**TI Designs**

**BeagleBone Cape for Programmable Logic Controller (PLC) Input/Output Module**

---

**TI Designs**

TI Designs provide the foundation that you need including methodology, testing, and design files to quickly evaluate and customize the system. TI Designs help you accelerate your time to market.

**Design Resources**

- **TIDA-00312** Tool Folder Containing Design Files
- **TIDA-00236** Tool Folder Containing Design Files
- **LMZ14201** Product Folder
- **TPS70933** Product Folder
- **TPS70918** Product Folder

---

**Design Features**

- Connects Input and Output (I/O) Daughter Cards to BeagleBone Board
- BeagleBone Board Auto-Detects the I/O Daughter Card and Loads the Appropriate Software Driver
- SPI and I/O Daughter Card Power Terminates on Terminal Block for Connection to Any Other Application Specific Integrated Circuit, MCU, or FPGA
- Web Server-Based Graphical User Interface (GUI) Running on the BeagleBone Board
- Application Programming Interfaces (APIs) Allow Development, Custom Test Functions, and Applications on BeagleBone Using Web Server
- DC Input Supply: 18- to 32-V Power Supply

**Featured Applications**

- PLC, Data Communications System (DCS), and Programmable Automated Controllers (PAC)
- Industrial Process Control and Automation
- Test and Measurement

---

An IMPORTANT NOTICE at the end of this TI reference design addresses authorized use, intellectual property matters and other important disclaimers and information.

---

All trademarks are the property of their respective owners.
1 System Description

The BeagleBone Black (BBB) Cape for the PLC I/O module is a platform for evaluation of the PLC I/O reference designs. The platform showcases TI's system solution that can be used in a PLC signal chain and allows evaluation of the signal chain performance. The Cape connects the PLC I/O reference design daughter card to the BBB board. The BBB board runs the evaluation software for the I/O card and a web server, allowing the user to view the performance from a PC.

The highlight of this design is the simple hardware and minimal software installation requirements on the PC for evaluation. TI's PLC I/O module reference designs have a complete signal chain for the PLC I/O modules. Evaluating the signal chain requires examination of the critical performance parameters of the hardware. Data collection, processing, and display are the typical functions required for evaluation. The easy-to-use GUI accelerates the performance of the I/O module evaluation process and reduces time to market.

The design files include the schematics, BOM, layer plots, Altium files, Gerber files, and an easy-to-use GUI.

2 Design Specifications

The following list highlights the design specifications of the I/O controller:

- The BeagleBone Black Cape
- A smart I/O interface to plug in TI's PLC I/O module reference design daughter cards
- A DC input supply: 18 V to 32 V
- Light-emitting diodes (LEDs) for the purposes of debugging or indication
Figure 1. PLC I/O Interface Cape Block Diagram
4 Theory of Operation

The BBB Cape for the PLC I/O module provides a convenient platform to test and evaluate smart I/O modules targeted for the PLC system. The cape platform allows functional and parametric signal-chain performance evaluation. The cape consists of a BBB interface, a complex programmable logic device (CPLD), a power supply unit, and a smart I/O module interface.

The BBB performs the primary functions like scanning data, running control sequences, and communication activities. The cape has an on-board power supply unit that converts the 24-V DC input power supply to the required output voltages. The power supply unit generates the 3.3 V required by a CPLD, the 5 V of DC required for a BBB, and the 24 V required for a smart I/O module.

The cape has a 50-pin interface connector where various smart I/O modules can be connected. The smart I/O interface has a dedicated serial peripheral interface (SPI) and I\(^2\)C to communicate with devices on the smart I/O module. These pluggable I/O modules are typically analog and digital, input and output modules, or a combination of both. The evaluation platform runs a webserver on the BBB for the performance evaluation of the I/O module, which can be accessed from a PC (through the Ethernet interface).

For more information on each of these devices, see the respective product folders at www.TI.com.

