Onboard communication systems for low cost small Satellites

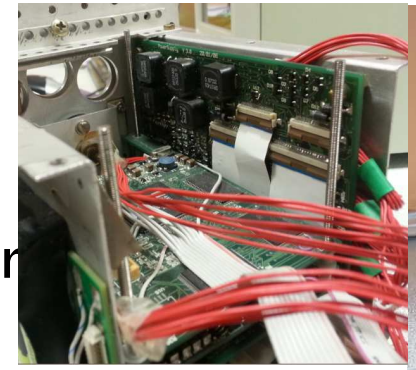
Muhammad Rizwan Mughal

Tutor: Prof. Leonardo M. Reyneri

Problem Statement

- Nowadays the biggest challenge to space industry is to design space systems
  - Cheaper-Lower the mission cost
  - Faster-Lower the design and implementation time
  - Better- Keep a high quality standard and achieve most mission targets

- How to achieve this Cheaper-Faster-Better philosophy?
  - Scale down the satellites
  - Simplify their design
  - Reduce Power and data har
  - Simplify their testing



Undesirable

Desirable

Outline

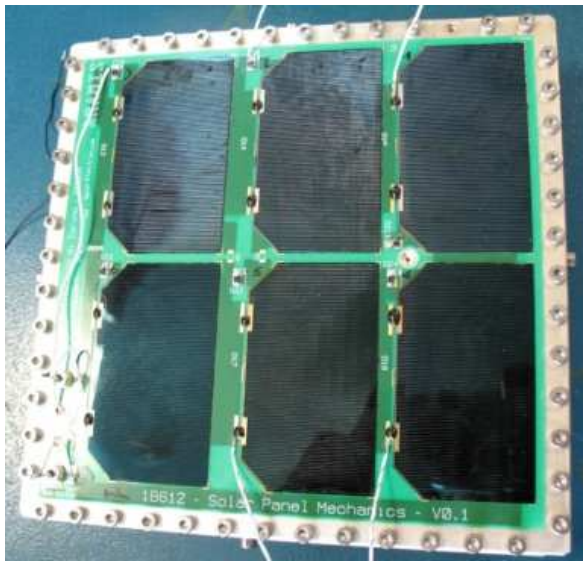
- AraMiS Project
- Concept of tiles
- Smart Harness
  - Embedded and smart harness
  - Module Life cycle
  - Spacecraft configurations
  - Test board for functional testing
- Inter-tile Communication
  - Module design: Wired inter-tile communication
  - Module design: Optical Based communication
  - Module design: Radio Frequency Based communication
- Conclusion

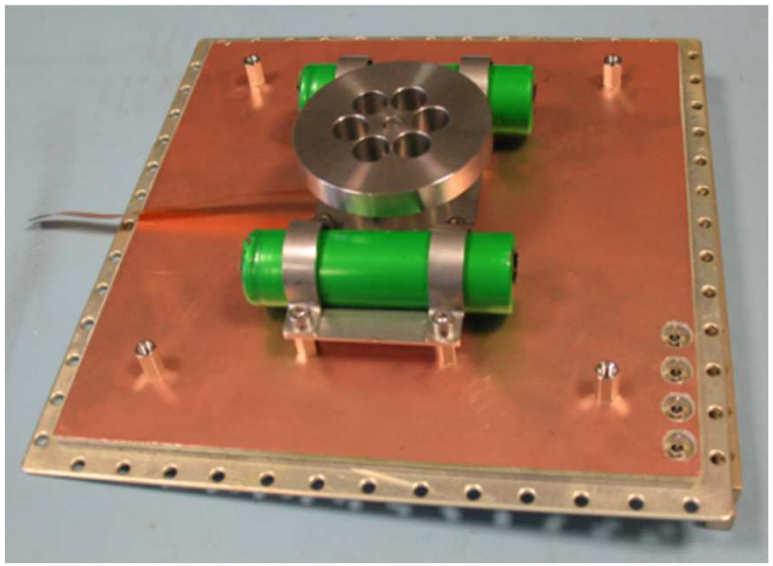
ARAMIS Project

- ARAMIS (Modular Architecture for Satellites) is an innovative modular architecture for flexible and more demanding satellite configurations.
- Panel bodies or tiles
  - Different size and technology
  - Power and data standardized interfaces
- Modularity
  - Mechanical, electronic and testing level
- Low cost
  - Design, qualification and test cost shared among multiple modules
- Mostly LEO Satellites (600 – 800 km)
- The size of the satellite varies based on payload demands

Hardware Architecture of Tile (1)

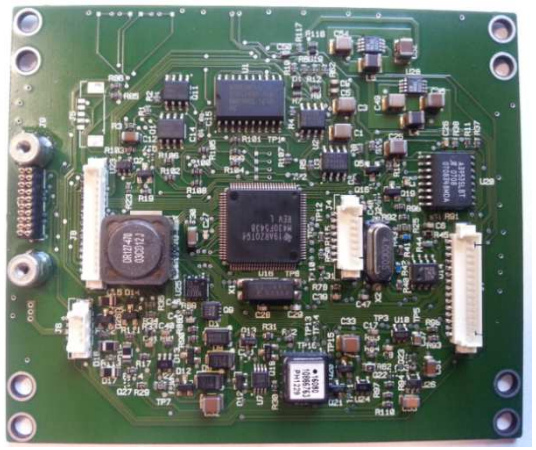
- Single-size Al: 16.5x16.5 cm^2 tile, a 1.6mm thick monolithic Aluminum structure, for cheaper and smaller configurations

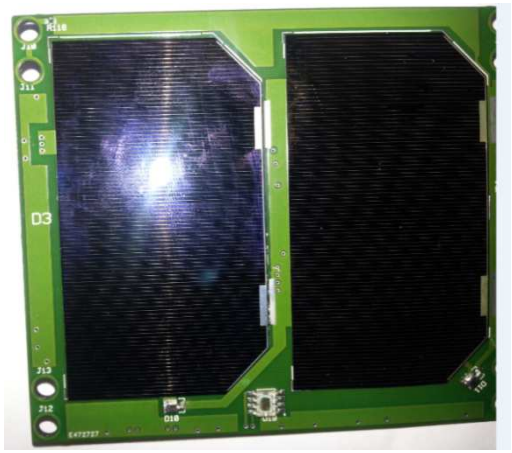




Hardware Architecture of Tile (2)

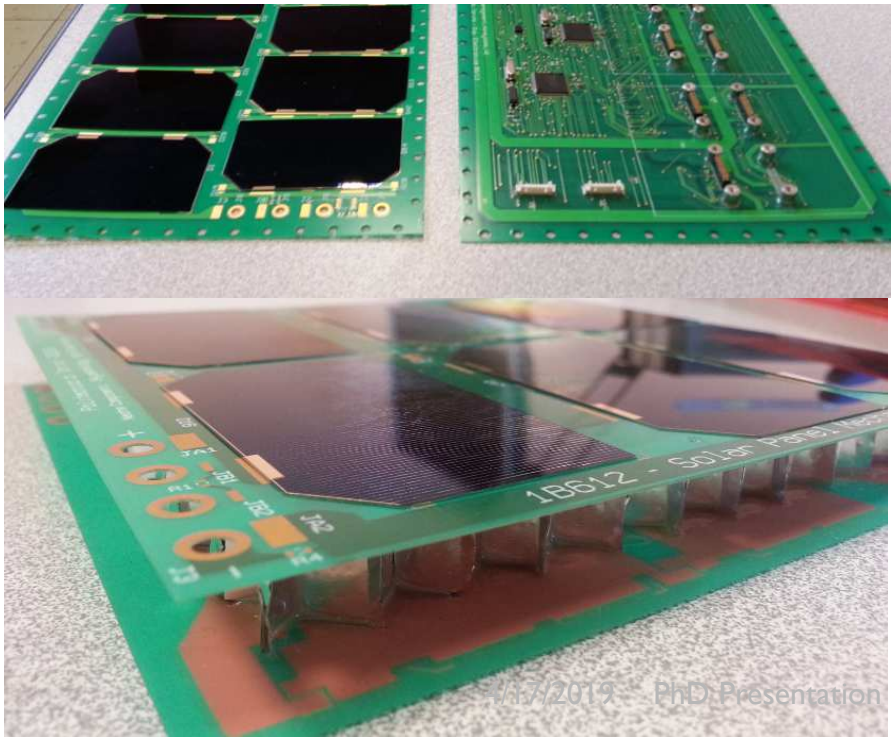
- CubeSat standard: (8.25 x 9.8cm^2) tile, with all electronic components integrated and compatible with CubeSat dimensions.
- All structure on PCB only
- All the subsystems integrated on each tile





Hardware Architecture of Tile (3)

- Honeycomb Structure: 16.5x33 cm^2 tile, with 10mm thick honeycomb structure for more rigid and larger structures



Smart harness

Plug and Play Modules

Spacecraft configurations

Physical Module based configuration: Honeycomb tile

Functional Test board

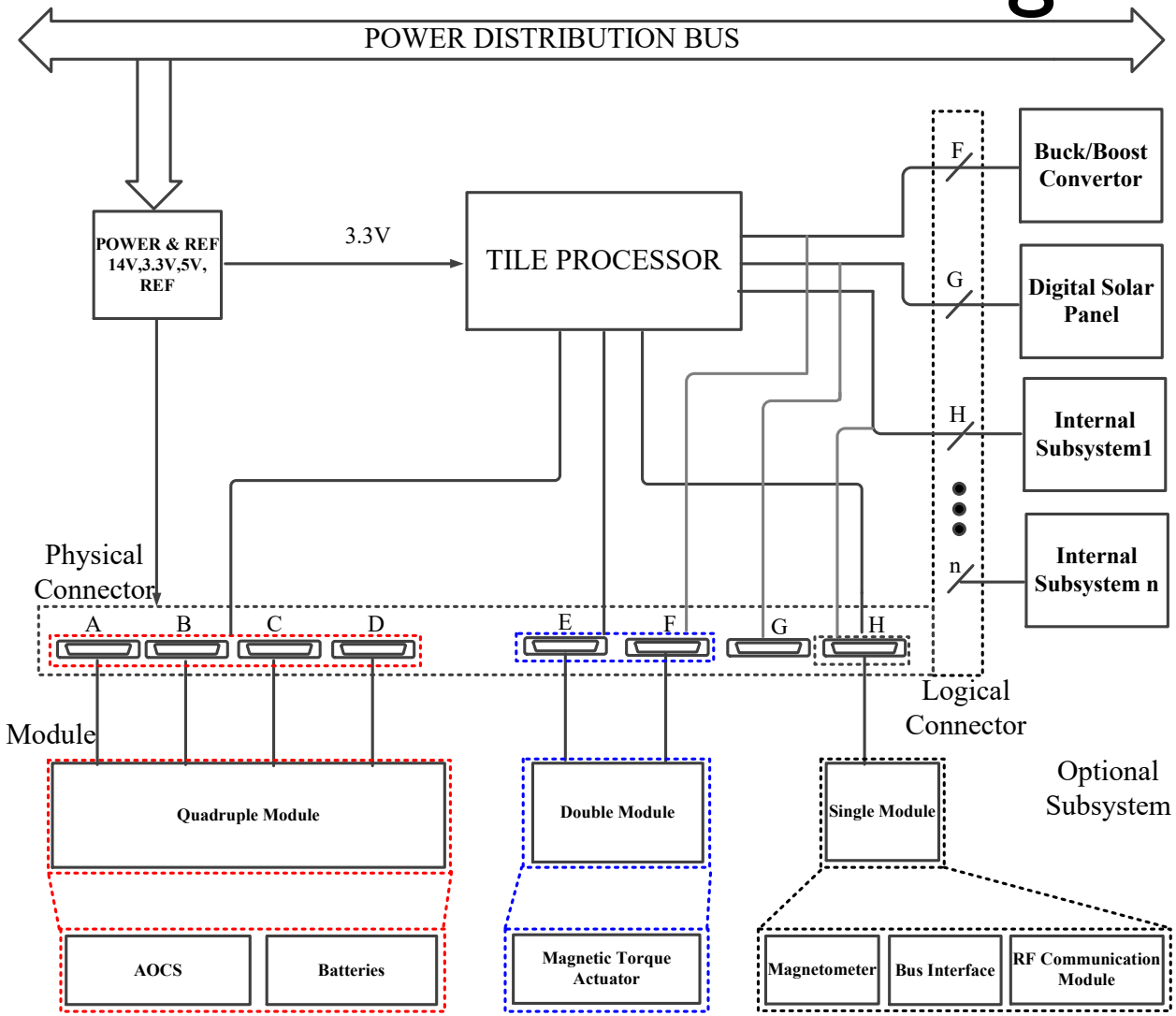
Embedded harness

- Distributes electrical power and data signals all around the spacecraft and payloads by
  - Minimizing power and data harness complexity
  - Reduction in harness mass by distributing power and data signals embedded in the printed circuit board
  - Embedded signals interfaced to other panels by
    - Multiple board to board connectors
  - Processing done by the central processor
  - Some space systems already employ this scheme. [1]

Smart Harness

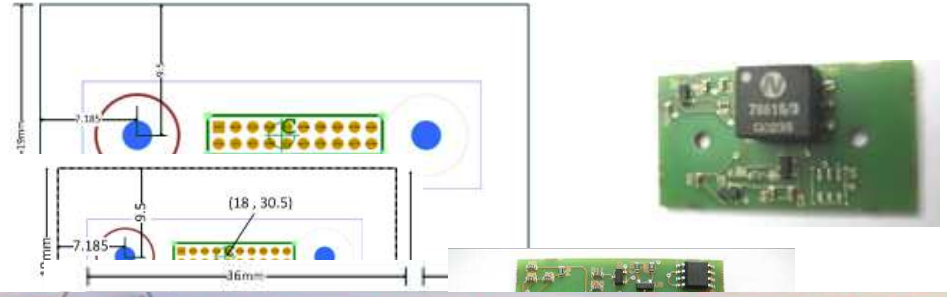
- Minimize Power, data, RF harness with additional signal processing capabilities.
  - Tiles: provide power, data standardize interfaces
  - Tile Processors: on every tile
    - Signal processing capabilities at tile level
  - Every subsystem is housed in small daughter boards pluggable on tiles
    - Internal subsystems interfaced with tile processors using slots
    - External subsystems interfaced with tile processors using pluggable connectors

