RADIATION HARDENED SYSTEM CONTROL BOARD FOR CUBESATS

THE CHALLENGE

CubeSats are very popular and growing in importance to fulfill more and more commercial space missions. The bulk of the ready-to-use CPU cards for the CubeSat market use commercial-off-the-shelf (COTS) semiconductor devices. While these have been shown to be at times sufficient up to 10 kRads, more and more missions are experiencing higher levels of radiation over their life span than COTs devices can survive or reliably operate. There have also been reports of devices exhibiting latch-up susceptibility to single event effects such as high energy neutron or proton strikes.

The challenge is to provide a cost-effective radiation hardened system control board / compute module that can be used in the standard form factor of CubeSat modules.

THE SOLUTION

VORAGO Technologies partnered with COSMIAC (a University of New Mexico research center), based on the expertise they bring in reconfigurable microsystems and the history they have in CubeSat electronics and radiation effects for spacecraft, to create a hardened compute module. The module is called "*HARDSAT* Compute Module" in reference to the underlying VORAGO technologies' silicon process used to combat ill effects of radiation.

The *HARDSAT* compute module (CM) and associated board stack were developed to allow rapid development, a high degree of configurability, a small form factor and a highly robust system for small satellite applications.

VORAGO Technologies already has proven radiation hardened ARM® Cortex®-M0 based Microcontroller Units (MCUs). The latest VORAGO Technologies' MCU with 128kbytes of code space is used for this project. It is envisioned that future modules using the same form factor and interconnect can include higher performance MCUs with more available memory. A compute module and an interface board to the CubeSat kit bus was developed and prototyped. See **Figure 1** for block diagrams of both boards. The rest of this brief provides more details of the solution.

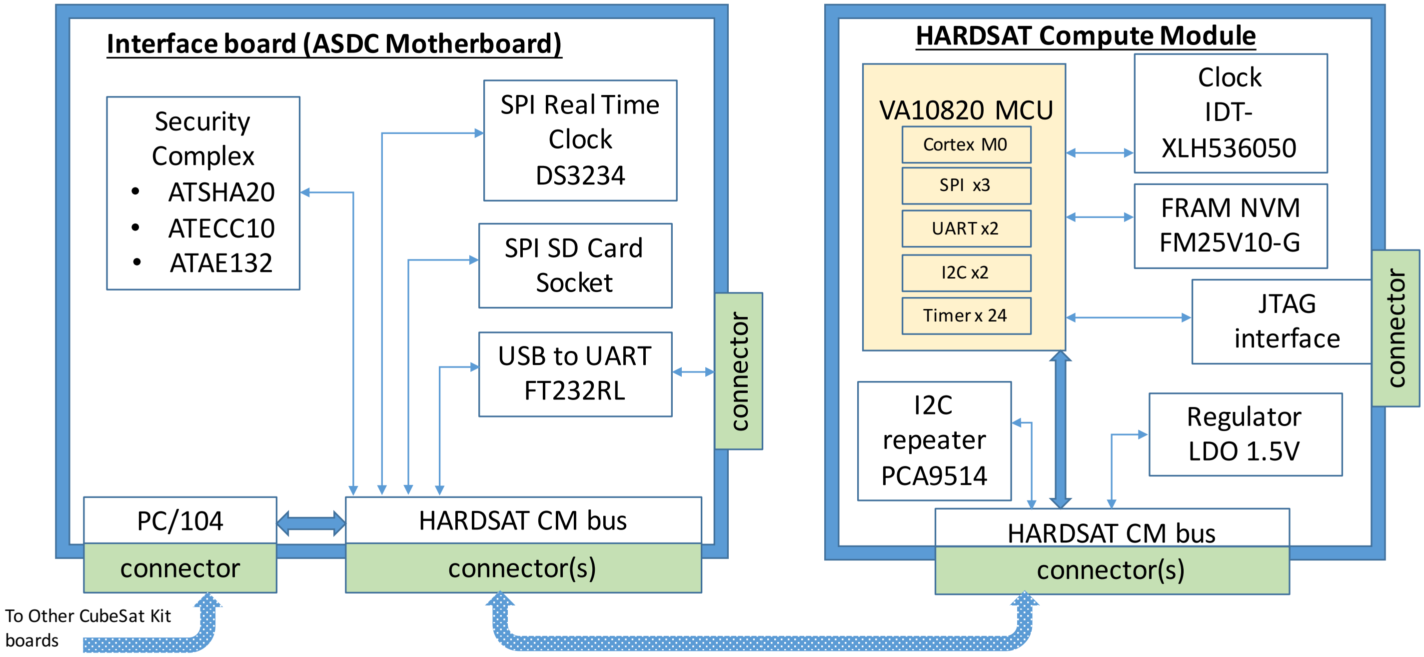


FIGURE 1- BLOCK DIAGRAM OF COMPUTE MODULE AND INTERFACE BOARD

CUBESAT COMPUTE MODULE SYSTEM REQUIREMENTS

The CubeSat form factor is established with many control boards and mission specific boards already implemented. Clyde Space, Pumpkin Inc., and GomSpace have a full portfolio of modules to select from that span communications, power supply, navigation / positioning, camera and propulsion units. For instance, GomSpace has three communication modules already available that will readily plug into the CubeSat Kit Bus which has the form factor of a PC/104 connector. These modules just require power and a small number of serial bus signals to perform in the system.

