BeagleBone AI-64 System Reference Manual

Pre-Release

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Supply comments and errors via:

https://git.beagleboard.org/beagleboard/beaglebone-ai-64/-/issues

All information in this document is subject to change without notice.

For an up to date version of this document refer to:

https://git.beagleboard.org/beagleboard/beaglebone-ai-64/-/tree/master/doc/
SRM

For all the graphics from this document refer to:

1. SRM images[2].
2. SRM cover page[3].

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[1] mailto:lorforlinux@beagleboard.org
[2] https://www.canva.com/design/DAFBB_G9tF8/LhD-uL0-aJAEH2MPMdyLkg/edit?
utm_content=DAFBB_G9tF8&utm_campaign=designshare&utm_medium=link2&utm_source=sharebutton
[3] https://www.canva.com/design/DAFCvXa2NAQ/raxKIYZjrd0DqYF9IFMbjw/edit?
utm_content=DAFCvXa2NAQ&utm_campaign=designshare&utm_medium=link2&utm_source=sharebutton

Preface

BEAGLEBONE AI-64 DESIGN

These design materials referred to in this document are **NOT SUPPORTED** and **DO NOT** constitute a reference design. Only "community" support is allowed via resources at *BeagleBoard.org forum*[1].

THERE IS NO WARRANTY FOR THE DESIGN MATERIALS, TO THE EXTENT PERMITTED BY APPLICABLE LAW. EXCEPT WHEN OTHERWISE STATED IN WRITING THE COPYRIGHT HOLDERS AND/OR OTHER PARTIES PROVIDE THE DESIGN MATERIALS "AS IS" WITHOUT WARRANTY OF ANY KIND, EITHER EXPRESSED OR IMPLIED, INCLUDING, BUT NOT LIMITED TO, THE IMPLIED WARRANTIES OF MERCHANTABILITY AND FITNESS FOR A PARTICULAR PURPOSE. THE ENTIRE RISK AS TO THE QUALITY AND THE PERFORMANCE OF THE DESIGN MATERIALS IS WITH YOU. SHOULD THE DESIGN MATERIALS PROVE DEFECTIVE, YOU ASSUME THE COST OF ALL NECESSARY SERVICING, REPAIRING, OR CORRECTION.

This board was designed as an evaluation and development tool. It was not designed with any other application in mind. As such, the design materials that are provided which include schematic, BOM, and PCB files, may or may not be suitable for any other purposes. If used, the design material becomes your responsibility as to whether or not it meets your specific needs or your specific applications and may require changes to meet your requirements.

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Should BeagleBone not meet the specifications indicated in the System Reference Manual, BeagleBone may be returned within 90 days from the date of

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[1] https://forum.beagleboard.org/

delivery to the distributor of purchase for a full refund. THE FOREGOING LIMITED WARRANTY IS THE EXCLUSIVE WARRANTY MADE BY SELLER TO BUYER AND IS IN LIEU OF ALL OTHER WARRANTIES, EXPRESSED, IMPLIED, OR STATUTORY, INCLUDING ANY WARRANTY OF MERCHANTABILITY OR FITNESS FOR ANY PARTICULAR PURPOSE. EXCEPT TO THE EXTENT OF THE INDEMNITY SET FORTH ABOVE, NEITHER PARTY SHALL BE LIABLE TO THE OTHER FOR ANY INDIRECT, SPECIAL, INCIDENTAL, OR CONSEQUENTIAL DAMAGES.

Please read the System Reference Manual and, specifically, the Warnings and Restrictions notice in the Systems Reference Manual prior to handling the product. This notice contains important safety information about temperatures and voltages.

No license is granted under any patent right or other intellectual property right of Supplier covering or relating to any machine, process, or combination in which such Supplier products or services might be or are used. The Supplier currently deals with a variety of customers for products, and therefore our arrangement with the user is not exclusive. The Supplier assumes no liability for applications assistance, customer product design, software performance, or infringement of patents or services described herein.

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BeagleBone is annotated to comply with Part 15 of the FCC Rules. Operation is subject to the following two conditions: (1) This device may not cause harmful interference, and (2) this device must accept any interference received, including interference that may cause undesired operation. Changes or modifications not expressly approved by the party responsible for compliance could void the user's authority to operate the equipment.

This Class A or B digital apparatus complies with Canadian ICES-003. Changes or modifications not expressly approved by the party responsible for compliance could void the user's authority to operate the equipment.

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For Feasibility Evaluation Only, in Laboratory/Development Environments. BeagleBone AI-64 is not a complete product. It is intended solely for use

for preliminary feasibility evaluation in laboratory/development environments by technically qualified electronics experts who are familiar with the dangers and application risks associated with handling electrical mechanical components, systems and subsystems. It should not be used as all or part of a finished end product.

Your Sole Responsibility and Risk you acknowledge, represent, and agree that:

1. You have unique knowledge concerning Federal, State, and local regulatory requirements (including but not limited to Food and Drug Administration regulations, if applicable) which relate to your products and which relate to your use (and/or that of your employees, affiliates, contractors or designees) of BeagleBone for evaluation, testing and other purposes.

2. You have full and exclusive responsibility to assure the safety and compliance of your products with all such laws and other applicable regulatory requirements, and also to assure the safety of any activities to be conducted by you and/or your employees, affiliates, contractors or designees, using BeagleBone. Further, you are responsible to assure that any interfaces (electronic and/or mechanical) between the BeagleBone and any human body are designed with suitable isolation and means to safely limit accessible leakage currents to minimize the risk of electrical shock hazard.

3. Since BeagleBone is not a completed product, it may not meet all applicable regulatory and safety compliance standards which may normally be associated with similar items. You assume full responsibility to determine and/or assure compliance with any such standards and related certifications as may be applicable. You will employ reasonable safeguards to ensure that your use of BeagleBone will not result in any property damage, injury, or death, even if BeagleBone should fail to perform as described or expected.

Certain Instructions. It is important to operate BeagleBone AI-64 within Supplier's *recommended specifications and environmental considerations per the user guidelines. Exceeding the specified BeagleBone ratings (including but not limited to input and output voltage, current, power, and environmental ranges) may cause property damage, personal injury, or death. If there are questions concerning these ratings please contact the Supplier representative before connecting interface electronics including input power and intended loads. Any loads applied outside of the specified output range may result in unintended*

and/or inaccurate operation and/or possible permanent damage to BeagleBone and/or interface electronics. Please consult the System Reference Manual before connecting any load to BeagleBone output. If there is uncertainty as to the load specification, please contact the Supplier representative. During normal operation, some circuit components may have case temperatures greater than 60 C as long as the input and output are maintained at a normal ambient operating temperature. These components include but are not limited to linear regulators, switching transistors, pass transistors, and current sense resistors which can be identified using BeagleBone schematic located at the link in the BeagleBone System Reference Manual. When placing measurement probes near these devices during normal operation, please be aware that these devices may be very warm to the touch. As with all electronic evaluation tools, only qualified personnel knowledgeable in electronic measurement and diagnostics normally found in development environments should use the BeagleBone.