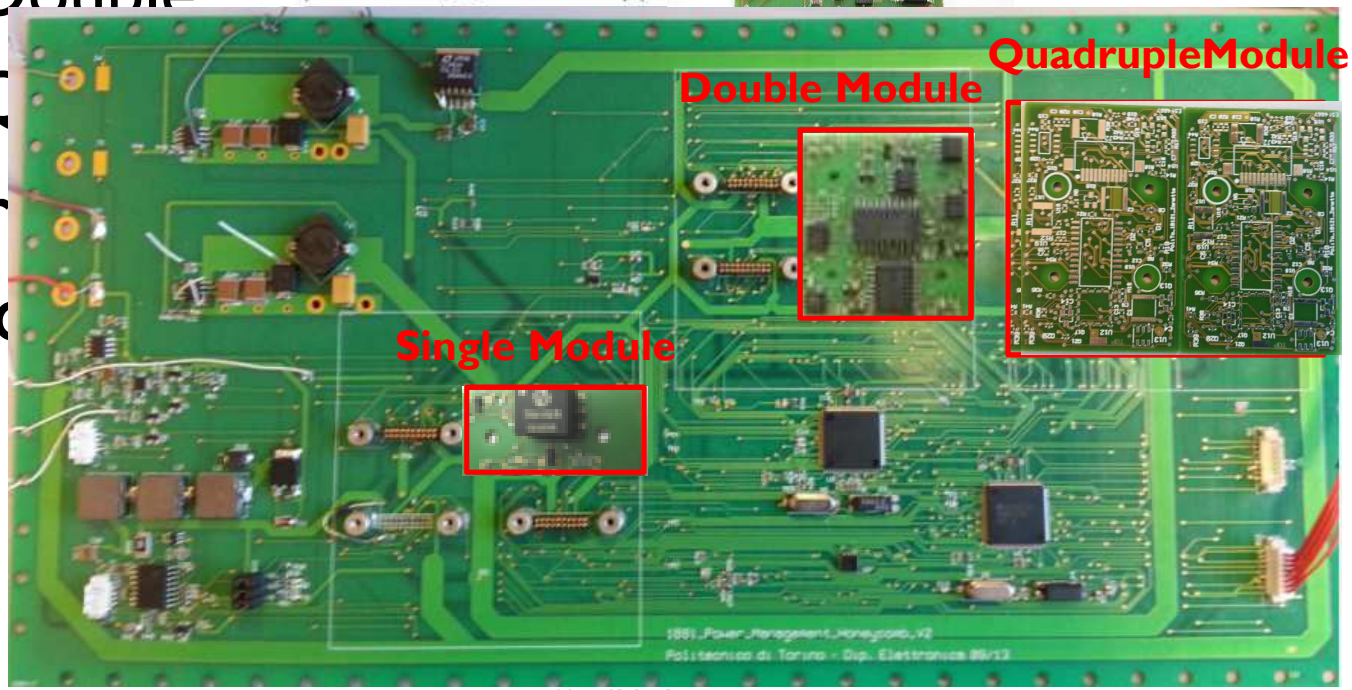
Smart Harness: Block Diagram



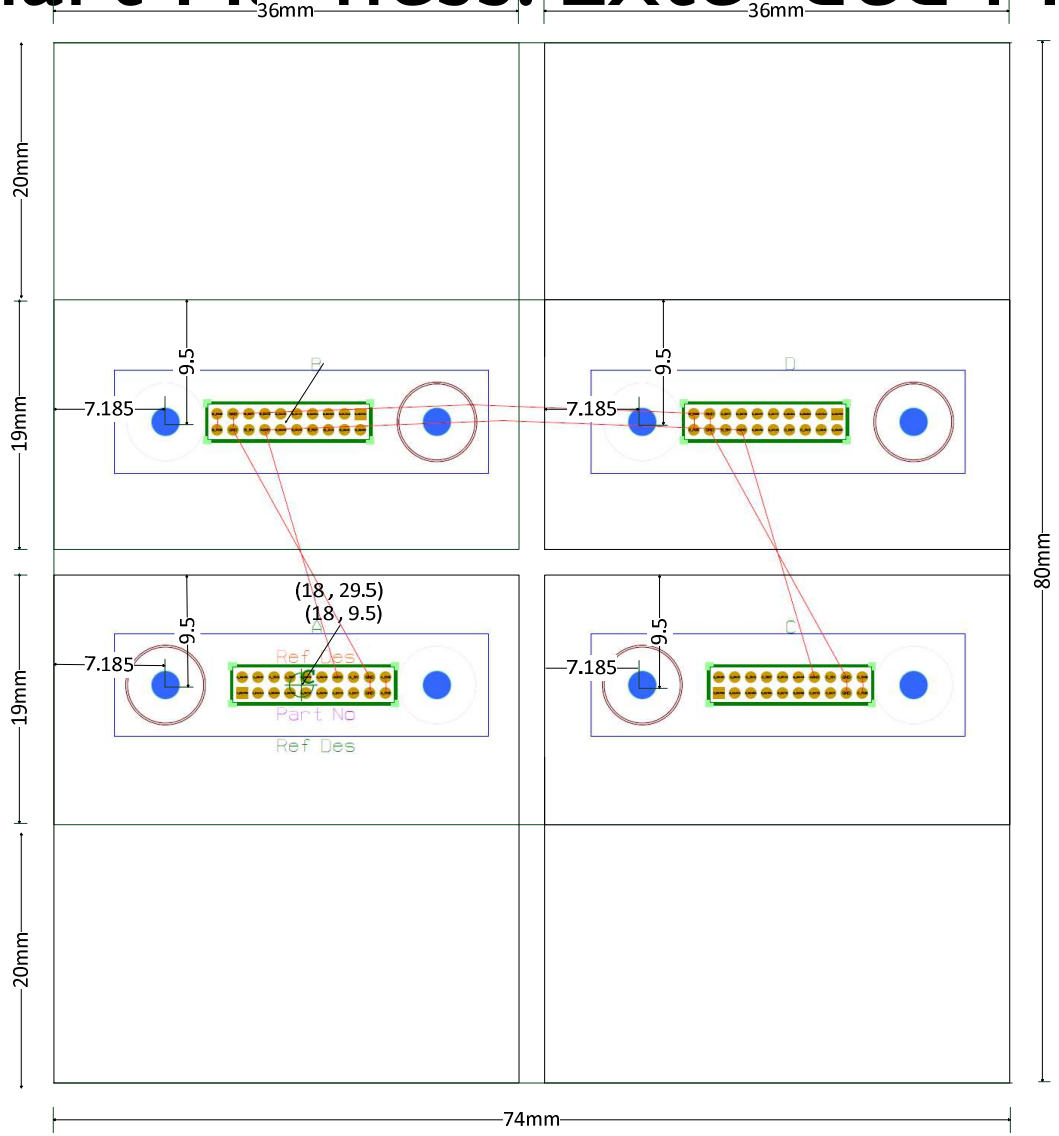
Smart Harness: Subsystem Modules

- Three types of daughter board modules on each t
  - Single
  - Double
  - C
- Spr
  plac

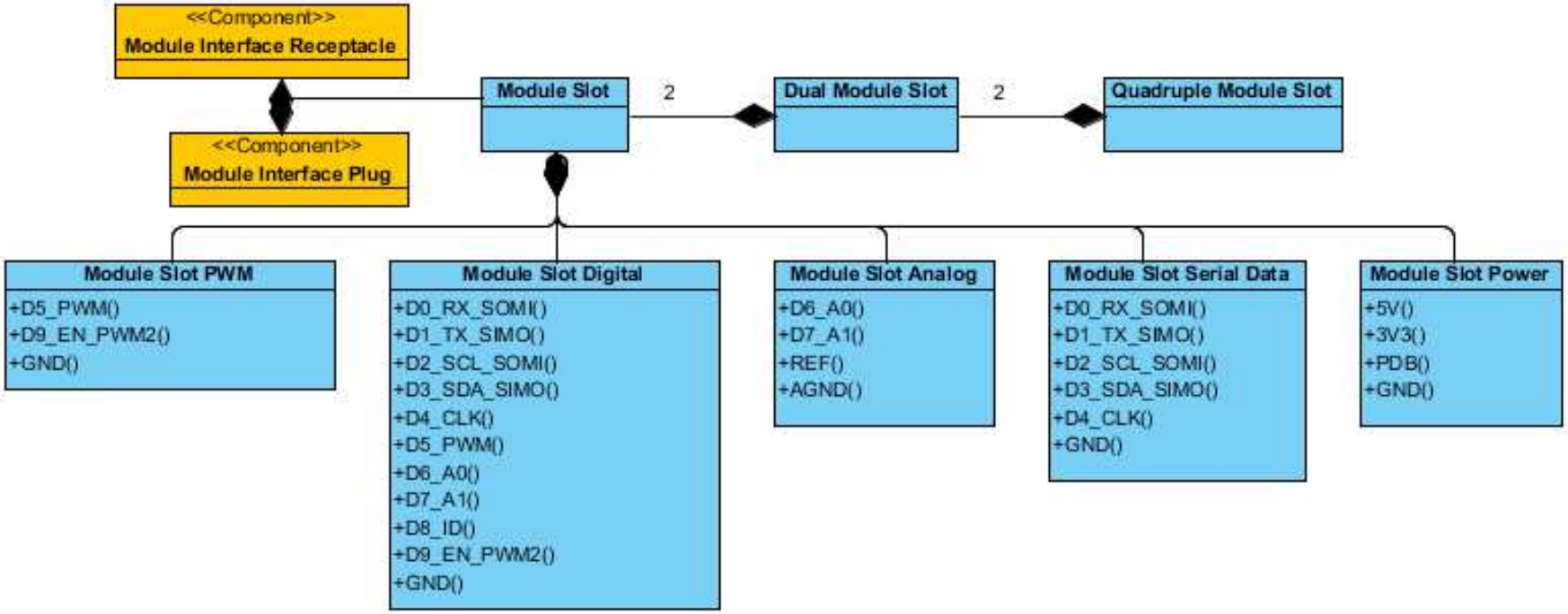




Smart Harness: Extended Modules



Smart Harness: Module Electrical Interface



Smart Harness: Module Slot Serial Data

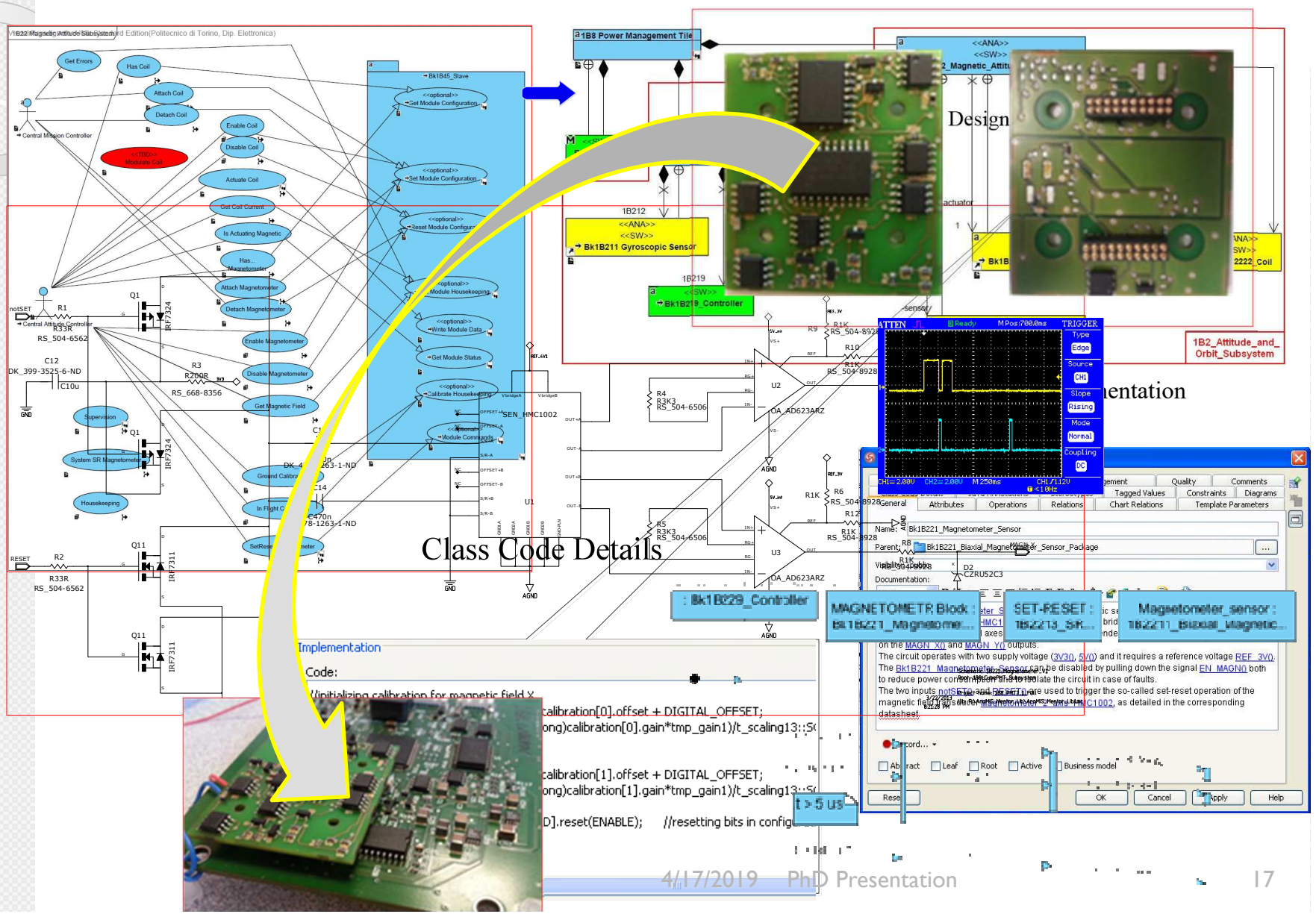
- RS232 signals on Odd Modules only (i.e. modules A, C, E, G)
- I^2C signals shared in pairs i.e.
  - connectors A, B share same I^2C channel
- SPI signals on Even Module (module B, D, F, H)
- Odd numbered module can be configured for SPI if not configured for RS232 mode

	A	B	C	D	SPI (O)	SPI (E)	I^2C	RS232 (O)
D0/RX/SOMI	SOMI / RX	TA1.2	SOMI / RX	TA0.1	✓			✓
D1/TX/SIMO	SIMO / TX	TA0.0	SIMO / TX	TA0.2	✓			✓
D2/SCL/SOMI	SCL	SCL / SOMI	SCL	SCL / SOMI		✓	✓	
D3/SDA/SIMO	SDA	SDA / SIMO	SDA	SDA / SIMO		✓	✓	
D4/CLK	CLK	CLK	CLK	CLK	✓	✓		
D5/PWM	TB0.0	TB0.1	TB0.2	TB0.3				
D6/A0	A0	A2	A4	A6				
D7/A1	A1	A3	A5	TB0CLK/ SMCLK				
D8/ID	TA0CLK/ ACLK	TA0.1	TA0.3	SMCLK				
D9/EN	D9	TA1.2	D9	TA0.1				

Smart Harness: Module Life Cycle

- UML to define, specify, design, implement, test and document a complete subsystem.
- Define intended functions: Use case diagrams
- Define electrical and functional requirements: Requirement diagrams
- Electrical/software/Mechanical design: Class diagrams
  - Code details: Software (SW) class
  - Schematics : Hardware (HW) class
  - Mechanical details: Mechanical class
  - Component selection: Component class
- Testing design: Sequence diagram
- Manufacturing: Commercial CAD tools
- Real Testing
- Redesign
- Production
- Integration

