Space Technology

Digital circuits and systems in space 2.

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Spacecraft data management

1. Control and surveillance: on-board computer
2. Payload monitoring and control: payload computer

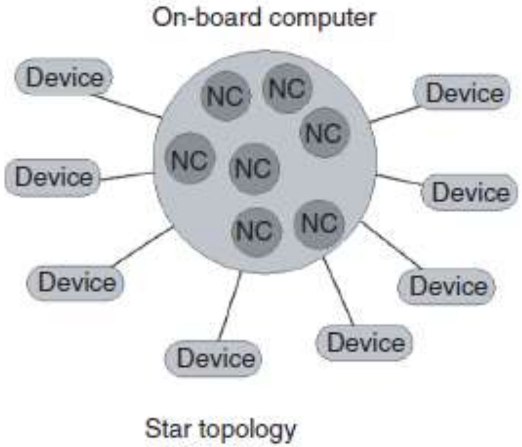
Central or distributed computers

- data reduction
- computing performance
- resource sharing
- replace HW functions with SW
- FPGA

Interconnection:

- ❑ Star
- ❑ Bus
- ❑ Mixed

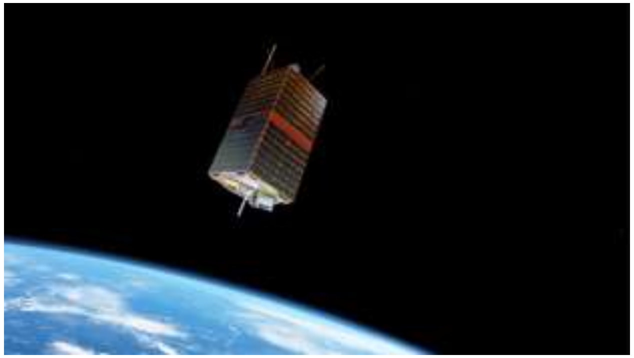
(Node Computer)



Onboard computer - sizes

<u>Picosatellites ... big satellites >1000 kg</u>

Miniature satellites:	< 500 kg
CubeSat:	1 kg, 10*10*10 cm
ESEO:	100 kg, 100*100*100 cm
ACTIVE (1989):	1570 kg