The purpose of the compute module is to flawlessly execute the mission specific command and control software in a radiation adverse environment. It will also provide bidirectional communication to the various modules via I2C, SPI or UART serial interfaces.

Here is a list of functions that the compute module and motherboard provide.

Category	Compute Mod	Motherboard
Processor	50 MHz, Cortex®-M0®	None
Memory	128k SPI FRAM	SD Card
Security	None	SHA and RNG
Timers	24 – 32-bit timers	RTC with battery
Serial interfaces	2 x I2C, 3 x SPI, 2 x UART	USB to UART converter

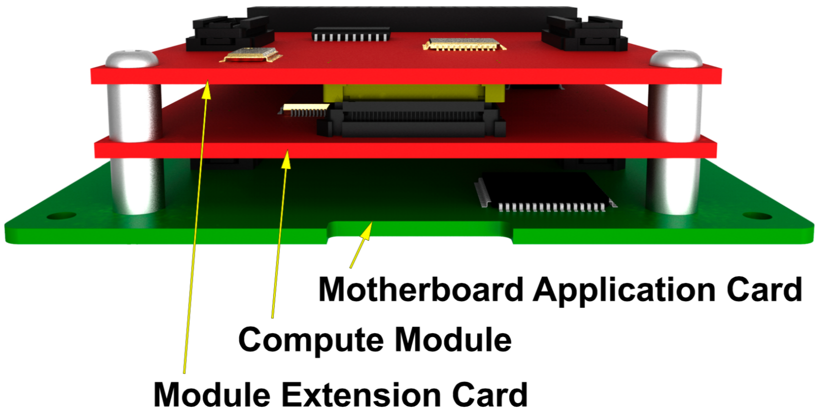
TABLE 1- LIST OF FUNCTIONS FOR THE COMPUTE MODULE AND MOTHERBOARD

IMPLEMENTATION STRATEGY

The main purpose of this project was to provide satellite developers with a scalable and cost-effective radiation hardened compute module for small satellite projects.

VORAGO Technologies already has proven radiation hardened Cortex M0-based MCUs. The latest version with 128kbyte of program space is used in this project. The dimensions of the compute module were selected to sit inside the cube satellite chassis to allow both a means to connect to the CubeSat PC/104 bus and have its own set of board-to-board connections allowing stacking of either compute modules or yet to be developed application specific daughter cards (ASDC). The first ASDC contains an SD memory card, a security platform for encryption and authentication, a real-time clock and a connector for interfacing a to the CubeSat Kit bus. It is referred to as a “motherboard” since it replaces much of the Pumpkin CubeSat motherboard.

See **Figure 2** for a drawing of the board stack.



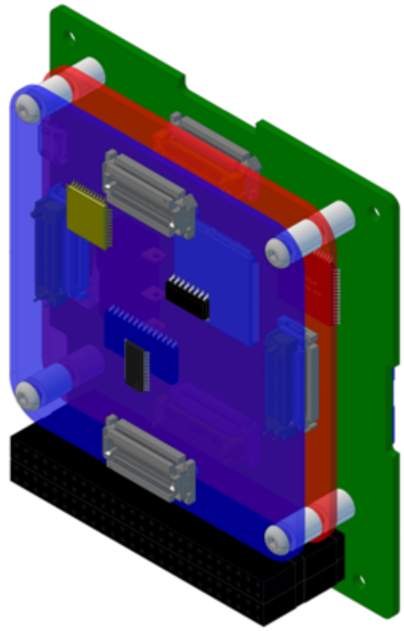


FIGURE 2 - BOARD STACK DRAWING, FRONT VIEW (LEFT) AND ROTATED VIEW (RIGHT)

The motherboard ASDC provides a bridge between the Pumpkin CubeSat kit bus and the *HARDSAT* communications bus. It allows direct connection to many existing CubeSat kit boards. Figure 3 shows board to board connections to the two separate busses.

The ASDC contains all the necessary functionality to comply with the CubeSat kit bus standard. This includes a removal before flight (RBF) and separation switch (SEP). All the control signals (I2C, UART, SPI, GPIO) are routed to the CubeSat kit bus through the PC/104 connector.

