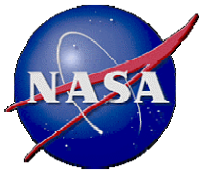

Limits on Interconnection Bandwidth for On-Board Processing

17th Annual Workshop Interconnections within High-Speed Digital Systems

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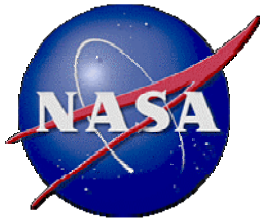
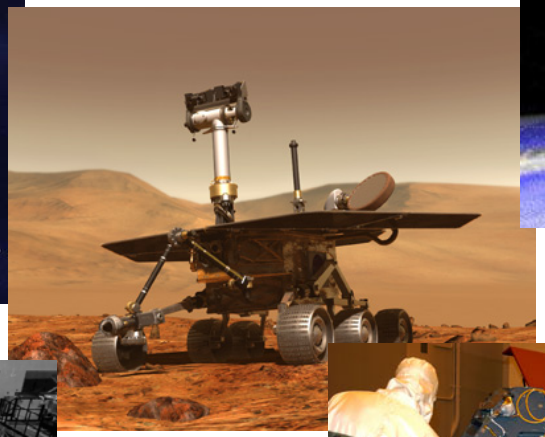
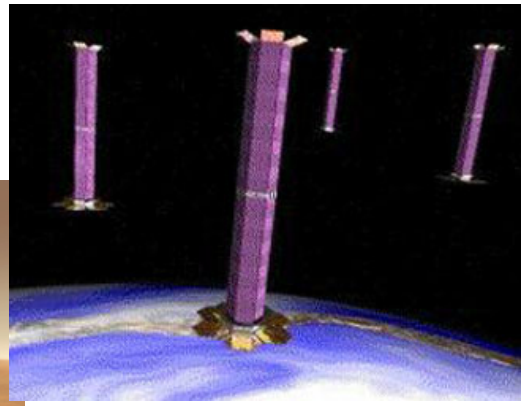
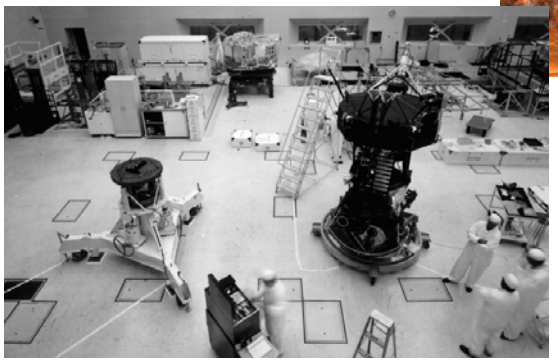
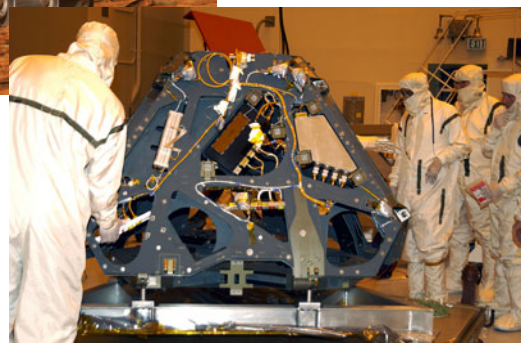