Agreement to Defend, Indemnify and Hold Harmless. You agree to defend, indemnify" *and hold the Suppliers, their licensors and their representatives harmless from and against any and all claims, damages, losses, expenses, costs and liabilities (collectively, "Claims") arising out of or in connection with any use of BeagleBone that is not in accordance with the terms of the agreement. This obligation shall apply whether Claims arise under the law of tort or contract or any other legal theory, and even if BeagleBone fails to perform as described or expected.*

Safety-Critical or Life-Critical Applications. If you intend to evaluate the components for possible" *use in safety critical applications (such as life support) where a failure of the Supplier's product would reasonably be expected to cause severe personal injury or death, such as devices which are classified as FDA Class III or similar classification, then you must specifically notify Suppliers of such intent and enter into a separate Assurance and Indemnity Agreement.*

Mailing Address:

BeagleBoard.org Foundation
4467 Ascot Ct
Oakland Twp, MI 48306 U.S.A.

WARRANTY: *BeagleBone AI-64 Assembly as purchased is warranted against defects in materials and workmanship for a period of 90 days from purchase.*

This warranty does not cover any problems occurring as a result of improper use, modifications, exposure to water, excessive voltages, abuse, or accidents. All boards will be returned via standard mail if an issue is found. If no issue is found or express return is needed, the customer will pay all shipping costs.

Before returning the board, please visit

BeagleBoard.org/support

For up to date SW images and technical information refer to https://beagleboard.org/latest-images

All support for this board is provided via community support at *BeagleBoard.org forum*[2]

To return a defective board for repair, please request an RMA at *beagleboard.org/support/rma*[3]

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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[2] https://forum.beagleboard.org/
[3] https://beagleboard.org/support/rma

Glossary

BeagleBoard.org   A Michigan,USA based 501(c)(3) non-profit corporation.

BeagleBone   Original BeagleBone

Board   BeagleBone AI-64

BeagleBone AI-64   BeagleBone AI-64

1

Introduction

This document is the **System Reference Manual** for BeagleBone AI-64 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 AI-64 / BeagleBone AI-64 as a reminder. There are also references to the BeagleBone Black as well, and it 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 frequently check the BeagleBone AI-64 git repository[1] for the most up to date support documents.

[1] https://git.beagleboard.org/beagleboard/beaglebone-ai-64/

2

Change History

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

2.1. Document Change History

<mark>Update table</mark>

Table 2.1. Change History

Rev	Changes	Date	By
A0	Preliminary	September 2021	JA
A1	Production release	December 2021	JA

2.2. Board Changes

Check the revision history in BeagleBone Ai-64 schematic file[1]. Also check the issues[2] list in BeagleBone AI-64 git repository.

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[1] https://git.beagleboard.org/beagleboard/beaglebone-ai-64/-/blob/master/BeagleBone%20AI%20-64_SCH_V1.02_211119.pdf
[2] https://git.beagleboard.org/beagleboard/beaglebone-ai-64/-/issues

2.2.1. Rev B0

We are starting with revision B based on this being an update to the original BeagleBone AI. However, because this board ended up being so different, we've decided to name it BeagleBone AI-64, rather than simply a new revision.

This is the initial engineering prototype release of the board. We will be tracking changes from this point forward.

Known issues

- USB SuperSpeed cannot function

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Connecting up your BeagleBone AI-64

This section provides instructions on how to hook up your board. This beagle requires a 5V ≥ 3A power supply to work properly via either USB Type-C power adapter or a barrel jack power adapter.

Recommended adapters:

- 5V @ 3A USB C power supply[1] adaptor for SBCs.
- 5V ≥ 3A laptop/mobile adaptor with USB-C cable.

All the BeagleBone AI-64 conections ports we will use in this chapter are shown in the figure below.

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[1] https://www.digikey.com/en/products/detail/raspberry-pi/RPI-USB-C-power-supply-White-US/10258760
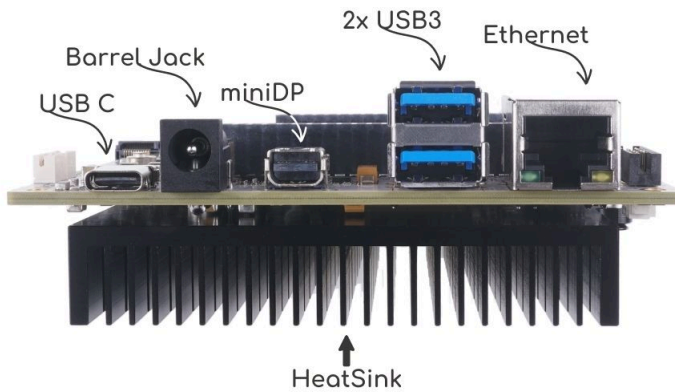
Figure 3.1. BeagleBone AI-64 conections ports.

3.1. 3.0.1 Methods of operation

1. Tethered to a PC, or
2. As a standalone development platform in a desktop PC configuration with a Display Port Monitor, power supply, keyboard, and mouse

3.2. What's In the Box

In the box you will find three main items as shown in BeagleBone AI-64 box image.

- BeagleBone AI-64.
- Instruction card.

Get yourself a USB-A to USB-C and you have a setup for the tethered scenario and creates an out of box experience where the board can be used immediately with no other equipment needed.

Figure 3.2. BeagleBone AI-64 box content

3.3. 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 referred to. 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 and

  - a virtual Ethernet connection.

- Standalone desktop

  - Display

  - Keyboard and mouse

  - External 5V ≥ 3A power supply

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

3.4. 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, Internet Explorer will not work properly. Tethered Configuration figure shows this configuration.
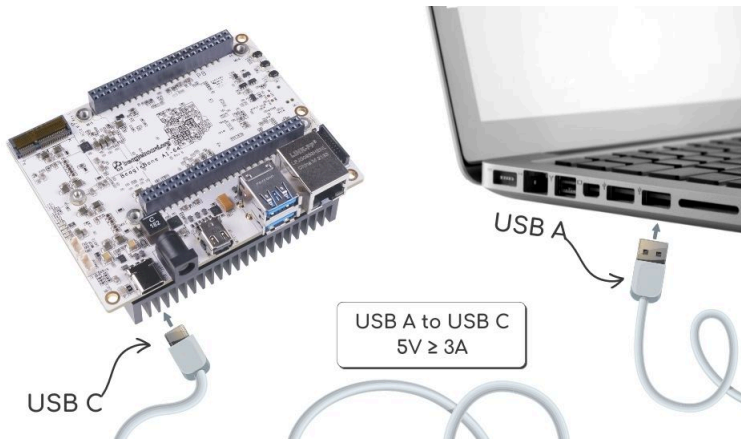

Figure 3.3. Tethered Configuration

At least 5V @ 3A is required to power the board, In most cases the PC may not be able to supply sufficient power for the board. You should always use an external 5V ≥ 3A DC power supply connected to the barrel jack.