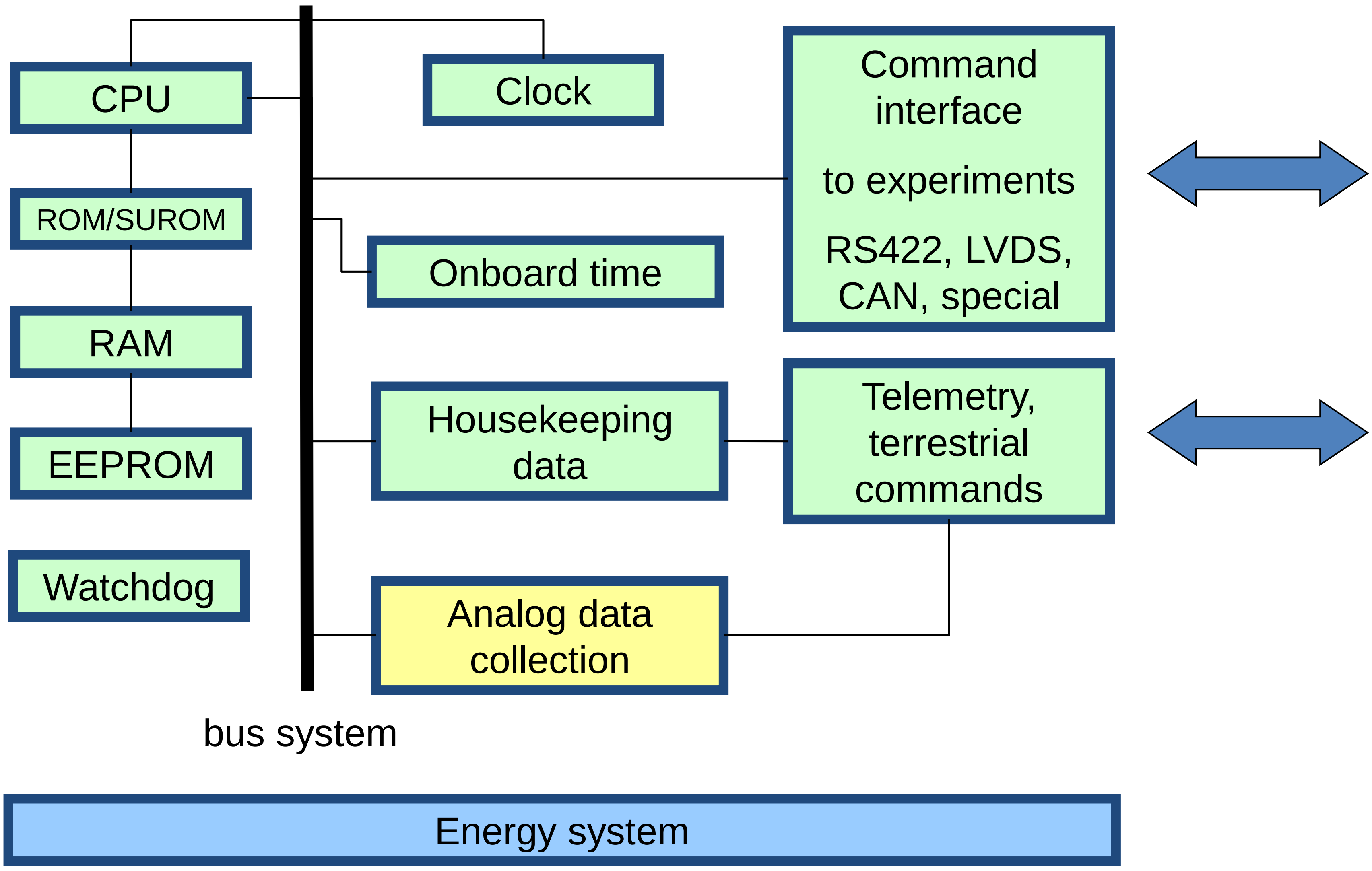


The onboard computer

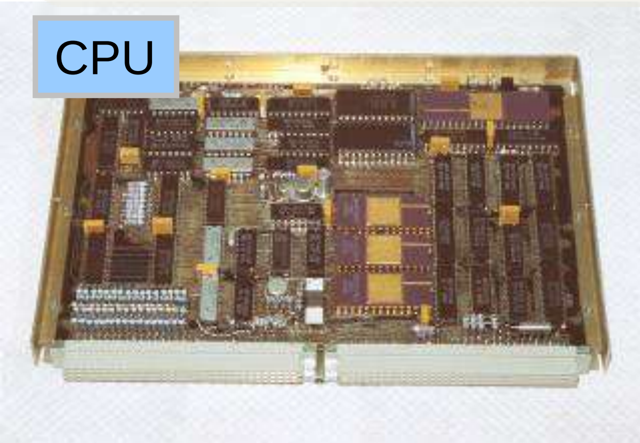
Multiple structure/complexity is possible – small satellites → big systems

- Role of central control unit
- External communication
- Control the onboard systems
- Create telemetry structure
- Data storage
- Control autonomous operation
- Measurement data collection

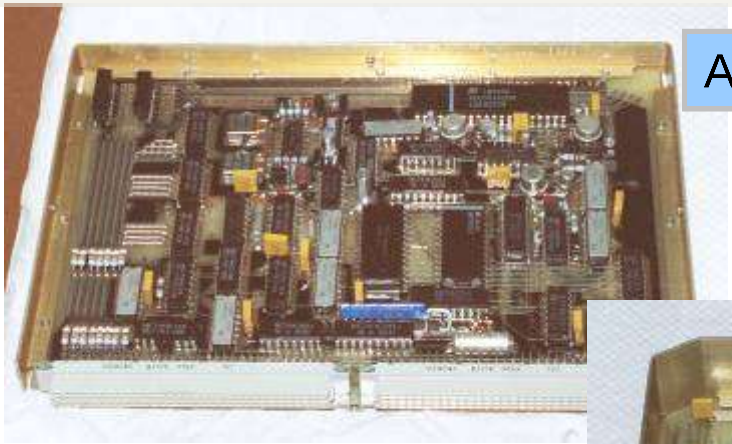
Block diagram



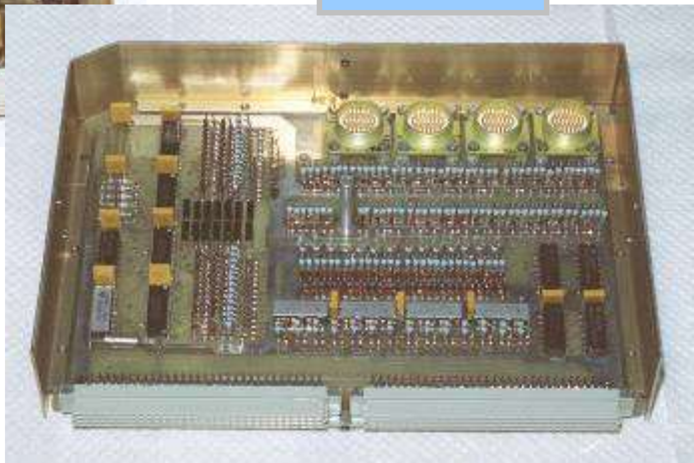
Historical example: uP-based onboard computer and data collection system (ODCS, 80-90th)