Smart Harness: Module Life Cycle



Smart harness

Plug and Play Modules

Spacecraft configurations

Physical Module based configuration: Honeycomb tile

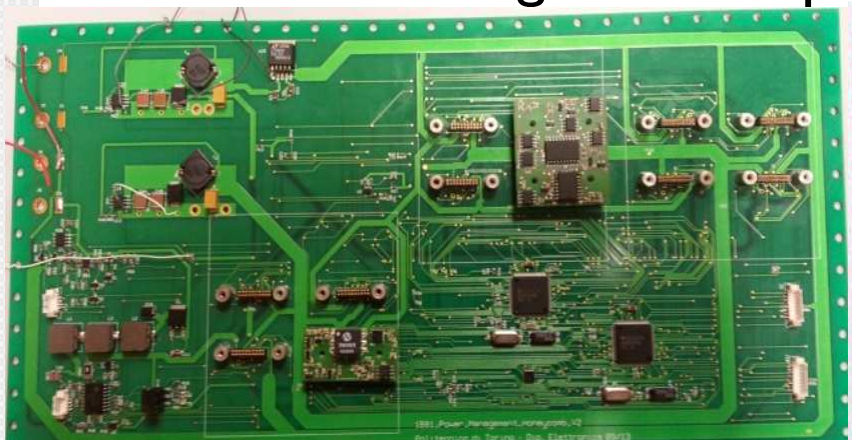
Functional Test board

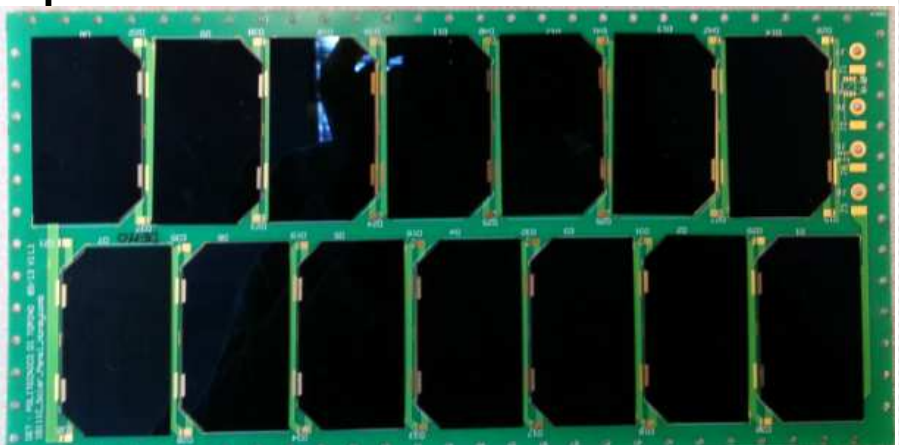
Smart Harness: Spacecraft Configurations

- Design the new subsystems either on single, double or quadruple module configuration.
- Test the subsystems on ground using development board.
- Integrate each physical module in a physical module based satellite configuration.
- Embed the logical modules in the main tile for a Satellite on demand configuration.
- The Satellite on demand configuration can be altered very easily for Reusable design configuration

Physical Module Based Configuration

- Develop standard tiles hosting multiple connectors
- Physical daughter boards connected to the tile via pluggable connectors
- The subsystem module only plugged if mission needs it.
- High level of design flexibility, testability and upgradability
- Testing of modules, tiles and whole satellite is needed
- For teaching/research purposes





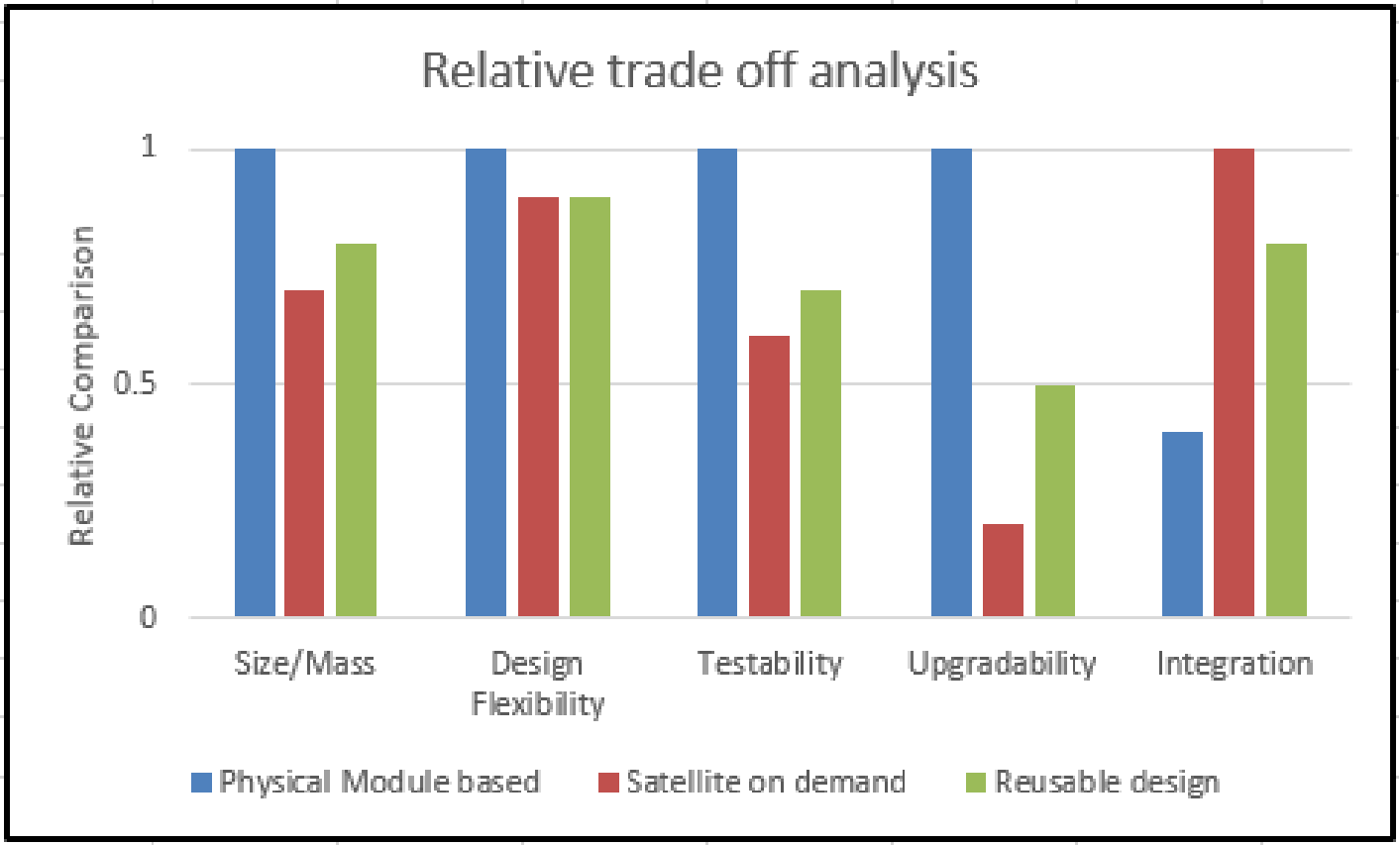
Satellite on demand Configuration

- Already tested modules integrated inside the PCB.
- Reusability of physical subsystem modules
- Permanent configuration
- Testing of modules: not required
- Testing of tiles and mission is required only
- CubeSat standard tile built using this approach

Reusable design configuration

- Optimised spacecraft configuration based on customer requirements
- Reuse of the satellite on demand configuration
- Minor addition or removal of subsystems on customer demands
- Follows the Cheaper-Faster-Better philosophy
- Module and tile testing: not required
- Only mission testing is needed for this configuration

Smart Harness: Design trade off



Smart harness

Plug and Play Modules

Spacecraft configurations

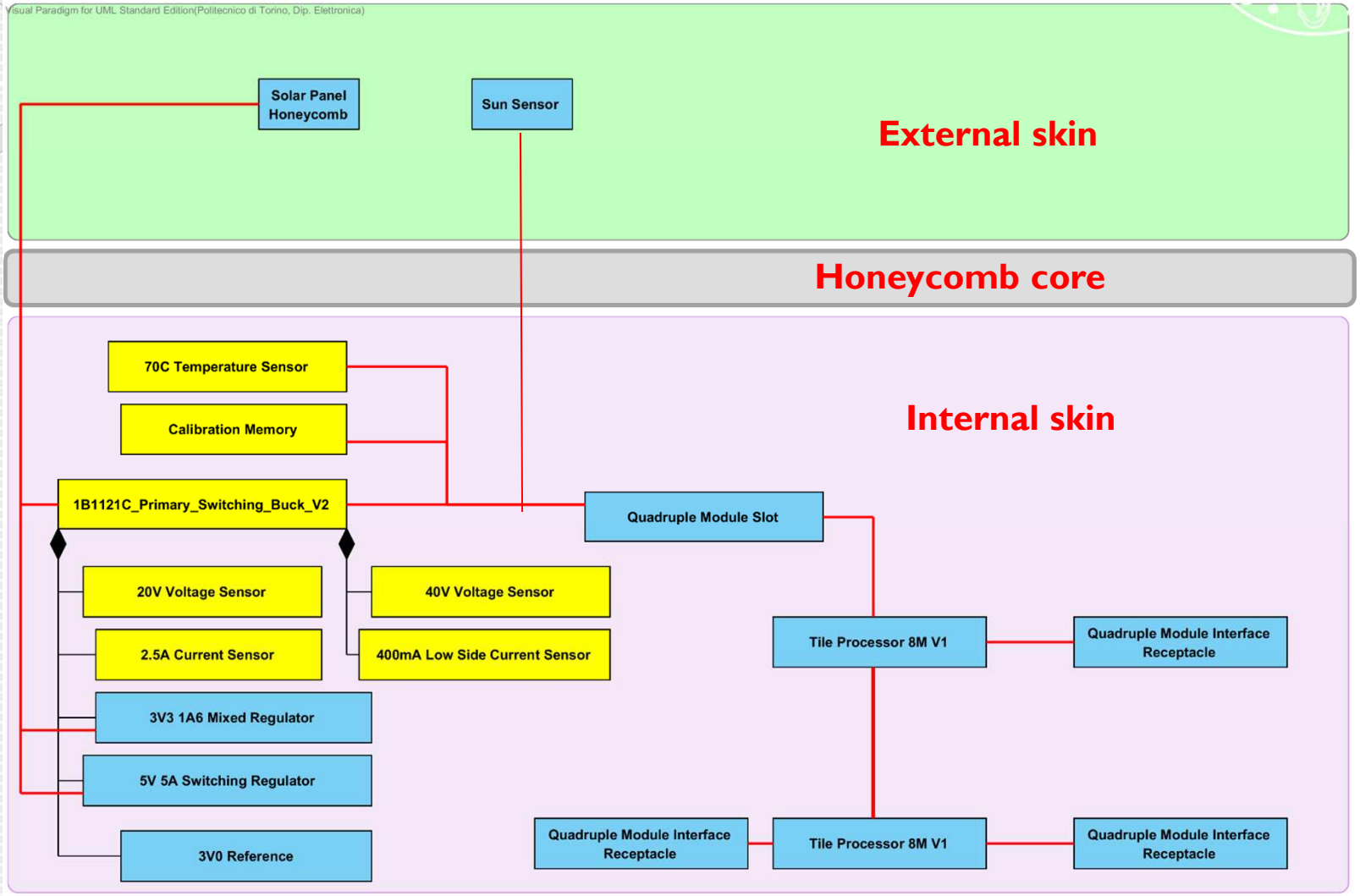
Physical Module based configuration: Honeycomb tile

Functional Test board

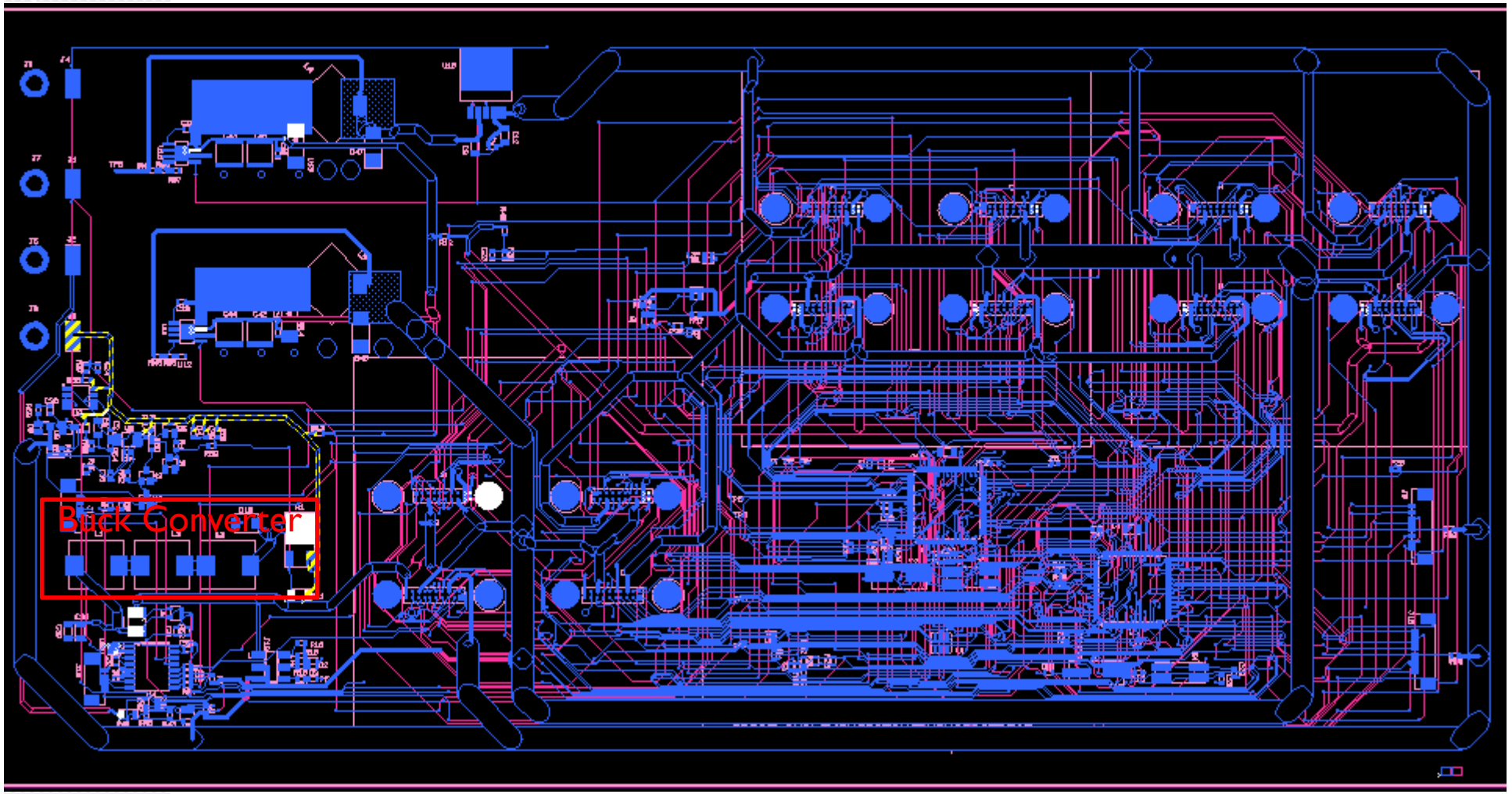
Honeycomb Tile

- Sandwich structure for lighter and more rigid spacecraft configurations.
- Honeycomb core: integrated between two lateral FR4 PCB skins
- Solar cells: 14 solar cells in series achieving 30.8V, 0.4A current and 12.32W output power.
- Tile processors: two MSP430F5438
- Module interface: Tile processor signals interfaced to slots and connectors
- Primary switching: MPPT Buck converter to achieve power distribution bus (PDB) level.
  - Regulators: 5V, 3.3V,3.0V
  - Sensors: Temperature (-30 to+70), voltage, current and sun sensors