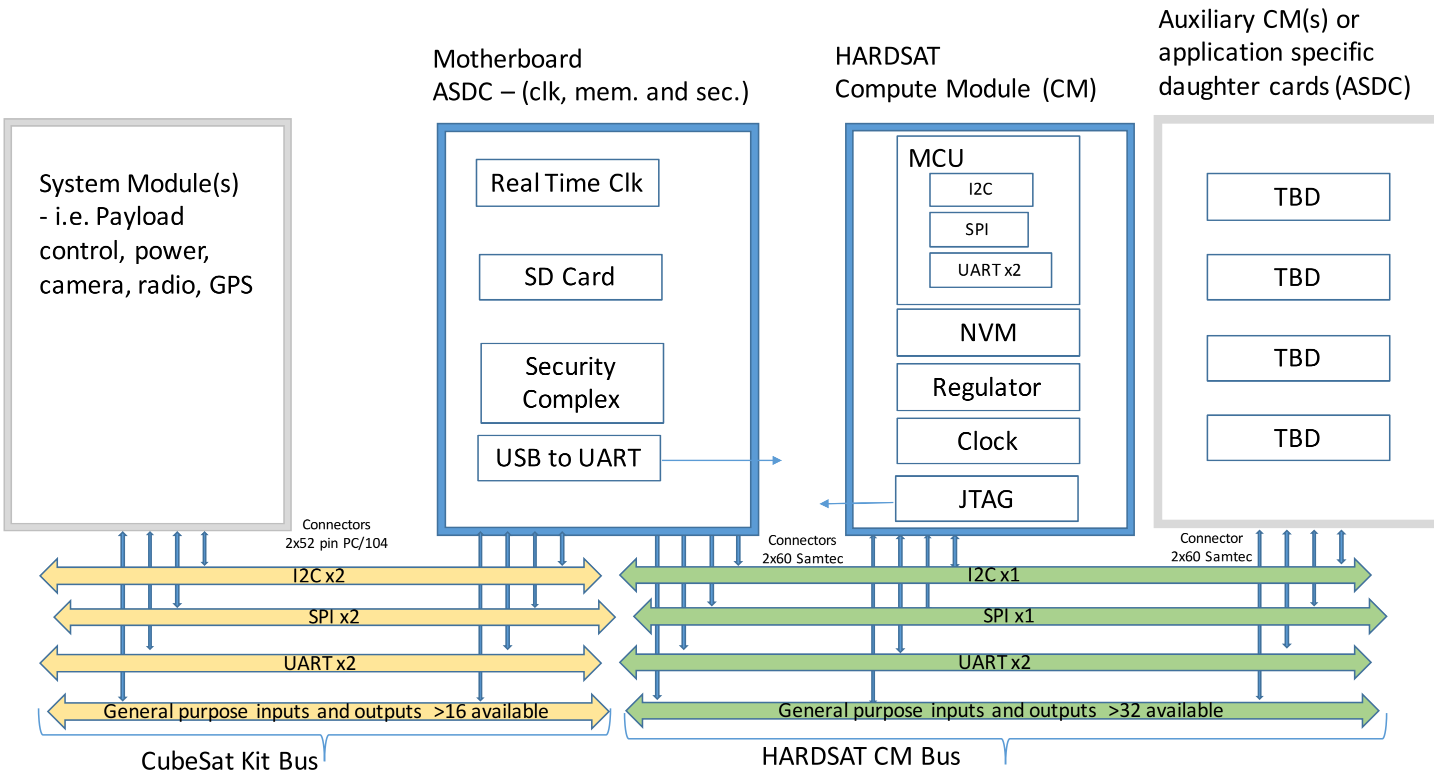


FIGURE 3 - BLOCK DIAGRAM OF BOARDS AND INTERCONNECT

The CM can operate alone or be attached to an Application Specific Daughter Card (ASDC). Together the CM and ASDC provide the capabilities needed for a specific task. It will also be possible to use extension boards such as a memory card, several compute cards or several ASDC's in a board stack.

The CM uses an MCU based on the ARM® Cortex®-M0 processor that incorporates VORAGO's *HARDSIL*® enhancements. Chips implemented using the standard foundry design rules with *HARDSIL*® enhanced processes have demonstrated the ability to meet stringent Single Event Effect (SEE), Single Event Latch-up (SEL), Dose Rate (DR), and Total Ionizing Dose (TID) requirements.

INNOVATION

The key innovations of this program relating to the Compute module are listed here.

