TI Designs
Thermal Printing With the PRU-ICSS on the BeagleBone Black Reference Design

TEXAS INSTRUMENTS

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Design Resources

TIDEP0056	Tool Folder Containing Design Files
AM3358 Sitara Processor	Product Folder
DRV8833 Motor Driver	Product Folder
SN74LVC1G123	Product Folder
LM1085 Low Dropout Regulator	Product Folder
Beaglebone Black	Tool Folder

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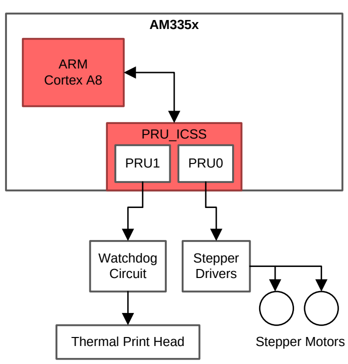
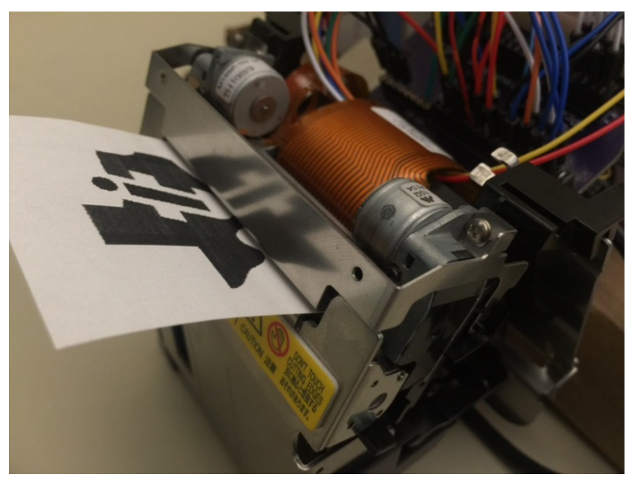
Design Features

- Interface Between Beaglebone Black and Fujitsu Thermal Printer
- ARM® to PRU® Interrupt Examples
- Real-Time Input and Output Control
- Software Stepper Motor Driver
- 100% Predictable Timing
- Watchdog Timer Protection Circuit

Featured Applications

- PRU Controlled Thermal Printer
- PRU Motor Control
- PRU Serial Data Out Generation





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1 Design Overview

The Programmable Realtime Unit– Industrial Communications Sub-System (PRU-ICSS) is a versatile component of the AM335x SoC that enables real-time, deterministic Input and Output, even when running a non-realtime operating system. This reference design provides a concrete use case and implementation of the PRU-ICSS to control a Fujitsu® thermal printer. Contained are C code examples for the ARM™ to the PRU® communication using the latest drivers, real-time GPIO pin control to drive the thermal print head elements and stepper motors, and the pinmux configuration for the BeagleBone Black.

2 Introduction

This design demonstrates a thermal printer application using the dual Programmable Real-Time Unit Subsystem and Industrial Communication SubSystem (PRU-ICSS). The PRU-ICSS may be found on several TI processors; in this design, the Sitara AM335x is used.

Off-the-shelf thermal printing modules typically include a controller board with a microcontroller driving the printer mechanisms a print head, and is interfaced to an applications processor through serial or parallel interfaces. In this design, all printer functions are controlled by the PRU-ICSS, and the printer controller board is removed.

Thermal printers have a few major components: stepper motors to control the paper advance and cutting functions, and of course a semiconductor-based thermal printing element that creates images line-by-line on thermally sensitive paper.

Did you know that Texas Instruments' Jack Kilby invented semiconductor-based thermal printing technology in 1965?

3 System Description

The thermal printer requires precise input waveforms for agile control of the stepper motors and print head. Agile control is not reliably generated on a superscalar CPU architecture while running a high-level operating system. Input and output timing cannot be guaranteed, resulting in poor print quality.

The PRU-ICSS is able to generate precise real-time, deterministic control signals and waveforms because of the PRU's architecture, and autonomy from the ARM host.

Section Section 3.1 discusses the ARM and PRU input and output timing in more detail.

For more detailed information, see the AM355x product folder for more technical literature.

3.1 ARM Cortex A-8

Access from the ARM Cortex A-8 to the L1, L2, and on-chip SRAM requires 1 cycle, 8 cycles, and 20 cycles respectively. Access to shared memory over the L3 interconnect requires 40 cycles. Figure 1 shows the ARM core and associated interconnect buses.

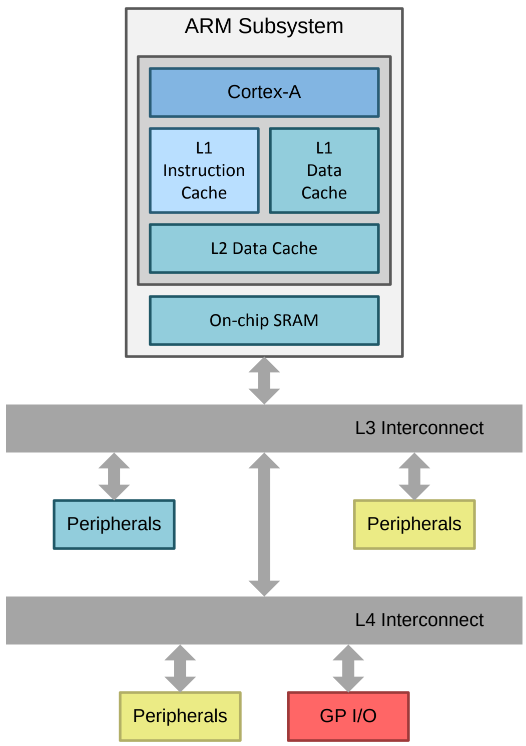

Figure 1. ARM Processor and Interconnects

3.2 PRU–ICSS Sub System

The PRU-ICSS is comprised of two independent 32-bit RISC cores that operate at 200 MHz. The PRU cores have single cycle architecture, resulting in deterministic execution. Each PRU core has access to its own 8-KB Data RAM, and 12-KB of Shared Data RAM. Figure 2 shows the PRU subsystem block diagram.