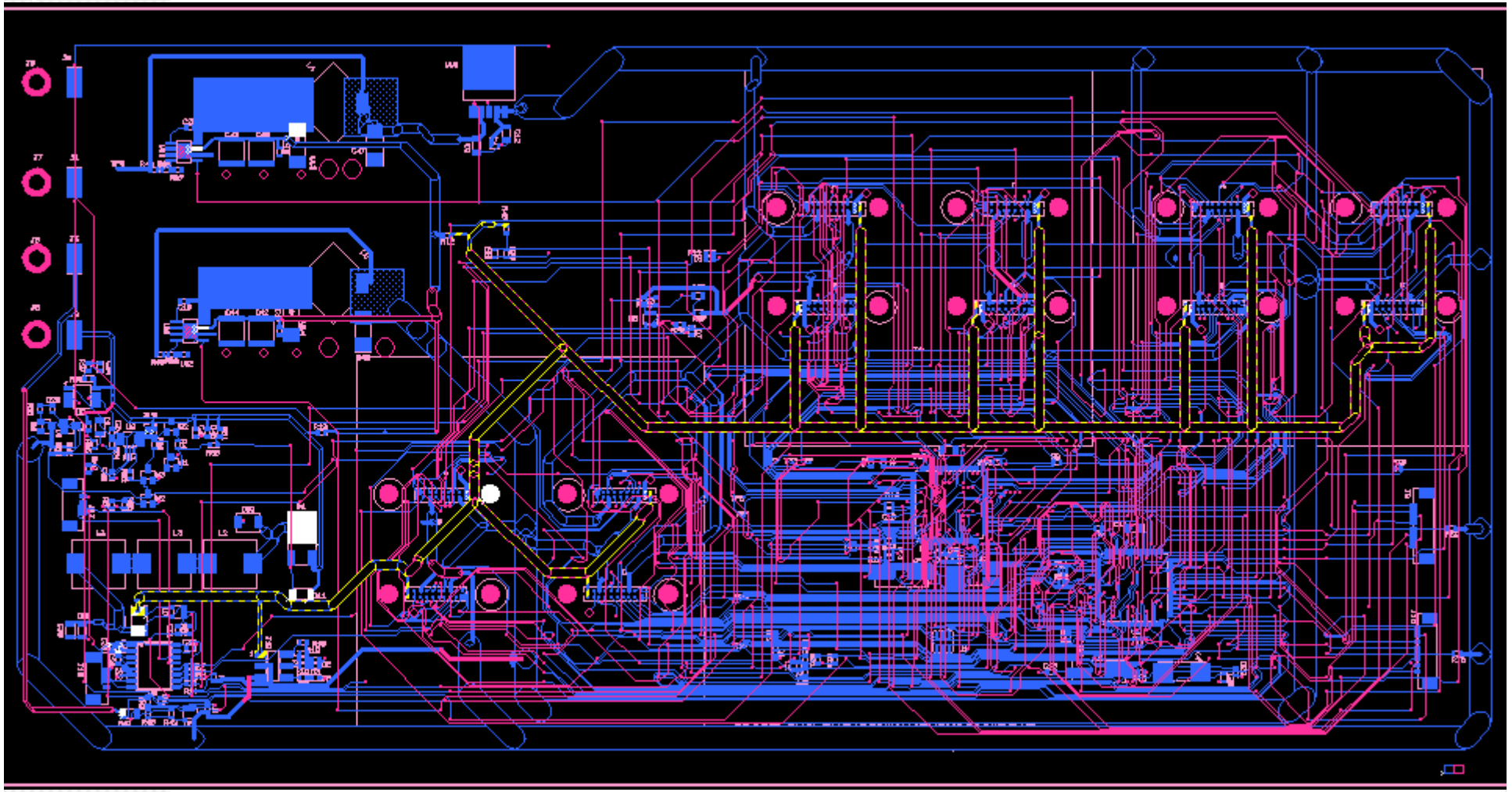
Honeycomb Tile



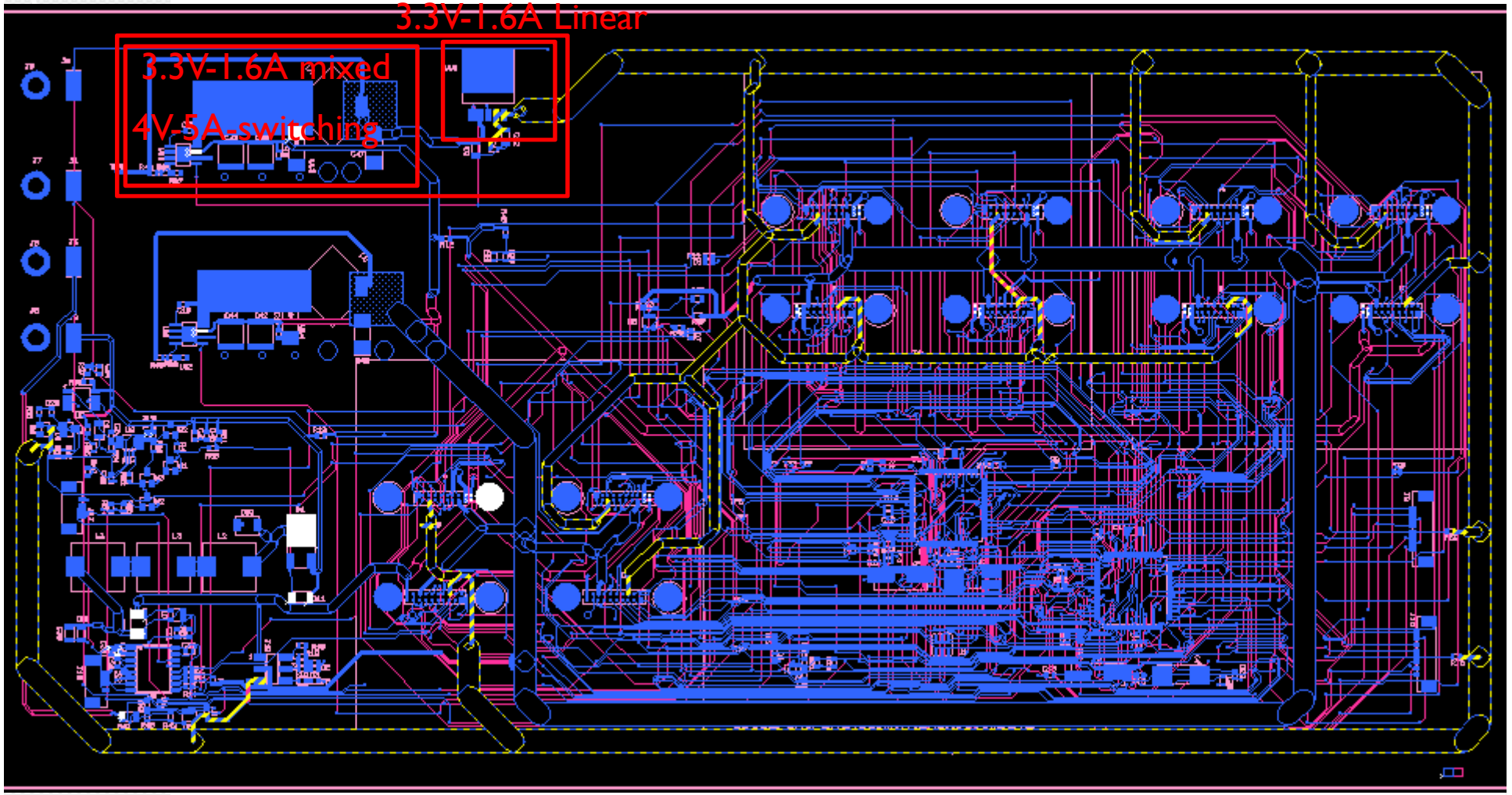
Honeycomb Tile-Solar In



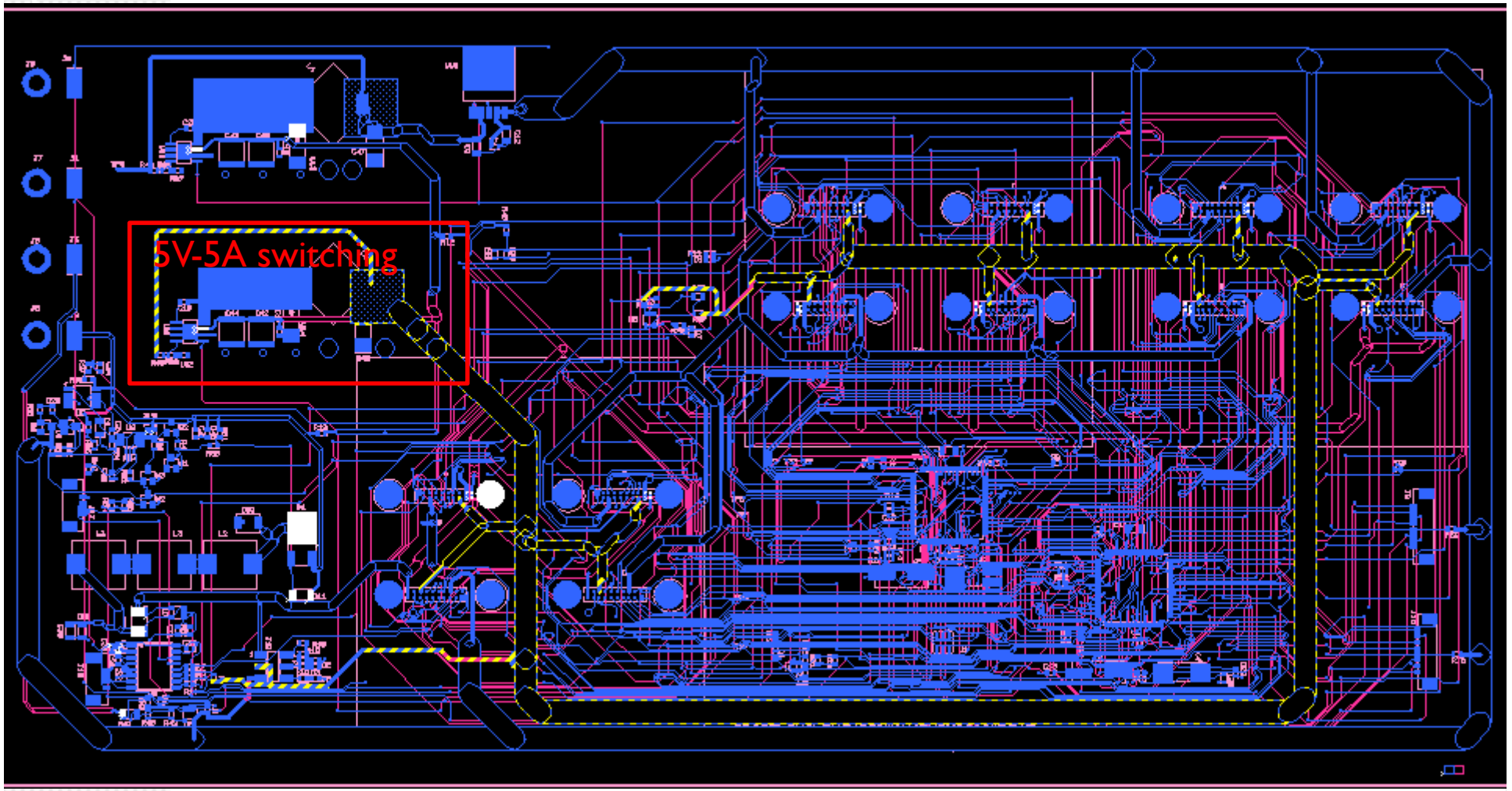
Honeycomb Tile-PDB (14-16 V)