- Allows for state-of-the-art commercial firmware and software to be used without the additional expense of coding for radiation effects.
- Reduces development time and cost given the CM uses standard interfaces that are well understood (I2C, SPI and UART).
- Describes the connector pin out which provides both pass-through signals and unique card identification depending on the position of the board in the stack.
- The CM allows for the developer to quickly adapt current designs to a more robust radiation hardened platform.
- Reduces the dependency on decades old radiation hardened parts.

PROTOTYPE RESULTS

Figure 4 shows the functioning prototype of the compute modules. Figure 5 shows the functioning motherboard.

Software was developed to communicate with the peripheral chips on the I2C, SPI and UART interfaces. This software was further refined and is now available as part of the board support package for the REB1 development board that can be found at: http://www.voragotech.com/products/reb1. Application notes with software for FreeRTOS, timers and SPI examples can be found at http://www.voragotech.com/resources

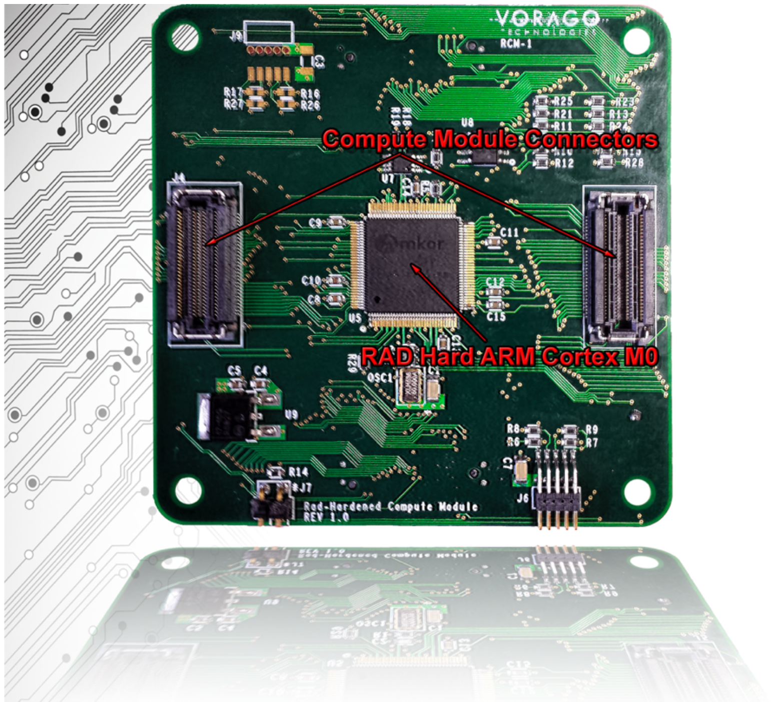


FIGURE 4 - PHOTO OF COMPUTE MODULE PCB PROTOTYPE

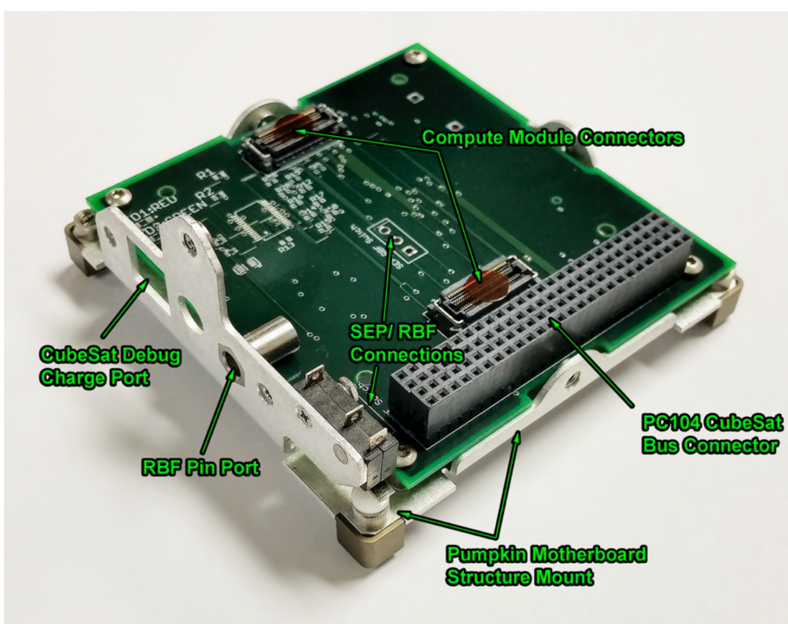


FIGURE 5 - PHOTO OF MOTHERBOARD ASDC PCB PROTOTYPE

SUMMARY

As the CubeSat markets and their applications increase, the need for similar components will continue to increase to keep these projects affordable. This implementation leverages the similarities in most CubeSats by applying a modular approach to the spacecraft main electronics, the motherboard.