Space is a (really) different place for equipment



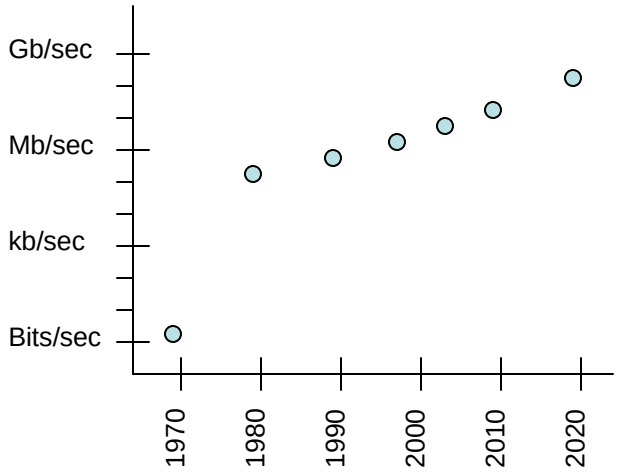


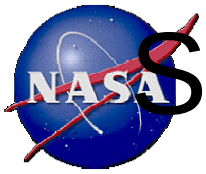




Data rates
Past, Present, Future

- Bottleneck: Radio link from spacecraft back to earth
  - 1970: 1-10 bit/s from Jupiter
  - 1980: 100 kb/s
  - 1990: 500 kb/s
  - 2000: 1 Mb/s
  - 2006: 6 Mb/s from Mars
  - 2010: 20-50 Mb/s from Moon
  - 2020: 20-50 Mb/s from Mars
- Onboard speeds can be higher
- Limited onboard storage (few Gbit)
- Compression is a challenge
  - How do you know what's noise (which can be compressed out) and what's science (which can't)



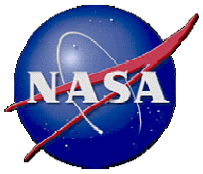


So, what's it like, building for a flight system?

- You're in it for the long haul (5-10 years, or more)
- It's a different environment out there!
- Mission/Quality Assurance is a very different animal in space than in consumer electronics
  - Qty 1 where failure is not an option vs Qty 10 million and managing warranty return ratios
  - You (usually) can't get the hardware back to fix it
- Conservativism reigns
  - You're going to generate a lot of analysis
  - You're going to explain it to lots of people at reviews
  - You're going to listen to other people explain their stuff
  - You're going to test the bejeebers out of it
  - You're going not going to "push the envelope"

Things that spacecraft designers worry about

- Power
  - Limited availability
  - EMI/EMC
  - Thermal
- Environments
  - Thermal
  - Radiation
- Programmatics
  - Decades long development/test/use cycle
  - Reliability philosophies & Mission Assurance



POWER!

- Spacecraft designers obsess about power consumption:
  - It's a precious resource
    - Solar panels are a few hundred watts/m^2
      - Every m^2 adds mass, which is also precious
    - You have to store it
      - Mass again, from those batteries
  - It eventually turns into heat, which you've got to get rid of
    - Heat is dissipated by radiation to cold space
      - Vacuum is a great insulator!
      - More heat = bigger radiators = more mass
    - Temperature limits on electronics
      - Heat must be conducted to the radiator
      - Maximum radiator temperature determines maximum rejection
  - High power sometimes means lots of EMI
    - Fast switching speeds, dv/dt issues
    - Compatibility with sensitive science instruments
- Impact on interconnections
  - Switching rates
    - Junction and transmission line capacitances have to be charged and discharged
    - CV^2f
  - Voltages and currents
    - Smaller swings are better, but you still need noise immunity
    - Losses in transmission lines can be important
  - Terminations
    - Some interfaces dissipate a surprising amount of power in the termination:
    - RS422: 12V into 100 ohm termination -> use RC termination
  - Drivers
    - Fast drivers might be less efficient than slow drivers