3.4.1. Connect the Cable to the Board

1. Connect the type C USB cable to the board as shown in USB Connection to the Board figure. The connector is on the top side of the board near barrel jack.
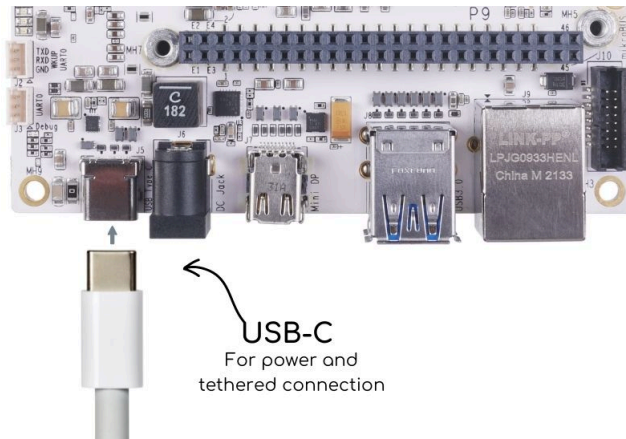
Figure 3.4. USB Connection to the Board

2. Connect the USB-A end of thecable tp your PC or laptop USB port as shown in the USB Connection to the PC/Laptop figure below.

Figure 3.5. USB Connection to the PC/Laptop

3. The board will power on and the power LED will be on as shown in Board Power LED figure below.
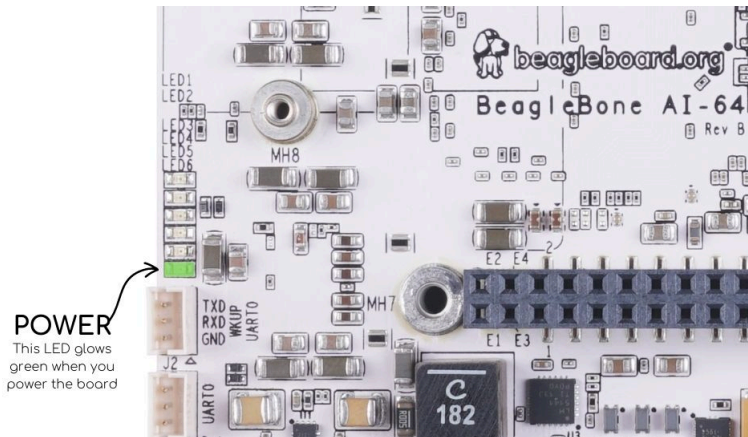
Figure 3.6. Board Power LED

4. When the board starts to the booting process started by the process of applying power, the LEDs will come on in sequence as shown in Board Boot Status figure 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 begins to boot the Linux kernel.
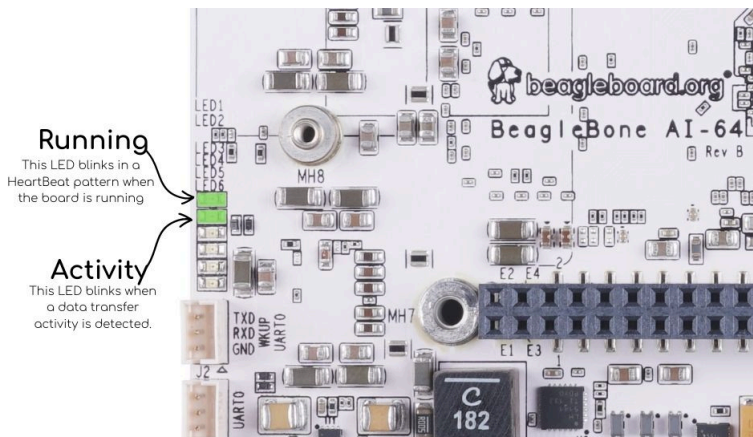

Figure 3.7. Board Boot Status

3.4.2. 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.htm**

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.

3.5. 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 Desktop Configuration figure. 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.
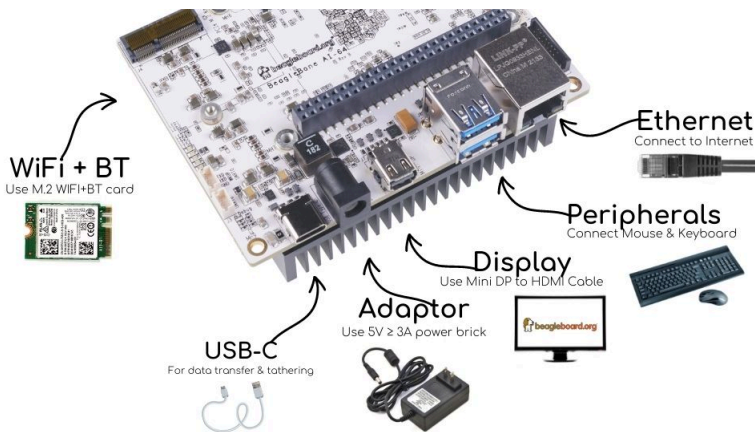

Figure 3.8. Desktop Configuration

Ethernet cable and M.2 WiFi + Bluetooth card are optional. They can be used if network access required.

3.5.1. Required Accessories

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

- 5VDC ≥ 3A power supply.

- Display Port or HDMI monitor.

- miniDP-DP or active miniDP-HDMI cable (or a recommended **miniDP-DP or active miniDP-HDMI adapter** https://www.amazon.com/dp/B089GF8M87 has been tested and worked beautifully.).

- USB wired/wireless keyboard and mouse.

- powered USB HUB (OPTIONAL). The board has only two USB Type-A host ports, so you may need to use a powered USB Hub if you wish to add additional USB devices, such as a USB WiFi adapter.

- M.2 Bluetooth & WiFi module (OPTIONAL). For wireless connections, a USB WiFi adapter or a recommended M.2 WiFi module can provide wireless networking.

3.5.2. Connecting Up the Board

1. Connect the miniDP to DP or active miniDP to HDMI cable from your BeagleBone AI-64 to your monitor.
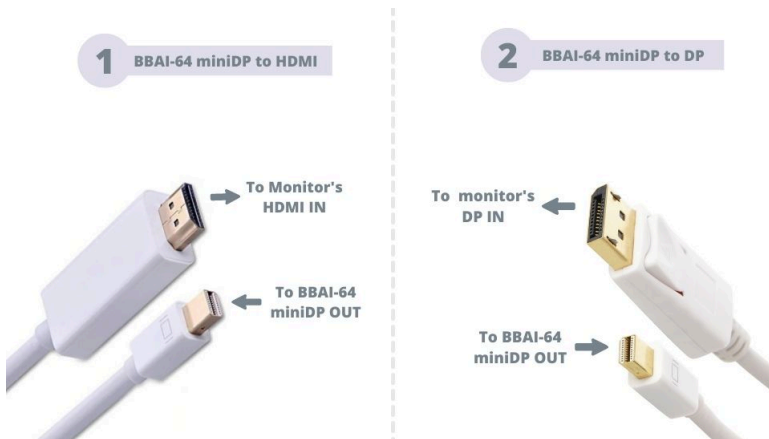

