagleBone Black design, this pin is connected to the MMC0_SDCD pin for use by the processor. You can also change the pin to GPIO0_6, which is able to wake up the processor from a sleep mode when an SD card is inserted into the connector.

Pullup resistors are provided on the signals to increase the rise times of the signals to overcome PCB capacitance.

Power is provided from the VDD_3V3B rail and a 10uf capacitor is provided for filtering.

### 6.6 User LEDs

There are four user LEDs on the BeagleBone Black. These are connected to GPIO pins on the processor. **Figure 34** shows the interfaces for the user LEDs.

![User LEDs Diagram](image)

**Figure 34. User LEDs**

**Table 7** shows the signals used to control the four LEDs from the processor.

<table>
<thead>
<tr>
<th>LED</th>
<th>GPIO SIGNAL</th>
<th>PROC PIN</th>
</tr>
</thead>
<tbody>
<tr>
<td>USR0</td>
<td>GPIO1_21</td>
<td>V15</td>
</tr>
<tr>
<td>USR1</td>
<td>GPIO2_22</td>
<td>U15</td>
</tr>
<tr>
<td>USR2</td>
<td>GPIO2_23</td>
<td>T15</td>
</tr>
<tr>
<td>USR3</td>
<td>GPIO2_24</td>
<td>V16</td>
</tr>
</tbody>
</table>

A logic level of “1” will cause the LEDs to turn on.
6.7 Boot Configuration

The design supports two groups of boot options on the board. The user can switch between these modes via the Boot button. The primary boot source is the onboard eMMC device. By holding the Boot button, the user can force the board to boot from the uSD slot. This enables the eMMC to be overwritten when needed or to just boot an alternate image. The following sections describe how the boot configuration works.

6.7.1 Boot Configuration Design

Figure 35 shows the circuitry that is involved in the boot configuration process. On power up, these pins are read by the processor to determine the boot order. S2 is used to change the level of one bit from HI to LO which changes the boot order.

![Processor Boot Configuration Design](image)

Figure 35. Processor Boot Configuration Design

It is possible to override these setting via the expansion headers. But be careful not to add too much load such that it could interfere with the operation of the HDMI interface or LCD panels. If you choose to override these settings, it is strongly recommended that you gate these signals with the SYS_RESETn signal. This insures that after coming out of reset these signals are removed from the expansion pins.
6.7.2  Default Boot Options

Based on the selected option found in Figure 36 below, each of the boot sequences for each of the two settings is shown.

![Figure 36. Processor Boot Configuration](image)

The first row in Figure 36 is the default setting. On boot, the processor will look for the eMMC on the MMC1 port first, followed by the uSD slot on MMC0, USB0 and UART0. In the event there is no uSD card and the eMMC is empty, UART0 or USB0 could be used as the board source.

If you have a uSD card from which you need to boot from, hold the boot button down. On boot, the processor will look for the SPI00 port first, then uSD on the MMC0 port, followed by USB0 and UART0. In the event there is no uSD card and the eMMC is empty, USB0 or UART0 could be used as the board source.
6.8 10/100 Ethernet

The BeagleBone Black is equipped with a 10/100 Ethernet interface. It uses the same PHY as is used on the original BeagleBone. The design is described in the following sections.

6.8.1 Ethernet Processor Interface

Figure 37 shows the connections between the processor and the PHY. The interface is in the MII mode of operation.

This is the same interface as is used on the BeagleBone. No changes were made in this design for the board.
6.8.2 Ethernet Connector Interface

The off board side of the PHY connections are shown in Figure 38 below.

This is the same interface as is used on the BeagleBone. No changes were made in this design for the board.
Ethernet PHY Power, Reset, and Clocks

Figure 39 shows the power, reset, and lock connections to the **LAN8710A** PHY. Each of these areas is discussed in more detail in the following sections.

6.8.2.1 *VDD_3V3B Rail*

The VDD_3V3B rail is the main power rail for the **LAN8710A**. It originates at the VD_3V3B regulator and is the primary rail that supports all of the peripherals on the board. This rail also supplies the VDDIO rails which set the voltage levels for all of the I/O signals between the processor and the **LAN8710A**.

6.8.2.2 *VDD_PHYA Rail*

A filtered version of VDD_3V3B rail is connected to the VDD rails of the LAN8710 and the termination resistors on the Ethernet signals. It is labeled as **VDD_PHYA**. The filtering inductor helps block transients that may be seen on the VDD_3V3B rail.
6.8.2.3  **PHY_VDDCR Rail**

The **PHY_VDDCR** rail originates inside the LAN8710A. Filter and bypass capacitors are used to filter the rail. Only circuitry inside the LAN8710A uses this rail.

6.8.2.4  **SYS_RESET**

The reset of the LAN8710A is controlled via the **SYS_RESETn** signal, the main board reset line.

6.8.2.5  **Clock Signals**

A crystal is used to create the clock for the LAN8710A. The processor uses the **RMII_RXCLK** signal to provide the clocking for the data between the processor and the LAN8710A.

6.8.3  **LAN8710A Mode Pins**

There are mode pins on the LAN8710A that sets the operational mode for the PHY when coming out of reset. These signals are also used to communicate between the processor and the LAN8710A. As a result, these signals can be driven by the processor which can cause the PHY not to be initiated correctly. To insure that this does not happen, three low value pull up resistors are used. Figure 40 below shows the three mode pin resistors.

```
MODE2
RXD1/MODE1
RXD0/MODE0
R114 1.5K,1%
R112 1.5K,1%
R113 1.5K,1%
VDD_3V3B
```

**Figure 40. Ethernet PHY Mode Pins**

This will set the mode to be 111, which enables all modes and enables auto-negotiation.

This design
6.9 HDMI Interface

The BeagleBone Black has an onboard HDMI framer that converts the LCD signals and audio signals to drive a HDMI monitor. The design uses an NXP TDA199988 HDMI Framer.

The following sections provide more detail into the design of this interface.