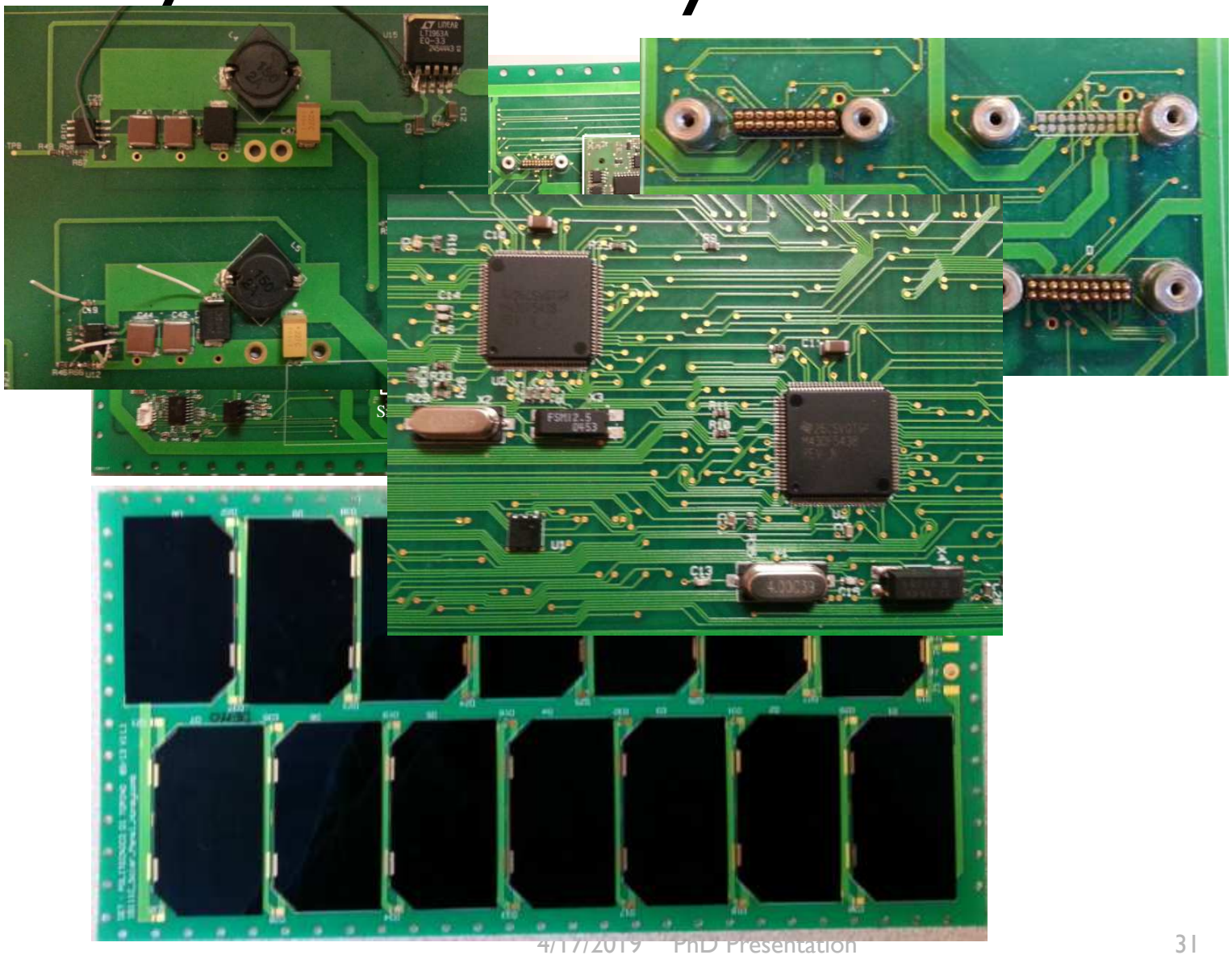
Honeycomb Tile-3.3V



Honeycomb Tile-5V



Honeycomb Tile-Physical view



Smart harness

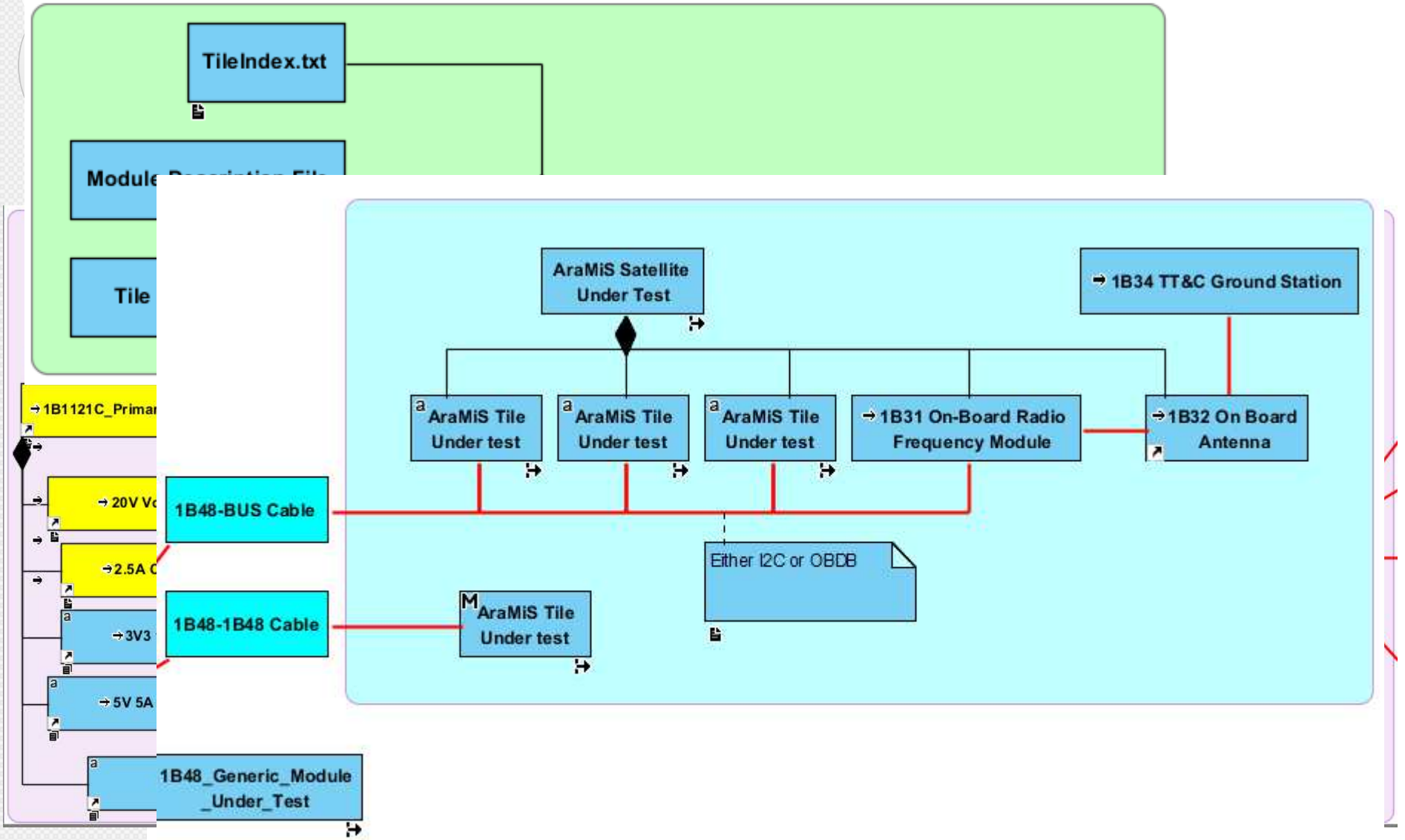
Plug and Play Modules

Spacecraft configurations

Physical Module based configuration: Honeycomb tile

Functional Test board

Smart Harness: Functional Test Board



Inter-tile Communication

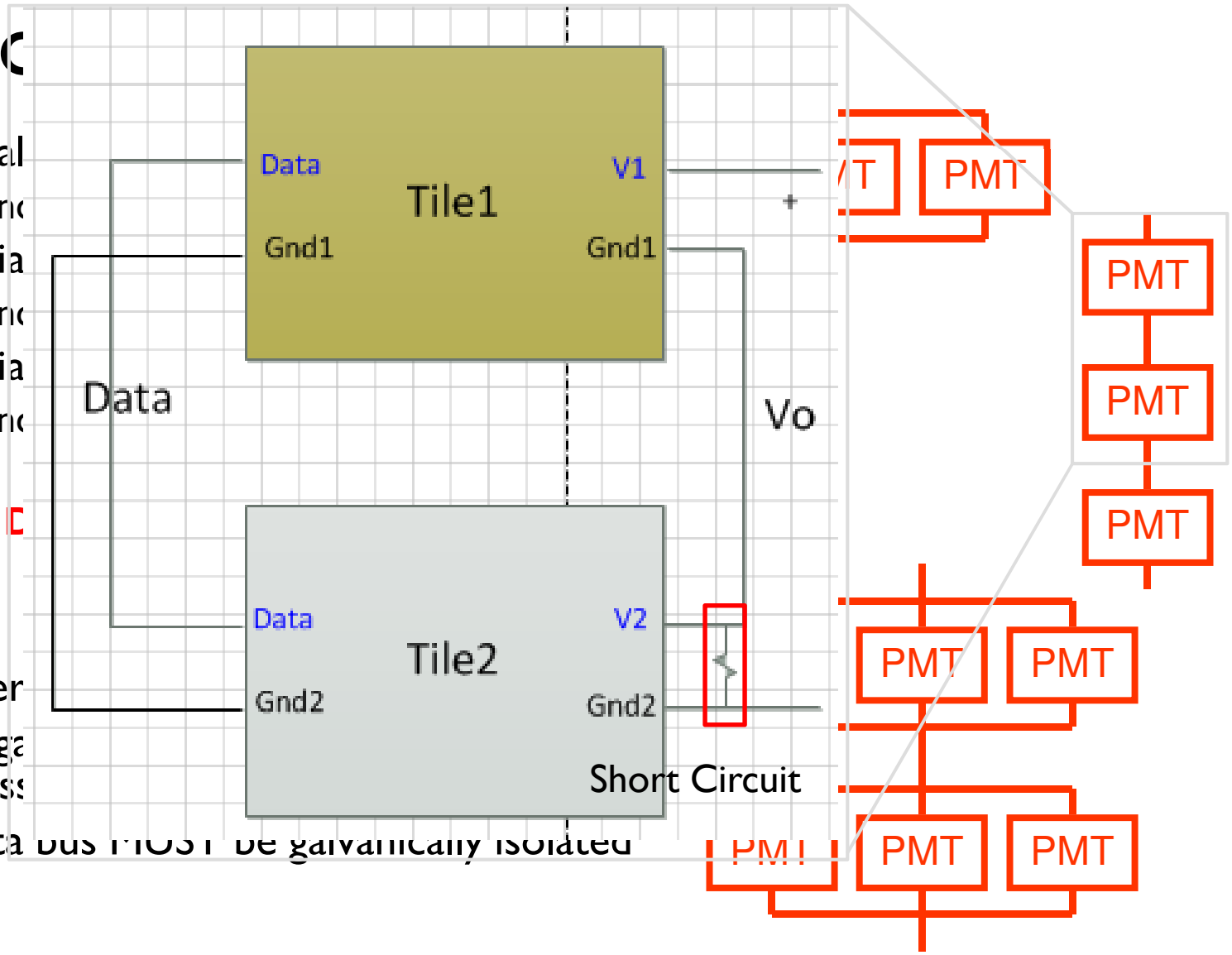
Module design: OBDB interface

Module design: Optical based

Module design: Radio frequency based

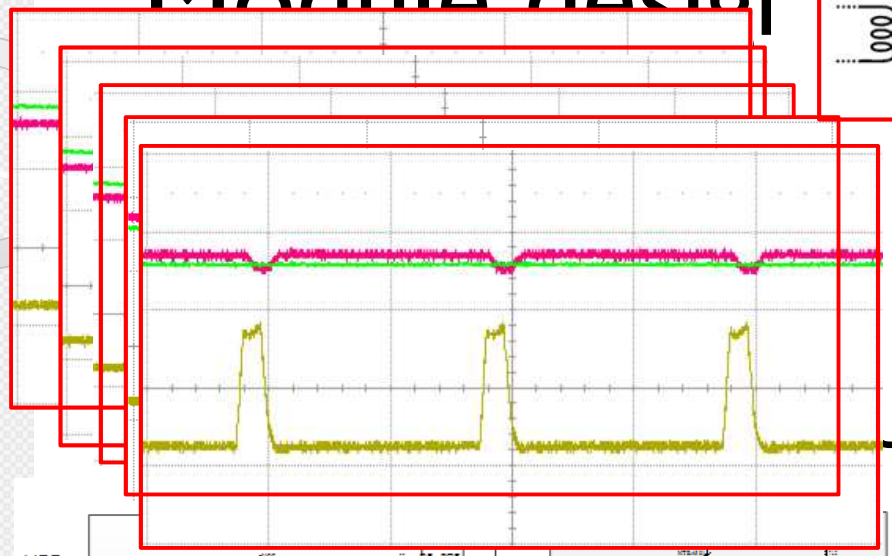
Co

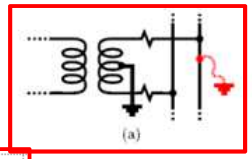
- Paral
  - Inc
- Seria
  - Inc
- Seria
  - Inc
  - D
- Ther
- Nega chass
- Data bus MUST be galvanically isolated

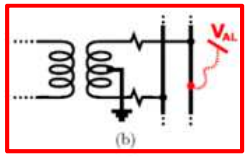


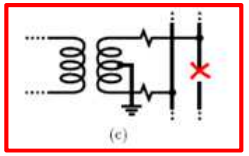
Module Design: OBDB interface

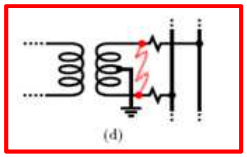
Module desig

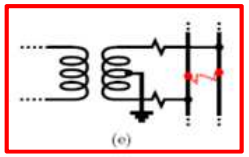


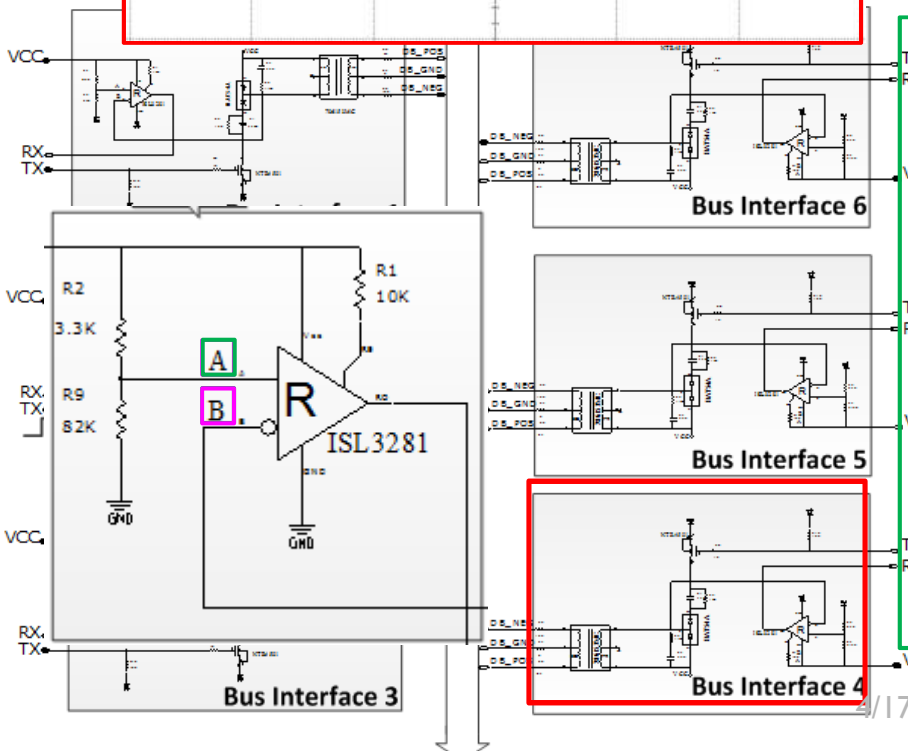












Fault (a)	Fault (b)	Fault (c)	Fault (d)	Fault (e)
2.85V	2.80V	2.85V	3.1V	3.25V
2.5V	2.5V	2.5V	2.5V	2.5V
2.85V	2.85V	2.8V	2.7V	3.15
2.9V	2.85V	2.8V	0V	3.2V
2.9V	2.85V	2.8V	2.7V	3.0V
2.9V	2.85V	2.8V	2.7V	3.0V