Figure 3.9. Connect miniDP-DP or active miniDP-HDMI cable to BeagleBone AI-64

2. If you have an Display Port or HDMI monitor with HDMI-HDMI or DP-DP cable you can use adapters as shown in. Display adaptors figure.
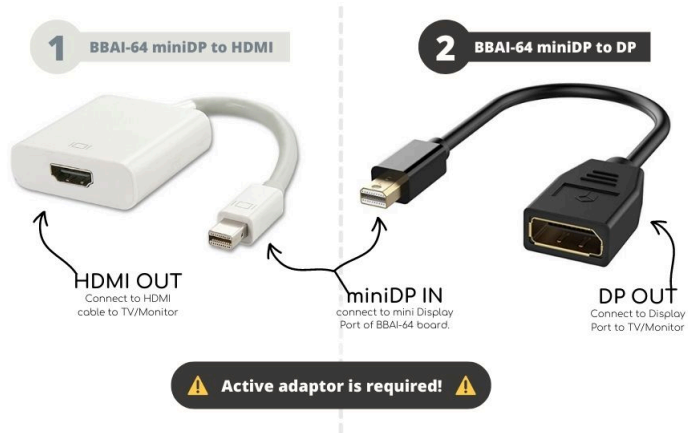
Figure 3.10. Display adaptors

3. If you have wired/wireless USB keyboard and mouse such as

    seen in Keyboard and Mouse figure below, you need to plug the receiver in the USB host port of the board as shown in Keyboard and Mouse figure.
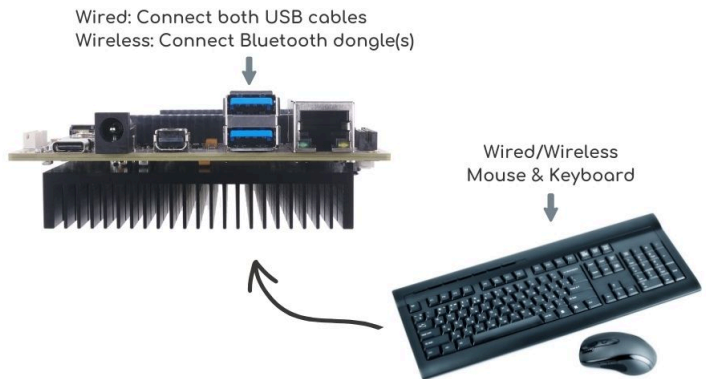
Figure 3.11. Keyboard and Mouse

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 <<ethernet-cable-figure>. Any standard 100M Ethernet cable should work.
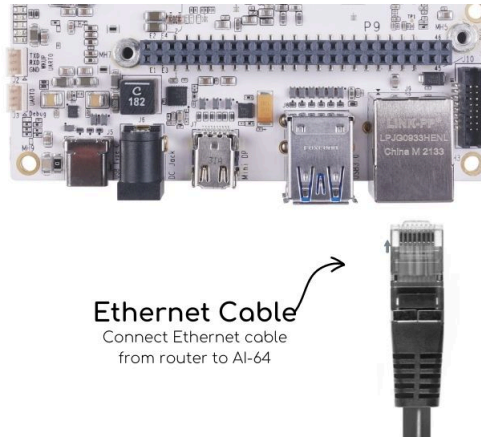
Figure 3.12. Ethernet Cable Connection

5. The final step is to plug in the DC power supply to the DC power jack as shown in External DC Power figure below.
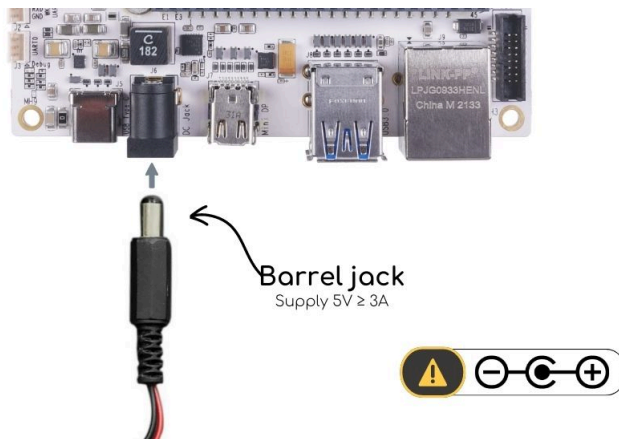
Figure 3.13. External DC Power

6. The cable needed to connect to your display is a miniDP-DP or active miniDP-HDMI. Connect the miniDP connector end to the board at this time. The connector is on the top side of the board as shown in miniDP to DP or active miniDP to HDMI connection figure below.
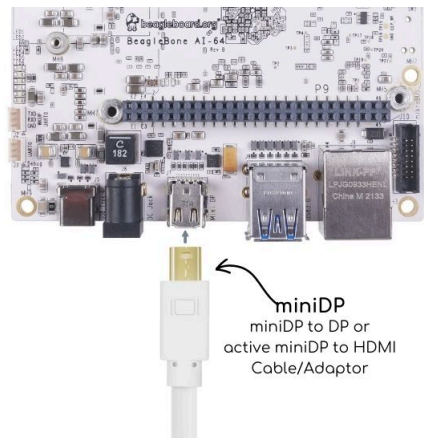
Figure 3.14. Connect miniDP to DP or active miniDP to HDMI Cable to the Board

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. 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.
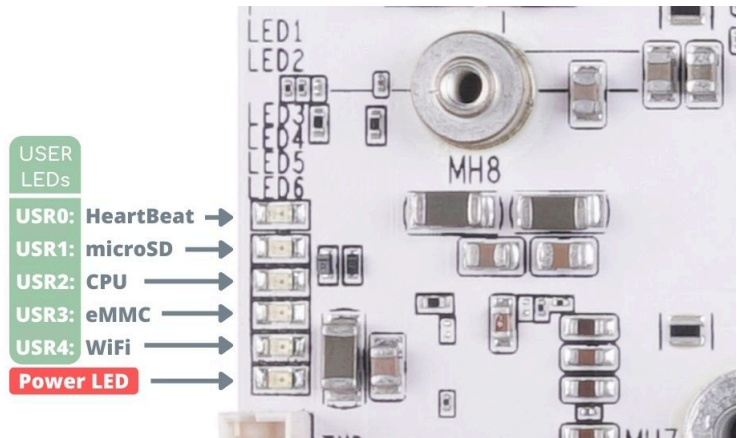
Figure 3.15. BeagleBone AI-64 LEDs

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

- **USR0** is the heartbeat indicator from the Linux kernel.
- **USR1** turns on when the microSD card is being accessed
- **USR2** is an activity indicator. It turns on when the kernel is not in the idle loop.
- **USR3** turns on when the onboard eMMC is being accessed.
- **USR4** is an activity indicator for WiFi.

8. A Booted System

   a. 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 monitor in a sleep mode.

   b. After a minute or two a login screen will appear. You do not have to do anything at this point.

   c. 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.

   d. And at this point you are ready to go! Figure 16 shows the desktop after booting.