The real power of this modular design concept is in giving the engineer a wide variety of design options with a single development environment. The motherboard is not the only component in a spacecraft. By providing a CM that is self-contained and has a standard interface, the engineer can add a radiation hardened, secure, and robust computation element to any subsystem or payload. The only requirement is connecting a CM to an ASDC that was created for the subsystem. In addition, the cost and time to develop a new subsystem is greatly reduced since manufacturing costs for the CM will decrease as more units are fabricated per run. The cost and development time of the ASDCs will also be reduced since the ASDC will be designed to route the connections of the CM that are needed. There is really no limit to what system can take advantage of the CMs features.

This modular approach allows for a radiation hardened single development environment for any size project. For example, a CM can provide a radiation hardened computation solution for an attitude control system ASDC, or an electrical power system ASDC. This modular approach shall significantly reduce development time and increase reliability.

VORAGO TECHNOLOGIES INFORMATION

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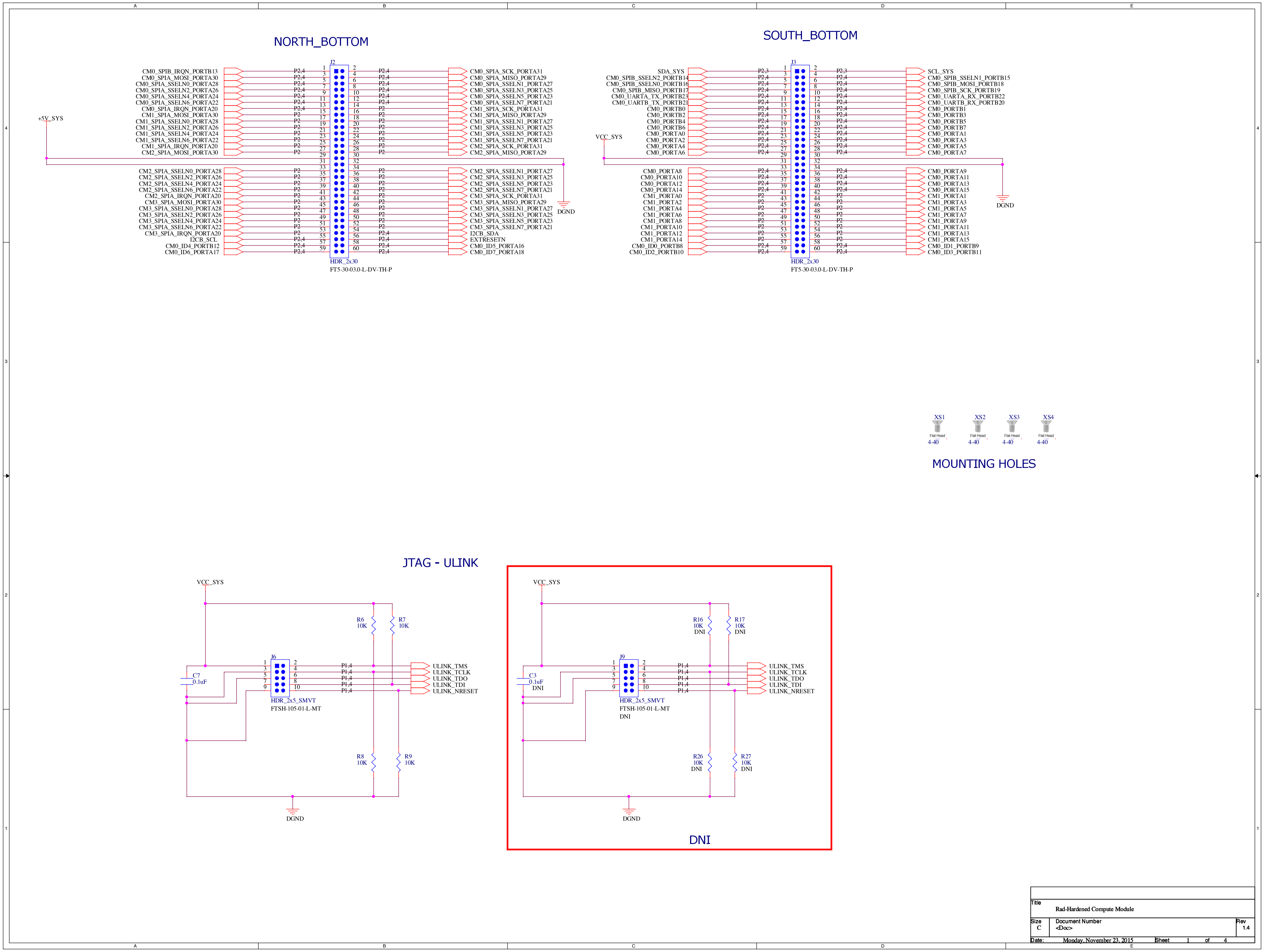
APPENDIX A – BILL OF MATERIALS FOR COMPUTE MODULE