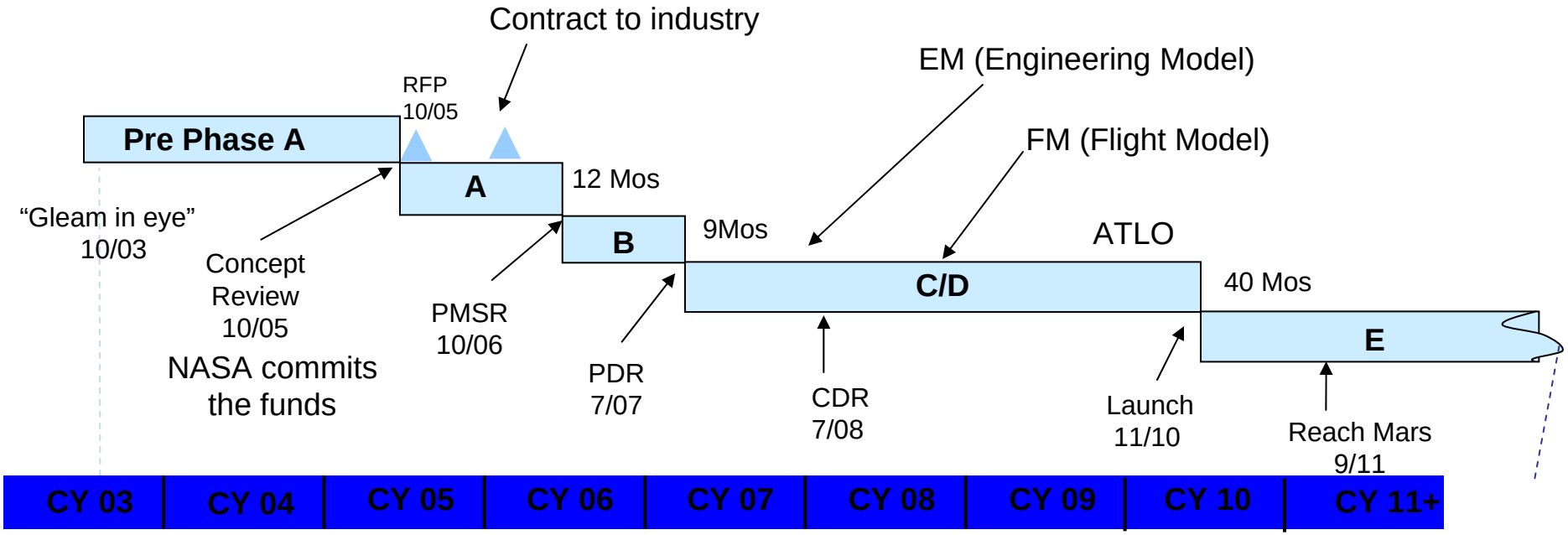
Peculiar Environments

- Vacuum
  - Thermal design impacts
  - Outgassing requirements
- Thermal
  - High gradients (one side cold, the other hot)
  - Dynamically changing gradients (in and out of shadow every 90 minutes)
- Radiation
  - Photons, electrons, protons, heavy ions, and neutrons, Oh My!
  - Earth has that nice thick atmosphere to help shield us
- Shock and Vibration
  - Launch, separation, and landing
- Electromagnetic
  - Can't interfere, and you might be next to a big transmitter!

All these have solutions, but remember the constraints!
Power, Mass, Volume, Risk

Schedules

Idealized “Mission to Mars”



But of course, this assumes all goes as planned..
What if there’s a realignment of priorities
Or a budget change
Or a launch vehicle problem

And, what if it’s a mission to an outer planet, with 7-10 years in flight?

Some Odd Consequences of the Long Life Cycle

- Parts availability
  - Mission manager will want parts with “proven heritage”
    - *i.e.* they worked the last time we flew them
  - 5 more years ‘til launch
  - Manufacturer support for 10 year old products?
- Engineer retention
  - Subsystems are delivered a year or two before launch
  - It may take 5 years after launch to get there, then what if you have a question about how something works?
- Development tools
  - Compilers, in circuit emulators, etc.
- Keep those old databooks!
  - Galileo (built in 1970s) used 1802 μP until 2003

“Flight Qualified” Equipment Design

- Design for Environments
  - Thermal
  - Radiation
  - Vacuum
  - Mechanical
- Testing
  - Performance
  - Environmental
- Analyses
  - Worst Case
  - FMEA
  - FMECA
  - Parts Stress

You won’t be able to go fix it.
It has to work, the first time and every time.

Parts is NOT Parts

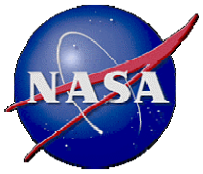
- Hot Buttons for spaceflight
  - Inspectability!
    - Can you see the solder joints?
  - Repeatability
    - Is the part I buy tomorrow the same as the part I bought yesterday?
  - Traceability
    - Preferably “back to sand”
    - *e.g.* GIDEP alerts: If a given part fails for someone else, we can know if that part is in our system, and then we can determine if it’s going to cause a problem
- These things aren’t always easy with current consumer oriented semiconductor business
  - Fabless manufacturers using multiple foundries
    - Traceability, repeatability is hard
  - Oriented towards large volumes
    - Millions a month vs 10 pcs a year
  - Rapid product cycles
    - 18 mo vs 10 years

The spacecraft designer's perspective (an example)

- Serial vs Parallel
  - Parallel wiring is simple
    - Lower data rates on each wire
    - EMI/EMC, high speed parts issues
  - Serial wiring has fewer pins on connectors and wires in the cable
    - Increased complexity from serializer/deserializer
    - Adds chips?
    - What if that mux/demux breaks?
- Trend towards high speed (>100 Mbps) serial
  - Every pin, every wire, has to be tested
    - with a procedure written, records kept, etc.
  - Every pin, every wire, weighs something and takes up room.
  - During assembly & testing, you have to mate/demate those connectors
- SpaceWire, Ethernet, TAXI, 1394, etc.
  - LVDS signalling
  - Various depths of OSI protocol stack

And why not optical?