Inter-tile Communication

Module Design: OBDB interface

Module Design: Optical (Free space and Glass based)

Module Design: Radio Frequency

Module Design: Optical

- No harness mass
  - To save cost and simplify integration
- Low datarate (~ 1Mbps)
  - Mainly for housekeeping and low-end payloads
- Insensitive to VHF or S-band noise
  - Should not be disturbed by on-board transceivers
- Short communication distance
  - Maximum 2 ÷ 3 m
- Low power consumption
  - Limited power budget

Commercial Devices

- Integrated Transceiver Modules

- Integrated Transceiver Controllers

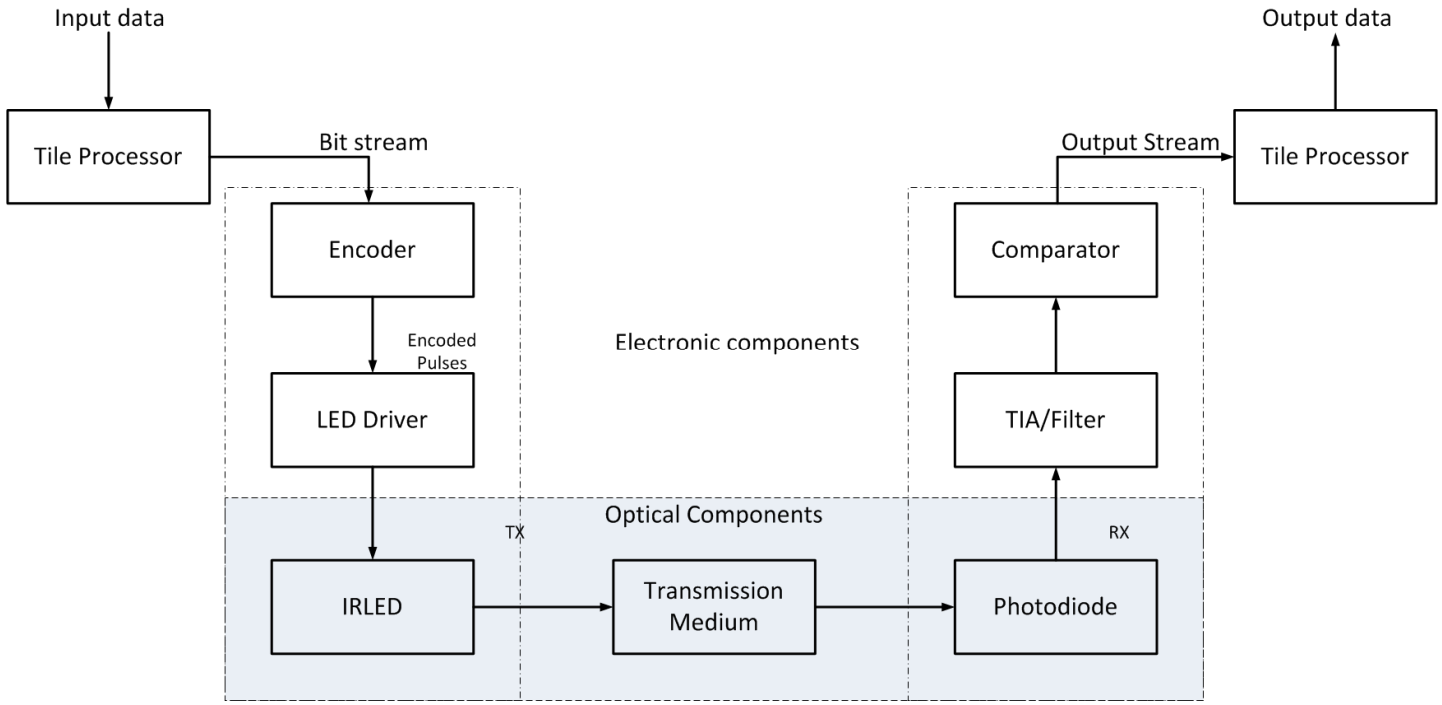
+ Low Power Consumption, Fast development time, Low Cost, Small Size

- Lack of Flexibility, Radiation testing complexity

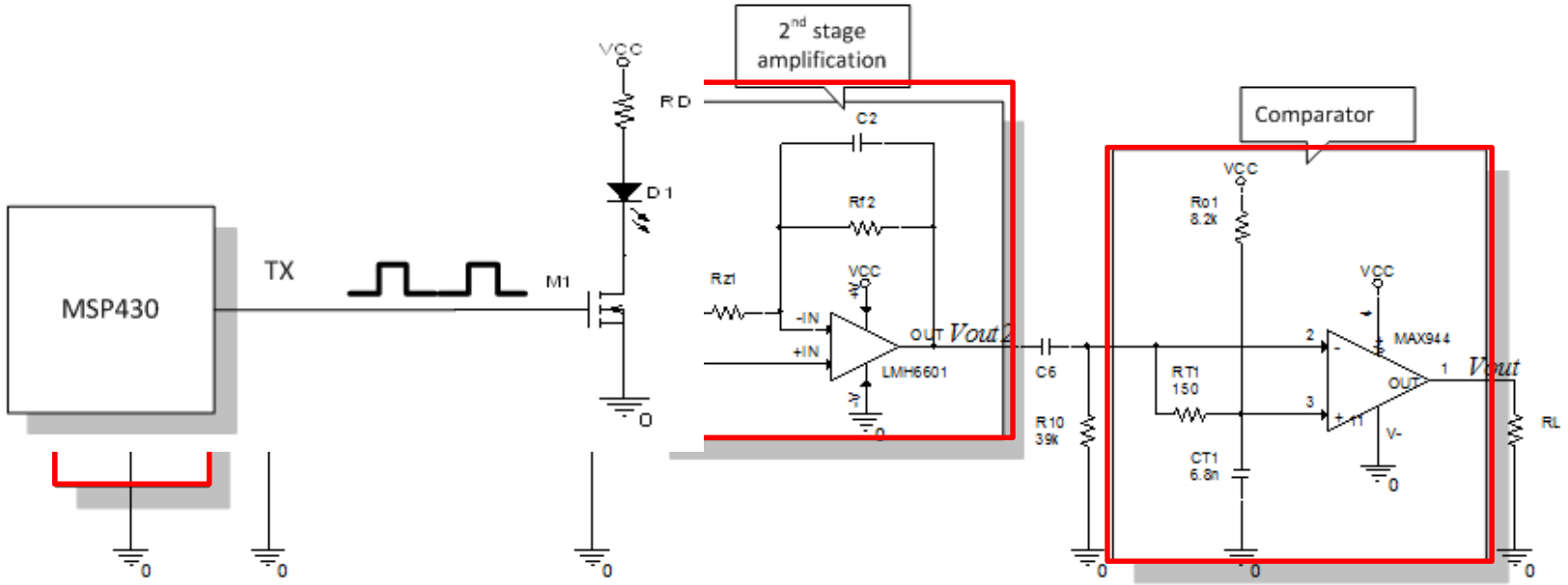
Our Solution - IrDARAMIS

- Develop an electronic front-end
  - + Flexibility in data rate and modulation
  - + Flexibility in component selection
  - - Longer development time
- Use a microcontroller to implement protocol stack
  - + Easy to implement and modify
  - + User selectable encoding scheme

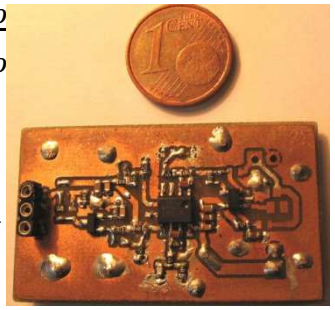
Inter Tile Communication: Optical Based



Optical Based: Transceiver Design

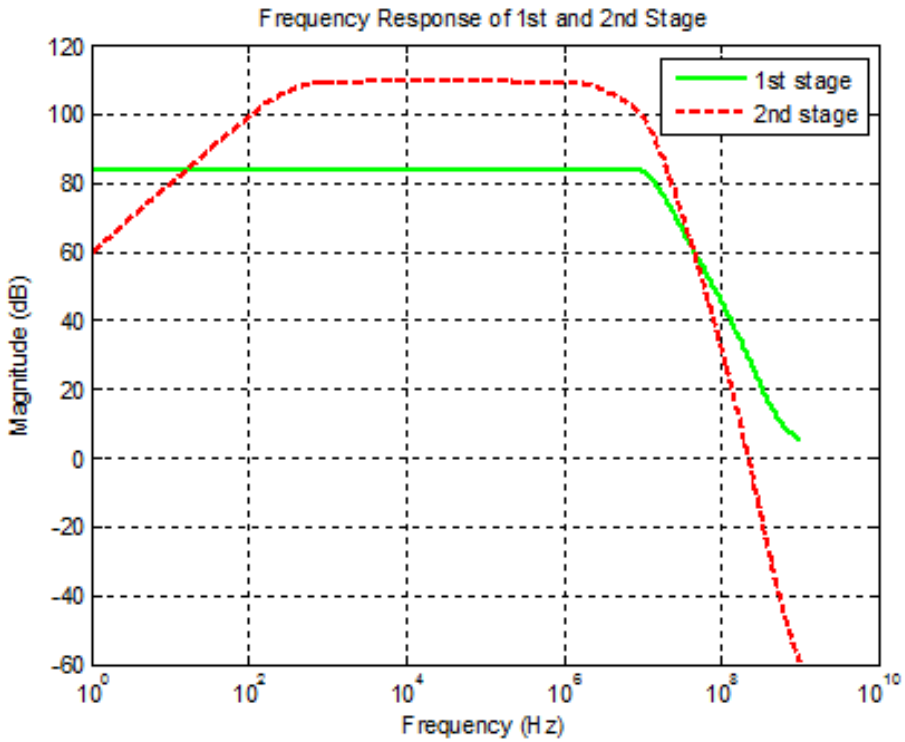


- First Stage TIA: $H_1(s) = -\frac{V_{out1}}{I_{in}} = -\frac{R_{f1}}{1+R_{f1}C_1 s}$
- Second Stage Voltage Amplification $H_2(s) = -\frac{V_o}{V_o}$ $-\frac{1}{1+R_{f2}C_2 s} * \frac{R_{f2}C_{z1}s}{1+R_{z1}C_{z1}s}$
- Dynamic Threshold Comparator $\frac{R_{01}}{R_{T1}} \leq \frac{V_{CC}}{V_{off}} - 1$