6.9.1 Supported Resolutions

The maximum resolution supported by the BeagleBone Black is 1280x1024 @ 60Hz. Table 8 below shows the supported resolutions. Not all resolutions may work on all monitors, but these have been tested and shown to work on at least one monitor. EDID is supported on the BeagleBone Black. Based on the EDID reading from the connected monitor, the highest compatible resolution is selected.

Table 8. HDMI Supported Monitor Resolutions

<table>
<thead>
<tr>
<th>Resolution</th>
<th>Refresh Rate</th>
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<tbody>
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<td>800 x 600</td>
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<tr>
<td>800 x 600</td>
<td>56Hz</td>
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<td>1024 x 768</td>
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<td>72Hz</td>
</tr>
<tr>
<td>720 x 480</td>
<td>72Hz</td>
</tr>
</tbody>
</table>

6.9.2 HDMI Framer

The TDA19988 is a High-Definition Multimedia Interface (HDMI) 1.4a transmitter. It is backward compatible with DVI 1.0 and can be connected to any DVI 1.0 or HDMI sink. The HDCP mode is not used in the design. The non-HDCP version of the device is used in the BeagleBone Black design.

This device provides additional embedded features like CEC (Consumer Electronic Control). CEC is a single bidirectional bus that transmits CEC over the home appliance network connected through this bus. This eliminates the need of any additional device to handle this feature. While this feature is supported in this device, as of this point, the SW to support this feature has not been implemented and is not a feature that is considered critical.

It can be switched to very low power Standby or Sleep modes to save power when HDMI is not used. TDA19988 embeds I²C-bus master interface for DDC-bus communication to read EDID. This device can be controlled or configured via I²C-bus interface.
6.9.3 HDMI Video Processor Interface

The Figure 41 shows the connections between the processor and the HDMI framer device. There are 16 bits of display data, 5-6-5 that is used to drive the framer. The reason for 16 bits is that allows for compatibility with display and LCD capes already available on the original BeagleBone. The unused bits on the TDA19988 are tied low. In addition to the data signals are the VSYNC, HSYNC, DE, and PCLK signals that round out the video interface from the processor.

Figure 41. HDMI Framer Processor Interface
6.9.4 HDMI Control Processor Interface

In order to use the TDA19988, the processor needs to setup the device. This is done via the I2C interface between the processor and the TDA19988. There are two signals on the TDA19988 that could be used to set the address of the TDA19988. In this design they are both tied low. The I2C interface supports both 400kHz and 100KHz operation. Table 9 shows the I2C address.

Table 9. TDA19988 I2C Address

<table>
<thead>
<tr>
<th>HDMI core address</th>
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<td>A6</td>
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<tr>
<td>----</td>
</tr>
<tr>
<td>1</td>
</tr>
</tbody>
</table>

6.9.5 Interrupt Signal

There is a HDMI_INT signal that connects from the TDA19988 to the processor. This signal can be used to alert the processor in a state change on the HDMI interface.

6.9.6 Audio Interface

There is an I2S audio interface between the processor and the TDA19988. Stereo audio can be transported over the HDMI interface to an audio equipped display. In order to create the required clock frequencies, and external 24.576MHz oscillator, Y4, is used. From this clock, the processor generates the required clock frequencies for the TDA19988.

There are three signals used to pass data from the processor to the TDA19988. SCLK is the serial clock. SPI1_CS0 is the data pin to the TDA19988. SPI1_D0 is the word sync pin. These signals are configured as I2S interfaces.
6.9.7 Power Connections

Figure 42 shows the power connections to the TDA19988 device. All voltage rails for the device are at 1.8V. A filter is provided to minimize any noise from the 1.8V rail getting back into the device.

![Figure 42. HDMI Power Connections](image)

All of the interfaces between the processor and the TDA19988 are 3.3V tolerant allowing for direct connection.
6.9.8 HDMI Connector Interface

Figure 43 shows the design of the interface between the HDMI Framer and the connector.

The connector for the HDMI interface is a microHDMI. It should be noted that this connector has a different pinout than the standard or mini HDMI connectors. D6 and D7 are ESD protection devices.
7.0 Connectors

This section describes each of the connectors on the board.

7.1 Expansion Connectors

The expansion interface on the board is comprised of two 46 pin connectors. All signals on the expansion headers are 3.3V unless otherwise indicated.

**NOTE: Do not connect 5V logic level signals to these pins or the board will be damaged.**

Figure 44 shows the location of the expansion connectors.

![Expansion Connector Location](image)

The location and spacing of the expansion headers are the same as on the original BeagleBone.
7.1.1 Connector P8

Table 10 shows the pinout of the P8 expansion header. Other signals can be connected to this connector based on setting the pin mux on the processor, but this is the default settings on power up. The SW is responsible for setting the default function of each pin. There are some signals that have not been listed here. Refer to the processor documentation for more information on these pins and detailed descriptions of all of the pins listed. In some cases there may not be enough signals to complete a group of signals that may be required to implement a total interface.

The PROC column is the pin number on the processor. The PIN column is the pin number on the expansion header. The MODE columns are the mode setting for each pin. Setting each mode to align with the mode column will give that function on that pin.
<table>
<thead>
<tr>
<th>PIN</th>
<th>PROC</th>
<th>NAME</th>
<th>MODE0</th>
<th>MODE1</th>
<th>MODE2</th>
<th>MODE3</th>
<th>MODE4</th>
<th>MODE5</th>
<th>MODE6</th>
<th>MODE7</th>
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</table>
7.1.2 Connector P9

Table 11 lists the signals on connector P9. Other signals can be connected to this connector based on setting the pin mux on the processor, but this is the default settings on power up.

There are some signals that have not been listed here. Refer to the processor documentation for more information on these pins and detailed descriptions of all of the pins listed. In some cases there may not be enough signals to complete a group of signals that may be required to implement a total interface.

The PROC column is the pin number on the processor. The PIN column is the pin number on the expansion header. The MODE columns are the mode setting for each pin. Setting each mode to align with the mode column will give that function on that pin.

