Space Technology

Digital circuits and systems in space 1.

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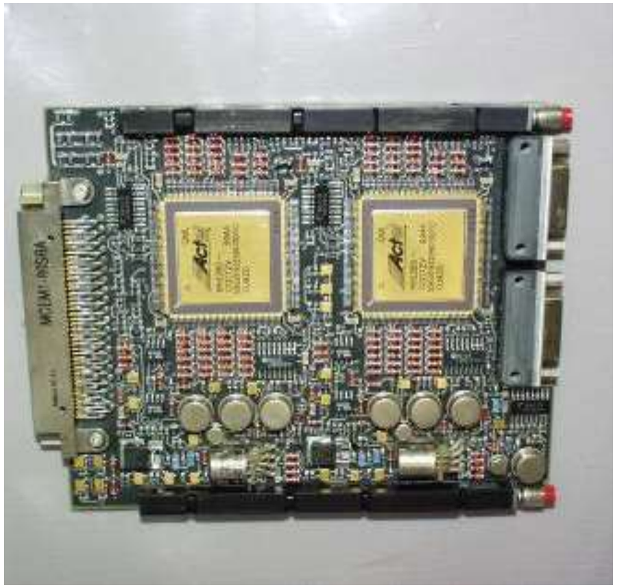
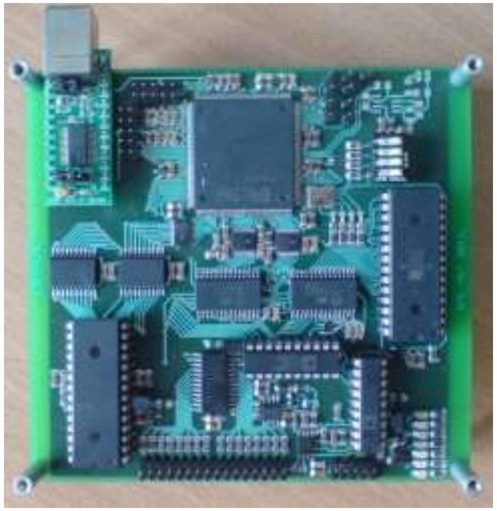
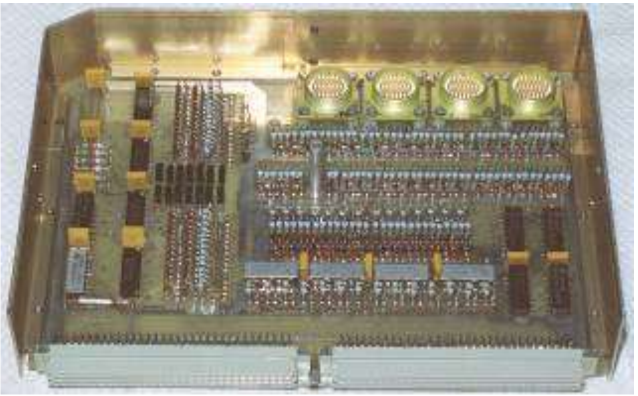
Scope of this lecture

- ❑ Application areas of the digital circuits
- ❑ Overview of the external effects
- ❑ Component selection criterions
- ❑ Digital design and reliability







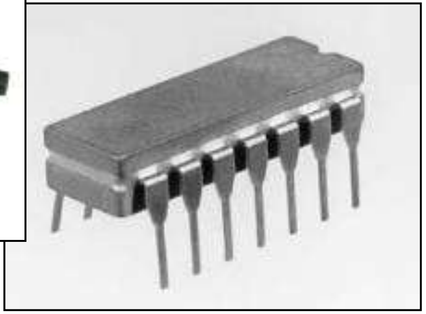
Digital circuits in space

- Power system
- Navigation and orientation system
- Telemetry, radio transmitters and receivers
- Onboard computer
- Central data collection system
- Experiments
- ...

Component requirements

- Reliability, robustness, redundancy
- Thermal (in/out of service)
- Vacuum
- Radiation hardening
- Power consumption
- Mechanical robustness, vibration
- No gravity
- Software quality, update, power

Basic rules



- Mechanics
  - vibration protection
  - gluing/fixing big components
  - vacuum-safe connectors/components
- Bipolar circuits(TTL)
  - power consumption ↔ radiation sensibility
- CMOS
  - low power↔ latchup danger–electronic protection required
- High integration density ↔ low radiation resistance
- HiRel components, 54 series(-55...+125 Cº, ceramic casing)
- EEPROM/flash memory limited
- Rad-hard or Rad-tolerant components

ESA Space Standards: https://escies.org/

ESCC

European Space Components Coordination

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EUROPEAN PREFERRED PARTS LIST

ISSUE 30 Revision A

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esa

Document Custodian: European Space Agency – see https://escies.org

European Preferred Parts List

European Space Components Information Exchange System, www.escies.org

- Components list for European space industry:
  - capacitors
  - connectors, switches
  - piezo-devices
  - diodes
  - filters
  - inductivities
  - microelectronic circuits, hybrid circuits
  - relays
  - resistors/thermistors
  - transistors
  - wires/cables
  - thermostat, RF passive circuits
  - etc.

EPPL components

- 80C32 microcontroller (ROM-less, 8051 core, obsolete)
- SPARC microprocessors (RISC, scalable register number, multiple types)
- SRAM, SDRAM
- EEPROM
- FLASH
- FPGA (programmable logic), ASIC (application-specific)
- Logical circuits: 4000 and 54 series