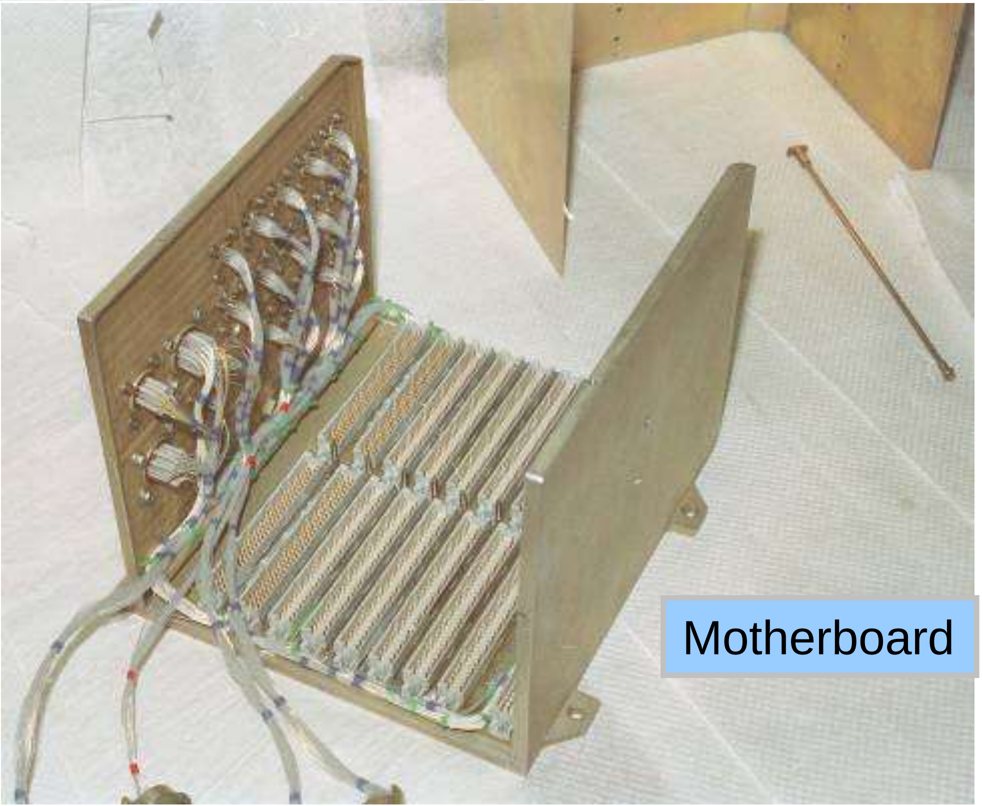
CPU



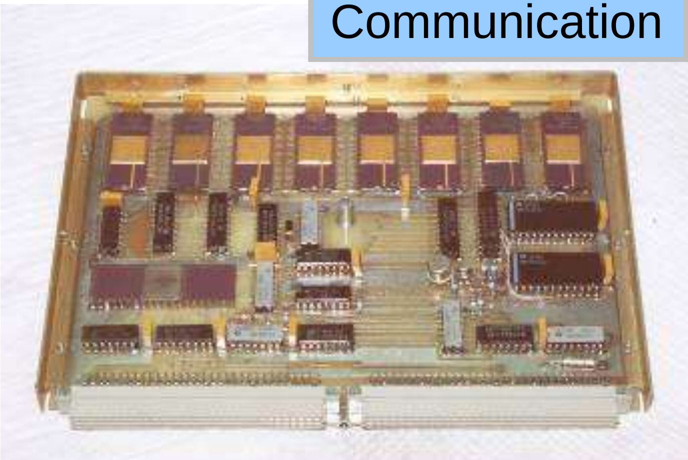
A/D



Interface

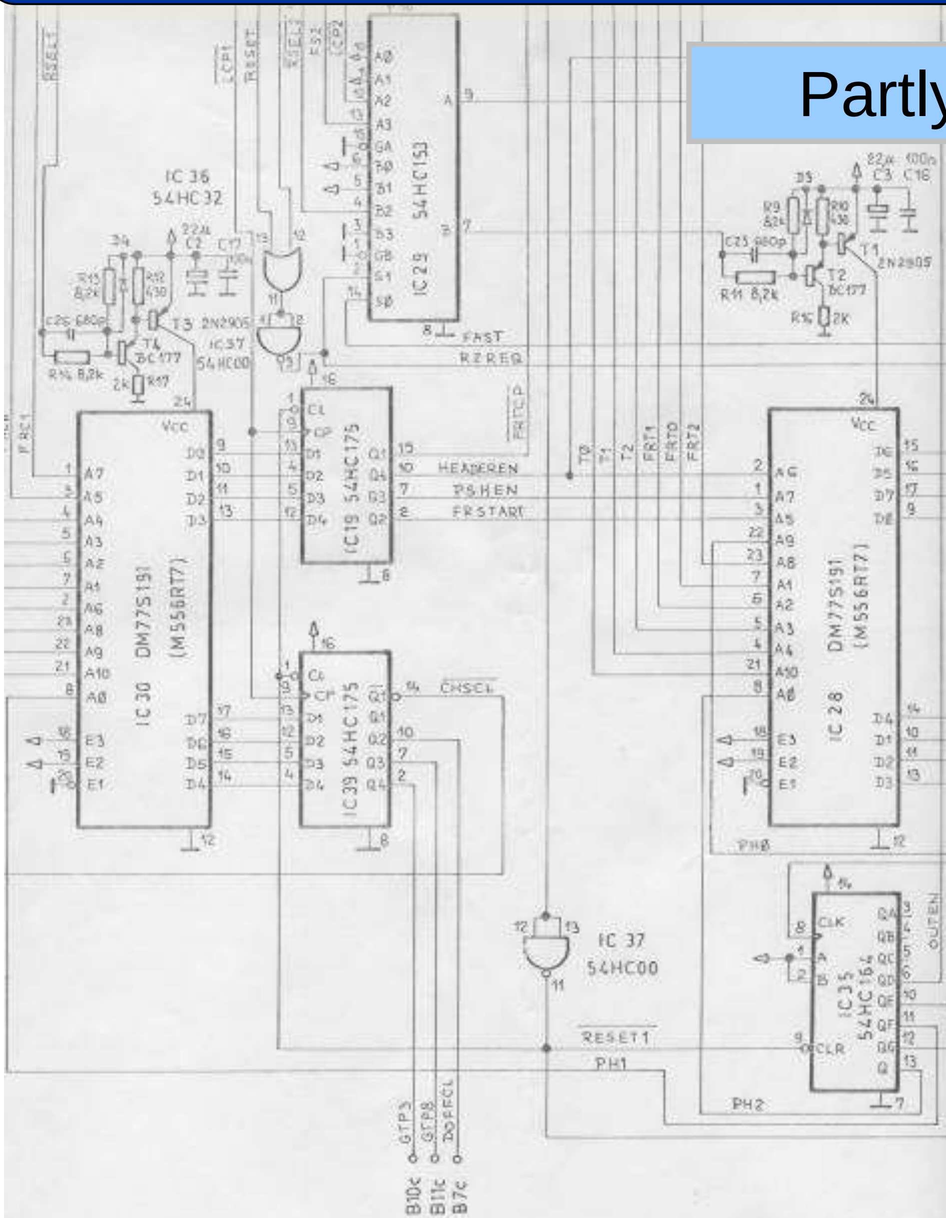


Motherboard



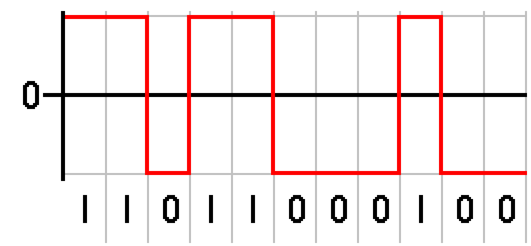
Communication

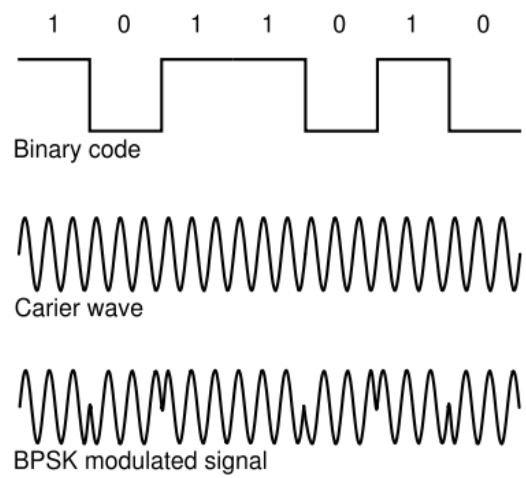