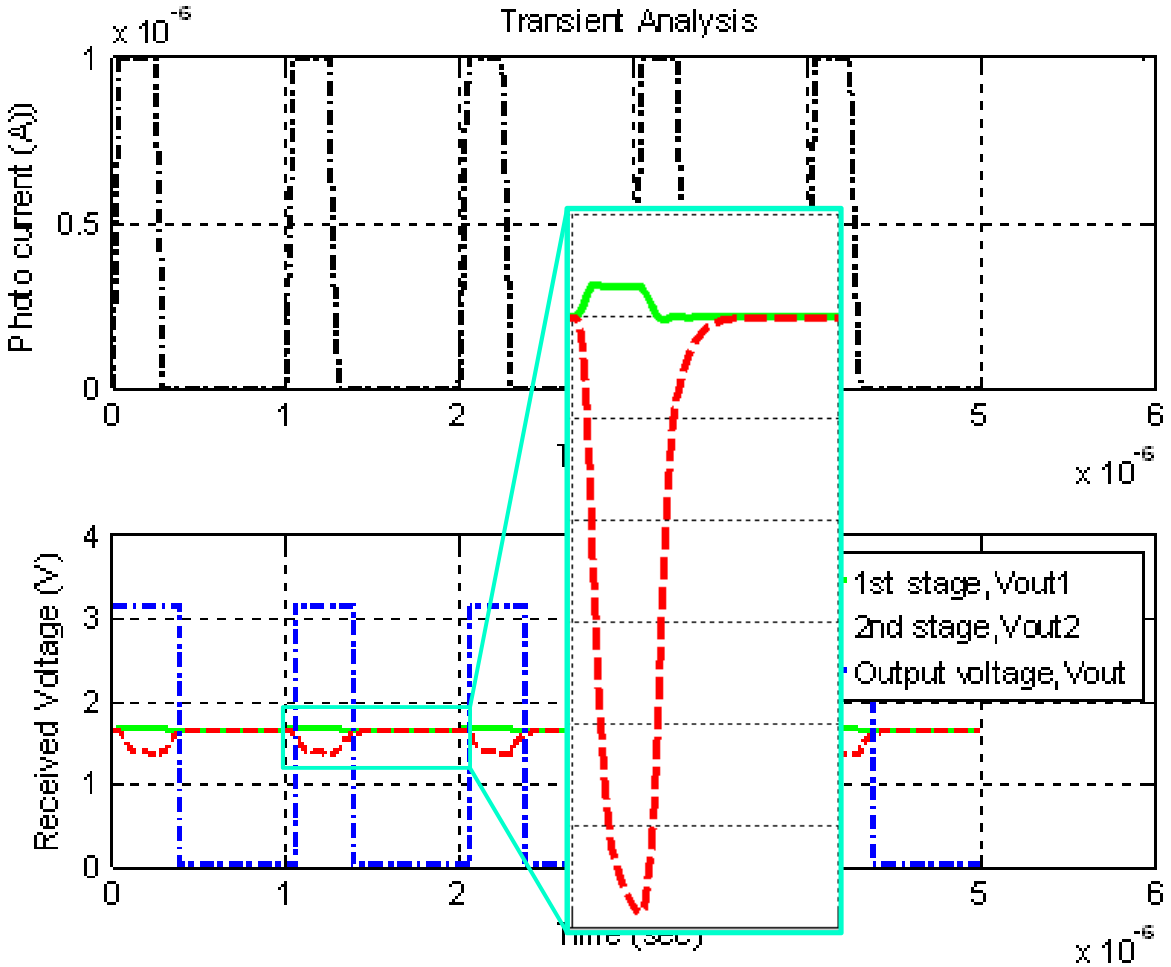


Transciever design:Frequency Response

- First Stage response
- Second Stage Response
  - Band Pass Filter

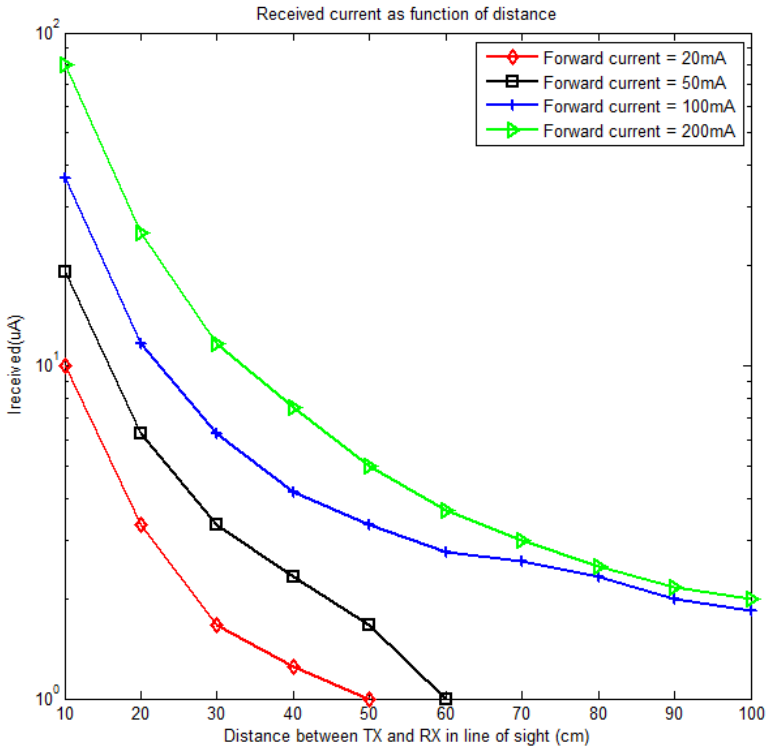


Transciever design: Transient Analysis



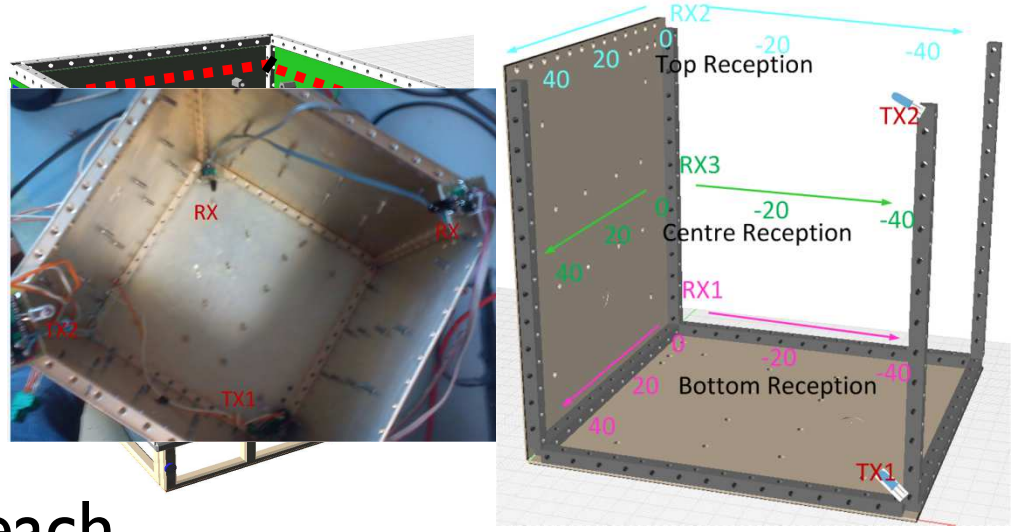
Transciever Design: Range testing

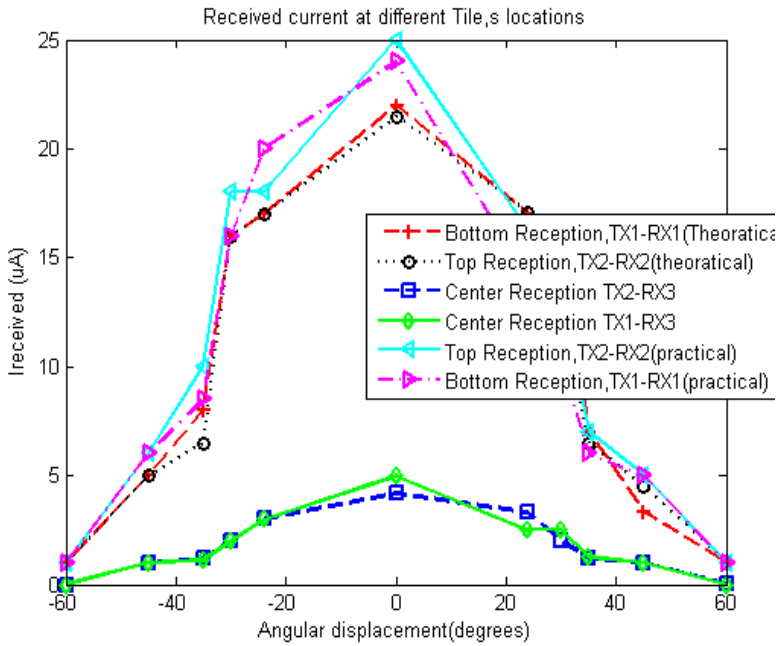
- Received current as a function of distance and input radiated optical power
- Can easily handle wide dynamic range



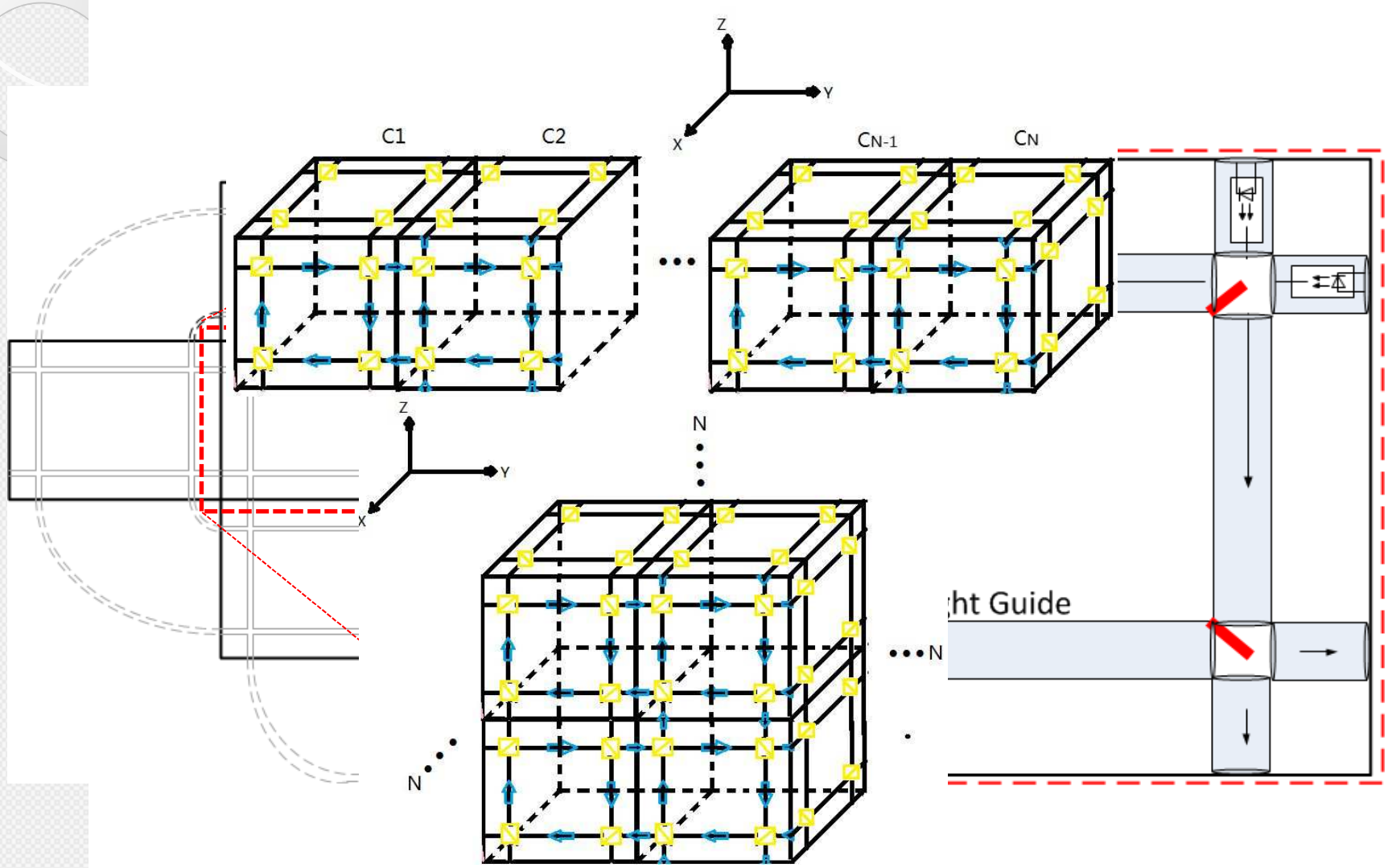
Bus Configuration - IrDARAMIS

- Line-of-Sight communication
  - Add small mirr the corner of each module
  - Different configuratior of transmitters and receivers in the cube





Otical:Glass Fiber Communication

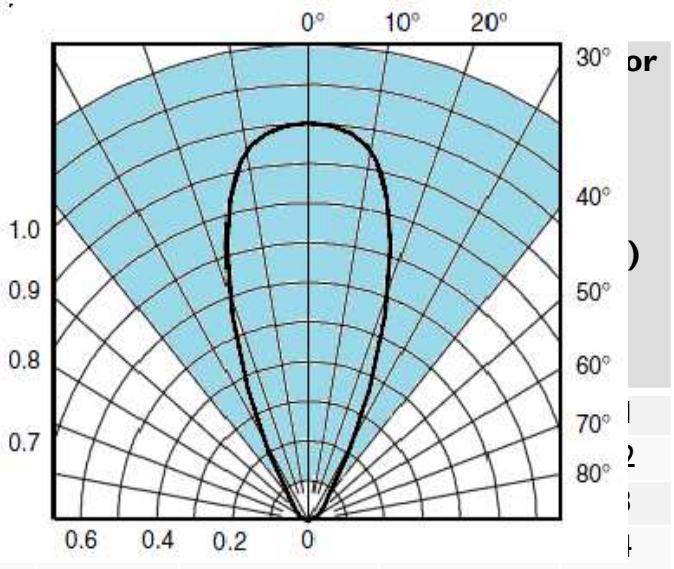


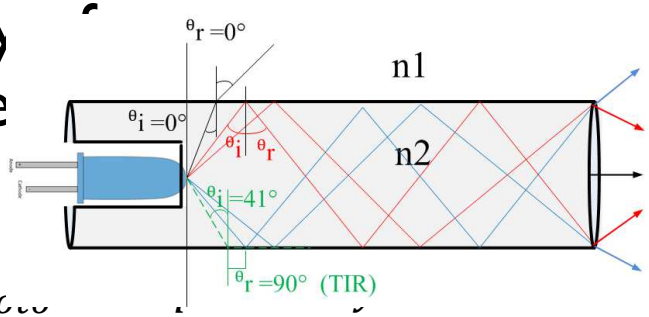
Optical Module:Glass Fiber Based

- $P_o = \eta . V I_{LED}$
- Snell,s Law
- $\frac{\sin \theta i}{\sin \theta r} = \frac{n_1}{n_2}$
- Critical Angle
- $\theta_i = \sin^{-1} \frac{1}{n_2}$
- Received current function of responsivity photodiode power

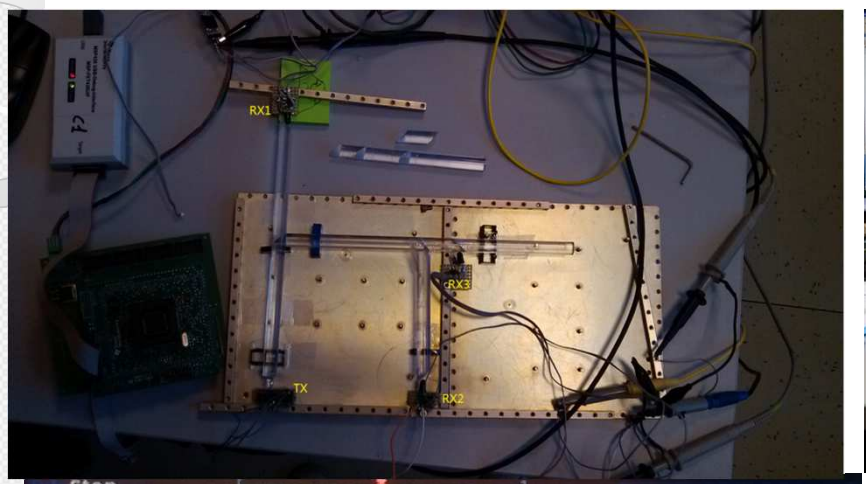
$$I_{received} = \frac{Po}{\frac{\pi}{4} * \emptyset^2} * A_{Phot}$$

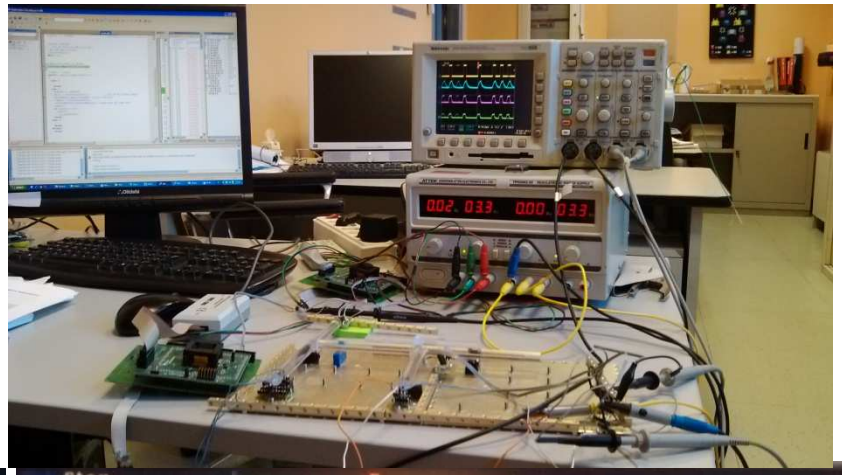
No. of Guides	S.No	Radiated Power PotmW
1	1	10
	2	20
2	3	10
	4	20





Optical Module: Testing Results





Inter-tile Communication

Module Design: OBDB interface

Module Design: Optical(Free space and glass based)

Module Design: Radio Frequency based

Module Design: Radio Frequency Based

- Radio Frequency Modules: For inter tile communication.
- Software: 1B45 subsystem serial data bus+ additional software needed
- Hardware: Based on TI CC2510/CC1110 transceivers.
  - Not yet fabricated on modules.
  - Therefore we use evaluation modules for testing purposes.
- We therefore concentrated on the software side
- SimpliciTI protocol was used in the design

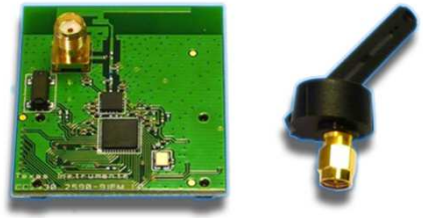
Inter Tile Communication: Wireless

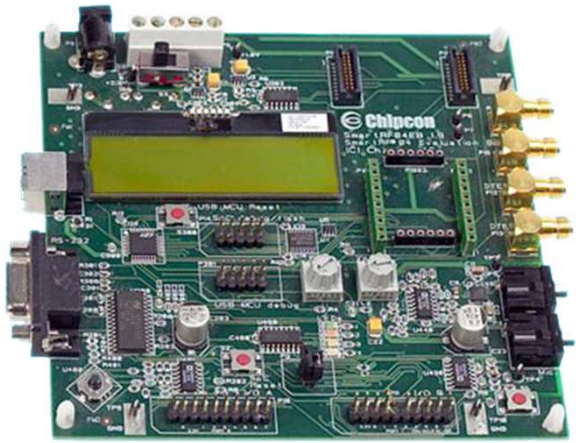
SimpliciTI

- A proprietary low-power radio frequency (RF) protocol by **Texas Instruments (TI).**
- It targets simple and small RF networks (less than 100 nodes).
- SimpliciTI network protocol was designed for easy implementation with minimal microcontroller resource requirements.
- Flexible: Direct device to device communication
- Utilizes a five command API.