Manufacturers: ATMEL, INTERSIL, TI, ACTEL, Analog Devices, Honeywell, Aeroflex

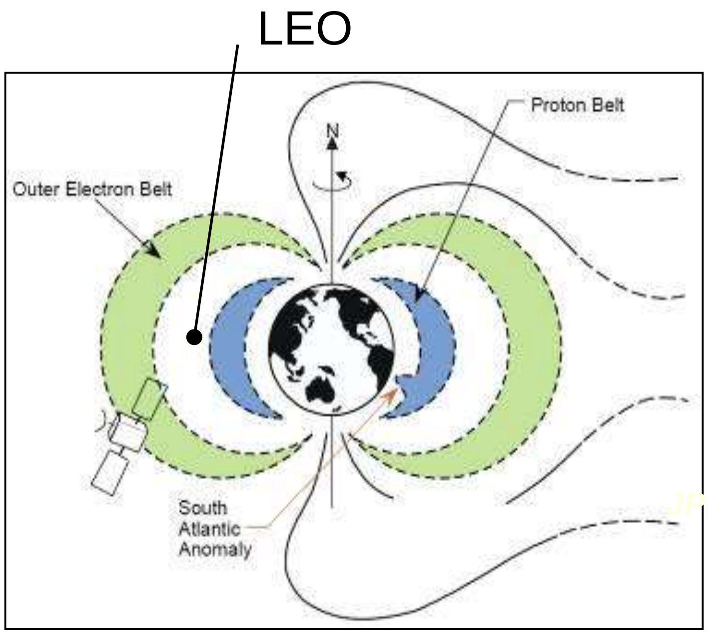
European Space Components Information Exchange System, ESCIES: https://escies.org/

Some data

- Cosmic background temperature (space): 2.725 K
- Vacuum
  - sublimation (material evaporation, metal welding ; lacquering may help)
- Temperature inside the satellite
  - Depends on surface and Sun distance
  - Usually inside of the component’s operating temperature range
  - Vacuum: heat transfer problem
  - External components: extreme conditions
- Mechanics
  - 1 Hz-10 kHz spectrum vibration (start)
  - ~20 g stress
- External magnetic field
  - Significant inducted voltages may arise
- Radiation
  - electromagnetic
  - particle

About radiation 1.

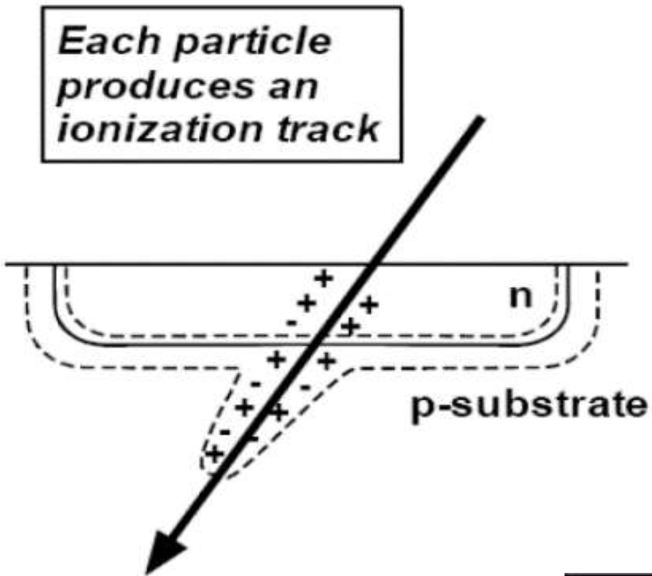
- **Base types**
  - Galactic cosmic rays
    - protons, α particles= He^{2+}, heavy ions
    - High energy (100MeV-10GeV) → cannot shielded
  - Solar flares
    - charged particles (proton, α)
    - medium energy → shieldeable
  - Earth specialty: a Van-Allen belt
    - Charged particles (proton, electron)
    - Concentrated by the Earth magnetic field

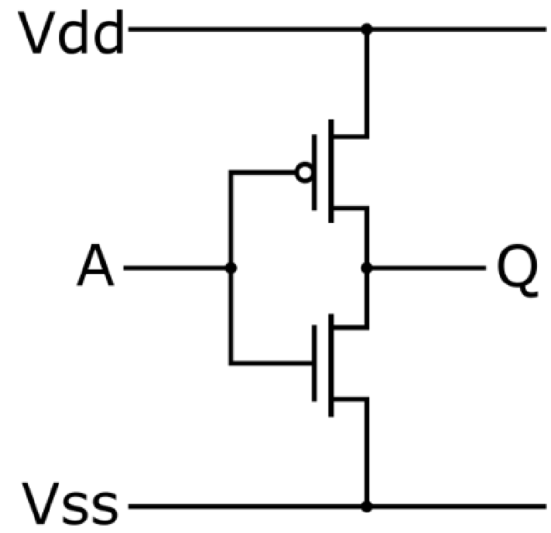


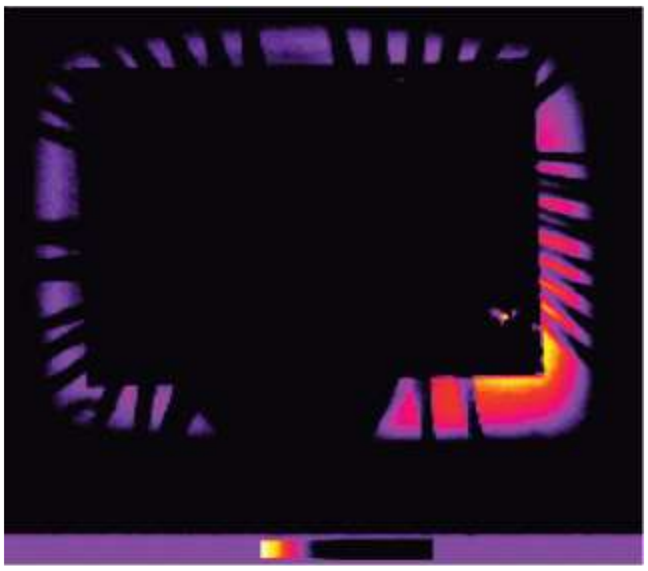
Van-Allen

- **Shielding**
  - proton/electron: aluminium 1-3 mm, polyethylene
  - using high atomic number materials (protons)
  - secondary radiation may arise
  - active protection: electrostatic or electromagnetic shielding
- Shielding electrons is easier, problem: shielding protons (ionizing radiation)
- **What and how are investigated**
  - single event effects (SEE), cause by a single particle:
    - SEL latch-up: soft / hard error (if Linear Energy Transfer Rate: 10-100 MeV/mg/cm^2)
    - SEU upset: soft error e.g. in memories
  - total ionizing dose / dose rate
  - displacement error (changing the crystal structure)

About radiation 2.