Digital telemetry system



Partly...

10/20/40/80 kbit/sec
NRZ/BPSK

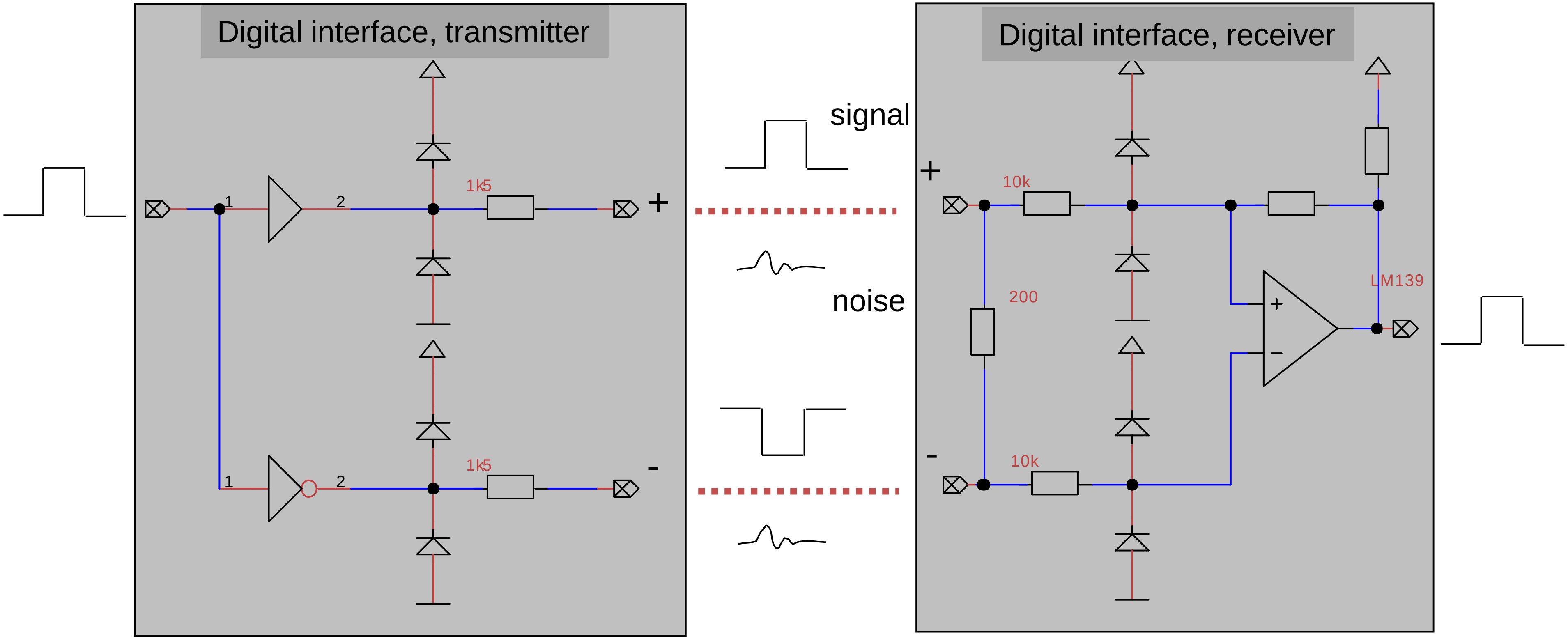




Data transfer between modules

- Usually a kind of serial data transmission is applied
  - USART, RS-232
  - RS-422
  - RS-485
  - LVDS
  - CAN-bus
  - SpaceWire