NOTES:

In the table are the following notations:

PWR_BUT is a 5V level as pulled up internally by the TPS65217C. It is activated by pulling the signal to GND.

# Both of these signals connect to pin 41 of P11. Resistors are installed that allow for the GPIO3_20 connection to be removed by removing R221. The intent is to allow the SW to use either of these signals, one or the other, on pin 41. SW should set the unused pin in input mode when using the other pin. This allowed us to get an extra signal out to the expansion header.

@ Both of these signals connect to pin 42 of P11. Resistors are installed that allow for the GPIO3_18 connection to be removed by removing R202. The intent is to allow the SW to use either of these signals, on pin 42. SW should set the unused pin in input mode when using the other pin. This allowed us to get an extra signal out to the expansion header.
## Table 11. Expansion Header P9 Pinout

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<th>PIN</th>
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<th>MODE0</th>
<th>MODE1</th>
<th>MODE2</th>
<th>MODE3</th>
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</table>

**References:**
- [Reference Manual](http://beagleboard.org/beaglebone-black-manual)
7.2 Power Jack

The DC power jack is located next to the RJ45 Ethernet connector as shown in Figure 45. This uses the same power connector as is used on the original BeagleBone. The connector has a 2.1mm diameter center post and a 5.5mm diameter outer dimension on the barrel.

![5VDC Power Jack](image)

**Figure 45. 5VDC Power Jack**

The board requires a regulated 5VDC +/-0.25V supply at 1A. A higher current rating may be needed if capes are plugged into the expansion headers.
7.3 USB Client

The USB Client connector is accessible on the bottom side of the board under the row of four LEDs as shown in Figure 46. It uses a 5 pin miniUSB cable, the same as is used on the original BeagleBone. The cable is provided with the board. The cable can also be used to power the board.

Figure 46. USB Client Connector

This port is a USB Client only interface and is intended for connection to a PC.
7.4 USB Host

There is a single USB Host connector on the board and is shown in Figure 47 below.

Figure 47. USB Host Connector

The port is USB 2.0 HS compatible and can supply up to 500mA of current. If more current or ports is needed, then a HUB can be used.
7.5 Serial Header

Each board has a debug serial interface that can be accessed by using a special serial cable that is plugged into the serial header as shown in Figure 48 below.

![Serial Debug Header](image)

**Figure 48. Serial Debug Header**

Two signals are provided, TX and RX on this connector. The levels on these signals are 3.3V. In order to access these signals, a FTDI USB to Serial cable is recommended as shown in Figure 49 below.

![FTDI USB to Serial Adapter](image)

**Figure 49. FTDI USB to Serial Adapter**

The cable can be purchased from several different places and must be the 3.3V version TTL-232R-3V3. Information on the cable itself can be found direct from FTDI at:
Pin 1 of the cable is the black wire. That must align with the pin 1 on the board which is designated by the white dot on the PCB.

Refer to the support WIKI http://circuitco.com/support/index.php?title=BeagleBoneBlack for more sources of this cable and other options that will work.
7.6 HDMI

Access to the HDMI interface is through the HDMI connector that is located on the bottom side of the board as shown in Figure 50 below.

Figure 50. HDMI Connector

The connector is microHDMI connector. This was done due to the space limitations we had in finding a place to fit the connector. It requires a microHDMI to HDMI cable as shown in Figure 37 below. The cable can be purchased from several different sources.

Figure 51. HDMI Connector
7.7 microSD

A microSD connector is located on the backside of the board as shown in Figure 52 below. The SD card is not supplied with the board.

![uSD Connector](image)

**Figure 52. uSD Connector**

When plugging in the SD card, the writing on the card should be up. Align the card with the connector and push to insert. Then release. There should be a click and the card will start to eject slightly, but it then should latch into the connector. To eject the card, push the SD card in and then remove your finger. The SD card will be ejected from the connector.

Do pull the SD card out or you could damage the connector.
7.8 Ethernet

The board comes with a single 10/100 Ethernet interface located next to the power jack as shown in Figure 53.

![Ethernet Connector](image)

Figure 53. Ethernet Connector

The PHY supports AutoMDX which means either a straight or a swap cable can be used.
8.0 Cape Board Support

The BeagleBone Black has the ability to accept up to four expansion boards or capes that can be stacked onto the expansion headers. The word cape comes from the shape of the board as it is fitted around the Ethernet connector on the main board. This notch acts as a key to insure proper orientation of the cape.

This section describes the rules for creating capes to insure proper operation with the BeagleBone Black and proper interoperability with other capes that are intended to co-exist with each other. Co-existence is not a requirement and is in itself, something that is impossible to control or administer. But, people will be able to create capes that operate with other capes that are already available based on public information as it pertains to what pins and features each cape uses. This information will be able to be read from the EEPROM on each cape.

This section is intended as a guideline for those wanting to create their own capes. Its intent is not to put limits on the creation of capes and what they can do, but to set a few basic rules that will allow the SW to administer their operation with the BeagleBone Black. For this reason there is a lot of flexibility in the specification that we hope most people will find liberating and in the spirit of Open Source Hardware. I am sure there are others that would like to see tighter control, more details, more rules and much more order to the way capes are handled.

Over time, this specification will change and be updated, so please refer to the latest version of this manual prior to designing your own capes to get the latest information.
8.1 BeagleBoneBlack Cape Compatibility

The main expansion headers are the same between the BeagleBone and BeagleBone Black. While the pins are the same, some of these pins are now used on the BeagleBone Black. The following sections discuss these pins.

The Power Expansion header was removed from the BeagleBone Black and is not available.

**PAY VERY CLOSE ATTENTION TO THIS SECTION AND READ CAREFULLY!!**

8.1.1 LCD Pins

The LCD pins are used on the BeagleBone Black to drive the HDMI framer. These signals are listed in Table 12 below.