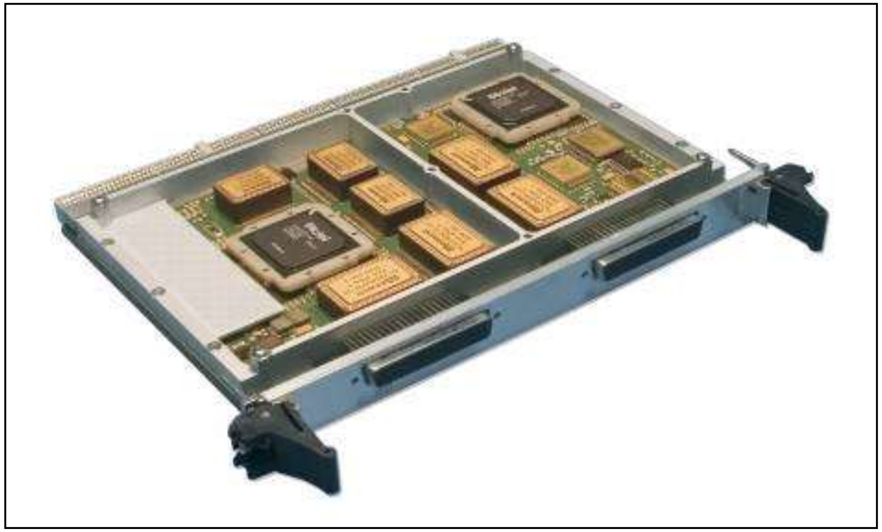






About radiation 3.

- The effect of charged particles in semiconductors
  - ionization, changing the crystal-lattice , heating
- Diodes: increase of back current and breakdown voltage
- Transistors: decrease of amplification, change of characteristics
  - FET / MOS : sensible to ionizing radiation
- Integrated circuits: according to the base components
- 1 rad = 10^{-5} Joule/g absorbed energy (>550 rad deadly)
- LEO orbit: ~4 krad/year (between atmosphere and inner Van A. belt, >300 km)
- Rosetta: >15 krad component tolerance / with 2mm Al shielding



Rad-Hard / Rad-Tolerant

	Radiation Tolerant	Radiation Hardened	Strategic Rad-Hard
Total Dose	< 300 Krad	300 Krad -1 Mrad	> 1 Mrad
Dose Rate Upset	$< 10^{7}$ rad/s	10^{7} - 10^{10} rad/s	$> 10^{10}$ rad/s
Dose Rate Survivability	$< 10^{10}$ rad/s	10^{10} - 10^{12} rad/s	$> 10^{12}$ rad/s
Single Event Upset	$> 10^{-10}$ errors/bit-day*	10^{-10} - 10^{-11} errors/bit-day*	$< 10^{-11}$ errors/bit-day*
Single Event Latchup	immune	immune	immune
Neutron	$< 10^{12}$ MeV-cm2/mg	10^{12} - 10^{14} MeV-cm2/mg	$> 10^{14}$ MeV-cm2/mg

Absorbed dose: energy/mass

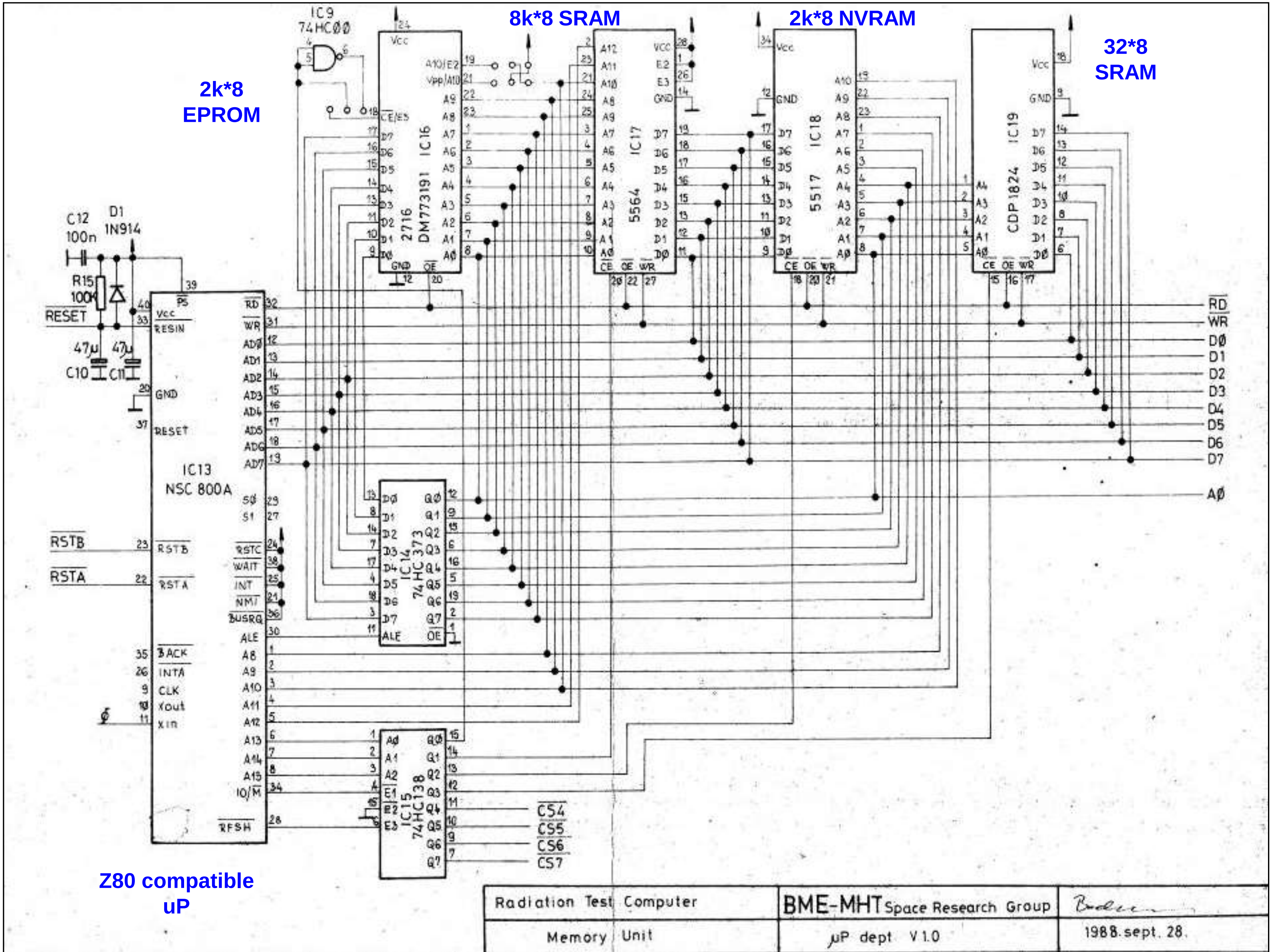
(www.honeywell.com)