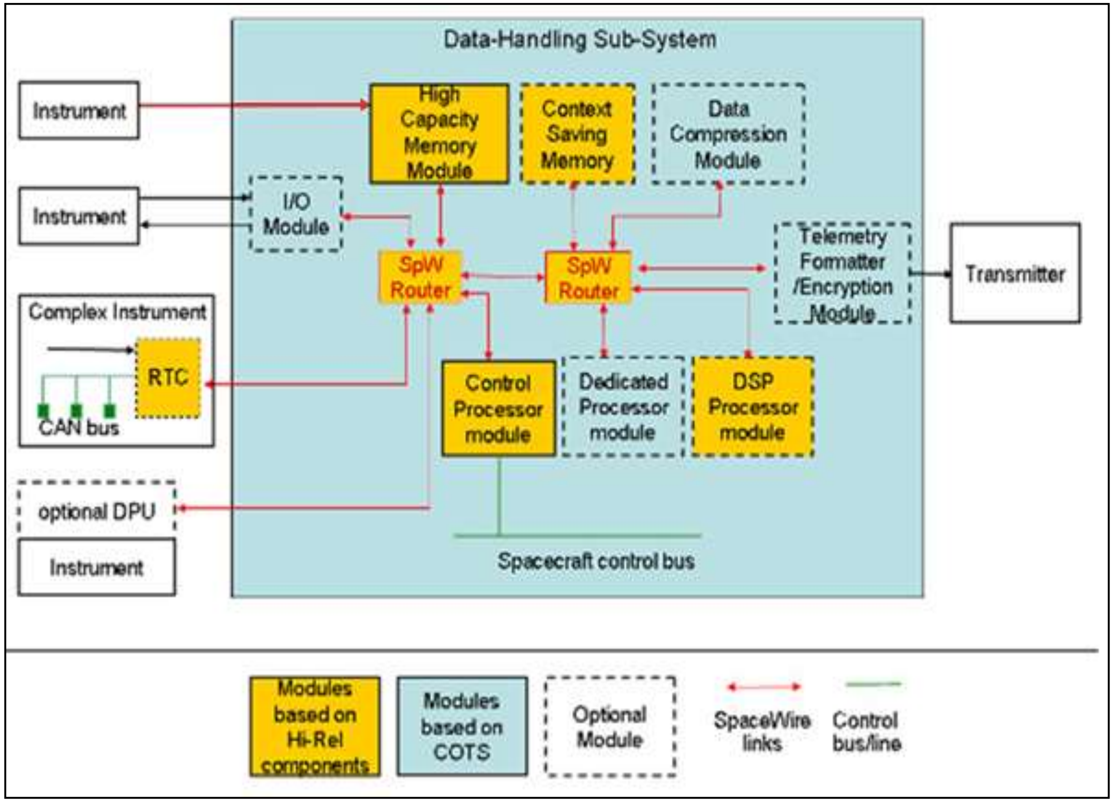
Noise-free digital data transmission



Symmetrical current loop

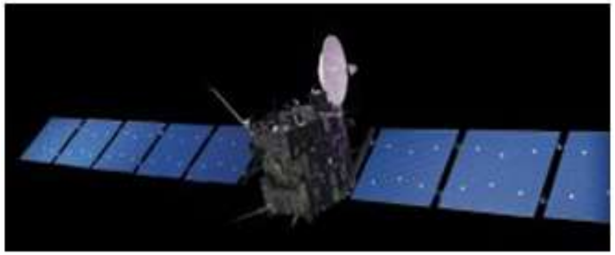
SpaceWire (ECSS-E50-12A standard)

- Communication between onboard devices - compatibility
- Serial data transmission (differential data/strobe signals)
- 2-200 Mbit/s
- Bidirectional, full duplex



- Implementable in FPGA (5-8000 gate)
- packet based data transfer
- error tolerant

Rosetta



Telecommand system (Earth-satellite)

- Contolling with command–delayed execution
- Direct commands–immediate execution
- Typical commands:
  - Energy system related
  - Telemetry/telecommand-system control
  - Communication related
  - Satellite positioning
  - Experiments (payload) control
- Command execution:
  - immediate
  - delayed
  - adaptive mode

Telemetry (satellite-Earth)

- Overall information relating to satellite
  - Pressure
  - Temperature
  - Vibration
  - Position
  - Acceleration
  - Power supply voltages
- Subsystem's data
- Experiment's data

Numerous, slowly variable signals

Command and telemetry format

- Frame structure is a general solution:

Synchronization	Device address	Command/ Status	Data	Error detection/ correction

ODCS (Onboard Data Collection System) frame structure:

Major frame (512 byte)

- **Subframe 1**
- **Subframe 2**
- **Subframe 3**
- **Subframe 4**

Structure-memory: programmable frame-system

3 byte frame synchron / 4 byte housekeeping / 121 byte data

Outputs from digital and analog data collection systems

ESEO telemetry

- UHF beacon 437MHz GFSK
- Simplified AX.25 protokoll, Reed-Solomon error correction