Figure 3.16. BeagleBone XFCE Desktop Screen

4

BeagleBone AI-64 Overview
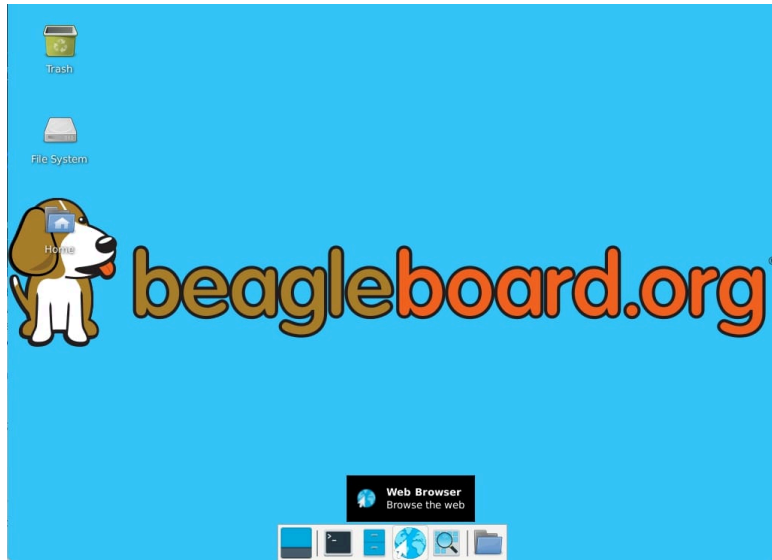
BeagleBone AI-64 is the latest addition to BeagleBoard.org family and like its predecessors, is designed to address the open-source Community, early adopters, and anyone interested in a low cost 64-bit Dual Arm® Cortex®-A72 processor based Single Board Computer (SBC).

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 BeagleBone AI-64 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 AI-64 is manufactured and warranted by partners listed at https://beagleboard.org/logo for the benefit of the community and its supporters including the current BeagleBoard.org Foundation board members

- Jason Kridner, principal of JK Embedded Consulting an independent contractor and architect for new Beagle designs.
- Drew Fustini, independent Linux developer
- Robert Nelson, applications engineer at Digi-Key
- Mark Yoder, professor at Rose-Hulman Institute of Technology

- Kathy Giori, product engineer at ZEDEDA

See bbb.io/about

BeagleBone AI-64 board is designed designed by Seeed Studio (Seeed Development Limited) under guidance from BeagleBoard.org Foundation.

4.1. BeagleBone Compatibility

The board is intended to be compatible with BeagleBone black expansion header 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.

- J721E DRA829/TDA4VM/AM752x, 2GHZ, 64 Bit, multicore processor.
- 4GB LPDDR4
- Debug TTL serial.
- EEPROM Reduced from 4KB to 1KB
- Onboard Managed NAND (16GB eMMC)
- There may be 10 less GPIO pins available
- Mini Display Port (miniDP) interface onboard
- Dual USB-3 ports.

4.2. BeagleBone AI-64 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.

	Feature
Processor	TI J721E DRA829/TDA4VM/AM752x
Graphics Engine	PowerVR® Series8XE GE8430
SDRAM Memory	LPDDR4 (4GB) Q3222PM1WDGTK-U
Onboard Flash	eMMC (16GB) EMMC16G-TB29-PZ90
PMIC	TPS65941213 and TPS65941111 PMICs regulator and one additional LDO.

	Feature
Debug Support	3 pin Serial Header
Power Source	USB C or DC Jack
PCB	This beagle is not the standard 3.4" x 2.1", It's grown in size to 4" x 3.1"
Indicators	1-Power, 5-User Controllable LEDs
HS USB-3.0 Client Port	Access to USB0, Client mode via USB-C
HS USB-3.0 Host Port	Access to USB1 & USB2, Type A Socket, 1.5A
Serial Port	1. WKUP_UART0: Wake-up domain serial port 2. UART0: Main domain serial port Access via 3 pin 3.3V TTL micro header.
Ethernet	Gigabit, RJ45
SD/MMC Connector	microSD , 1.8/3.3V
User Input	1. Reset Button 2. Boot Button 3. Power Button
Video Out	miniDP
Audio	via miniDP Interface, Stereo
Weight	192gm (with heatsink)
Power	Refer to ??? section

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. Board components

BeagleBone AI-64 board components figure below shows the locations of the connectors, LEDs, and switches on the PCB layout of the board.
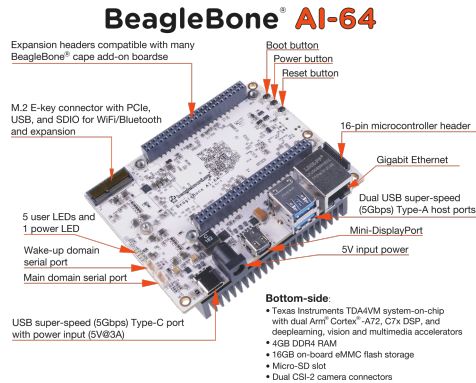

Figure 4.1. BeagleBone AI-64 board components

- **DC Power** is the main DC input that accepts 5V power.

- **Power Button** alerts the processor to initiate the power down sequence and is used to power down the board.

- **GigaBit Ethernet** is the connection to the LAN.

- **Serial Debug ports** WKUP_UART0 for early boot from the management MCU and UART0 is for the main processor.

- **USB Client** is a USB-C connection to a PC that can also power the board.

- **BOOT switch** can be used to force a boot from the microSD card if the power is cycled on the board, removing power and reapplying the power to the board..

- There are five green **LEDs** that can be used by the user.

- **Reset Button** allows the user to reset the processor.

- **microSD** slot is where a microSD card can be installed.

- **miniDP** connector is where the display is connected to.

- **USB Host** can be connected different USB interfaces such as Wi-Fi, BT, Keyboard, etc.

On bottom side we have,

- **TI J721E DRA829/TDA4VM/AM752x** processor.

- **4GB LPDDR4L** Dual Data Rate RAM memory.

- **Ethernet PHY** physical interface to the network.

- **eMMC** onboard MMC chip that holds up to 16GB of data.

- **miniDP** Framer provides control for a DP/HDMI display with an adapter.

5

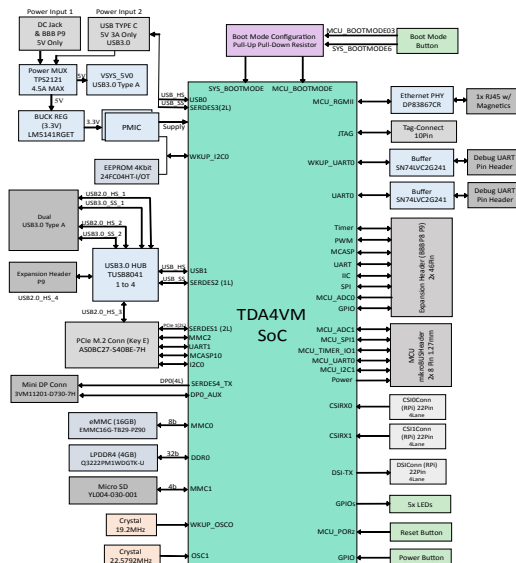# BeagleBone AI-64 High Level Specification

BeagleBone AI-64 Key Components figure below shows the high level block diagram of BeagleBone AI-64 board surrounding TDA4VM SoC.