Investigation of electronic components radiation sensitivity in cyclotron BME-ATOMKI, 1988

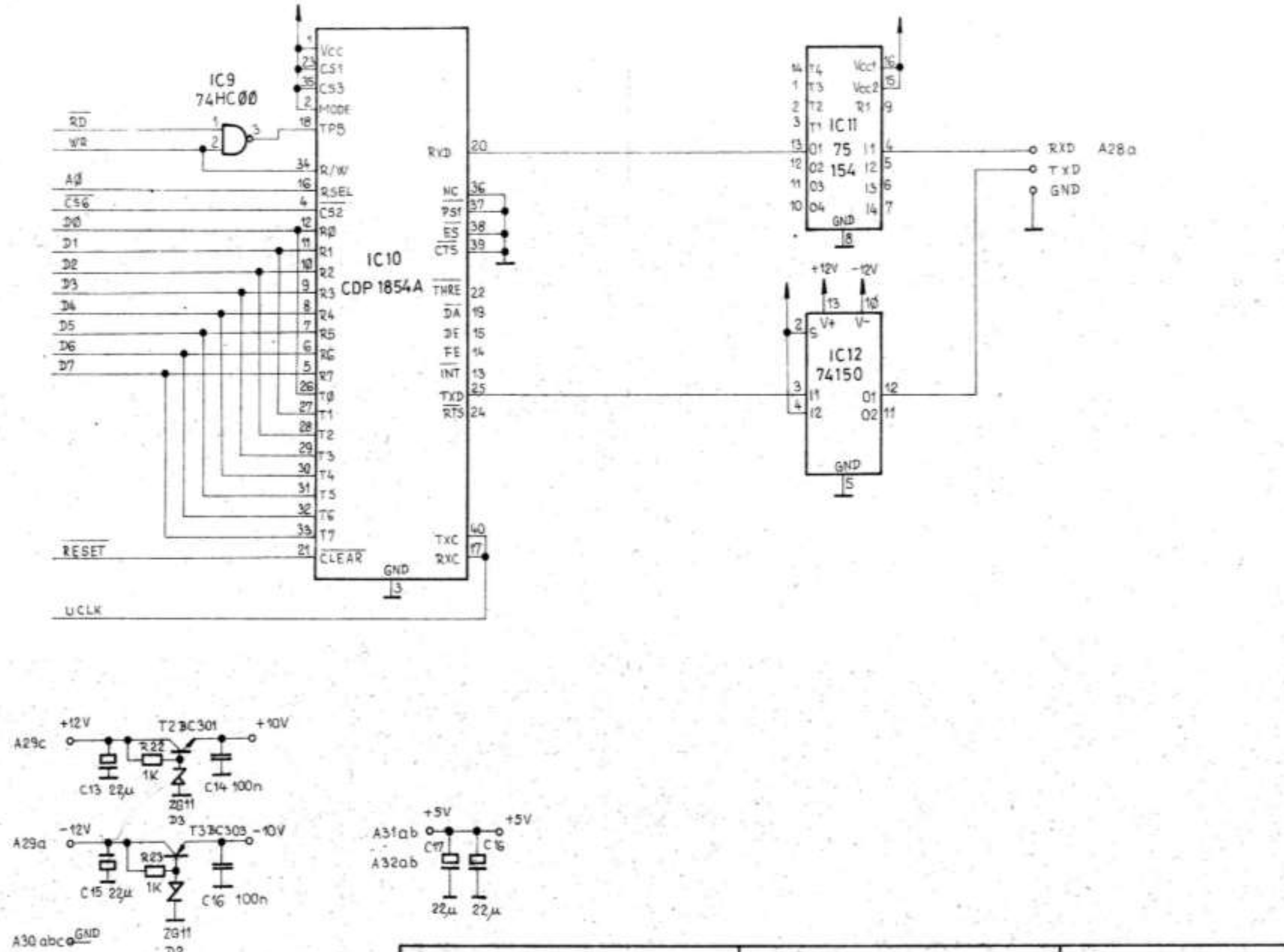
- Circuit board with several components
- Positionong X-Y mechanics
- Data collection program
- MGC-20E cyclotron, proton beam
  - 5 MeV and18 MeV energy, Ø 35 mm, 10^9 proton/cm^2
- Device tested:
  - discrete components, digital circuits, reference source and amplifier, memory, processor, A/D converter, UART