- Great from EMI/EMC standpoint
- Great for common mode voltage/galvanic isolation
- Radiation?
  - Degradation over time
    - Displacement damage
    - Radiation degrades glass in fibers
    - Ranges from 0.001 dB/m to 12dB/m degradation with 100kRad
      - (highly dependent on fiber composition and doping)
    - Situation is improving, and, for short runs, increased loss may be handled by suitable margins
    - If you have 40 dB margin in the link, 12 dB of degradation may not hurt you.
- Can we trust it?
  - Spacecraft designers are a very conservative lot
  - Hundreds of FO links on ISS
  - There IS a difference between deep space and human missions

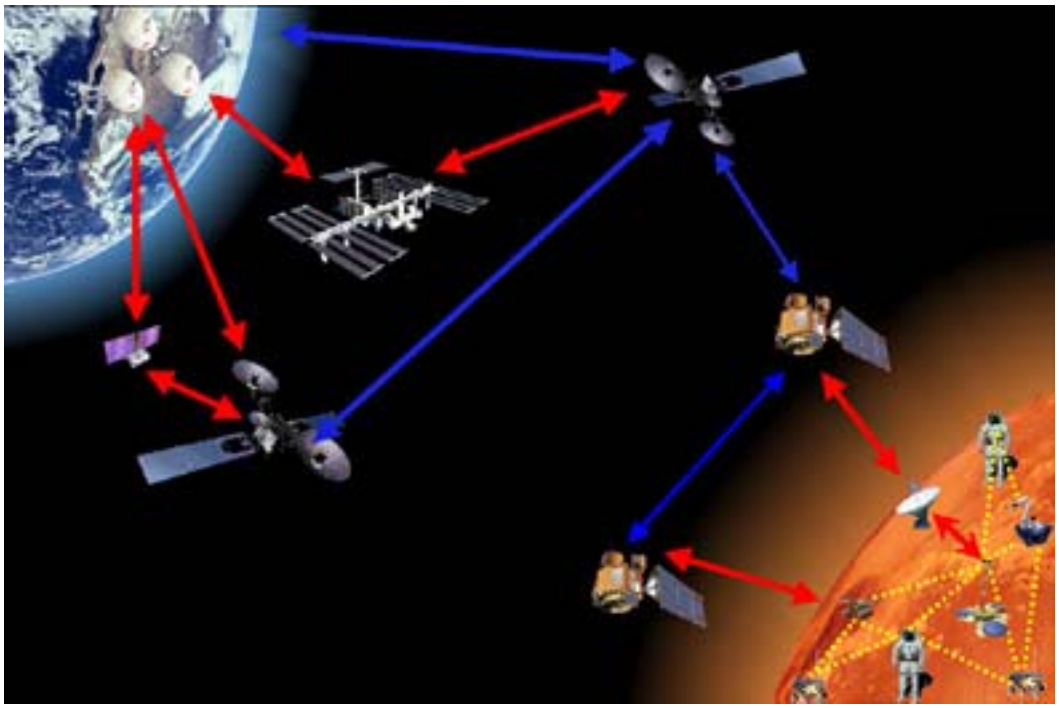


Wireless?

JPL

- It’s a wonderful new world..
  - Zero mass wiring harness!
  - No connectors to mate/demate!
- Candidates:
  - Optical free-space (like IrDA for your PDA)
  - RF – Bluetooth, Zigbee, 802.xx, etc.
- Technology questions
  - Component/environment issues
    - Radiation effects and optoelectronics
    - RF devices vis a vis EMI/EMC
  - Consumer market driven towards highly integrated solutions
    - Our needs may not map well onto consumer products
  - Speed, Power, Propagation
    - Sending information through space (optical or RF) is not as efficient as sending it down a wire or fiber
    - All interconnects live or die by Shannon and Nyquist, ultimately

Future Network



- Historically s/c to earth (stovepipe)
- Future is Interplanetary networks
- Interconnection not just between boxes on a spacecraft, but between spacecraft