Adapting Linux-based Computing to CubeSats

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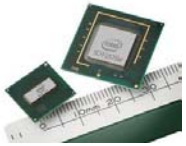
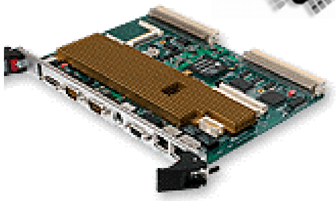
Flavors of Linux Computing H/W

- Desktop PCs / laptops / netbooks etc.
- Android®-based smartphones & tablets
- VME-based Linux computing
- PC/104 and similar Single-Board Computers (SBCs)
- BeagleBoard / gumstix / Raspberry Pi / SheevaPlug
- Microprocessors (e.g. Intel Atom®)
- Microcontrollers (e.g. ARM-based STM32 family)

All consumer products!



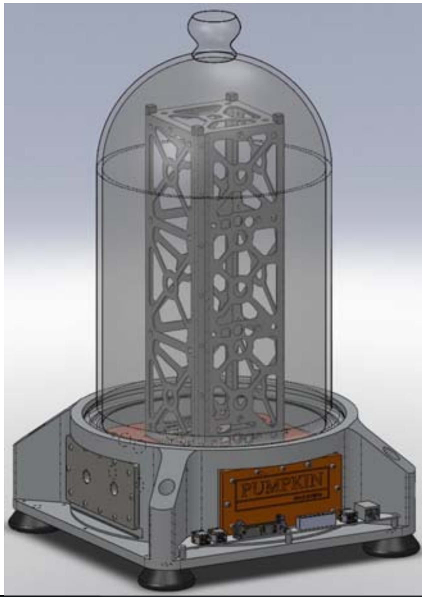


Space Environment – Radiation

- Transistor counts are getting so large and process geometries so small that even terrestrial deployments are starting to worry / react.
- Microcontrollers have 10,000 - 250,000 transistors.
- FPGAs have 500,000-5,000,000 transistors, and an Intel® Atom® has 47,000,000 transistors. For these expensive chips, latest generations are built on newer, smaller processes (now 28nm).
- Some systems have external / hardware WDTs built in, but that's relatively rare.

Space Environment – Vacuum

- Vacuum compatibility is not a design goal for consumer products!
- Vacuum compatibility with these components is therefore achieved by *chance* or by *rework / alterations* to design.
- Some simple rules help, e.g. avoid electrolytic capacitors.
- More complex issues (e.g. prismatic Li-Po cells vs. cylindrical Li-Ion cells) must be addressed
- Best option is to test under vacuum.
- To say nothing about the plastics involved …