Some results

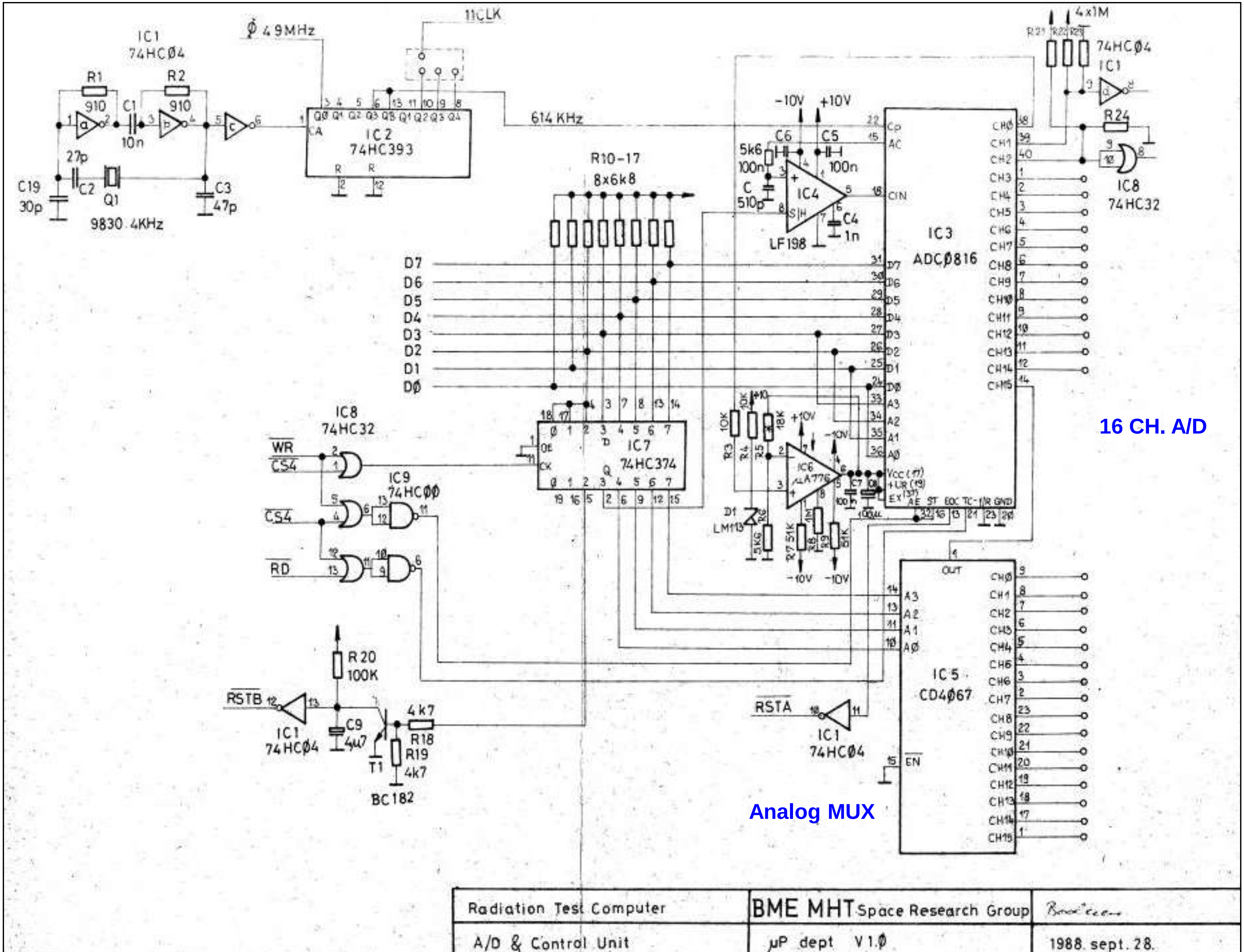
- Diodes, transistors, optocouplers: regeneration after irradiation
- LSI CMOS integrated circuits: charged particles are changing the bias voltage → output complementary transistors opened at the same time = short circuit (latch-up)
  - Solution: current limiting with serial resistor or with active protection
- VLSI integrated circuits:
  - 18 MeV → ~3 sec operation, 5 MeV → casing protects



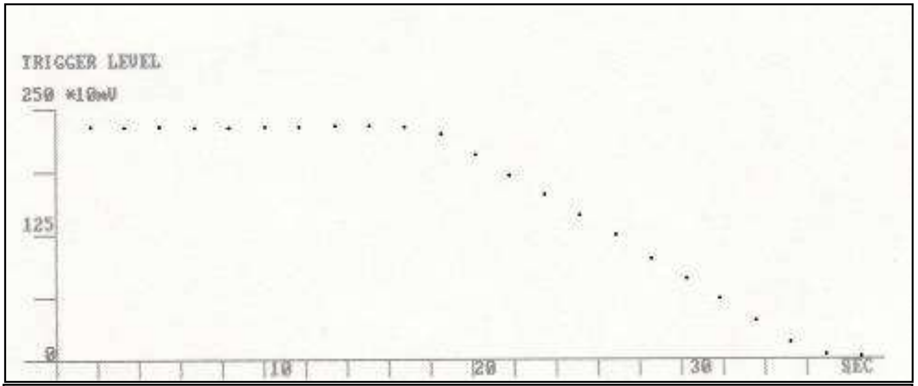
2k*8 EPROM
8k*8 SRAM
2k*8 NVRAM
32*8 SRAM
Z80 compatible uP
IC9 74HC00
IC16 2716 DM773191
IC17 5564
IC18 5517
IC19 CDP1824
IC13 NSC 800A
IC14 74HC373
IC15 74HC138
C12 100n
D1 1N914
R15 100k
47µ C10
47µ C11
RESET
RSTB
RSTA
RD
WR
DØ
D1
D2
D3
D4
D5
D6
D7
AØ
CS4
CS5
CS6
CS7
Radiation Test Computer
Memory Unit
BME-MHT Space Research Group
µP dept V 1.0
1988. sept. 28.



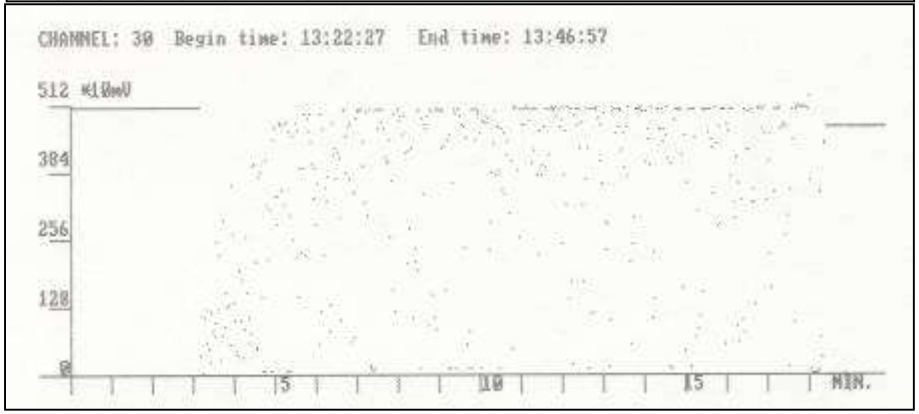
Radiation Test Computer	BME-MHT Space Research Group	1988 szept 26
Serial I/O	µP dept. V1.0	Bodnar