GNU Radio decoding

```
0000: 8a a6 8a 9e 40 40 60 92 ae 68 88 aa 98 61 d2 00
0010: f0 04 7a 66 03 87 03 9e 03 9e 03 5b 03 4f 03 00
0020: 00 05 00 02 00 02 00 01 00 0c 00 3d ff 6c ff bf
0030: ff 63 00 65 00 5a 00 5a 00 5f 00 59 00 7f 00 7d
0040: 00 7a 00 80 00 76 00 71 00 cd 5f 00 aa ac 00 a0
0050: 00 07 00 5b 00 02 00 00 00 1a 00 01 00 7a 00 02
0060: 00 01 00 02 00 00 00 00 00 00 00 17 00 64 00 01
0070: 00 00 00 00 00 01 00 60 00 00 00 00 00 01 00 00
0080: 00 3f d0 00 02 00 e0 ff 01 00 00 00 00
```

- Decoded data (parts)

```
 pm_temp = 17.2
           16.0
pm_obdh_main_current = 7
pm_rx_main_current = 91
pm_tx_main_current = 2
pm_ss_main_current = 0
pm_mm_main_current = 26
pm_mw_main_current = 1
pm_mt_main_current = 122
pm_mps_current = 2
pm_tritel_current = 1
pm_hstx_current = 2
pm_gps_current = 0
```

```
pm_mps_valve_m_current = 0
pm_dom_1_current = 0
pm_obdh_red_current = 23
pm_rx_red_current = 100
pm_tx_red_current = 1
pm_ss_red_current = 0
pm_mm_red_current = 0
pm_mw_red_current = 1
pm_mt_red_current = 96
pm_es_current = 0
pm_ucam = 0
pm_amsat_current = 1
pm_lmp_current = 0
```

(https://sites.google.com/site/eseodecoded/home)

Onboard software 1.

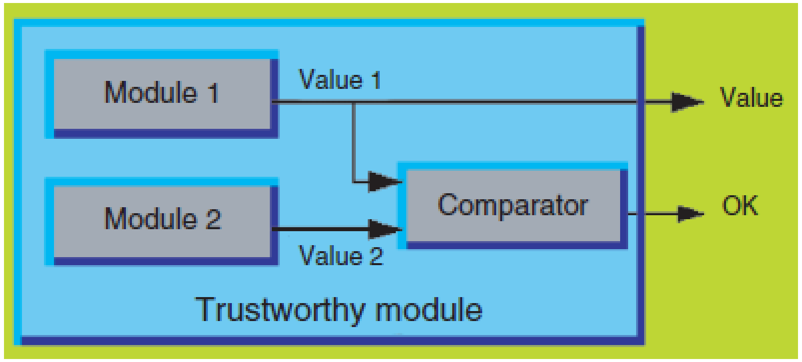
- The core of a space mission: similar to a subsystem
- Complexity is increasing: testing is difficult
- Software functions:
  - Boot sequence and OS
  - Running applications (multitasking)
  - Payload data management and reduction
  - On-the-fly processing
  - Real-time operation
  - Housekeeping
  - Telemetry/command interpreter
  - Controlling subsystems

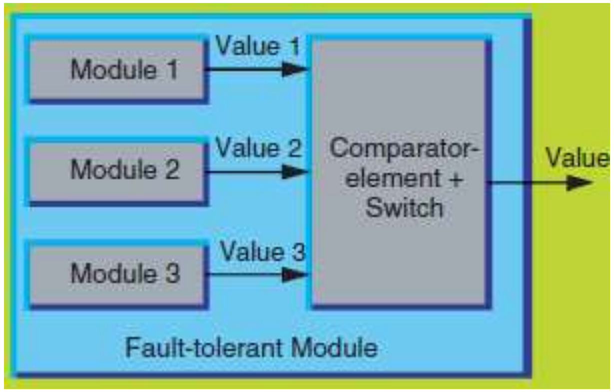
Onboard software 2.

- Fault tolerant solutions required
  - Code checksum
  - PZ pattern (observing memory pattern)
  - Applying watchdog
  - Command checking, error correction
  - Multitasking/scheduler
  - Telemetry redundancy, error correction
  - On-board memory, data storage

Safety and reliability

- Reliability of the control system
  - 10^{-9}-10^{-6} failure/hr
- Decrease complexity for the lowest possible level
- Implement fast recovery strategies
- Optimize redundancy level
- Fault tolerant systems
  - voter, watchdog, EDAC/EDC