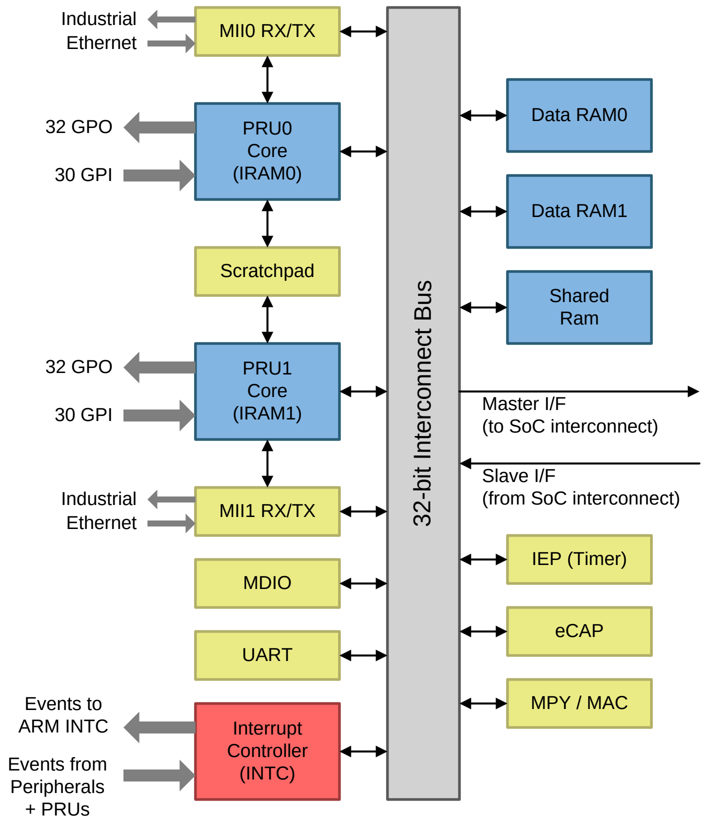

Figure 2. PRU Subsystem Block Diagram

3.3 AM3358 System-on-Chip (SoC)

The AM3358 SoC allows the ARM host to control the PRU cores through interrupts that are polled by the PRU firmware. In the accompanying software, the ARM host sends commands to each PRU core to execute specific actions.

In this thermal printer application, the PRU0 is loaded with firmware responsible for transferring line data and controlling the print head through a simple serial interface. PRU1 is loaded with firmware directly controlling stepper motors responsible for paper advance and paper cutting mechanisms.

4 Block Diagram

The system includes the AM335x SoC, with the ARM and PRU cores, on the BeagleBone Black providing easy access to the input and output signals controlled by the PRU. Each PRU core performs a task: PRU0 outputs stepper motor patterns, and PRU1 operates the thermal print head. Figure 3 shows the block diagram of the overall system.

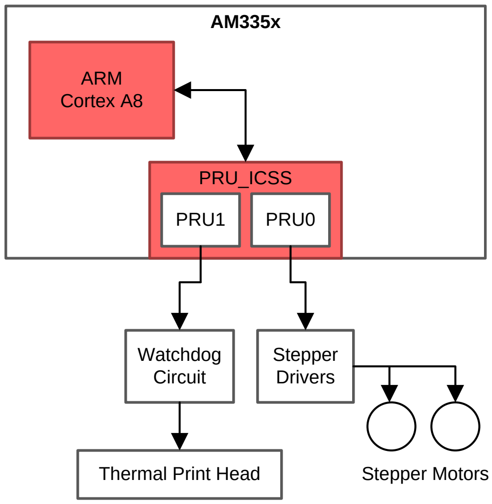

Figure 3. Block Diagram of the Thermal Printer System

4.1 Highlighted Products

In addition to the BeagleBone Black at the heart of the system, this reference design uses several discrete integrated circuits made by TI, highlighting the depth and breadth of the portfolio:

- DRV8833: Low-voltage dual-brushed DC or single bipolar stepper motor driver.
- SN74LVC1G123: Single retriggerable monostable multivibrator with Schmitt-Trigger inputs.
- SN74LVC244A: Octal buffer and driver with 3-state outputs.
- SN74AHC1G32: Single 2-input positive-or gate.
- SN74AHC08: Quadruple 2-input positive-and gates.
- LM1085: 3 A low dropout regulator (5 V).

4.1.1 BeagleBone Black

See http://www.beagleboard.org/black for more information, or to purchase a Beaglebone Black from a vendor. For the system reference manual and the technical reference manual for the AM335x, see the documentation at http://www.ti.com/tool/TIDEP0056.

4.1.2 Stepper Motor Control

The DRV8833 device provides a dual-bridge motor driver solution for toys, printers, and other mechatronic applications.

The device has two H-bridge drivers that drive two DC brush motors, a bipolar stepper motor, solenoids, or other inductive loads. The bipolar stepper motor function is used in this application (two DRV8833 devices are required).

The output driver block of each H-bridge consists of N-channel power MOSFETs configured as an H-bridge to drive the motor windings. Each H-bridge includes circuitry to regulate or limit the winding current.

Internal shutdown functions with a fault output pin are provided for overcurrent protection, short-circuit protection, undervoltage lockout, and overtemperature. A low-power sleep mode is also provided. External signals are not implemented on this design, however, must be used in a final end product.

The DRV8833 was selected to highlight the capability of the PRU– all stepping patterns are generated in software, controlled by an SoC running Linux®.