IC1 74HCØ4
R1 910
R2 910
C1 10n
27p
C19 30p
C2
Q1
9830.4KHz
C3 47p
Φ 4.9MHz
11CLK
IC2 74HC393
614 KHz
R10-17 8x6k8
D7
D6
D5
D4
D3
D2
D1
DØ
-10V
+10V
C6
C5
5k6
100n
100n
C 510p
IC4
S|H
LF198
C4 1n
IC3 ADCØ816
R21 R22 R23
4x1M
74HCØ4 IC1
R24
IC8 74HC32
16 CH. A/D
IC8 74HC32
WR
CS4
IC9 74HCØØ
CS4
RD
IC7 74HC374
R3 10K
R4 10K
R5 18K
IC6 μA776
D1 LM113
R6 5K6
R7 51K
R8
R9 51K
IC5 CD4Ø67
OUT
EN
R20 100K
RSTB
IC1 74HCØ4
C9 4μ7
T1
BC182
4k7 R18
R19 4k7
RSTA
IC1 74HCØ4
Analog MUX
Radiation Test Computer
A/D & Control Unit
BME MHT Space Research Group
μP dept V 1.Ø
1988. sept. 28.

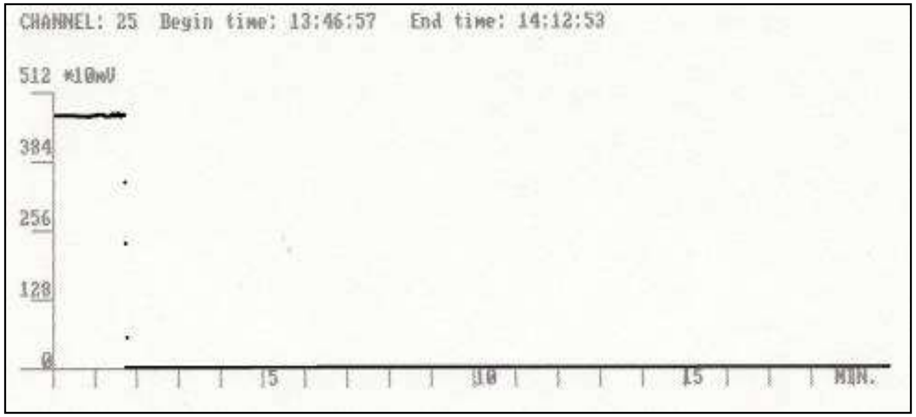
Some measurement results



Changing of the gate trigger level



Noise (optocoupler)



Short-circuit on CMOS output (Latch-up)

Data relating to components

- **Latch-up protected?**
- **Processor: ~60 krad**
  - **Atmel 80C32: 30 krad, Latch-up free up to 80 MeV/mg/cm²**
  - **Microchip 16/18 series microcontrollers (low-cost missions)**
- **RT/RH FPGA: 10-300 krad TID (Total Ionizing Dose)**
- **54 series:**
  - **-55 – 125 C°**
  - **~100 krad**
- **A/D: ~100 krad**
  - **AD7892: ~22 krad**
- **Memory: CMOS PROM, EEPROM, SRAM ~100 krad (special, RH devices), bipolar PROM >200 krad**

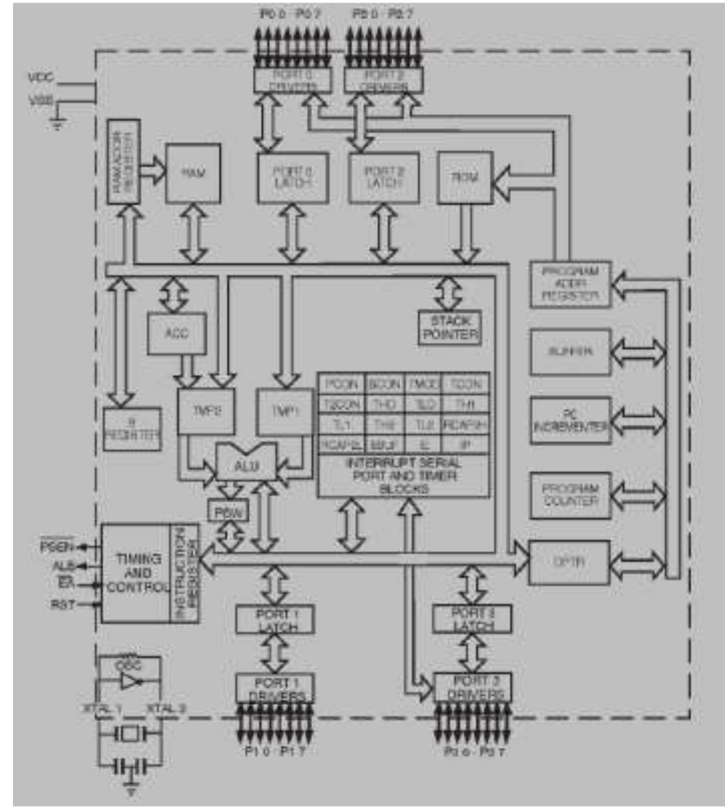
Technológy	Error level[Krad]
Linear IC	2 - 50
Mixed-signal IC	2 - 30
Flash Memory	5 - 15
DRAM	15 - 50
Mikroprocessor	15 – 70

(source: JPL/NASA)

CPU selection 1.