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</table>

If you are using these pins for other functions, there are a few things to keep in mind:

- On the HDMI Framer, these signals are all inputs so the framer will not be driving these pins.
- The HDMI framer will add a load onto these pins.
- There are small filter caps on these signals which could also change the operation of these pins if used for other functions.
When used for other functions, the HDMI frame cannot be used.
There is no way to power off the framer as this would result in the framer being powered through these pins which would not be a good idea.

In order to use these pins, the SW will need to reconfigure them to whatever function you need the pins to do. To keep power low, the HDMI framer should be put in a low power mode via the SW using the I2C interface.

8.1.2 eMMC Pins

The BeagleBone Black uses 10 pins to connect to the processor that also connect to the P8 expansion connector. These signals are listed below in Table 13.

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<td>GPIO0_27</td>
<td>mmc1_dat3</td>
</tr>
<tr>
<td>19</td>
<td>U10</td>
<td>EHRPWM2A</td>
<td>mmc1_dat0</td>
</tr>
<tr>
<td>20</td>
<td>V9</td>
<td>GPIO1_31</td>
<td>mmc1_cmd</td>
</tr>
<tr>
<td>21</td>
<td>U9</td>
<td>GPIO1_30</td>
<td>mmc1_clk</td>
</tr>
</tbody>
</table>

If using these pins, several things need to be kept in mind when doing so:

- On the eMMC device, these signals are inputs and outputs.
- The eMMC device will add a load onto these pins.
- When used for other functions, the eMMC cannot be used. This means you must boot from the uSD slot.
- If using these pins, you need to put the eMMC into reset.

On power up, the eMMC is NOT reset. If you hold the Boot button down, this will force a boot from the uSD. This is not convenient when a cape is plugged into the board. There are two solutions to this issue:

1. Wipe the eMMC clean. This will cause the board to default to uSD boot. If you want to use the eMMC later, it can be reprogrammed.
2. You can also tie LCD_DATA2 low on the cape during boot. This will be the same as if you were holding the boot button. However, in order to prevent unforeseen
issues, you need to gate this signal with RESET, when the data is sampled. After reset goes high, the signal should be removed from the pin.

**BEFORE** the SW reinitializes the pins, it **MUST** put the eMMC in reset. This is done by taking eMMC_RSTn (GPIO1_20) LOW. This pin does not connect to the expansion header and is accessible only on the board.

**DO NOT** automatically drive any conflicting pin until the SW enables it. This puts the SW in control to insure that the eMMC is in reset before the signals are used from the cape.

### 8.2 EEPROM

Each cape must have its own EEPROM containing information that will allow the SW to identify the board and to configure the expansion headers pins as needed. The one exception is proto boards intended for prototyping. They may or may not have an EEPROM on them. An EEPROM is required for all capes sold in order for them operate correctly when plugged into the BeagleBone Black.

The address of the EEPROM will be set via either jumpers or a dipswitch on each expansion board. **Figure 54** below is the design of the EEPROM circuit.

The EEPROM used is the same one as is used on the BeagleBone and the BeagleBone Black, a CAT24C256. The CAT24C256 is a 256 kb Serial CMOS EEPROM, internally organized as 32,768 words of 8 bits each. It features a 64-byte page write buffer and supports the Standard (100 kHz), Fast (400 kHz) and Fast–Plus (1 MHz) I2C protocol.

**Figure 54. Expansion Board EEPROM Without Write Protect**

The addressing of this device requires two bytes for the address which is not used on smaller size EEPROMs, which only require only one byte. Other compatible devices may
be used as well. Make sure the device you select supports 16 bit addressing. The part package used is at the discretion of the cape designer.

8.2.1 EEPROM Address

In order for each cape to have a unique address, a board ID scheme is used that sets the address to be different depending on the setting of the dipswitch or jumpers on the capes. A two position dipswitch or jumpers is used to set the address pins of the EEPROM.

It is the responsibility of the user to set the proper address for each board and the position in the stack that the board occupies has nothing to do with which board gets first choice on the usage of the expansion bus signals. The process for making that determination and resolving conflicts is left up to the SW and, as of this moment in time, this method is a something of a mystery due t the new Device Tree methodology introduced in the 3.8 kernel.

Address line A2 is always tied high. This sets the allowable address range for the expansion cards to 0x54 to 0x57. All other I2C addresses can be used by the user in the design of their capes. But, these addresses must not be used other than for the board EEPROM information. This also allows for the inclusion of EEPROM devices on the cape if needed without interfering with this EEPROM. It requires that A2 be grounded on the EEPROM not used for cape identification.

8.2.2 I2C Bus

The EEPROMs on each expansion board are connected to I2C2 on connector P9 pins 19 and 20. For this reason I2C2 must always be left connected and should not be changed by SW to remove it from the expansion header pin mux settings. If this is done, then the system will be unable to detect the capes.

The I2C signals require pullup resistors. Each board must have a 5.6K resistor on these signals. With four capes installed this will be an effective resistance of 1.4K if all capes were installed and all the resistors used were exactly 5.6K. As more capes are added the resistance is reduced to overcome capacitance added to the signals. When no capes are installed the internal pullup resistors must be activated inside the processor to prevent I2C timeouts on the I2C bus.

The I2C2 bus may also be used by capes for other functions such as I/O expansion or other I2C compatible devices that do not share the same address as the cape EEPROM.

8.2.3 EEPROM Write Protect
The design in Figure 55 has the write protect disabled. If the write protect is not enabled, this does expose the EEPROM to being corrupted if the I2C2 bus is used on the cape and the wrong address written to. It is recommended that a write protection function be implemented and a Test Point be added that when grounded, will allow the EEPROM to be written to. To enable write protect, Pin 7 of the EEPROM should be tied to ground. Whether or not Write Protect is provided is at the discretion of the cape designer.