4.1.3 Print Head Longevity and Isolation Features

Most software developers have single-stepped through their code to track down troublesome bugs. When software is directly controlling hardware, caution must be exercised. Because a thermal print head works by applying voltage across a resistive element, it is possible to shorten the lifespan of the print head, or cause a hazard if allowed to overheat for extended periods of time. To prevent destroying the print head during a software debug, a simple hardware watchdog timer has been implemented with discrete logic.

The SN74LVC1G123 is a single retriggerable monostable multivibrator. This device generates a single fixed-duration pulse for each input trigger, based on external discrete components. Crucially, the pulse period is reset for each input trigger (this is why it is a *retriggerable* device). The output pulse is AND'd with the raw strobe signal from the PRU to form a hardware watchdog circuit. Under normal circumstances, this operation is transparent because the strobe duration is always shorter than the watchdog pulse. In situations where the strobe from the PRU is extended, this protection circuit ensures the strobe duration seen by the print head does not exceed a certain period, as shown in Figure 4.

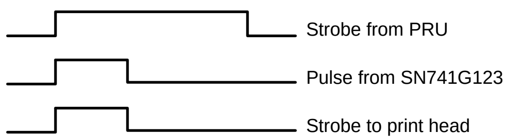

Figure 4. Watchdog Circuit De-asserts Strobe if Asserted for Extended Period of Time

This simple protection circuit is critical when developing for the Fujitsu thermal printer as it ensures that the strobe signals for the print head are not asserted for longer than they should be. When the strobe signals are asserted for too long, the paper sticks to the head, or damages the print head. Additionally, all PRU signals from the BeagleBone pass through CMOS buffers to isolate and protect the SoC IO cells.

5 System Theory of Operation

This TI Design is a complete thermal printer solution leveraging the dual-PRU cores of the AM335x for realtime control of the thermal printer element and associated stepper motors. This section explains the theory of operation from both the hardware and software views.

5.1 Hardware

The hardware depicted in the cape schematic has only been validated on a breadboard. The user may easily prototype the cape design using a 7.2V (VH) and 3.3V (VDD) power supply. The operation of the system is fairly simple from the hardware view. All signals output from the BeagleBone Black GPIO pins pass through octal buffers (SN74LVC244A) before splitting between motor drivers (DRV8833C), or the watchdog timer circuit. The two motor drivers then drive the paper advance and paper cutter stepper motors. The watchdog timer circuit uses the retriggerable monostable multivibrator and all of the strobe signals OR’ed together to create a *strobe head enable signal* that lasts for a few milliseconds.

The pulse width of the enable signal is determined by the values of the capacitor and resistor pair connected to pins 6 and 7 of the multivibrator. The multivibrator is configured to require a positive clock edge to be retriggered. Finally, the enable signal is AND’ed with each individual print strobe signal before driving the actual thermal print head inputs. The watchdog timer circuit is a hardware dependent system that ensures that the strobe signals do not remain *high* for long enough to cause permanent damage to the thermal print head.

5.2 Software

From a high level, the ARM host handles the user interface, image processing, and sending of commands to each PRU core. The PRU0 controls the print head signals, while the PRU1 controls the paper advance and paper cutter stepper motors. This forms a master and slave relationship between the ARM host and the PRU cores. The ARM host sends commands encoding print data that generates an interrupt. The PRU cores are constantly polling for these interrupts and handle the interrupts according to the commands encoded.

6 Getting Started Hardware

This section lists all of the hardware required to get started. All integrated circuits used in this design may be ordered from http://www.ti.com.

6.1 BeagleBone Black

See http://www.beagleboard.org/black for more information and to purchase a BeagleBone black from a vendor. For the system reference manual and the technical reference manual for the AM335x, see the documentation posted on the TI Design website.

6.2 Thermal Printer Module

The Fujitsu FTP-628MCL401 Thermal Printer Module was chosen for this TI Design because it is a complete integrated package. Most thermal print heads follow a similar electronic interface, so other units may be adapted to work with this TI Design. See http://www.fujitsu.com/us/pdut/detail/1188150/thermal-printers/FTP-628MCL401 for more information, or to purchase a FTP-628MCL401 Thermal Printer. Be sure to look in the *how to buy* section.

6.3 Discrete Integrated Circuits

See for individual part numbers and the schematic for putting this design together. The mount ICs were ordered from ti.com and the surface mount adaptors were used to prototype the components on a breadboard.

7 Getting Started Software

7.1 Software Requirements

To use the demo software provided with this design, it is assumed the following software is downloaded. If not, download the latest versions of each software package:

- AM335x Processor SDK v02.00.00.00.
- Processor SDK PRU-ICSS Add-On Package v04.00.00.00.
- PRU-ICSS Compiler v2.1.2.
- PRU-ICSS Thermal Printer Software Package v01.00.00.00

7.2 AM335x Processor-SDK Installation

This getting started guide was written using a 32-Bit version of Ubuntu® 12.04 LTS host machine.

- Processor SDK v02.00.00.00, download page: Processor-SDK Download Page.
- Additional libraries if running a 64-Bit distro: 64-Bit Ubuntu Support.
- Processor SDK Linux Getting Started Guide.

7.3 Processor SDK PRU–ICSS Add-On Package Installation

This support package includes all of the necessary additions to start developing firmware for the PRUs. Install the support package on a clean installation of the Processor-SDK to minimize any conflicts. If not, you may have to apply some of the patches manually.

- Download page: PRU Software Add-on Package

The install directory is referred to as *${PRU_SW_PKG}*.

7.4 PRU–ICSS Compiler Installation

The PRU-ICSS C/C++ Compiler is provided with CCSv6, however, for users that do not want to install CCS, the version used to build the PRU sources in this design guide may be found here.