Item Number	Qty	Part Reference	PCB Footprint	Value	Manufacturer	Part#	Part Description	Note
1	2	C1 C7	capc3216x190n	0.1uF	AVX	12061C104KAT2A	CAP CER 0.1UF 100V 10% X7R 1206	
2	1	C2	capc1608x95n	15pF	Murata	GQM1885C1H150JB01D	CAP CER 15PF 50V NP0 0603	
3	1	C3	capc3216x190n	0.1uF	AVX	12061C104KAT2A	CAP CER 0.1UF 100V 10% X7R 1206	Do not populate
4	2	C4 C5	capc1608x95n	10uF	TDK	C1608X5R0J106M080AB	CAP CER 10UF 6.3V 20% X5R 0603	
5	2	C8 C10	capc1608x95n	1uF	TDK	CGA3E1X7R1E105K080AC	CAP CER 1UF 25V 10% X7R 0603	
6	6	C9 C11 C12 C13 C14 C15	capc1608x95n	0.1uF	Murata Electronics	GRM188R71H104KA93D	Multilayer Ceramic Capacitors MLCC - SMD/SMT 0603 0.1uF 50volts X7R 10%	
7	2	J2 J3	CONN_FT-5_2x30_SMVT	HDR_2x30	Samtec	FT5-30-03.0-L-DV-TH-P	Conn High Speed Floating Contact HDR 60 POS 0.5mm Solder ST SMD	
8	2	J4 J5	CONN_FS5_2x30_SMVT	SS_2x30_SMVT	Samtec	FS5-30-04.0-L-DV-TH-K	Conn .5MM HIGH SPEED FLOATING CONTACT SOCKET STRIP	
9	1	J6	CONN_FTSH_2x5_MT	HDR_2x5_SMVT	Samtec	FTSH-105-01-L-MT	CONN HEADER 10POS DL.05" PCB/SMD	
10	1	J7	HDR_THRT_1x2_254	1x2_THRT	Samtec	TSW-102-08-T-S-RA	CONN HEADER 2POS .100" SNGL R/A	
11	1	J9	CONN_FTSH_2x5_MT	HDR_2x5_SMVT	Samtec	FTSH-105-01-L-MT	CONN HEADER 10POS DL.05" PCB/SMD	Do not populate
12	1	OSC1	OSC_4P_JS4	50Mhz	IDT	XLH536050.000JS4I8	OSC 50MHZ SMD	
13	20	R1 R4 R5 R6 R7 R8 R9 R10 R11 R12 R13 R14 R15 R20 R21 R22 R23 R24 R28 R29	resc1608x84n	10K	Panasonic - ECG	ERJ-3EKF1002V	RES THICK FILM 10.0K OHM 1/10W ±1% 0603	
14	4	R16 R17 R26 R27	resc1608x84n	10K	Panasonic - ECG	ERJ-3EKF1002V	RES THICK FILM 10.0K OHM 1/10W ±1% 0603	Do not populate
15	3	R18 R19 R25	resc1608x84n	4.99K	Panasonic - ECG	ERJ-3EKF4991V	RES SMD 4.99K OHM 1% 1/10W 0603	
16	1	U5	QFN40P1600X1600X160-128N	VA10820	VORAGO	VA10820	.40mm pitch 128QFP	
17	1	U7	sop65p490x110-8n	PCA9514ADP,118	NXP	PCA9514ADP,118	IC ACCELERATR I2C HOTSWAP 8TSSOP	
18	1	U8	soic127p600x175-8n	FM25V10-G	Cypress Semicondu	FM25V10-G	IC FRAM 1MBIT 40MHZ 8SOIC	
19	1	U9	TO_252_431	NCP1117DT15G	ON Semiconductor	NCP1117DT15G	IC REG LDO 1.5V 1A DPAK	

APPENDIX B – COMPUTE MODULE SCHEMATIC (NEXT FOUR PAGES)