4.1 CPLD

![Figure 2. CPLD Interface](image-url)
The cape board is a simple glue logic that connects the BBB and the smart I/O reference design daughter card. The glue logic is mostly implemented in a CPLD. Figure 3 shows the CPLD interface. The CPLD allows the use of an elastic buffer in the SPI, which can compensate for the round-trip delays due to the digital isolators.

### Table 1. Pin Assignment for BBB and Smart I/O Interface

<table>
<thead>
<tr>
<th>BBB</th>
<th>Smart I/O</th>
<th>BBB Direction</th>
</tr>
</thead>
<tbody>
<tr>
<td>SPI1_D0</td>
<td>MISO</td>
<td>In</td>
</tr>
<tr>
<td>SPI1_D1</td>
<td>MOSI</td>
<td>Out</td>
</tr>
<tr>
<td>SPI1_CS0</td>
<td>CS0</td>
<td>Out</td>
</tr>
<tr>
<td>SPI1_SCLK</td>
<td>SCLK</td>
<td>Out</td>
</tr>
<tr>
<td>I2C2_SCL</td>
<td>EVM_ID_SCL</td>
<td>Bidirectional</td>
</tr>
<tr>
<td>I2C2_SDA</td>
<td>EVM_ID_SDA</td>
<td>Bidirectional</td>
</tr>
<tr>
<td>GPIO1_16</td>
<td>EVM_GPIO0</td>
<td>Out</td>
</tr>
<tr>
<td>GPIO1_17</td>
<td>EVM_GPIO1</td>
<td>Out</td>
</tr>
<tr>
<td>GPIO3_21</td>
<td>EVM_GPIO2</td>
<td>Out</td>
</tr>
<tr>
<td>GPIO0_7</td>
<td>EVM_GPIO3</td>
<td>In-Out</td>
</tr>
<tr>
<td>GPIO1_28</td>
<td>SDRDY</td>
<td>In</td>
</tr>
</tbody>
</table>

#### 4.1.1 Smart I/O Interface

![Figure 3. Smart I/O-BBB Interface](image)
TI Designs also provides the reference design for pluggable smart I/O modules, like:
- TIDA-00119: A 12-bit analog input module for PLCs
- TIDA-00118: A 16-bit analog output module for PLCs
- TIDA-00236: A low-side, 0.5-A, 8-channel digital output module for PLCs

In SPI protocol, the master and slave configuration asserts the data on one clock edge and reads the data on the next or opposite clock edge. SPI communication functions well as long as the total round-trip propagation delay is less than half of the clock period. The digital isolators delay to the timing of the SPI. The minimum time required for the data from the slave device to reach the master device is twice the maximum propagation delay. The propagation delay of the isolator reduces the data throughput by imposing a limit on the SPI clock speed.

The CPLD implements an elastic buffer in the master in-slave out (MISO) SPI, which compensates for the round-trip delays due to the digital isolators. The elastic buffer delays the MISO in such a way that the current sample is delayed until the next sample time.
4.2 Power Supply

The cape has an on-board power supply unit that converts the 24-V DC input power supply to the required output voltages. The power supply unit generates the 3.3 V required by a CPLD, the 5-V DC required for a BBB, and the 24 V required for a smart I/O module. Input reverse protection is implemented with a diode.

Figure 5. Power Supply Tree Diagram of I/O Controller
5 Test Setup

The test setup consists of the cape (TIDA-00312) to which the BBB is connected. The low-side, 0.5 A, 8-channel digital output module for PLCs (TIDA-00236) smart I/O daughter board plugs into the smart I/O interface. The TIDA-00236 is capable of turning resistive, inductive, or capacitive loads on or off. The TIDA-00236 has eight output lines with three LEDs per output to indicate the output status. View more information on the control and LED status in the TIDA-00236 data sheet.

The Ethernet port of BBB connects to a local area network (LAN). A computer that is connected to the LAN can access the web server page of the BBB to control the TIDA-00236 output line.