Figure 5.1. BeagleBone AI-64 Key Components

5.1. Processor

BeagleBone AI-64 uses TI J721E DRA829[1]/ TDA4VM[2] whoch is part of the K3 Multicore SoC architecture platform and it is targeted for the reliability and low-latency needs of the automotive market provide for a great general purpose platform suitable for industrial automation, mobile robotics, building automation and numerous hobby projects.

The SoC designed as a low power, high performance and highly integrated device architecture, adding significant enhancement on processing power, graphics capability, video and imaging processing, virtualization and coherent memory support. In addition, these SoCs support state of the art security and functional safety features. For the remaining of this section device, SoC, and processor will be used interchangeably.

Some of the main distinguished characteristics of the device are:

- 64-bit architecture with virtualization and coherent memory support, which leverages full processing capability of 64-bit Arm® Cortex®-A72

- Fully programmable industrial communication subsystems to enable future-proof designs for customers that need to adopt the new Gigabit Time-sensitive Networks (TSN) standards, but still need full support on legacy protocols and continuous system optimization over the product deployment

- Integration of vision hardware processing accelerators to facilitate extensive processing requirements in low power budget for automotive ADAS and machine vision applications

- Integration of a general-purpose microcontroller unit (MCU) with a dual Arm® Cortex®-R5F MCU subsystem, available for general purpose use as two cores or in lockstep, intended to help customers achieve functional safety goals for their end products

- Integration of a next-generation fixed and floating-point C71x Digital Signal Processor (DSP) that significantly boosts power over a broad range of general signal processing tasks for both general applications and automotive functions which also incorporates advanced techniques to improve control

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[1] https://www.ti.com/product/DRA829V
[2] https://www.ti.com/product/TDA4VM

code efficiency and ease of programming such as branch prediction, protected pipeline, precise exception and virtual memory management

- Tightly coupled Matrix Multiplication Accelerator (MMA) that extends the C71x DSP architecture's scalar and vector facilities enabling deep learning and enhance vision, analytics and wide range of general applications. The achieved total TOPS (Tera Operations Per Second) performance significantly differentiates the device for single board computer in machine vision and deep learning applications

- Key display features including flexibility to interface with different panel types (eDP, DSI, DPI) with multi-layer hardware composition

- Integration of hardware features that help applications to achieve functional safety mechanisms

- Robust security architecture with sandboxed DMSC controller managing all secure configurations with high performance client-server messaging scheme between secure DMSC and all cores

- Simplified solution for power supply management, enabling lower cost system solution (on-die bias LDOs and power good comparators for minimal power sequencing requirements consistent with low cost supply design)

The device is composed of the following main subsystems, across different domains of the SoC, among others:

- One dual-core 64-bit Arm Cortex-A72 microprocessor subsystem at up to 2.0 GHz and up to 24K DMIPS (Dhrystone Million Instructions per Second)

- Up to three Microcontroller Units (MCU), based on dual-core Arm Cortex-R5F processor running at up to 1.0 GHz, up to 12K DMIPS

- Up to two TMS320C66x DSP CorePac modules running at up to 1.35 GHz, up to 40 GFLOPS

- One C71x floating point, vector DSP running at up to up to 1.0 GHz, up to 80 GFLOPS

- One deep-learning MMA, up to 8 TOPS (8b) at 1.0 GHz

- Up to two gigabit dual-core Programmable Real-Time Unit and Industrial Communication Subsystems (PRU_ICSSG)

- Two Navigator Subsystems (NAVSS) for data movement and control

- One multi-pipeline Display Subsystem (DSS) with one MIPI® Display Serial Interface Controller (DSI) and shared MIPI D-PHY Transmitter (DPHY_TX), one Embedded DisplayPort Transmitter (EDP) with shared Serializer/Deserializer (SERDES), and two MIPI Display Pixel Interface (DPI) ports

- Two Camera Streaming Interface Receivers (CSI_RX_IF) with dedicated MIPI D-PHYs (DPHY_RX)

- One Camera Streaming Interface Transmitter (CSI_TX_IF) with MIPI D-PHY Transmitter (DPHY_TX) shared with DSI

- One Vision Processing Accelerator (VPAC) with image signal processor

- One Depth and Motion Processing Accelerator (DMPAC)

- One dual-core multi-standard HD Video Decoder (DECODER)

- One dual-core multi-standard HD Video Encoder (ENCODER)

- One Graphics Processing Unit (GPU)

- One Device Management and Security Controller (DMSC)

The device provides a rich set of peripherals such as:

- General connectivity peripherals, including:

  ○ Two 12-bit general purpose Analog-to-Digital Converters (ADC)

  ○ Ten Inter-Integrated Circuit (I2C) interfaces

  ○ Three Improved Inter-Integrated Circuit (I3C) controllers

  ○ Eleven master/slave Multichannel Serial Peripheral Interfaces (MCSPI)

  ○ Twelve configurable Universal Asynchronous Receiver/Transmitter (UART) interfaces

  ○ Ten General-Purpose Input/Output (GPIO) modules

- High-speed interfaces, including:

  ○ Two Gigabit Ethernet Switch (CPSW) modules

  ○ Two Dual-Role-Device (DRD) Universal Serial Bus Subsystems (USBSS) with integrated PHY

  ○ Four Peripheral Component Interconnect express (PCIe) Gen3 subsystems

- Flash memory interfaces, including:

  - One Octal SPI (OSPI) interface and one Quad SPI (QSPI) or one QSPI and one HyperBus^{TM}

  - One General Purpose Memory Controller (GPMC) with Error Location Module (ELM) and 8- or 16- bit-wide data bus width (supports parallel NOR or NAND FLASH devices)

  - Three Multimedia Card/Secure Digital (MMCSD) controllers

  - One Universal Flash Storage (UFS) interface

- Industrial and control interfaces, including:

  - Sixteen Controller Area Network (MCAN) interfaces with flexible data rate support

  - Three Enhanced Capture (ECAP) modules

  - Six Enhanced Pulse-Width Modulation (EPWM) subsystems

  - Three Enhanced Quadrature Encoder Pulse (EQEP) modules

- Audio peripherals, including:

  - One Audio Tracking Logic (ATL)

  - Twelve Multichannel Audio Serial Port (MCASP) modules supporting up to 16 channels with independent TX/RX clock/sync domain

- One Video Processing Front End (VPFE) interface module

The device also integrates:

- Power distribution, reset controls and clock management components

- Power-management techniques for device power consumption minimization:

  - Adaptive Voltage Scaling (AVS)

  - Dynamic Frequency Scaling (DFS)