**Variable & MAC Memory**

![Variable & MAC Memory Diagram](image)

Figure 55. Expansion Board EEPROM Write Protect
8.2.4 EEPROM Data Format

Table 14 shows the format of the contents of the expansion board EEPROM. Data is stored in Big Endian with the least significant value on the right. All addresses read as a single byte data from the EEPROM, but two byte addressing is used. ASCII values are intended to be easily read by the user when the EEPROM contents are dumped.

### Table 14. Expansion Board EEPROM

<table>
<thead>
<tr>
<th>Name</th>
<th>Offset</th>
<th>Size (bytes)</th>
<th>Contents</th>
</tr>
</thead>
<tbody>
<tr>
<td>Header</td>
<td>0</td>
<td>4</td>
<td>0xAA, 0x55, 0x33, 0xEE</td>
</tr>
<tr>
<td>EEPROM Revision</td>
<td>4</td>
<td>2</td>
<td>Revision number of the overall format of this EEPROM in ASCII =A1</td>
</tr>
<tr>
<td>Board Name</td>
<td>6</td>
<td>32</td>
<td>Name of board in ASCII so user can read it when the EEPROM is dumped. Up to developer of the board as to what they call the board.</td>
</tr>
<tr>
<td>Version</td>
<td>38</td>
<td>4</td>
<td>Hardware version code for board in ASCII. Version format is up to the developer. i.e. 02.1…00A1…..10A0</td>
</tr>
<tr>
<td>Manufacturer</td>
<td>42</td>
<td>16</td>
<td>ASCII name of the manufacturer. Company or individual’s name.</td>
</tr>
<tr>
<td>Part Number</td>
<td>58</td>
<td>16</td>
<td>ASCII Characters for the part number. Up to maker of the board.</td>
</tr>
<tr>
<td>Number of Pins</td>
<td>74</td>
<td>2</td>
<td>Number of pins used by the daughter board including the power pins used. Decimal value of total pins 92 max, stored in HEX.</td>
</tr>
<tr>
<td>Serial Number</td>
<td>76</td>
<td>12</td>
<td>Serial number of the board. This is a 12 character string which is: WWYY&amp;&amp;&amp;&amp;&amp;nnnn where: WW = 2 digit week of the year of production YY = 2 digit year of production &amp;&amp;&amp;&amp;=Assembly code to let the manufacturer document the assembly number or product. A way to quickly tell from reading the serial number what the board is. Up to the developer to determine. nnnn = incrementing board number for that week of production</td>
</tr>
</tbody>
</table>

Pin Usage

<table>
<thead>
<tr>
<th>Name</th>
<th>Offset</th>
<th>Size (bytes)</th>
<th>Contents</th>
</tr>
</thead>
<tbody>
<tr>
<td>Two bytes for each configurable pins of the 74 pins on the expansion connectors</td>
<td>88</td>
<td>148</td>
<td>MSB</td>
</tr>
<tr>
<td>Bit 15…………Pin is used or not………..0=Unused by cape 1=Used by cape</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Bit 14-13………Pin Direction…………….0=Output 1=Input 11=BDIR</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Bits 12-7……….Reserved………………….should be all zeros</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Bit 6…………….Slew Rate ……………….0=Fast 1=Slow</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Bit 5…………….Rx Enable……………….0=Disabled 1=Enabled</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Bit 4…………….Pull Up/Dn Select………..0=Pulldown 1=PullUp</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Bit 3…………….Pull Up/Down enabled…0=Enabled 1=Disabled</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Bits 2-0 ………..Mux Mode Selection……Mode 0-7</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

VDD_3V3B Current

<table>
<thead>
<tr>
<th>Name</th>
<th>Offset</th>
<th>Size (bytes)</th>
<th>Contents</th>
</tr>
</thead>
<tbody>
<tr>
<td>VDD_3V3B Current</td>
<td>236</td>
<td>2</td>
<td>Maximum current in millamps. This is HEX value of the current in decimal 1500mA=0x05 0x0C 325mA=0x01 0x45</td>
</tr>
</tbody>
</table>

VDD_5V Current

<table>
<thead>
<tr>
<th>Name</th>
<th>Offset</th>
<th>Size (bytes)</th>
<th>Contents</th>
</tr>
</thead>
<tbody>
<tr>
<td>VDD_5V Current</td>
<td>238</td>
<td>2</td>
<td>Maximum current in millamps. This is HEX value of the current in decimal 1500mA=0x05 0x0C 325mA=0x01 0x45</td>
</tr>
</tbody>
</table>

SYS_5V Current

<table>
<thead>
<tr>
<th>Name</th>
<th>Offset</th>
<th>Size (bytes)</th>
<th>Contents</th>
</tr>
</thead>
<tbody>
<tr>
<td>SYS_5V Current</td>
<td>240</td>
<td>2</td>
<td>Maximum current in millamps. This is HEX value of the current in decimal 1500mA=0x05 0x0C 325mA=0x01 0x45</td>
</tr>
</tbody>
</table>

DC Supplied

<table>
<thead>
<tr>
<th>Name</th>
<th>Offset</th>
<th>Size (bytes)</th>
<th>Contents</th>
</tr>
</thead>
<tbody>
<tr>
<td>DC Supplied</td>
<td>242</td>
<td>2</td>
<td>Indicates whether or not the board is supplying voltage on the VDD_5V rail and the current rating 000=No 1-0xFFFF is the current supplied storing the decimal equivalent in HEX format</td>
</tr>
</tbody>
</table>

Available

<table>
<thead>
<tr>
<th>Name</th>
<th>Offset</th>
<th>Size (bytes)</th>
<th>Contents</th>
</tr>
</thead>
<tbody>
<tr>
<td>Available</td>
<td>244</td>
<td>32543</td>
<td>Available space for other non-volatile codes/data to be used as needed by the manufacturer or SW driver. Could also store presets for use by SW.</td>
</tr>
</tbody>
</table>
8.2.5 Pin Usage

Table 15 is the locations in the EEPROM to set the I/O pin usage for the cape. It contains the value to be written to the Pad Control Registers. Details on this can be found in section 9.2.2 of the AM335x Technical Reference Manual. The table is left blank as a convenience and can be printed out and used as a template for creating a custom setting for each cape. The 16 bit integers and all 16 bit fields are to be stored in Big Endian format.