Measurement data collection: common tasks

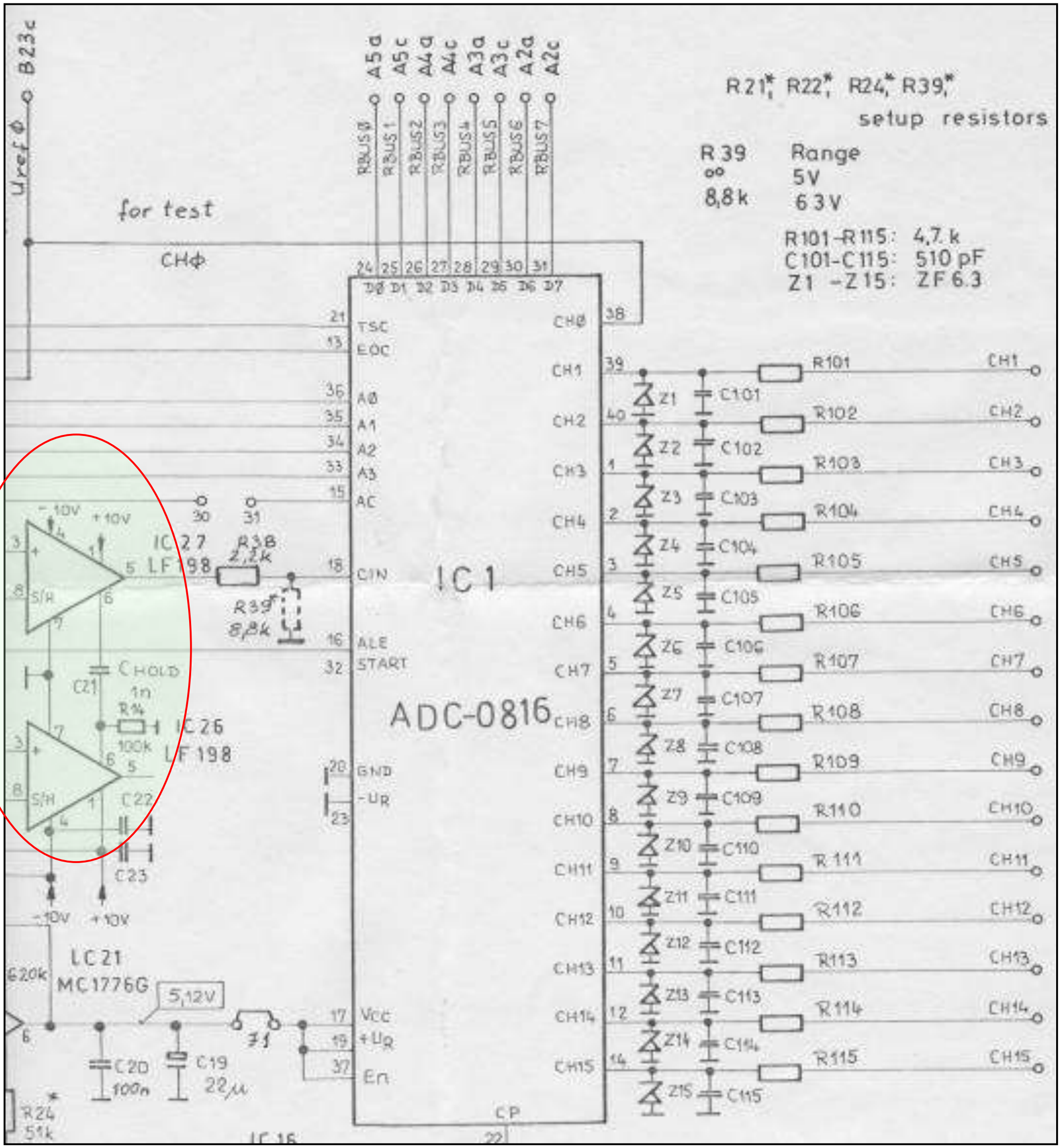
- Sampling analog channels
  - Multiplexing
  - Input level, mode, amplification
  - External/internal clocks
  - Single/continous/burst sampling (FIFO!)
  - Pre/post trigger
- Digital channel sampling
- Timer/counter functions
- Trigger signal generation
- Analog output (PWM, D/A)
  - D/A FIFO cyclic signal generation
- Advanced interrupt logic (multiple sources, priority, level ...)

The onboard data collection system

- A simple case: the onboard computer acts as data collection system
- Close cooperation with telemetry system
- Main functions of the data collecting system:
  - collect digital data
  - collect analog data
  - interface to experiments
  - level translation
  - communication with the onboard computer

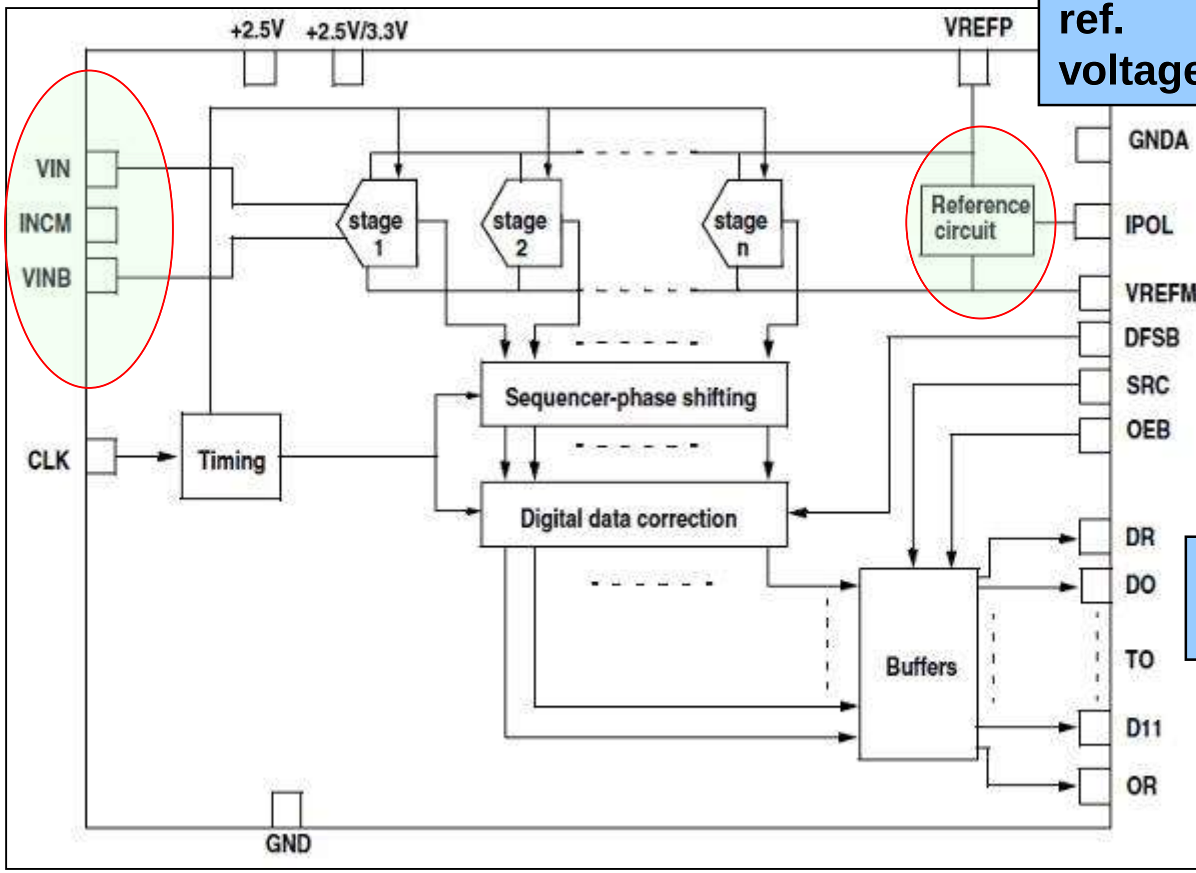
ADC0816: 8 bit, 16 ch, 100 µs, 15 mW, single supply