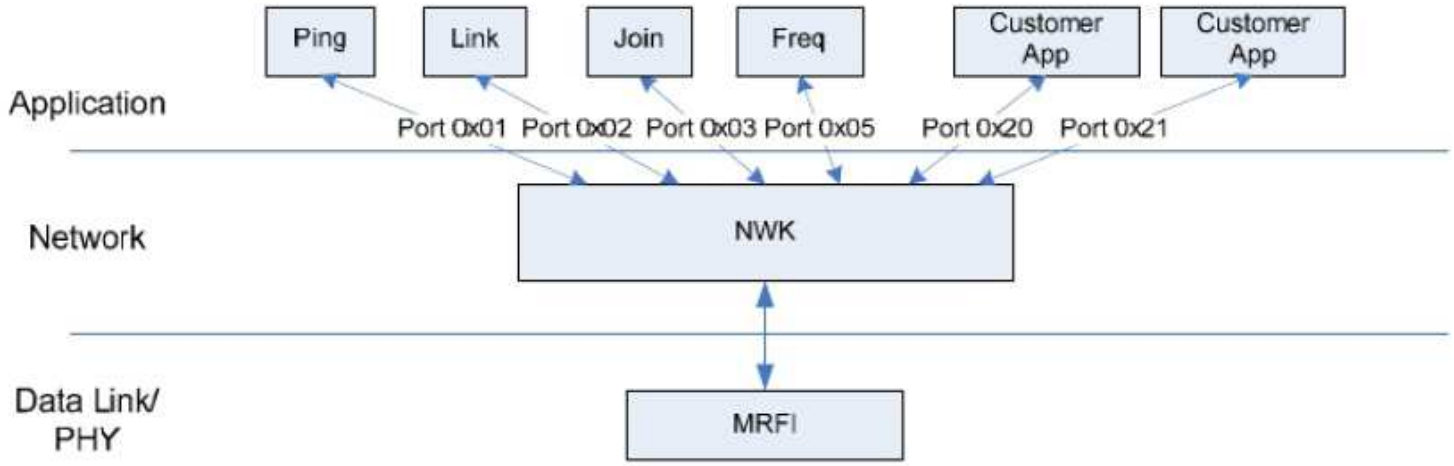
SimpliciTI Protocol: Transceiver

- The CC2510/CC1110 System-on-Chip (SoC) transceiver used for SimpliciTI applications.
- It comes with 32/64/128 KB of flash memory and 8051 MCU core.
- Range: 5-500 Meters, depending on the RF environment and the power output consumption required for a given application.
- The SmartRF04EB used as main platform in the development kit.





SimpliciTI: Architectural Overview



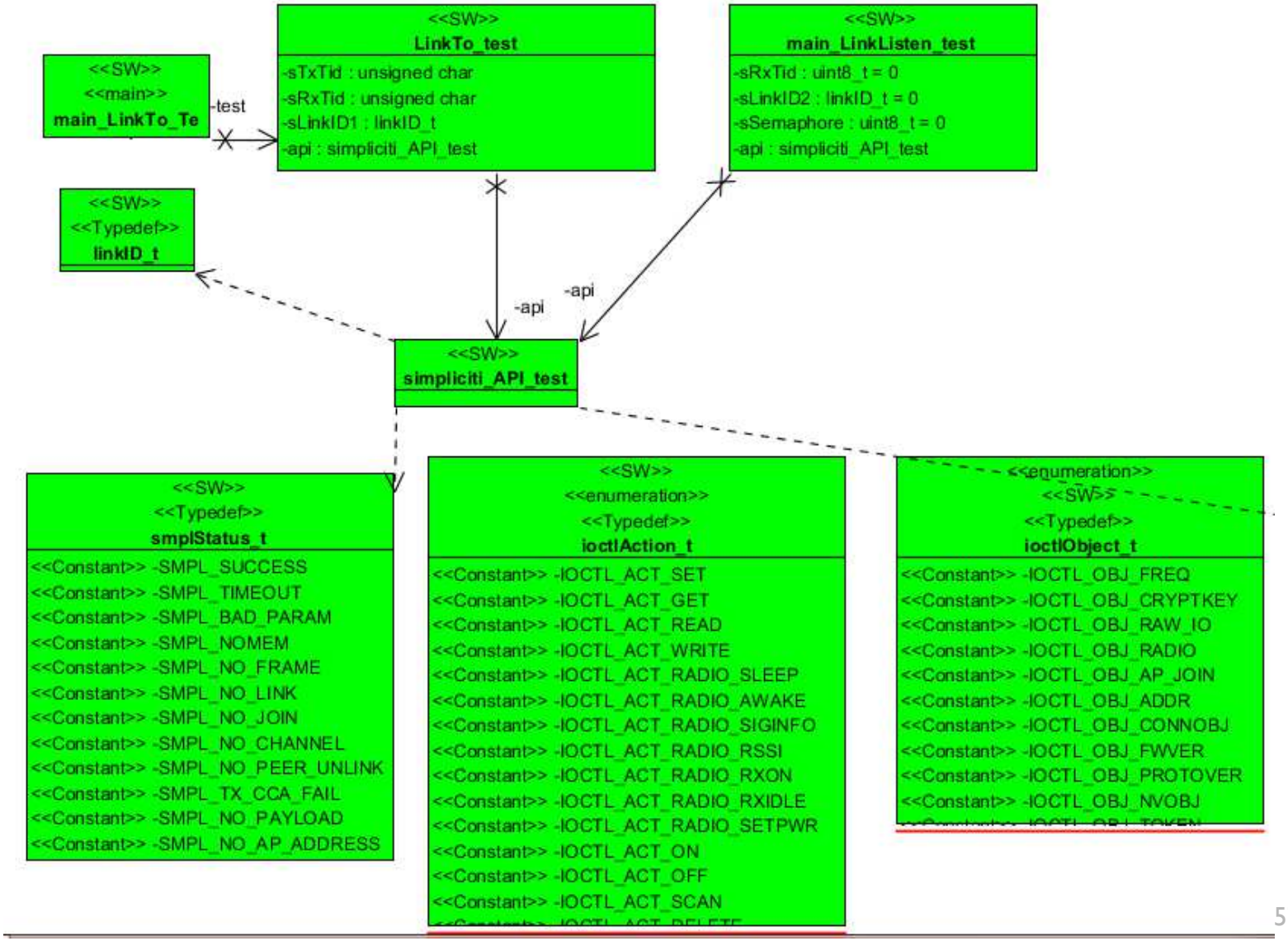
- Layers
  - MRFI ("minimal RF interface")
  - NWK
  - nwk applications (modules)
  - customer applications

- Network Support
  - init
  - ping
  - link / linklisten
  - nwk mgmt
  - send / receive
  - I/O

SimpliciTI: API

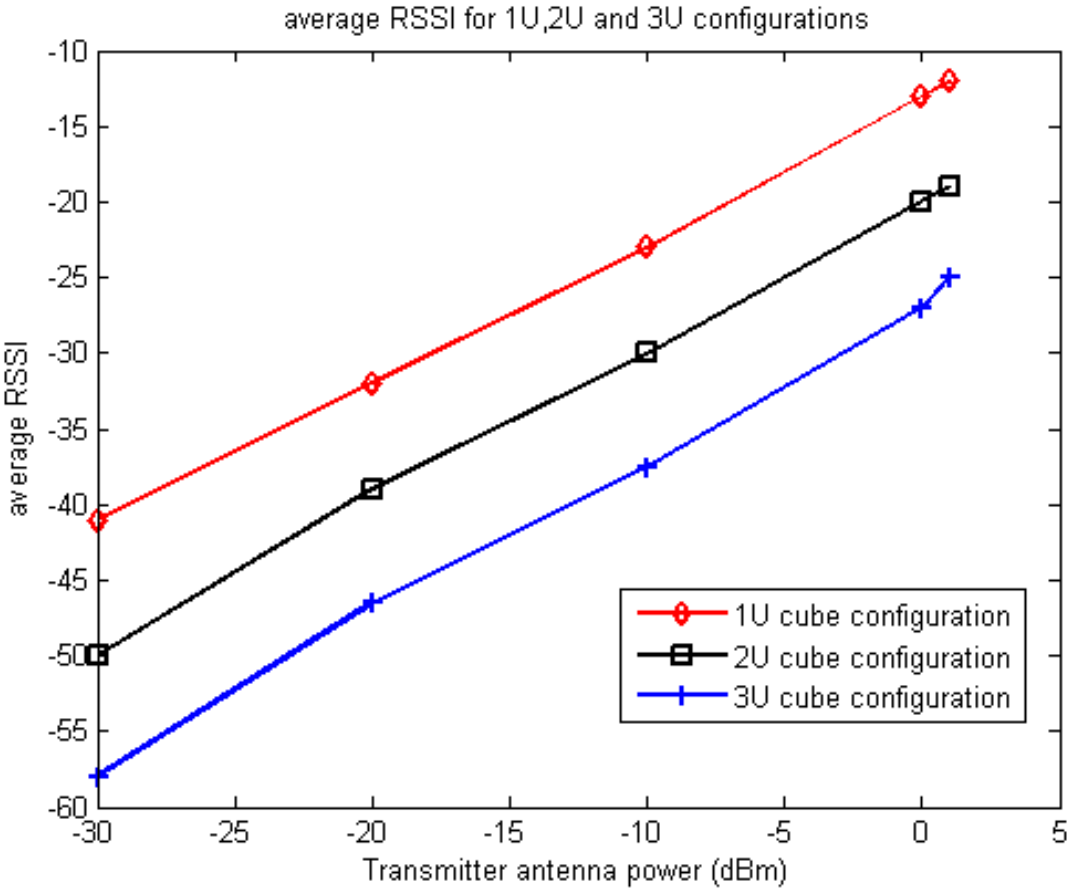
- initialization
  - smplStatus_t SMPL_Init(uint8_t (*callback)(linkID_t));
- linking (bi-directional by default)
  - smplStatus_t SMPL_Link(linkID_t *linkID);
  - smplStatus_t SMPL_LinkListen(linkID_t *linkID);
- peer-to-peer messaging
  - smplStatus_t SMPL_Send(lid, *msg, len);
  - smplStatus_t SMPL_Receive(lid, *msg, *len);
- configuration
  - smplStatus_t SMPL_Ioctl(object, action, *val);

SimpliciTI: Class diagram



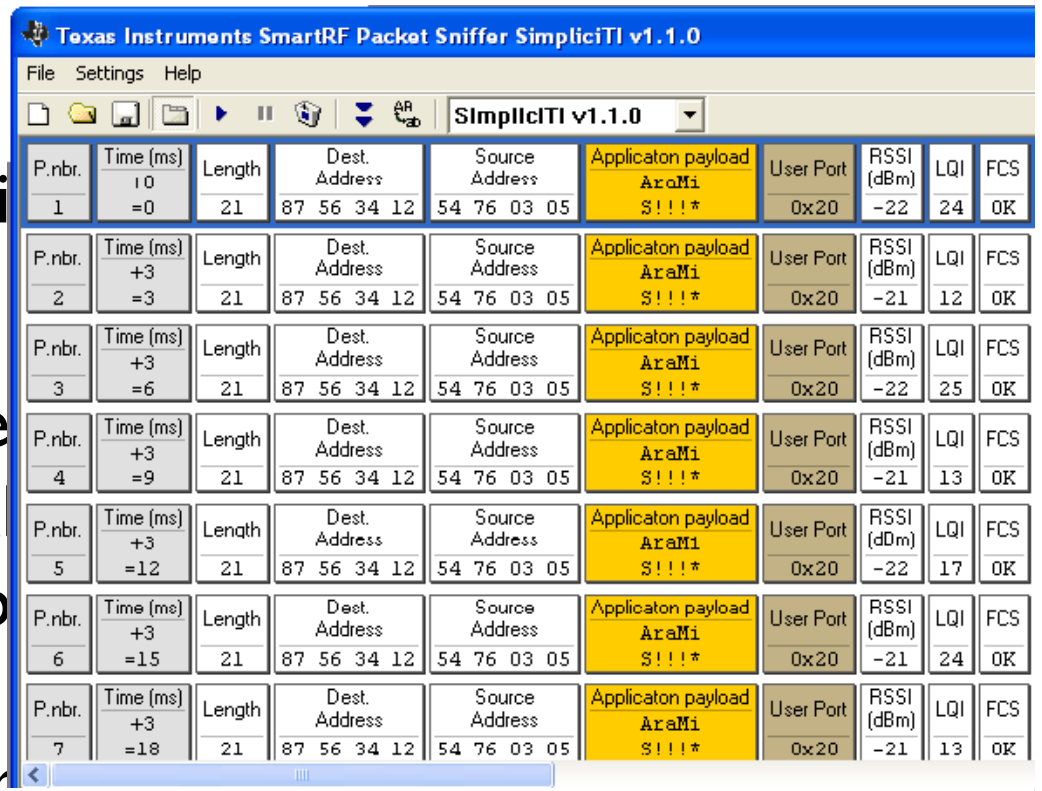
SimpliciTI: Measured RSSI

- Results for equivalent length of CubeSat in open air conditions



Packet Sniffer

- The packet sniffer visualizes all RF traffic and content i a graphical format.
- Each packet receive a time stamp and R protocol flow can b inspected in chronological order



Conclusion

- The wiring and data harness has been reduced by the proposed smart harness technique
- The proposed spacecraft configurations are very flexible and modular
- The proposed test board can easily test the modules, tiles and whole satellites
- The modularity has been achieved at mechanical, electrical, protocol and testing level.
- Multiple communication protocols realizable in small spacecrafts using proposed intelligent mapping
- Optical and radio frequency based module design for innovations in on-board communication and highly reduction in harness mass

Thank You !!!

References

[1]. Komninou, M.Vasile, E. Minisci, Optimal Power Harness Routing for Small-Scale Satellite, in: IAC-11,C3,3,5,x10550, 62nd International Astronautical Congress, 3-7 October 2011, Cape Town, South Africa.