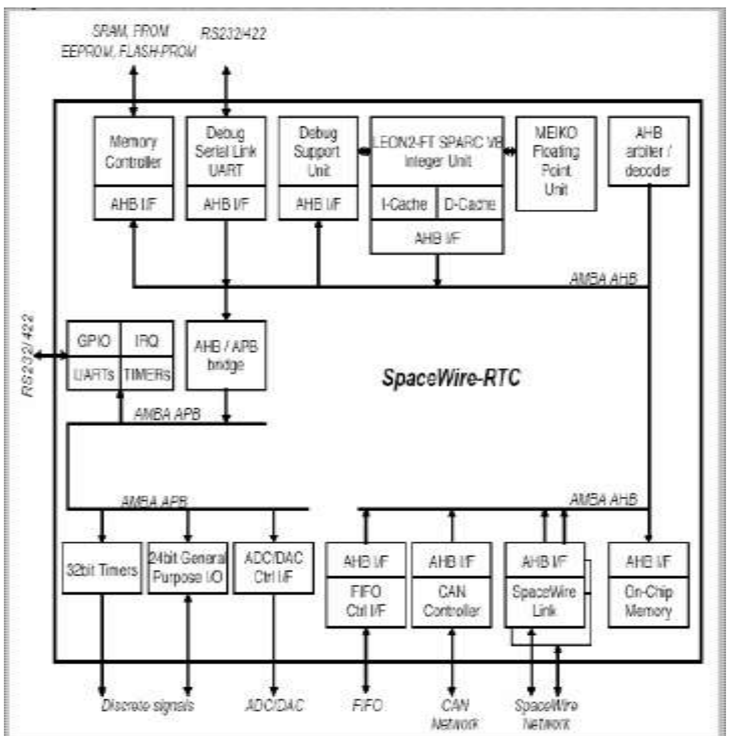
80C32 based microcontrollers (ATMEL)

radiation tolerant ROMless microcontroller
0.8µm CMOS technology, 30 Krad
Latch-up free below 80 MeV/mg/cm^2 LET
44 pin package
ATMEL announced end of life in 2010/11



AT7913E SpaceWire RT Controller (ATMEL)

LEON2-FT System-On-Chip, 85 Mips
cache & internal RAM
CAN, SPW, FIFO, ADC/DAC interfaces
MCGA package, 349 pins

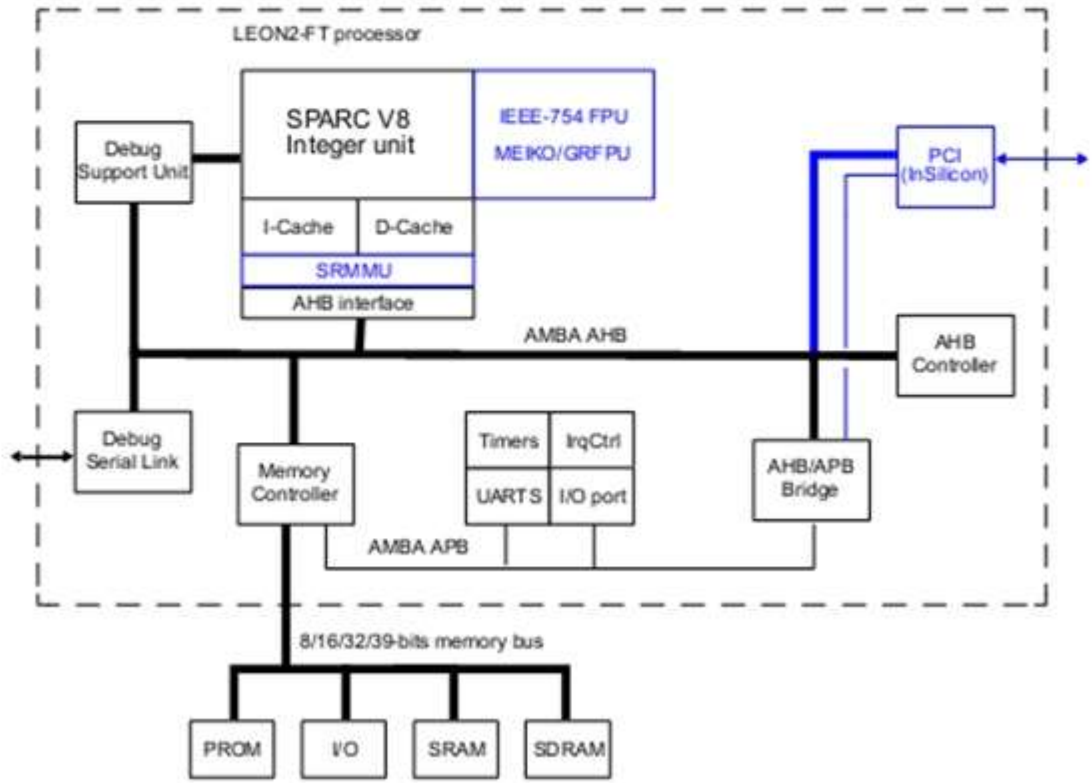


CPU selection 2.