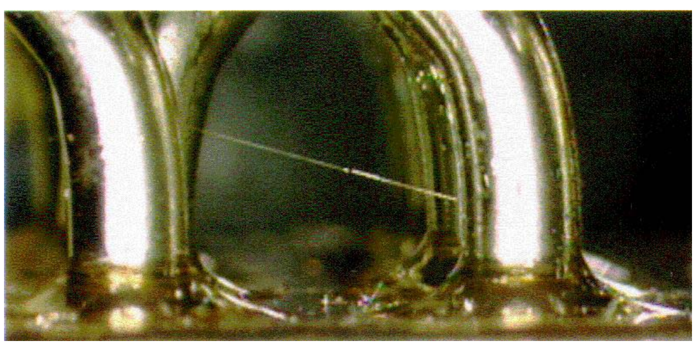


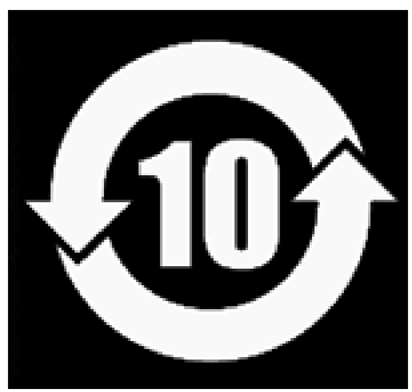
Space Environment – Temperature

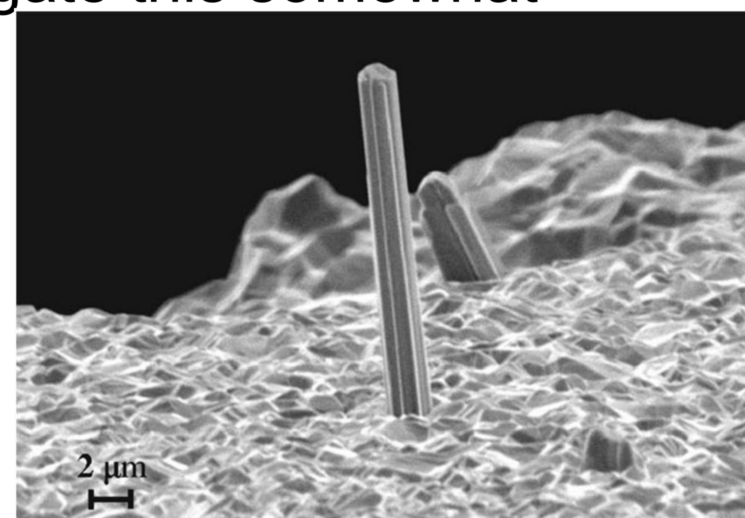
- For LEO missions:
  - -40C to +85C (industrial temp range) is acceptable, but
    - Batteries and radios will fail at edges of this range
    - Some “add-in” components (e.g. SD Cards, Bluetooth modules) may not be available over the industrial / extended temperature range – shop around and compare
- Heatsinking within a CubeSat is an option, though not particularly mature. Only heat transfer mechanisms are radiative and conduction – no convection.

Tin Whiskers

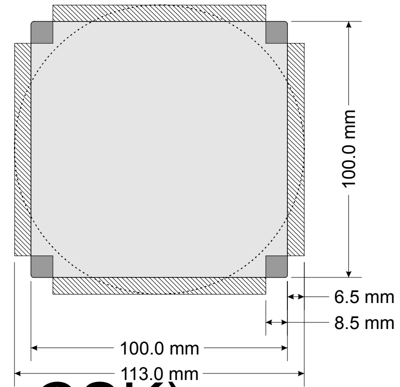
- European-led RoHS initiative has essentially all consumer electronics on the lead-free bandwagon
- Tin whiskers grow spontaneously in the absence of mitigating lead (solder) – on earth and in space
- As a result, many products have a projected limited lifetime / shelf life *and there's nothing you can do about it*
- Space-grade components can mitigate this somewhat due to their RoHS exemptions



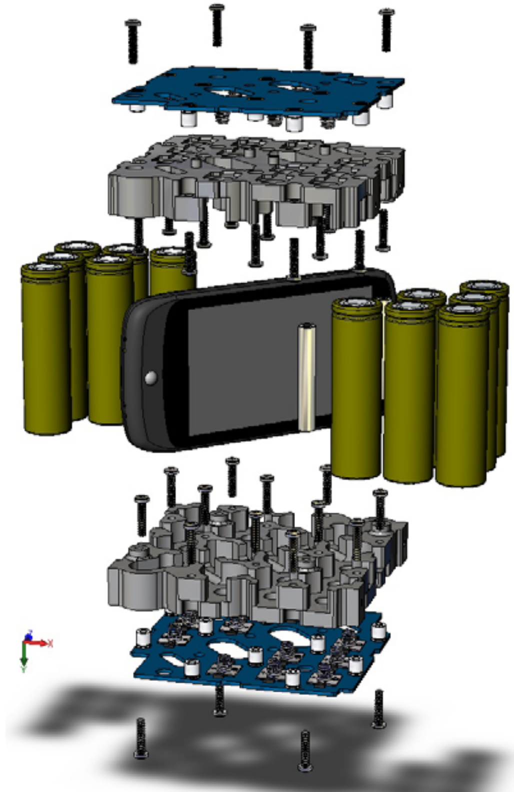




CubeSat Physical Constraints



- Stacking in the Z-axis:
  - 100x100mm cross-section limits board size
  - Real limit is closer to 97x97mm (e.g. Pumpkin CSK), due to unavoidable wall thickness
- Stacking in X- or Y-axis
  - Width still limited to 100 (97) mm
  - Max. length tops out at ca. 325mm, practical limit closer to 200mm for real implementations
- Working the diagonals: sqrt(2) → 40% more length to play with



PC-class Interconnects inside

- PC/104 has a clearly-defined (and space-proven) interconnect technology *between modules*. Handles power and the ISA bus. PCI/104 expands this with PCI bus as well.