See the PRU-ICSS Getting Started Guide for more information. Also see the PRU Optimizing C/C++ Compiler document for PRU C/C++ support.

7.5 PRU–ICSS Thermal Printer Software Package Installation

Run the installer from the terminal. Provide the installation directory when prompted. The installer will not check for proper versions of the previously installed SDK components for those simply interested in examining the code.

Check the *readme files* in the software package for more in-depth project information not found in this document.

7.6 Apply Device Tree Overlay PinMuxing Patch

Apply the device tree patch provided by:

```
${PRU-ICSS-TP-DESIGN}/sw/patches/0001-AM335x-PRU-entries-and-overlay-for-tp-project.patch
```

to the Linux kernel source found in the Processor SDK.

```
# git am 0001-AM335x-PRU-entries-and-overlay-for-tp-project.patch
```

The *readme file* provided by the design software package contains a full list of the GPIO pins used.

7.7 Build the Linux Kernel, Device Tree, and Modules With PRU-ICSS Support

1. From the *${Processor-SDK}/board-support/linux-X.XX.XX*/* directory run the commands:

NOTE: Make sure to add the cross-compiler toolchain to your PATH variable first. If you don't understand any of the following commands please read the Processor SDK Linux Kernel Users Guide.

- # make ARCH=arm CROSS_COMPILE=arm-linux-gnueabihf- distclean.
- # make ARCH=arm CROSS_COMPILE=arm-linux-gnueabihf- tisdk_am335x-evm_defconfig
- # make ARCH=arm CROSS_COMPILE=arm-linux-gnueabihf- menuconfig

2. Navigate to *Device Drivers→Remoteproc* drivers
3. Type *M* next to *TI PRUSS remoteproc support* to indicate that the *remoteproc* driver must be dynamically loadable into the kernel.
4. How a module is loaded is explained later.
5. Navigate to *Device Drivers→Rpmsg* drivers (it will appear next to the *Remoteproc* drivers).
6. Type *M* next to *PRU RPMsg Communications driver* to indicate that the RPMsg module is dynamically loadable into the kernel.
7. Figure 5 shows how the *menuconfig* appears.

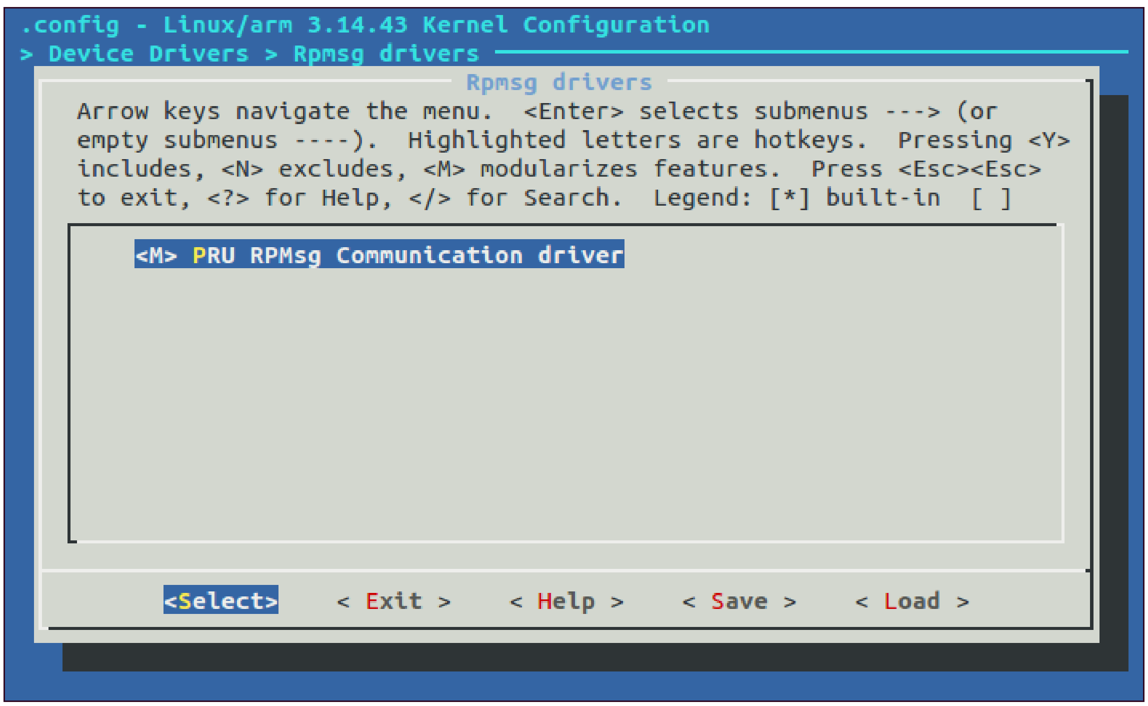

Figure 5. Menuconfig Screenshot

8. Save the *.config* and exit *menuconfig*.
9. Run the following commands:

- # make ARCH=arm CROSS_COMPILE=arm-linux-gnueabihf- zImage
- # make ARCH=arm CROSS_COMPILE=arm-linux-gnueabihf- am335x-boneblack.dtb
- # make ARCH=arm CROSS_COMPILE=arm-linux-gnueabihf- modules

At this point, Linux has been configured Linux to include the *pruss_remoteproc* driver as well as the *pru_rpmsg* driver that is required for the demo applications. The last three steps in this section rebuilt the Linux kernel, the device tree, and the kernel modules.