NORTH_BOTTOM
J2
HDR_2x30
FT5-30-03.0-L-DV-TH-P
+5V_SYS
DGND
SOUTH_BOTTOM
J3
HDR_2x30
FT5-30-03.0-L-DV-TH-P
VCC_SYS
DGND
XS1
XS2
XS3
XS4
4-40
MOUNTING HOLES
JTAG - ULINK
VCC_SYS
C7
0.1uF
J6
HDR_2x5_SMVT
FTSH-105-01-L-MT
R6
10K
R7
10K
R8
10K
R9
10K
ULINK_TMS
ULINK_TCLK
ULINK_TDO
ULINK_TDI
ULINK_NRESET
DGND
VCC_SYS
C3
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HDR_2x5_SMVT
FTSH-105-01-L-MT
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R16
10K
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R17
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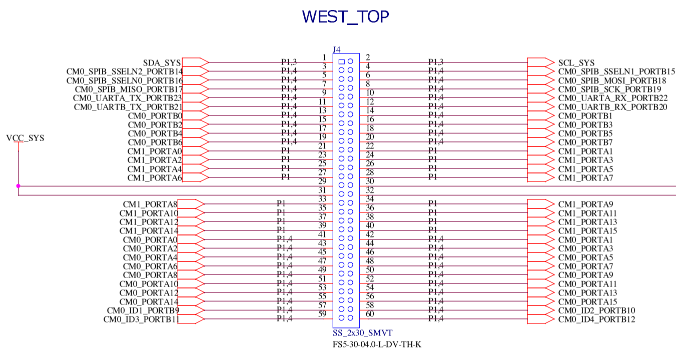

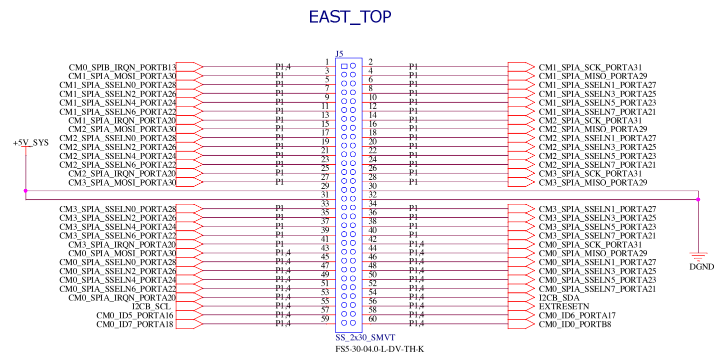

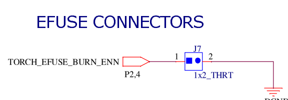

Revisions:

1.0 - Created Schematic
1.1 - Changed 5K to 4.9K
1.2 - Removed one EFUSE
1.3 - DNI JTAG (one)
1.4 - Add 2 0.1uf on 1.5V and 3.3V (VCC_SYS)

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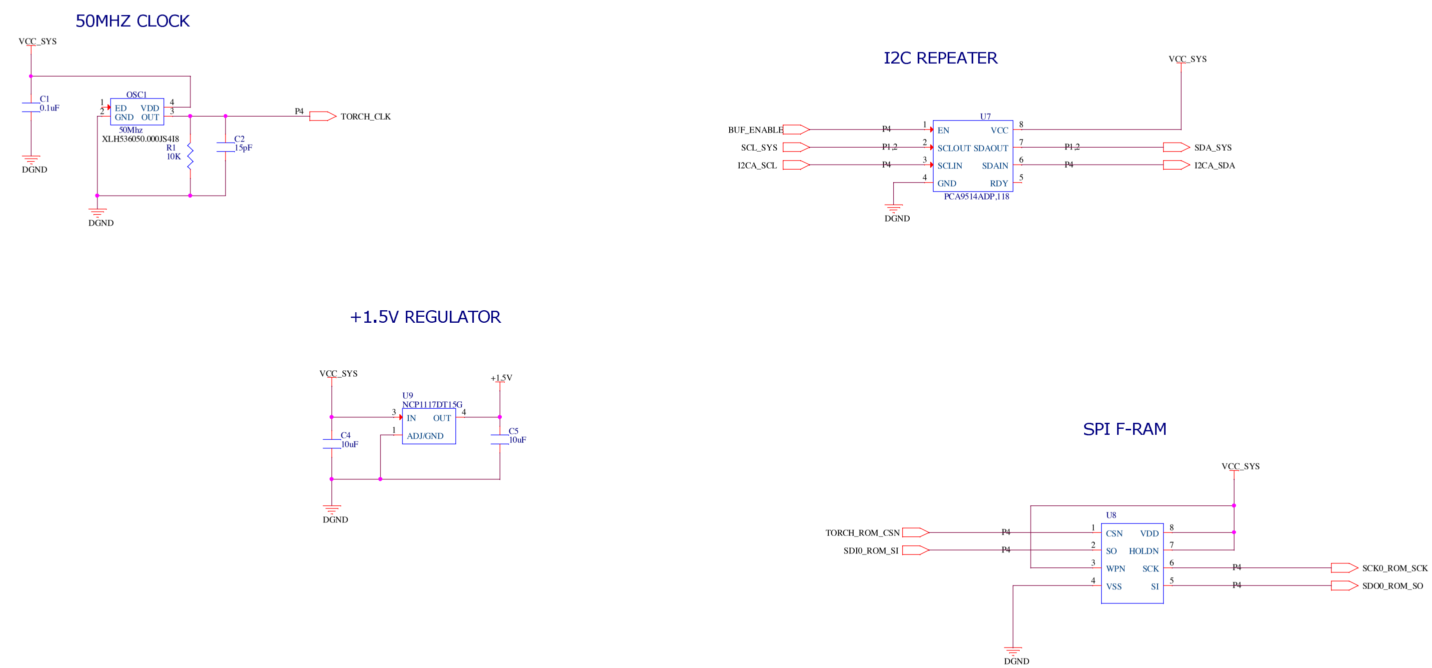
Date: Monday, November 23, 2015	Sheet 2 of 4	