- The “closer” a Linux implementation is to PCs, the more standardized the connectors (e.g. USB, 10/100/1000BaseT Ethernet). Many of these interconnects are *controlled-impedance*, and *non-locking*, non-hermetic, and relatively large.
- Replacing these connectors with point-to-point wiring (while maintaining correct impedances) negates much of the convenience and flexibility that made them popular.
- Connector problem must be resolved on both sides (i.e. host and device) – example: CSK MB’s H9

Nonstandardized Interconnects

- Non-PC-based Linux implementations:
  - Linux processor on CubeSat Kit-compatible bus (e.g. RAX Payload Interface Module)
  - Linux processor in alternate CubeSat architecture
  - gumstix, Raspberry Pi, BeagleBoard, etc.

Power Issues

- PCs aren’t too concerned with the low power levels typical of CubeSats, can be a problem.
  - Example: Lippert Cool SpaceRunner LX-800: Inrush current of 6.5A(!) 25μs @5Vdc
- OTOH, PC-like SBCs are setup to deliver plenty of power, e.g., 6 USB ports = 15W of peripherals!
  - Example: SSDLCAM architecture can host multiple 2.5W experiments over USB
- Cooling?
- Battery dependencies -- smartphones

Not Everything in Linux-land is Open

- GigE Vision is a popular interface for high-speed cameras
- Works over Gigabit Ethernet via 1000BASE-T cabling
- GigE Vision standard is proprietary:
  - One consequence of the license is that it is not possible to write open source software using the GigE Vision specification, as it could reveal the details of the standard, which is why most image acquisition SDKs for GigE Vision are closed source. There is currently at least two different free software projects trying to implement the GigE Vision protocol by reverse engineering.*
- Consequence is that not all typical Linux options (e.g., distributions) are available – SSDL experienced that GiGE Vision drivers were (are?) only available for RedHat & CentOS, and not Debian. Major consequences!

* Wikipedia entry for GigE vision

Trades

Platform	Pros	Cons
PC/104- and similar SBCs	• Interchangeable with Desktop PCs • Lots of peripheral interconnectivity • Often designed for –40C to +85C • Can provide power (e.g. via USB)	• Relatively expensive • Power-hungry (>5W)
Smartphones	• Cheap, popular, reliable • Built-in advanced features	• Rapidly obsolete • Designed around battery operation • Little / constrained expandability
BeagleBoard / gumstix / Raspberry Pi	• Powerful, energy-efficient • Some have wide range of add-ons	• No match for mass-market reliability
Dedicated microprocessors & microcontrollers	• Easily tailored to mission requirements • Low-power	• Require investment in learning embedded computing • No large market •Driver support may not exist

Conclusion

- Wide range of small Linux computing platforms available to CubeSat users
- Focus on consumer portable devices means low-power, but often with limited external connectivity
- Development environment costs limited to just the hardware you're running on
- Drivers for chosen peripherals may drive platform choices more than anything else
- Pumpkin's CubeSat architecture can accommodate all flavors of Linux platforms.

Q&A Session

Thank you for attending this Pumpkin presentation at the 2012 CubeSat Developers' Summer Workshop!

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Appendix

- Speaker information
  - Dr. Kalman is Pumpkin's president and chief technology architect. He entered the embedded programming world in the mid-1980's. After co-founding Euphonix, Inc – the pioneering Silicon Valley high-tech pro-audio company – he founded Pumpkin, Inc. to explore the feasibility of applying high-level programming paradigms to severely memory-constrained embedded architectures. He is the creator of the Salvo RTOS and the CubeSat Kit. He holds several United States patents. He is a consulting professor in the Department of Aeronautics & Astronautics at Stanford University and directs the department's Space Systems Development Laboratory (SSDL). Contact Andrew at aek@pumpkininc.com.
- Acknowledgements
  - Pumpkin's Salvo, CubeSat Kit and MISC customers, whose real-world experience with our products helps us continually improve and innovate.
- CubeSat Kit information
  - More information on Pumpkin's CubeSat Kit can be found at http://www.cubesatkit.com/. Patented and Patents pending.
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