7.8 Compiling the PRU-ICSS Sources

Navigate to the top-level directory of the PRU-ICSS Thermal Printer Software Package on the host machine (referred to as *${PRU-ICSS-TP-DESIGN}*). A *Makefile* is provided for building both PRU firmware images, and the ARM binary. To successfully compile these binaries, the following environment variables must be manually exported (modify to reflect the correct path on your system):

ARM Cross-Compile Toolchain

```
export ARM_CCT=${HOME}/ti-processor-sdk-linux-am335x-evm-02.00.00.00/linux-devkit/sysroots/x86_64-arago-linux/usr/bin
```

PRU Code Generation Tools

```
export PRU_CGT=${HOME}/ti/ccs_v6_1_0/ccsv6/tools/compiler/ti-cgt-pru_2.1.2
```

PRU Software Support Package

```
export PRU_SSP=${HOME}/ti-processor-sdk-linux-am335x-evm-02.00.00.00/example-applications/pru
```

To build the binaries, change to the *sw* directory, and execute the *make* command:

```
# cd ${PRU-ICSS-TP-DESIGN}/sw/
# make
```

NOTE: This top-level *makefile* simply calls make files in each project folder and may be called directly to rebuild each binary separately, if desired.

If nothing was missing, the binaries are located in the newly created *gen* folder inside of each of the three project folders:

1. ARM user space application binary
   - ${PRU-ICSS-TP-DESIGN}/sw/pruprint/gen/pruprint
2. PRU0 firmware binary
   - ${PRU-ICSS-TP-DESIGN}/sw/pruprint_fw_0/gen/pruprint_fw_0.out
3. PRU1 firmware binary
   - ${PRU-ICSS-TP-DESIGN}/sw/pruprint_fw_1/gen/pruprint_fw_1.out

7.9 Copying Files to the Filesysytem of the Board

Now that all of the required modules, binaries, and firmwares have been built, they must be moved over into the file system.

NOTE: During development, there are multiple ways to provide a kernel, device tree, file system, kernel modules, and more. The user may use whatever method they choose (SD card, TFTP boot, NFS server). It is expected that the user knows how to take the kernel image and device tree built above, and boot their board. If you are struggling with this, TI recommends to go through the Processor SDK Linux Getting Started Guide before returning to this guide.

NOTE: Make sure that you are booting from the *zImage* and the *am335x-boneblack.dtb* file that was created above Section 7.7.

1. Create a new directory and name it *modules* in the home directory of your board's file system.
   - (/home/root/modules)
2. Copy the following modules from the development machine into the newly created modules folder:
   - *${Processor-SDK}/board-support/linux-X.XX.XX*/drivers/remoteproc/pruss_remoteproc.ko*
   - *${Processor-SDK}/board-support/linux-X.XX.XX*/drivers/rpmsg/virtio_rpmsg_bus.ko*
   - *${Processor-SDK}/board-support/linux-X.XX.XX*/drivers/rpmsg/rpmsg_pru.ko*
3. Copy the ARM binary that was built to the home directory of the board's file system (/home/root/):
   - ${PRU-ICSS-TP-DESIGN}/sw/pruprint/gen/pruprint
4. Copy the sample images provided to the home directory of the board's file system (/home/root/):
   - ${PRU-ICSS-TP-DESIGN}/sw/images/ti_logo.png
   - ${PRU-ICSS-TP-DESIGN}/sw/images/ti_logo_long.png

NOTE: The *pruprint* user application requires a 1-bit per pixel PNG image as input. PNG images with greater color depth must be converted first.

5. Copy the two PRU firmwares into the lib/firmware/directory of the board's file system (/lib/firmware/):
   - ${PRU-ICSS-TP-DESIGN}/sw/pruprint_fw_0/gen/pruprint_fw_0.out
   - ${PRU-ICSS-TP-DESIGN}/sw/pruprint_fw_1/gen/pruprint_fw_1.out
6. Rename the two PRU firmwares copied above to the name that the *pruss_remoteproc* module expects to find (leave the files in the /lib/firmware/directory, just rename them).
   - pruprint_fw_0.out→am335x-pru0-fw
   - pruprint_fw_1.out→am335x-pru1-fw
7. The user now has three kernel modules, the ARM application, and the two PRU firmwares copied over from the development machine to the file system of the board.

7.10 Booting and Running the Printer

Everything should now be in place, and the board is ready to be booted. Make sure the 3.3 V FTDI UART cable is connected to the board, and that you have your favorite terminal emulator program (Minicom, picocom, screen, etc) ready for output from the board.

1. Connect a 7.2 V supply to the regulator to power the BeagleBone Black.
2. The printer is approximately 4.5–8.5 V tolerant, but be sure to use at least a 7 V supply so the regulator may still power the BeagleBone Black at 5 V.
3. Access the BeagleBone terminal.
4. After booting completes, the following instructions load the modules that were built and copied earlier:
   (a) # cd /home/root/modules
   (b) # insmod virtio_rpmsg_bus.ko

(c) # insmod rpmsg_pru.ko

NOTE: If you have issues inserting these modules, then you are most likely not using the newly built *zImage* from Section 7.7.

(d) # insmod pruss_remoteproc.ko

(e) Run #*lsmod* to ensure that the modules have loaded.

(f) The user may also type #ls /dev/ to ensure that there are two character devices named *rpmsg_pru30* and *rpmsg_pru 31*). This is how the ARM core communicates with the PRU cores).

5. After these commands are executed, the PRU firmware has been loaded and is running, polling for commands from the ARM host.
6. Change back to the home directory, and execute the ARM program for each of the sample images:

(a) # cd /home/root/

(b) # ./pruprint -i ti_logo.png

(c) # ./pruprint -i ti_logo_long.png

The print sequence for each image is initiated.

7.11 Software Disclaimer

The software provided is in its infancy, and some features have not completely been implemented. There is significant room for expanding the software provided to create a more capable piece of software.