6 Software Description

The software uses a standard Ubuntu distribution, version 14.04. View further information about using Ubuntu with the BBB at: http://elinux.org/BeagleBoardUbuntu. Typically, any Linux distribution can be used. There are many Linux distributions that have been ported to BeagleBone boards and all of this information is available on www.BeagleBoard.org. There is no particular reason to restrict use to the Ubuntu distribution—Debian, Yellowdog Updater, Modified (yum), or any other distribution is sufficient to use for the design.
The PLC I/O module evaluation software is implemented as an Internet of Things (IoT) device. The main objective behind programming the PLC to function as an IoT device is to provide control over the network and the web. This control makes the network and web easy to operate and evaluate. An IoT device must have a network connection, which the Ethernet port of the BeagleBone provides. A Node.js® web server runs on the board and uses SPI to connect to the PLC I/O board. The web server of the board serves an HTML page that uses user interface elements to control the digital outputs on the I/O cape board. The user can connect to the PLC I/O web page from anywhere on the web, click on the digital output controls, and write the data to the board using the web interface. The web page communicates back to the server and (depending on the user input controls), the digital output on the PLC digital output module. Figure 7 shows the PLC I/O evaluation software stack.

### 6.1 Software Components

- **Ubuntu 14.04**: Ubuntu for BeagleBone Black is available with instructions at [http://elinux.org/BeagleBoardUbuntu](http://elinux.org/BeagleBoardUbuntu).
- **Node.js**: Node.js is a platform built on the JavaScript runtime for the Google Chrome™ browser to easily build fast, scalable network applications. Node.js uses an event-driven, non-blocking I/O model that makes Node.js lightweight, efficient, and perfect for data-intensive, real-time applications that run across distributed devices. View more information at [http://nodejs.org/](http://nodejs.org/).
- **Express.js**: Express is a minimalist web framework for Node.js applications. Express provides the web server functionality in the node application. View more information at [http://expressjs.com/](http://expressjs.com/).
- **Node SPI module**: The node SPI module is a Node.js interface to the SPI bus and is typically found on embedded Linux machines such as BeagleBone Black. The module uses a native interface and a wrapped .js interface with a better API. View more information at [https://github.com/RussTheAerialist/node-spi](https://github.com/RussTheAerialist/node-spi).
- **Socket.IO**: Socket.IO enables real-time, bidirectional, event-based communication. The Socket.IO works on every platform, browser, or device and focuses equally on reliability and speed. View more information at [http://socket.io/](http://socket.io/).
- **TI's PLC I/O cape HTML and JavaScript code**: The node-based web server running on BeagleBone Black serves an HTML page that uses standard HTML components to visualize the digital outputs on the PLC I/O cape. The HTML page is accessible by anyone connected to the network and has a two-way communication established with the Beagle Bone Black-based web server. The two-way communication not only allows control of the digital I/Os, but also to retrieve the status of the I/Os that reflect in the current status. This HTML page is based on standard JavaScript.
Connectors and Other Features of TIDA-00312

<table>
<thead>
<tr>
<th>CONNECTOR</th>
<th>DESCRIPTION</th>
</tr>
</thead>
<tbody>
<tr>
<td>J1</td>
<td>Smart I/O connector—to plug in the smart I/O board</td>
</tr>
<tr>
<td>J2 and J3</td>
<td>BBB connector—to plug in the BBB</td>
</tr>
<tr>
<td>J4</td>
<td>Xilinx® CPLD JTAG programming connector</td>
</tr>
<tr>
<td>J5</td>
<td>Smart I/O signal probe connector</td>
</tr>
<tr>
<td>J6</td>
<td>24-V DC power input connector</td>
</tr>
<tr>
<td>D1</td>
<td>3.3-V power LED</td>
</tr>
</tbody>
</table>

GUI Software and Testing

The testing procedure follows the test setup described in Section 5. The BBB typically stores the PLC I/O module image on the SD card.