- sample & hold circuit
- differential input



RHF1201 300 krad, 12 bit, 50 Msps/100 mW, CMOS

differencial analog input



ref. voltage

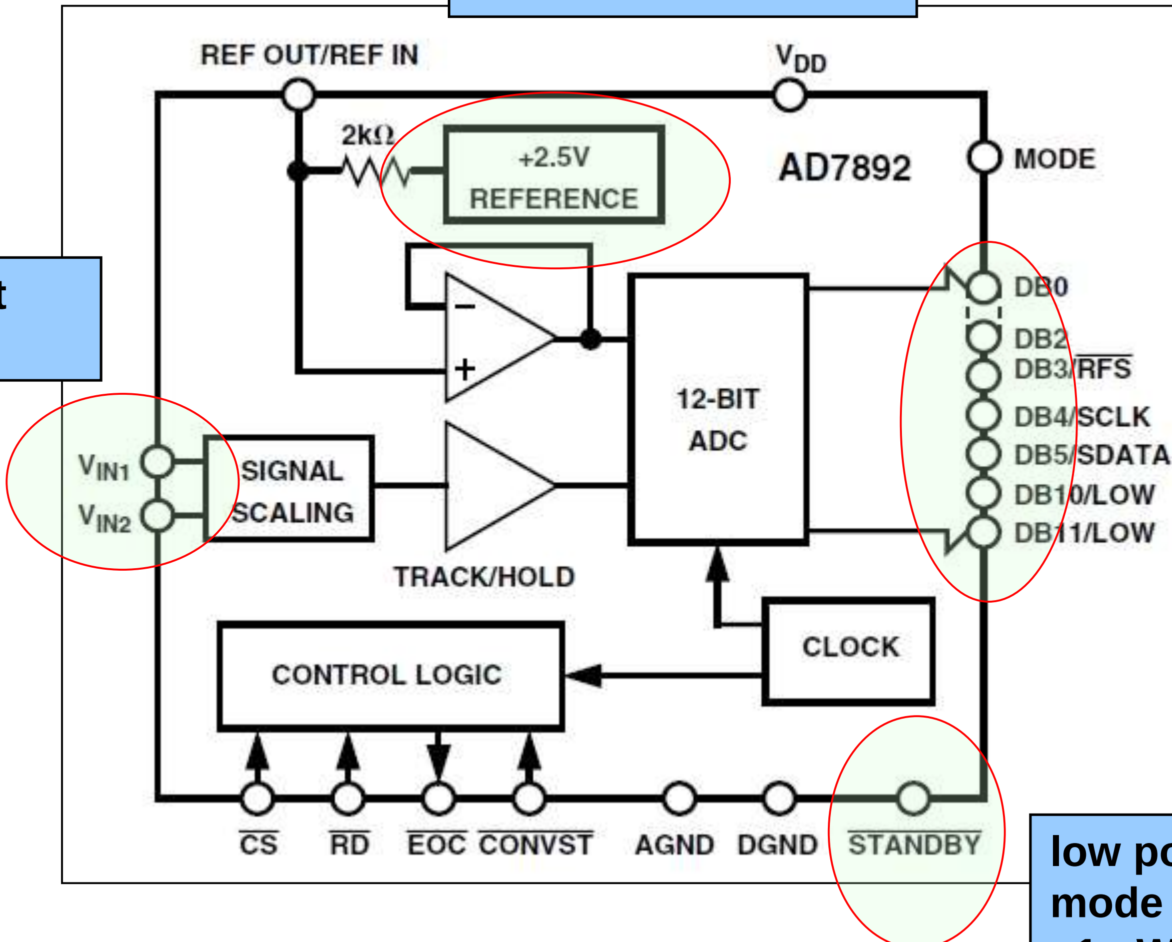
digital output

(STMicroelectronics)

AD7892, 12 bit, 600 ksps/60 mW LC²MOS ~20 krad (Rosetta)

internal reference

multiple input modes



digital output

low power mode <1mW

Main topics / questions

- The role of the onboard data handling system
- The telemetry and the telecommand system
- A simple telemetry frame structure
- The onboard data collection system
- Onboard serial communication types