8 Test Setup

A basic cape was created to interface the ribbon cables of the thermal print head to the BeagleBone PRU channels. The design files for this basic cape are provided. All other circuits were prototyped in a breadboard.Figure 6 shows a top-down view of the cape prototype connected to the BeagleBone Black, TPCape, and the Fujitsu thermal printer. Figure 6 shows the thermal printer cape prototype.

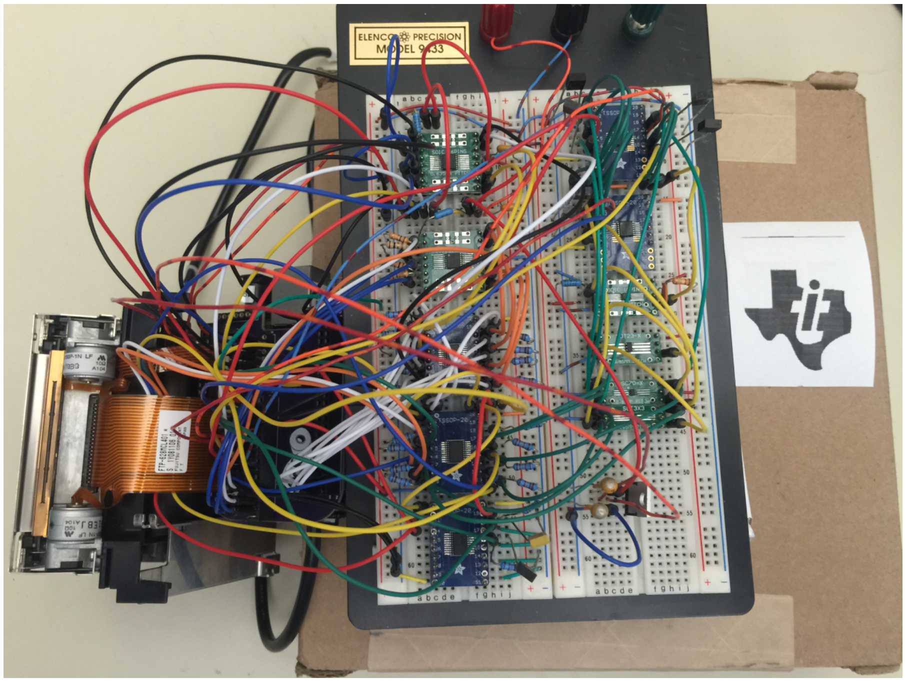

Figure 6. Thermal Printer Cape Prototype

9 Test Data

With the provided cape design and software, a clean cut and contrast-rich PNG image was printed.

9.1 Print Example

Figure 7 shows an example of a print job from this printer and software combination.

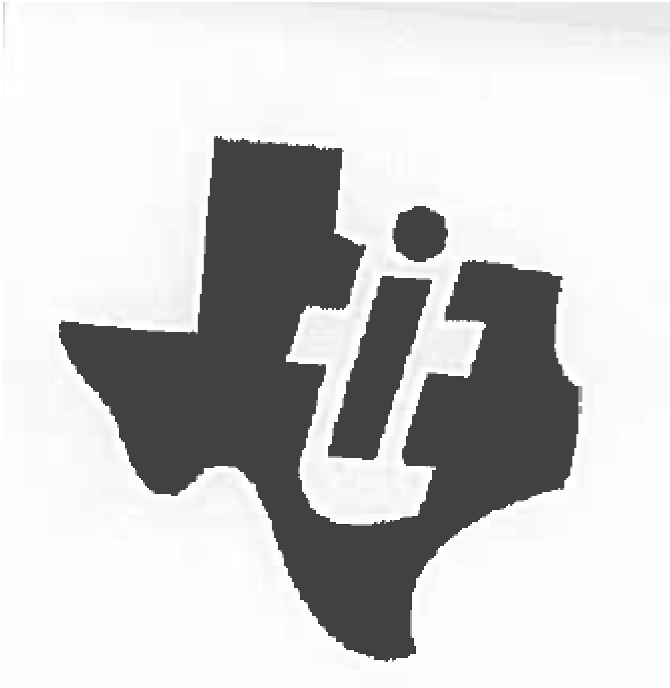

Figure 7. Actual Printed Output

9.2 PRU vs ARM

The PRU is able to toggle GPIO pins much faster than the ARM host. Figure 8 and Figure 9 show the difference between the PRU and the ARM host. Overall, the PRU is about 40 times faster than the ARM host.