The BBB connects to the LAN and acquires an internet protocol (IP) address for the BBB. The Dynamic Host Configuration Protocol (DHCP) server assigns the IP address. The user can locate the IP address assigned to the BBB by using the USB port of the BBB. View further details at http://beagleboard.org/getting-started and http://elinux.org/Beagleboard:Terminal_Shells. For the purposes of testing this design, consider that the assigned IP is "w.x.y.z". Note that the assigned IP is independent of the smart I/O module plugged into the cape board (TIDA-00312).

Access the BBB from a PC that is connected to the LAN using the BBB IP (w.x.y.z). The control page at http://w.x.y.z:9000/#/ is accessible using either the Firefox® or Chrome browser. The browser opens the control page of the digital output module.

The control page of the module (in this case, the TIDA-00236 digital output module), has 24 LED toggle buttons and a Write to Board command button. Buttons D41 through D56 correspond to status LEDs D41 through D48 of the TIDA-00236 device. Similarly, D69 through D76 correspond to output level LEDs D69 through D76 on the TIDA-00236 board.

Change the status of the LEDs by clicking the LED buttons. Send the status to the output board by clicking the Write to Board button. Turn the output lines on or off by clicking buttons D69 through D76 to set or reset. Then click the Write to Board button to update the digital outputs in TIDA-00236.
Figure 8 shows the control page for TIDA-00236.
9 Design Files

9.1 Schematics
To download the schematics, see the design files at TIDA-00312.
BeagleBone Cape for Programmable Logic Controller (PLC) Input/Output Module

Copyright © 2015, Texas Instruments Incorporated
Figure 11. Cape Power Supply Schematic
9.2 **BOM**

To download the Bill of Materials, see the design files at [TIDA-00312](#).

9.3 **Layer Plots**

To download the layer plots, see the design files at [TIDA-00312](#).

![Figure 12. Top Overlay](#)

![Figure 13. Top Solder Mask](#)

![Figure 14. Top Layer](#)

![Figure 15. Bottom Layer](#)
Figure 16. Bottom Solder Mask

Figure 17. Bottom Overlay

Figure 18. M1 Board Outline
9.4 **Altium Project**

To download the Altium project files, see the design files at [TIDA-00312](https://www.ti.com).
9.5 Gerber Files

To download the Gerber files, see the design files at TIDA-00312.

Figure 20. Fabrication Drawing
9.6 Assembly Drawings

To download the assembly drawings, see the design files at TIDA-00312.

Figure 21. Top Assembly Drawing

Figure 22. Bottom Assembly Drawing

9.7 Software Files

To download the software files, see the design files at TIDA-00312.

10 References

2. Texas Instruments, Low Side 0.5-A, 8-Ch Digital Output Module for PLC, User's Guide (TIDU470).
# Revision History A

Changes from Original (January 2015) to A Revision

<table>
<thead>
<tr>
<th>Description</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>Changed TLV70033 to TPS70933 in Tool Folder Containing Design Files</td>
<td>1</td>
</tr>
<tr>
<td>Added TPS70918 Product Folder</td>
<td>1</td>
</tr>
<tr>
<td>Changed to reflect correct device names in figure</td>
<td>7</td>
</tr>
<tr>
<td>Changed Figures 10 to 22</td>
<td>13</td>
</tr>
<tr>
<td>Changed Bottom Assembly Drawing to an updated image</td>
<td>19</td>
</tr>
</tbody>
</table>

NOTE: Page numbers for previous revisions may differ from page numbers in the current version.
Texas Instruments Incorporated (“TI”) reference designs are solely intended to assist designers (“Buyers”) who are developing systems that incorporate TI semiconductor products (also referred to herein as “components”). Buyer understands and agrees that Buyer remains responsible for using its independent analysis, evaluation and judgment in designing Buyer’s systems and products. TI reference designs have been created using standard laboratory conditions and engineering practices. TI has not conducted any testing other than that specifically described in the published documentation for a particular reference design. TI may make corrections, enhancements, improvements and other changes to its reference designs.