<table>
<thead>
<tr>
<th>Bit</th>
<th>PIN USAGE</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>15</td>
<td>PIN USAGE</td>
<td>Bit 15: PIN USAGE is an indicator and should be a 1 if the pin is used or 0 if it is unused.</td>
</tr>
<tr>
<td>14-7</td>
<td>RESERVED</td>
<td>Bits 14-7: RESERVED is not to be used and left as 0.</td>
</tr>
<tr>
<td>6</td>
<td>SLEW CONTROL</td>
<td>Bit 6: SLEW CONTROL 0=Fast 1=Slow</td>
</tr>
<tr>
<td>5</td>
<td>RX Enabled</td>
<td>Bit 5: RX Enabled 0=Disabled 1=Enabled</td>
</tr>
<tr>
<td>4</td>
<td>PU/PD</td>
<td>Bit 4: PU/PD 0=Pulldown 1=Pullup.</td>
</tr>
<tr>
<td>3</td>
<td>PULLUP/DN</td>
<td>Bit 3: PULLUP/DN 0=Pullup/pulldown enabled 1= Pullup/pulldown disabled</td>
</tr>
<tr>
<td>2-0</td>
<td>MUX MODE SELECT</td>
<td>Bit 2-0: MUX MODE SELECT Mode 0-7. (refer to TRM)</td>
</tr>
</tbody>
</table>

Refer to the TRM for proper settings of the pin MUX mode based on the signal selection to be used.

The AIN0-6 pins do not have a pin mux setting, but they need to be set to indicate if each of the pins is used on the cape. Only bit 15 is used for the AIN signals.
Table 15. EEPROM Pin Usage

<table>
<thead>
<tr>
<th>Offset</th>
<th>Conn</th>
<th>Name</th>
<th>Pin Usage</th>
<th>Type</th>
<th>Reserved</th>
<th>SLEW</th>
<th>RX</th>
<th>PUD</th>
<th>PD</th>
<th>DEN</th>
<th>Mux Mode</th>
</tr>
</thead>
<tbody>
<tr>
<td>88</td>
<td>P9-22</td>
<td>UART2_RXD</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>90</td>
<td>P9-21</td>
<td>UART2_TXD</td>
<td></td>
<td></td>
<td></td>
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<td></td>
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<tr>
<td>92</td>
<td>P9-18</td>
<td>I2C1_SDA</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<td></td>
<td></td>
<td></td>
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<tr>
<td>94</td>
<td>P9-17</td>
<td>I2C1_SCL</td>
<td></td>
<td></td>
<td></td>
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<td></td>
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<td></td>
<td></td>
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<tr>
<td>96</td>
<td>P9-42</td>
<td>GPIO0_7</td>
<td></td>
<td></td>
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<td></td>
</tr>
<tr>
<td>98</td>
<td>P8-35</td>
<td>UART4_CTSN</td>
<td></td>
<td></td>
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<tr>
<td>100</td>
<td>P8-33</td>
<td>UART4_RTSN</td>
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<td>102</td>
<td>P8-31</td>
<td>UART5_CTSN</td>
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<td>P8-32</td>
<td>UART5_RTSN</td>
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<td>106</td>
<td>P9-19</td>
<td>I2C2_SCL</td>
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<td>108</td>
<td>P9-20</td>
<td>I2C2_SDA</td>
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<tr>
<td>110</td>
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<td>UART1_RXD</td>
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<td>112</td>
<td>P9-24</td>
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<td>114</td>
<td>P9-41</td>
<td>CLKOUT2</td>
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<td>116</td>
<td>P8-19</td>
<td>EHRPWM2A</td>
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<td>P8-25</td>
<td>GPIO1_0</td>
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<td>P8-5</td>
<td>GPIO1_2</td>
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<td>P8-23</td>
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<td>P8-22</td>
<td>GPIO1_5</td>
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<td>GPIO1_12</td>
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<td>GPIO1_14</td>
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<td>152</td>
<td>P9-15</td>
<td>GPIO1_16</td>
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<td></td>
<td></td>
</tr>
<tr>
<td>Offset</td>
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</tr>
</tbody>
</table>
8.3 Pin Usage Consideration

This section covers things to watch for when hooking up to certain pins on the expansion headers.

8.3.1 Boot Pins

There are 16 pins that control the boot mode of the processor that are exposed on the expansion headers. Figure 56 below shows those signals:

![Figure 56. Expansion Boot Pins](image)

- If you plan to use any of these signals, then on power up, these pins should not be driven. If you do, it can affect the boot mode of the processor and could keep the processor from booting or working correctly.

- If you are designing a cape that is intended to be used as a boot source, such as a NAND board, then you should drive the pins to reconfigure the boot mode, but only at reset. After the reset phase, the signals should not be driven to allow them to be used for the...
other functions found on those pins. You will need to override the resistor values in order to change the settings. The DC pull-up requirement should be based on the AM335x Vih min voltage of 2 volts and AM335x maximum input leakage current of 18uA. Also take into account any other current leakage paths on these signals which could be caused by your specific cape design.

The DC pull-down requirement should be based on the AM335x Vil max voltage of 0.8 volts and AM335x maximum input leakage current of 18uA plus any other current leakage paths on these signals.

8.4 Expansion Connectors

A combination of male and female headers is used for access to the expansion headers on the main board. There are three possible mounting configurations for the expansion headers:

- **Single**-no board stacking but can be used on the top of the stack.
- **Stacking**-up to four boards can be stacked on top of each other.
- **Stacking with signal stealing**-up to three boards can be stacked on top of each other, but certain boards will not pass on the signals they are using to prevent signal loading or use by other cards in the stack.

The following sections describe how the connectors are to be implemented and used for each of the different configurations.