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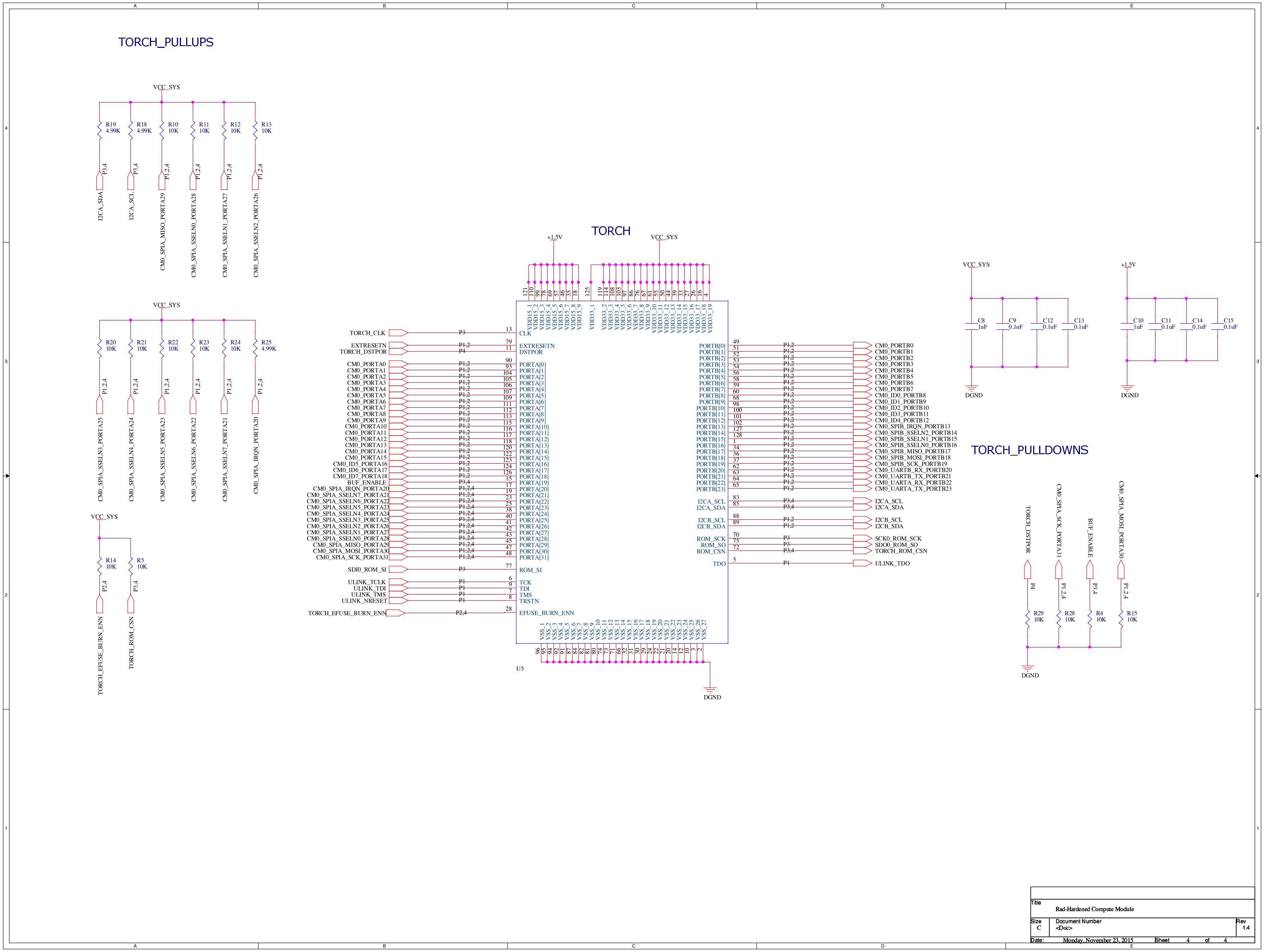

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