  - Gated clocks

  - Multiple voltage domains

  - Independently controlled power domains for major modules

  - Voltage and Temperature Management (VTM) module

- ◦ Power-on Reset Generators (PRG)

- ◦ Power Sleep Controllers (PSC)

- Optimized interconnect (CBASS) architecture to enable latency-critical real time network and IO applications

- Control modules (CTRL_MMRs) mainly associated with device top-level configurations such as:

  - ◦ IO Pad and pin multiplexing configuration

  - ◦ PLL control and associated High-Speed Dividers (HSDIV)

  - ◦ Clock selection

  - ◦ Analog function controls

- Multicore Shared Memory Controller (MSMC)

- DDR Subsystem (DDRSS) with Error Correcting Code (ECC), supporting LPDDR4

- 1KB RAM with ECC support for C71x boot vectors

- 2KB RAM with ECC support for A72 and R5F boot vectors

- 512KB On-Chip SRAM protected by ECC

- One Global Time Counter (GTC) module

- Thirty 32-bit counter timers with compare and capture modes

- Debug and trace capabilities

The device includes different modules for functional safety requirements support:

- MCU island with dual lock step Arm Cortex-R5F

- Safety enabled interconnect with implemented features to help with Freedom From Interference (FFI)

- Twelve Real Time Interrupt (RTI) modules with Windowed Watchdog Timer (WWDT) functionality to monitor processor cores

- Sixteen Dual-Clock Comparators (DCC) to monitor clocking sources during run-time

- Three Error Signaling Modules (ESM) to enable error monitoring

- Temperature monitoring sensors

- ECC on all critical memories

- Dedicated hardware Memory Cyclic Redundancy Check (MCRC) blocks

The device supports the following main security functionalities among others:

- Secure Boot Management

- Public Key Accelerator (PKA) for large vector math operation

- Cryptographic acceleration (AES, 3DES, MD5, SHA1, SHA2-224, 256, 512 operation)

- Trusted Execution Environment (TEE)

- Secure storage support

- On-the-fly encryption and authentication support for OSPI interface

The device is partitioned into three functional domains as shown in Device Top-level Block Diagram, each containing specific processing cores and peripherals:

- Wake-up (WKUP) domain

- Microcontroller (MCU) domain with one of the dual Cortex-R5 cluster

- MAIN domain

Figure 5.2. Device Top-level Block Diagram

5.2. Memory

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

5.2.1. 4GB LPDDR4

A single (1024M x 16bits x 2channels) LPDDR4 4Gb memory device is used. The memory used is is:

• Q3222PM1WDGTK-U

5.2.2. 4Kb EEPROM

A single 4Kb EEPROM (24FC04HT-I/OT) is provided on I2C0 that holds the board information. This information includes board name, serial number, and revision information.

5.2.3. 16GB Embedded MMC

A single 16GB 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, the SD card slot, for booting from the SD card as a result of removing and reapplying the power to the board. Simply pressing the reset button will not change the boot mode. 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.

5.2.4. 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 microSD cards. The microSD 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.

5.2.5. Boot Modes

As mentioned earlier, there are two 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 microSD card or an microSD card writer.
- **SD Boot…**This mode will boot from the microSD 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.

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 a removal and reapplication of power without a microSD 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 try to boot from the eMMC. If it is empty, then it will try booting from the microSD slot, followed by the serial port, and then the USB port.
- If you hold the boot switch down during the removal and reapplication of power to the board, and you have a microSD card inserted with a bootable image, the board will boot from the microSD card.

NOTE: Pressing the RESET button on the board will NOT result in a change of the boot mode. You MUST remove power and reapply power to change the boot mode. The boot pins are sampled during power on reset from the PMIC to the processor. The reset button on the board is a warm reset only and will not force a boot mode change.

5.3. Power Management

The **TPS65941213 and TPS65941111** power management device is used along with a separate LDO to provide power to the system. The**TPS65941213 and**

TPS65941111 version provides for the proper voltages required for the LPDDR4. 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 **TPS65941213 and TPS65941111** to support the new voltages.

5.4. PC USB Interface

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

5.5. Serial Debug Ports

Two serial debug ports are provided on board via 3pin micro headers,

1. WKUP_UART0: Wake-up domain serial port
2. UART0: Main domain serial port

In order to use the interfaces a 3pin micro to 6pin dupont adaptor header[3] is required with a 6 pin USB to TTL adapter. The header is compatible with the one provided by FTDI and canbe purchased for about 12 to 20 from various sources. Signals supported are TX and RX. None of the handshake signals are supported.

5.6. 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 1.5A of current at 5V. Under USB power, the board will not be able to supply the full 1.5A, but should be sufficient to supply enough current for a lower power USB device supplying power between 50 to 100mA.

5.7. Power Sources

The board can be powered from two different sources:

• A 5V ≥ 3A power supply plugged into the barrel jack.
• A wall adaptor with 5V ≥ 3A output power.

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[3] https://uk.farnell.com/element14/1103004000156/beaglebone-ai-serials-cable/dp/3291081

The power supply is not provided with the board but can be easily obtained from numerous sources. A 5V ≥ 3A supply is mandatory to have with 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.

5.8. Reset Button

When pressed and released, causes a reset of the board.

5.9. Power Button

This button takes advantage of the input to the PMIC for power down features.

5.10. Indicators

There are a total of six green LEDs on the board.

- One green power LED indicates that power is applied and the power management IC is up.
- Five blue LEDs that can be controlled via the SW by setting GPIO pins.

6

BeagleBone AI-64 Mechanical

6.1. Dimensions and Weight

Size: 102.5 x 80 (4" x 3.15")

Max height: <mark>TODO</mark>

PCB Layers: <mark>TODO</mark>

PCB thickness: 2mm (0.08")