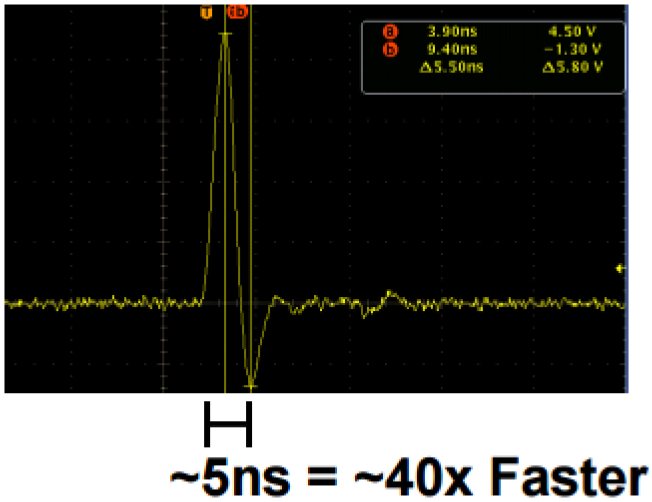

Figure 8. PRU Toggle: 5 ns

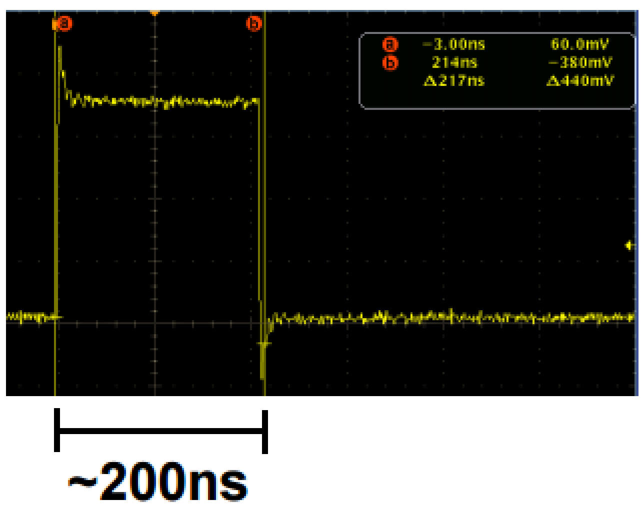

Figure 9. ARM Toggle: 200 ns

10 Design Files

10.1 Schematics

To download the schematics for each board, see the design files at http://www.ti.com/tool/TIDEP0056.

Figure 10 shows the PRU thermal printer schematic.

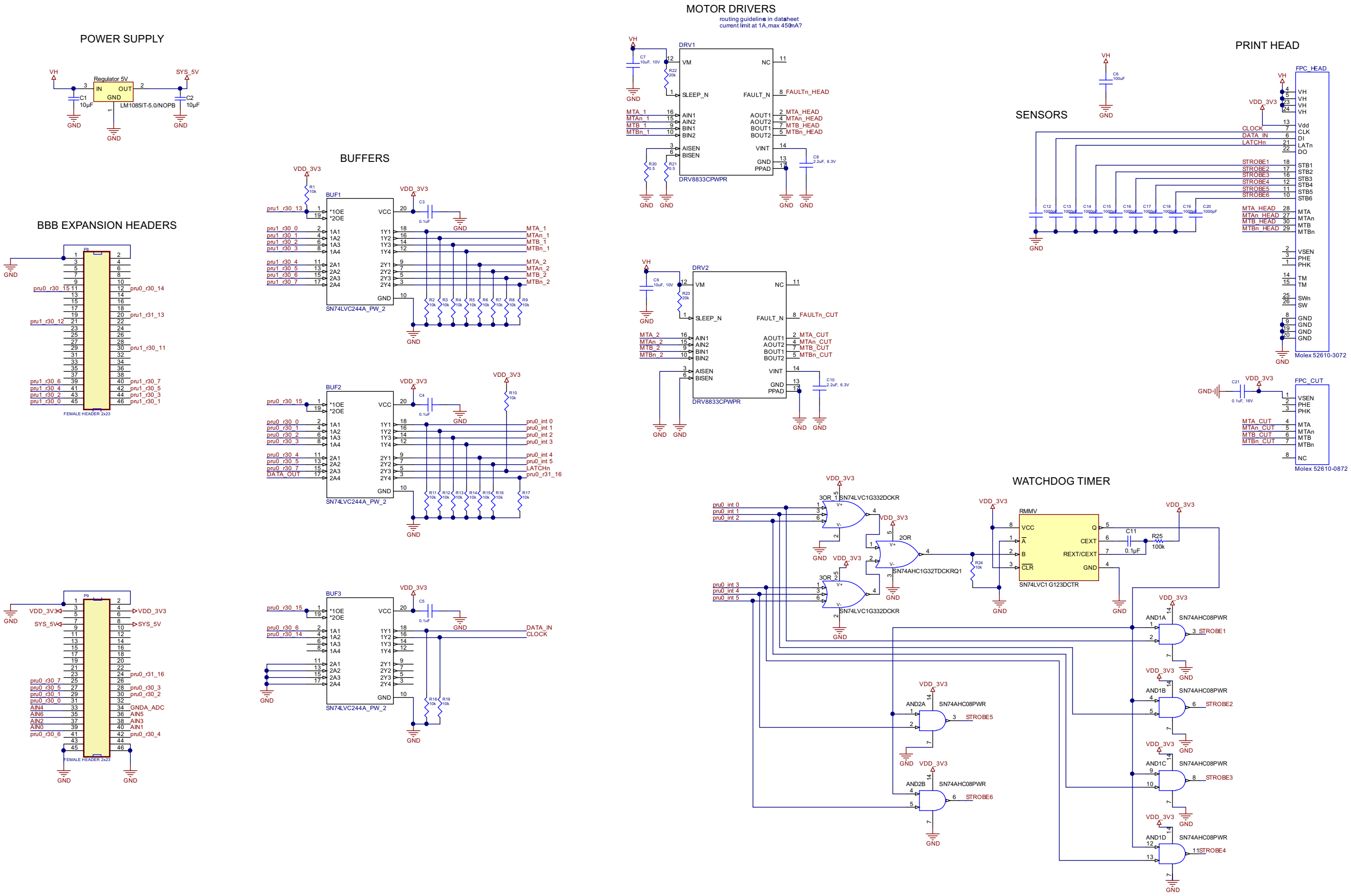

Figure 10. PRU Thermal Printer Schematic

10.2 Bill of Materials

To download the bill of materials (BOM), see the design files at http://www.ti.com/tool/TIDEP0056, or go to:

`${PRU-ICSS-TP-DESIGN}/hw/PRUTP_TI_Design_BOM.xlsx`

Table 1 and Table 2 list the bill of materials.