8.4.1 Non-Stacking Headers-Single Cape

For non-stacking capes single configurations or where the cape can be the last board on the stack, the two 46 pin expansion headers use the same connectors. Figure 57 is a picture of the connector. These are dual row 23 position 2.54mm x 2.54mm connectors.

![Figure 57. Single Expansion Connector](image)

The connector is typically mounted on the bottom side of the board as shown in Figure 58. These are very common connectors and should be easily located. You can also use two single row 23 pin headers for each of the dual row headers.
It is allowed to only populate the pins you need. As this is a non-stacking configuration, there is no need for all headers to be populated. This can also reduce the overall cost of the cape. This decision is up to the cape designer.

For convenience listed in Table 16 are some possible choices for part numbers on this connector. They have varying pin lengths and some may be more suitable than others for your use. It should be noted, that the longer the pin and the further it is inserted into the BeagleBone Black connector, the harder it will be to remove due to the tension on 92 pins. This can be minimized by using shorter pins or removing those pins that are not used by your particular design. The first item in Table 16 is on the edge and may not be the best solution. Overhang is the amount of the pin that goes past the contact point of the connector on the BeagleBone Black.

<table>
<thead>
<tr>
<th>SUPPLIER</th>
<th>PARTNUMBER</th>
<th>TAIL LENGTH(in)</th>
<th>OVERHANG(in)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Major League</td>
<td>TSHC-123-D-03-145-G-LF</td>
<td>.145</td>
<td>.004</td>
</tr>
<tr>
<td>Major League</td>
<td>TSHC-123-D-03-240-G-LF</td>
<td>.240</td>
<td>.099</td>
</tr>
<tr>
<td>Major League</td>
<td>TSHC-123-D-03-255-G-LF</td>
<td>.255</td>
<td>.114</td>
</tr>
</tbody>
</table>

The G in the part number is a plating option. Other options may be used as well as long as the contact area is gold. Other possible sources are Sullins and Samtec for these connectors. You will need to insure the depth into the connector is sufficient.

### 8.4.2 Main Expansion Headers-Stacking

For stacking configuration, the two 46 pin expansion headers use the same connectors. Figure 59 is a picture of the connector. These are dual row 23 position 2.54mm x 2.54mm connectors.
The connector is mounted on the top side of the board with longer tails to allow insertion into the BeagleBone Black. Figure 60 is the connector configuration for the connector.

Figure 60. Stacked Cape Expansion Connector

For convenience listed in Table 18 are some possible choices for part numbers on this connector. They have varying pin lengths and some may be more suitable than others for your use. It should be noted, that the longer the pin and the further it is inserted into the BeagleBone Black connector, the harder it will be to remove due to the tension on 92 pins. This can be minimized by using shorter pins. There are most likely other suppliers out there that will work for this connector as well. If anyone finds other suppliers of compatible connectors that work, let us know and they will be added to this document. The first item in Table 13 is on the edge and may not be the best solution. Overhang is the amount of the pin that goes past the contact point of the connector on the BeagleBone Black.

The third part listed in Table 17 will have insertion force issues.

<table>
<thead>
<tr>
<th>SUPPLIER</th>
<th>PARTNUMBER</th>
<th>TAIL LENGTH(in)</th>
<th>OVERHANG(mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Major League</td>
<td>SSHQ-123-D-06-G-LF</td>
<td>.190</td>
<td>0.049</td>
</tr>
<tr>
<td>Major League</td>
<td>SSHQ-123-D-08-G-LF</td>
<td>.390</td>
<td>0.249</td>
</tr>
<tr>
<td>Major League</td>
<td>SSHQ-123-D-10-G-LF</td>
<td>.560</td>
<td>0.419</td>
</tr>
</tbody>
</table>

There are also different plating options on each of the connectors above. Gold plating on the contacts is the minimum requirement. If you choose to use a different part number for plating or availability purposes, make sure you do not select the “LT” option. Other possible sources are Sullins and Samtec but make sure you select one that has the correct mating depth.

8.4.3 Stacked Capes w/Signal Stealing

Figure 61 is the connector configuration for stackable capes that does not provide all of the signals upwards for use by other boards. This is useful if there is an expectation that other boards could interfere with the operation of your board by exposing those signals for expansion. This configuration consists of a combination of the stacking and non-stacking style connectors.
8.4.4 Retention Force

The length of the pins on the expansion header has a direct relationship to the amount of force that is used to remove a cape from the BeagleBone Black. The longer the pins extend into the connector the harder it is to remove. There is no rule that says that if longer pins are used, that the connector pins have to extend all the way into the mating connector on the BeagleBone Black, but this is controlled by the user and therefore is hard to control.

This section will attempt to describe the tradeoffs and things to consider when selecting a connector and its pin length.

8.4.5 BeagleBone Black Female Connectors

Figure 62 shows the key measurements used in calculating how much the pin extends past the contact point on the connector, what we call overhang.
To calculate the amount of the pin that extends past the Point of Contact, use the following formula:

\[ \text{Overhang} = \text{Total Pin Length} - \text{PCB thickness (.062)} - \text{contact point (.079)} \]

The longer the pin extends past the contact point, the more force it will take to insert and remove the board. Removal is a greater issue than the insertion.

### 8.5 Signal Usage

Based on the pin muxing capabilities of the processor, each expansion pin can be configured for different functions. When in the stacking mode, it will be up to the user to insure that any conflicts are resolved between multiple stacked cards. When stacked, the first card detected will be used to set the pin muxing of each pin. This will prevent other modes from being supported on stacked cards and may result in them being inoperative.

In Section 7.1 of this document, the functions of the pins are defined as well as the pin muxing options. Refer to this section for more information on what each pin is. To simplify things, if you use the default name as the function for each pin and use those functions, it will simplify board design and reduce conflicts with other boards.

Interoperability is up to the board suppliers and the user. This specification does not specify a fixed function on any pin and any pin can be used to the full extent of the functionality of that pin as enabled by the processor.

### 8.6 Cape Power

This section describes the power rails for the capes and their usage.