Buyers are authorized to use TI reference designs with the TI component(s) identified in each particular reference design and to modify the reference design in the development of their end products. HOWEVER, NO OTHER LICENSE, EXPRESS OR IMPLIED, BY ESTOPPEL OR OTHERWISE TO ANY OTHER TI INTELLECTUAL PROPERTY RIGHT, AND NO LICENSE TO ANY THIRD PARTY TECHNOLOGY OR INTELLECTUAL PROPERTY RIGHT, IS GRANTED HEREIN, including but not limited to any patent right, copyright, mask work right, or other intellectual property right relating to any combination, machine, or process in which TI components or services are used. Information published by TI regarding third-party products or services does not constitute a license to use such products or services, or a warranty or endorsement thereof. Use of such information may require a license from a third party under the patents or other intellectual property of the third party, or a license from TI under the patents or other intellectual property of TI.

TI reference designs are provided “as is”. TI makes no warranties or representations with regard to the reference designs or use of the reference designs, express, implied or statutory, including accuracy or completeness. TI disclaims any warranty of title and any implied warranties of merchantability, fitness for a particular purpose, quiet enjoyment, quiet possession, and non-infringement of any third party intellectual property rights with regard to TI reference designs or use thereof. TI shall not be liable for and shall not defend or indemnify Buyers against any third party infringement claim that relates to or is based on a combination of components provided in a TI reference design. In no event shall TI be liable for any actual, special, incidental, consequential or indirect damages, however caused, on any theory of liability and whether or not TI has been advised of the possibility of such damages, arising in any way out of TI reference designs or Buyer’s use of TI reference designs.

TI reserves the right to make corrections, enhancements, improvements and other changes to its semiconductor products and services per JESD46, latest issue, and to discontinue any product or service per JESD48, latest issue. Buyers should obtain the latest relevant information before placing orders and should verify that such information is current and complete. All semiconductor products are sold subject to TI’s terms and conditions of sale supplied at the time of order acknowledgment.

TI warrants performance of its components to the specifications applicable at the time of sale, in accordance with the warranty in TI’s terms and conditions of sale of semiconductor products. Testing and other quality control techniques for TI components are used to the extent TI deems necessary to support this warranty. Except where mandated by applicable law, testing of all parameters of each component is not necessarily performed.

TI assumes no liability for applications assistance or the design of Buyers’ products. Buyers are responsible for their products and applications using TI components. To minimize the risks associated with Buyers’ products and applications, Buyers should provide adequate design and operating safeguards.

Reproduction of significant portions of TI information in TI data books, data sheets or reference designs is permissible only if reproduction is without alteration and is accompanied by all associated warranties, conditions, limitations, and notices. TI is not responsible or liable for such altered documentation. Information of third parties may be subject to additional restrictions.

Buyer acknowledges and agrees that it is solely responsible for compliance with all legal, regulatory and safety-related requirements concerning its products, and any use of TI components in its applications, notwithstanding any applications-related information or support that may be provided by TI. Buyer represents and agrees that it has all the necessary expertise to create and implement safeguards that anticipate dangerous failures, monitor failures and their consequences, lessen the likelihood of dangerous failures and take appropriate remedial actions. Buyer will fully indemnify TI and its representatives against any damages arising out of the use of any TI components in Buyer’s safety-critical applications.

In some cases, TI components may be promoted specifically to facilitate safety-related applications. With such components, TI’s goal is to help enable customers to design and create their own end-product solutions that meet applicable functional safety standards and requirements. Nonetheless, such components are subject to these terms.

No TI components are authorized for use in FDA Class III (or similar life-critical medical equipment) unless authorized officers of the parties have executed an agreement specifically governing such use.

Only those TI components that TI has specifically designated as military grade or “enhanced plastic” are designed and intended for use in military/aerospace applications or environments. Buyer acknowledges and agrees that any military or aerospace use of TI components that have not been so designated is solely at Buyer’s risk, and Buyer is solely responsible for compliance with all legal and regulatory requirements in connection with such use.

TI has specifically designated certain components as meeting ISO/TS16949 requirements, mainly for automotive use. In any case of use of non-designated products, TI will not be responsible for any failure to meet ISO/TS16949.