RoHS Compliant: Yes
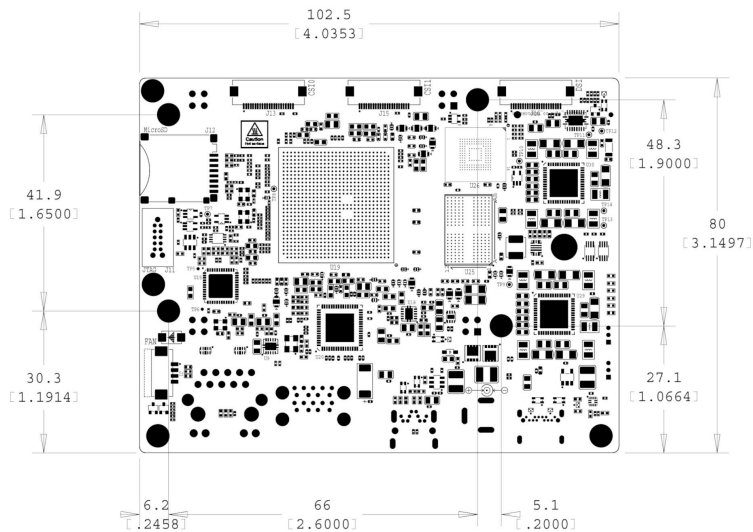
Weight: 192gm

6.2. Silkscreen and Component Locations
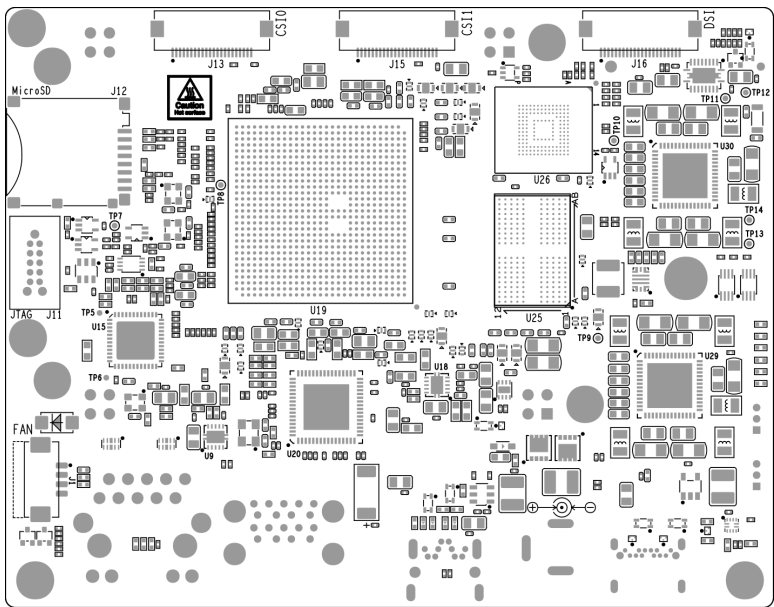

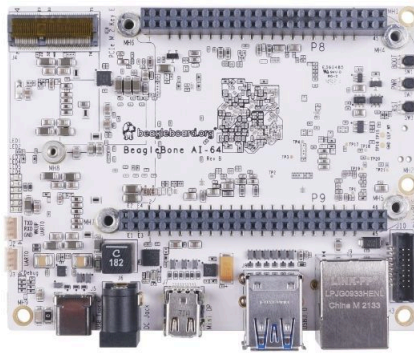**Figure 6.1. Board Dimensions**

Figure 6.2. Top silkscreen

Figure 6.3. Bottom silkscreen

7

Pictures

Figure 7.1. BeagleBone AI-64 front
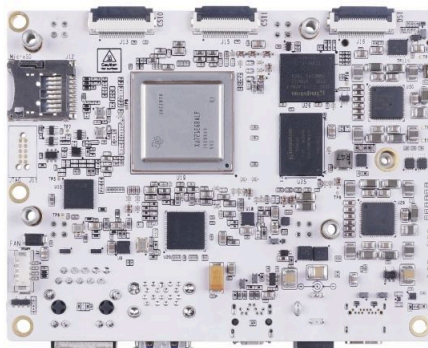
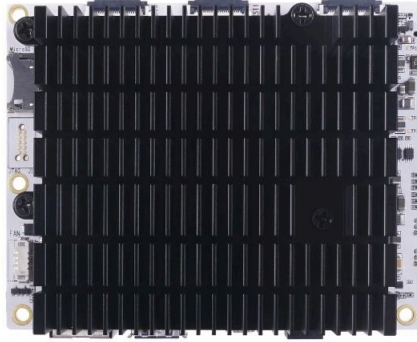**Figure 7.2. BeagleBone AI-64 back**

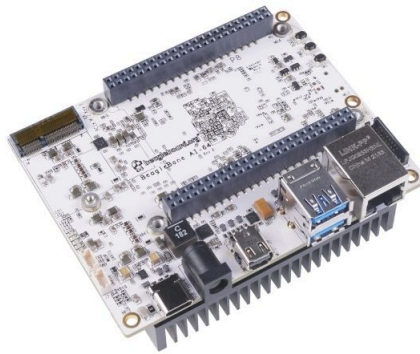**Figure 7.3. BeagleBone AI-64 back with heatsink**

Figure 7.4. BeagleBone AI-64 front at 45° angle

Figure 7.5. BeagleBone AI-64 back at 45° angle

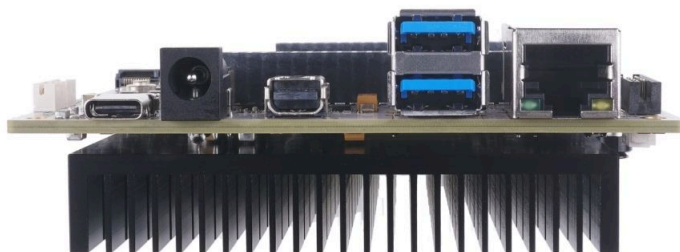**Figure 7.6. BeagleBone AI-64 back with heatsink at 45° angle**

Figure 7.7. BeagleBone AI-64 ports

8

Support Information

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

BeagleBoard.org fourm[1].

8.1. Hardware Design

You can find all BeagleBone AI-64 hardware files here[2].

8.2. Software Updates

You can download and flash the supported image onto your BeagleBone AI-64 from this[3] source.

To see what SW revision is loaded into the eMMC check `/etc/dogtag`. It should look something like as shown below,

```
root@BeagleBone:~# cat /etc/dogtag
BeagleBoard.org Debian Bullseye Xfce Image 2022-01-14
```

8.3. RMA Support

If you feel your board is defective or has issues, request an Return Merchandise Application (RMA) by filling out the form at http://beagleboard.org/support/rma .

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[1] https://forum.beagleboard.org/
[2] https://git.beagleboard.org/beagleboard/beaglebone-ai-64/-/tree/master/hw
[3] https://debian.beagle.cc/images/bbai64-emmc-flasher-debian-11.2-xfce-arm64-2022-01-14-8gb.img.xz

You will need the serial number and revision of the board. The serial numbers and revisions keep moving. Different boards can have different locations depending on when they were made. The following figures show the three locations of the serial and revision number.

8.4. Troubleshooting video output issues

Only use miniDP-DP or active miniDP-HDMI adaptor with BeagleBone AI-64 miniDP output port as shown in Display adaptors figure.

8.4.1. Getting Help

If you need some up to date troubleshooting techniques, you can post your queries on BeagleBoard.org fourm[4] .

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[4] https://forum.beagleboard.org/

Bibliography

Datasheets

TDA4VM Jacinto™ Processors for ADAS and Autonomous Vehicles Silicon Revisions 1.0 and 1.1 datasheet (Rev. J)[1]

DRA829/TDA4VM Technical Reference Manual (Rev. C)[2]

Books

BeagleBone Cookbook[3]

Bad to the Bone[4]

Exploring BeagleBone[5]

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[1] https://www.ti.com/lit/ds/symlink/tda4vm.pdf
[2] https://www.ti.com/lit/zip/spruil1
[3] https://beagleboard.org/cookbook
[4] https://beagleboard.org/bad-to-the-bone
[5] http://derekmolloy.ie/exploring-beaglebone-tools-and-techniques-for-building-with-embedded-linux/

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