#### 8.6.1 Main Board Power

The Table 18 describes the voltages from the main board that are available on the expansion connectors and their ratings. All voltages are supplied by connector P9. The current ratings listed are per pin.

<table>
<thead>
<tr>
<th>Current</th>
<th>Name</th>
<th>P9</th>
<th>Name</th>
<th>Current</th>
</tr>
</thead>
<tbody>
<tr>
<td>250mA</td>
<td>GND</td>
<td>1</td>
<td>GND</td>
<td></td>
</tr>
<tr>
<td>1000mA</td>
<td>VDD_5V</td>
<td>5</td>
<td>VDD_5V</td>
<td>1000mA</td>
</tr>
<tr>
<td>250mA</td>
<td>SYS_5V</td>
<td>7</td>
<td>SYS_5V</td>
<td>250mA</td>
</tr>
<tr>
<td></td>
<td>GND</td>
<td>43</td>
<td>GND</td>
<td></td>
</tr>
<tr>
<td></td>
<td>GND</td>
<td>45</td>
<td>GND</td>
<td></td>
</tr>
</tbody>
</table>
The **VDD\_3V3B** rail is supplied by the LDO on the BeagleBone Black and is the primary power rail for expansion boards. If the power requirement for the capes exceeds the current rating, then locally generated voltage rail can be used. It is recommended that this rail be used to power any buffers or level translators that may be used.

**VDD\_5V** is the main power supply from the DC input jack. This voltage is not present when the board is powered via USB. The amount of current supplied by this rail is dependent upon the amount of current available. Based on the board design, this rail is limited to 1A per pin from the main board.

The **SYS\_5V** rail is the main rail for the regulators on the main board. When powered from a DC supply or USB, this rail will be 5V. The available current from this rail depends on the current available from the USB and DC external supplies.

### 8.6.2 Expansion Board External Power

A cape can have a jack or terminals to bring in whatever voltages may be needed by that board. Care should be taken not to let this voltage feedback into any of the expansion header pins.

It is possible to provide 5V to the main board from an expansion board. By supplying a 5V signal into the **VDD\_5V** rail, the main board can be supplied. This voltage must not exceed 5V. You should not supply any voltage into any other pin of the expansion connectors. Based on the board design, this rail is limited to 1A per pin to the BeagleBone Black.

### 8.7 Mechanical

This section provides the guidelines for the creation of expansion boards from a mechanical standpoint. Defined is a standard board size that is the same profile as the BeagleBone Black. It is expected that the majority of expansion boards created will be of standard size. It is possible to create boards of other sizes and in some cases this is required, as in the case of an LCD larger than the BeagleBone Black board.

#### 8.7.1 Standard Cape Size

**Figure 63** is the outline of the standard cape. The dimensions are in inches.
Figure 63. Cape Board Dimensions

A slot is provided for the Ethernet connector to stick up higher than the cape when mounted. This also acts as a key function to insure that the cape is oriented correctly. Space is also provided to allow access to the user LEDs and reset button on the main board.

Some people have inquired as to the difference in the radius of the corners of the BeagleBone Black and why they are different. This is a result of having the BeagleBone fit into the Altoids style tin.

It is not required that the cape be exactly like the BeagleBone Black board in this respect.

8.7.2 Extended Cape Size

Capes larger than the standard board size are also allowed. A good example would be an LCD panel. There is no practical limit to the sizes of these types of boards. The notch for the key is also not required, but it is up to the supplier of these boards to insure that the BeagleBone Black is not plugged in incorrectly in such a manner that damage would be cause to the BeagleBone Black or any other capes that may be installed. Any such damage will be the responsibility of the supplier of such a cape to repair.

As with all capes, the EEPROM is required and compliance with the power requirements must be adhered to.
8.7.3 Enclosures

There are numerous enclosures being created in all different sizes and styles. The mechanical design of these enclosures is not being defined by this specification.

The ability of these designs to handle all shapes and sizes of capes, especially when you consider up to four can be mounted with all sorts of interface connectors, it is difficult to define a standard enclosure that will handle all capes already made and those yet to be defined.

If cape designers want to work together and align with one enclosure and work around it that is certainly acceptable. But we will not pick winners and we will not do anything that impedes the openness of the platform and the ability of enclosure designers and cape designers to innovate and create new concepts.
9.0 BeagleBone Black Mechanical

9.1 Dimensions and Weight

- Size: 3.5” x 2.15” (86.36mm x 53.34mm)
- Max height: .187” (4.76mm)
- PCB Layers: 6
- PCB thickness: .062”
- RoHS Compliant: Yes
- Weight: 1.4 oz
9.2 Silkscreen and Component Locations

Figure 64. Board Dimensions
Figure 65. Component Side Silkscreen
Figure 66. Component Side Silkscreen
10.0 Pictures

Figure 67. Top Side
Figure 68. Bottom Side
11.0 Support Information

All support for this design is through the BeagleBoard.org community at:

beagleboard@googlegroups.com
or
http://beagleboard.org/discuss.

11.1 Hardware Design

Design information can be found on the SD card that ships with board under the documents/hardware directory when connected using the USB cable. Provided there is:

- Schematic in PDF
- Schematic in OrCAD (Cadence Design Entry CIS 16.3)
- PCB Gerber
- PCB Layout File (Allegro)
- Bill of Material
- System Reference Manual (This document).

You can also download the files from http://beagleboard.org/hardware/design or from the Circuitco WIKI at http://circuitco.com/support/index.php?title=BeagleBoneBlack

11.2 Software Updates

It is a good idea to always use the latest software. Instructions for how to update your software to the latest version can be found at:

http://circuitco.com/support/index.php?title=BeagleBoneBlack#Updating_the_eMMC_Software
11.3 RMA Support

If you feel your board is defective or has issues, request an RMA by filling out the form at http://beagleboard.org/support/rma. You will need the serial number and revision of the board as shown in the Figure 69 below.

Figure 69. Bottom Side