Table 1. Bill of Materials

ITEMS ON SCHEMATIC	DESCRIPTION	DESIGNATOR	FOOTPRINT	LIBREF	QUANTITY
SN74AHC1G32TDCKRQ1	Single 2-Input Positive-OR Gate, DCK0005A	2OR	DCK0005A_N	SN74AHC1G32TDCKRQ1	1
SN74LVC1G332DCKR	Single 3-Input Positive-OR Gate, DCK0006A	3OR_1, 3OR_2	DCK0006A_N	SN74LVC1G332DCKR	2
SN74AHC08PWR	QUADRUPLE 2-INPUT POSITIVE-AND GATES, PW0014A	AND1, AND2	PW0014A_N	SN74AHC08PWR	2
SN74LVC244A_PW_2	Imported	BUF1, BUF2, BUF3	PW20	SN74LVC244A_PW_2	3
CL05A106MP5NUNC	CAP, CERM, 10 µF, 10 V, ±20%, X5R, 0402	C1, C2	0402	CL05A106MP5NUNC	2
0.1 uF	No description	C3, C4, C5	402	CAP SMD	3
100 uF	Bulk capacitor for motor drive	C6	RD205SMD_250D	CAP SMD	1
10 uF, 10 V	Low-ESR ceramic bypass capacitor	C7, C9	805	CAP SMD	2
2.2 uF, 6.3 V	No description	C8, C10	402	CAP SMD	2
CL03A104KP3NNNC	CAP, CERM, 0.1 µF, 10 V, ±10%, X5R, 0201	C11	0201	CL03A104KP3NNNC	1
1000 pF	No description	C12–C20	402	CAP SMD	9
0.1 uF, 16 V	No description	C21	402	CAP SMD	1
DRV8833CPWPR	Imported	DRV1, DRV2	DRV8833CPWPR	DRV8833CPWPR	2
Molex 52610-0872	FPC connector for Fujitsu FTP-628MCL401 (Molex 52610-0871 is obsolete)	FPC_CUT	Molex 52610-0872	Molex 52610-0872	1
Molex 52610-3072	FPC connector for Fujitsu FTP-628MCL401 print head (Molex 52610-3071 is obsolete)	FPC_HEAD	Molex 52610-3072	Molex 52610-3072	1
Female Header 2×23	CONN HEADER FMAL 46PS.1" DL GOLD	P8, P9	HDR2×23	HDR_46_F_2_0.1_0.1	2
10k	RES 10K OHM 1/16W 5% 0402 SMD	R1–R19, R24	402	RES SMD	20
0.5	RES 10K OHM 1/16W 5% 0402 SMD	R20, R21	402	RES SMD	2
20k	RES 10K OHM 1/16W 5% 0402 SMD	R22, R23	402	RES SMD	2
RT0603BRD07100KL	RES, 100 k, 0.1%, 0.1 W, 0603	R25	0603	RT0603BRD07100KL	1
LM1085IT-5.0/NOPB	3A Low Dropout Positive Regulators, 3-pin TO-220, Pb-Free	Regulator 5 V	T03B	LM1085IT-5.0/NOPB	1
SN74LVC1G123DCTR	SINGLE RETRIGGERABLE MONOSTABLE MULTIVIBRATOR WITH SCHMITT-TRIGGER INPUTS, DCT0008A	RMMV	DCT0008A_N	SN74LVC1G123DCTR	1

Table 2. Bill of Materials Continued

ITEMS NOT ON SCHEMATIC	DESCRIPTION	LINKS	QUANTITY
Tpcape Breakout Board v0.1	BBB cape to break out 30 pin ribbon cable	https://oshpark.com/shared_projects/kP1HCuRb	1
Molex 30 pin ribbon cable FFC/FPC connector	Connect ribbon cable to breakout pins	http://www.molex.com/molex/products/datasheet.jsp?part=active/0526103072_FFC_FPC_CONNECTORS.xml&channel=Products&Lang=en-us	1
Molex 8 pin ribbon cable FFC/FPC connector	Connect ribbon cable to breakout pins	http://www.molex.com/molex/products/datasheet.jsp?part=active/0526100872_FFC_FPC_CONNECTORS.xml&channel=Products&Lang=en-us	1
2x23 Stackable Female Header	Stacking Headers to connect to BBB. (Long pins)	https://www.sparkfun.com/products/12790?gclid=CObQqurmzsYCFQGJaQoduyEJuQ	3
2x15 Female Header	Need to hack together a 2×15 female header from 2×23 header. (cut pins shorter)		1 (made from 1 2×23 Header)
TSSOP-20 Breakout PCB	Need 5 total breakout PCBs for the 3 signal buffers and two AND gate Ics	https://www.adafruit.com/products/1206	2 (3-pack)
Schmartboard Inc. ez 0.635mm Pitch SOIC to DIP adapter	Adapters for motor drivers	http://www.microcenter.com/product/419383/ez_0635mm_Pitch_SOIC_to_DIP_adapter	2
Schmartboard Inc. EZSOT 23 & SC70 SMT to DIP Adapter	Adapters for or gates, and multivibrators	http://www.microcenter.com/product/419371/EZSOT_23_-_SC70_SMT_to_DIP_Adapter	1
About 100 pins for surface mount breakout boards	TSSOP-20 breakout boards do not ship with pins		150

10.3 PCB Layout Recommendations

This design has been validated on a breadboard and the schematics are provided. A PCB layout has not been designed by TI, but users may create their own layout and design based on the materials provided in this reference design.

10.4 Software Files

To download the software files, see the design files at http://www.ti.com/tool/TIDEP0056.

11 Terminology

1. **PRU–ICSS:** Programmable Real-Time Unit– Industrial Sub Systems
2. **BOM:** Bill of Materials
3. **E2E:** Engineer to Engineer: http://e2e.ti.com/

12 About the Author

MICHAEL SNOOK is a catalog embedded processors Intern at TI, where he is developing reference design solutions for the PRU-ICSS. Michael brings a fresh point of view to the PRU-ICSS, allowing for new and innovative applications and solutions. Michael is pursuing his Bachelors of Science in Computer Engineering from Iowa State University in Ames, IA.

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