LEON 2-4 family: based on V8uC Microcontroller IP-core

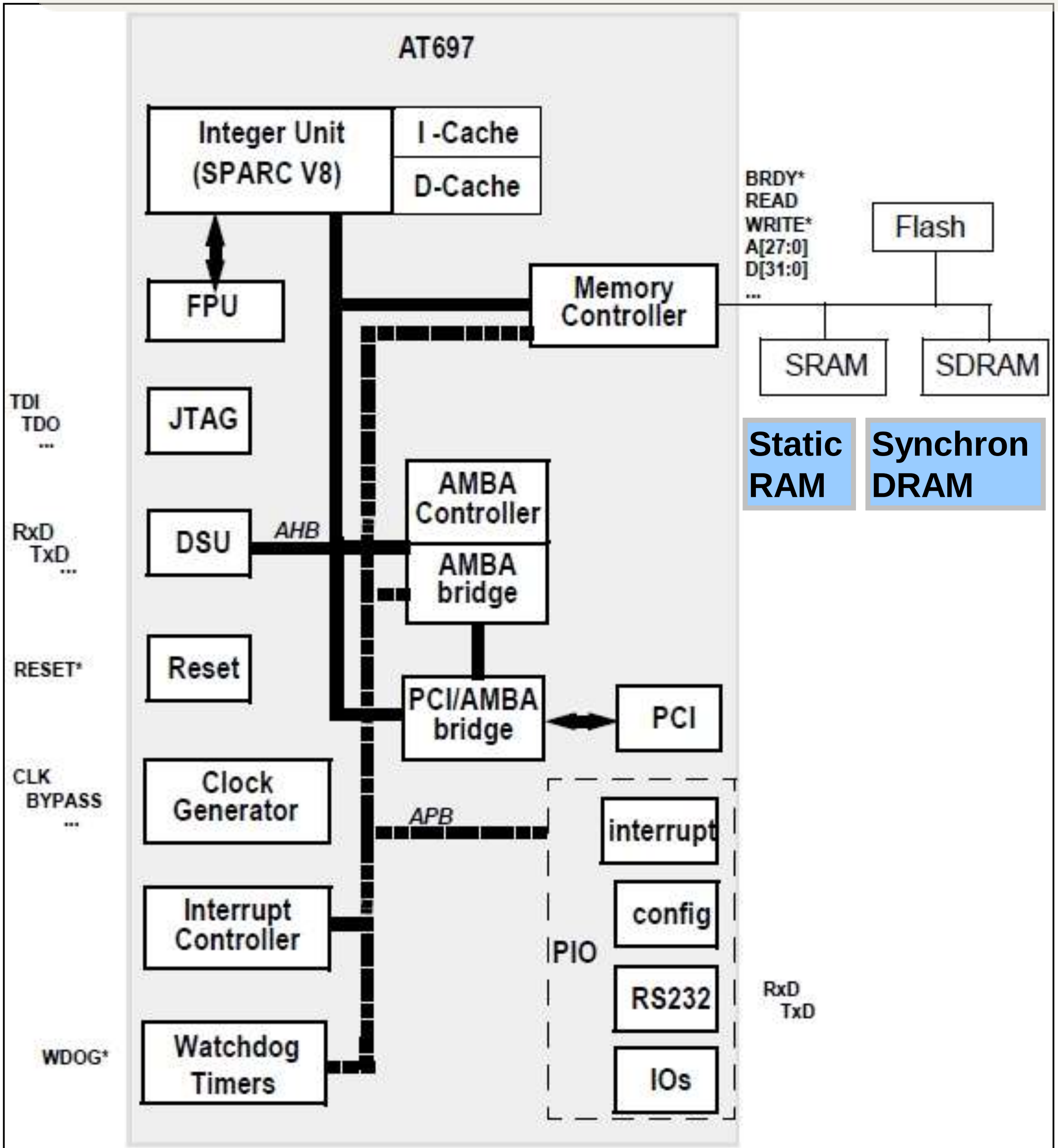
LEON-2:

- 5-stage integer pipeline
- separate instruction and data caches
- hardware multiplier and divider
- memory management unit
- interrupt controller
- debug support unit with trace buffer
- two 24-bit timers
- two UARTs
- power-down function
- watchdog
- 16-bit I/O port
- Flexible memory controller



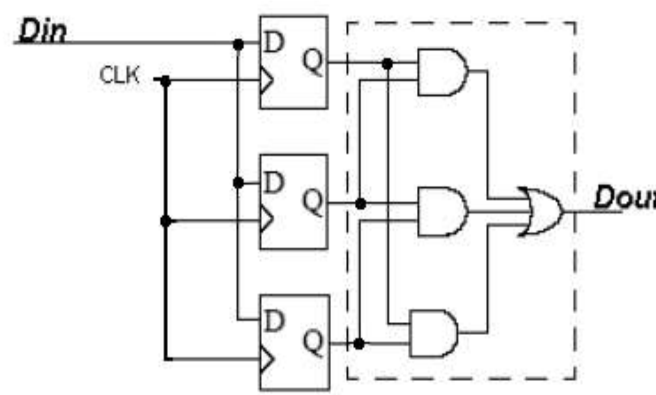
LEON: 32-bit CPU microprocessor core, based on the SPARC-V8 RISC architecture and instruction set (VHDL)
European Space Research and Technology Centre (ESTEC)

CPU selection 3. Atmel AT697E SPARC processor
Rad-Hard, fault tolerant, RISC, 1 instruction/1 clock cycle



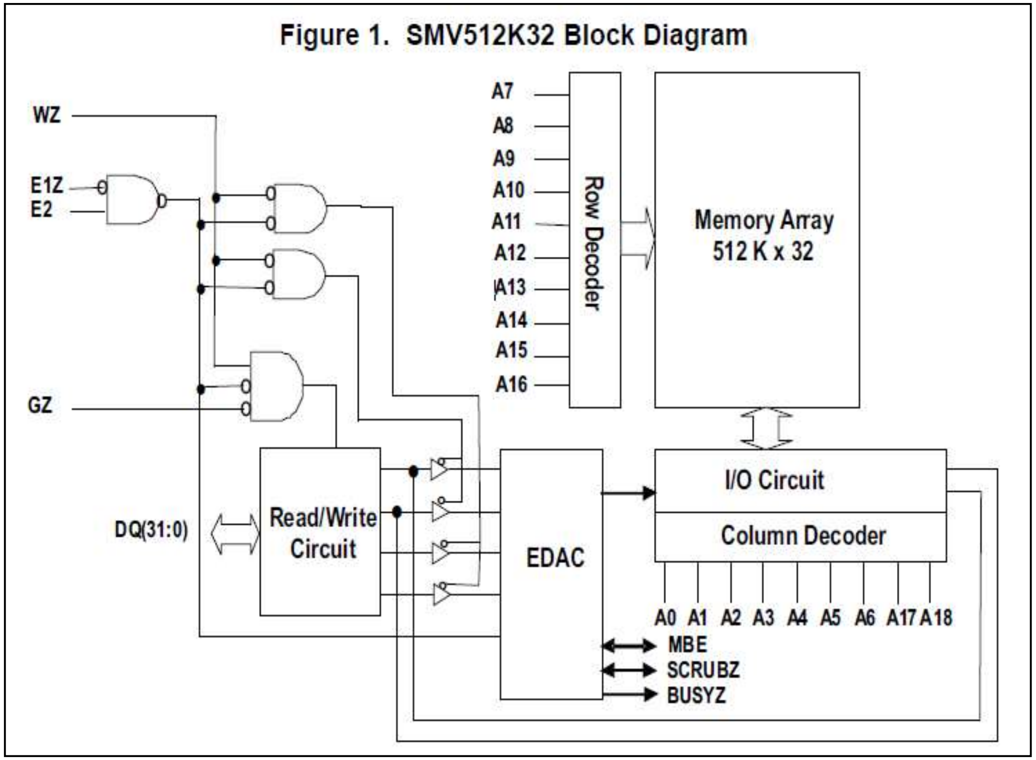
- 86 MIPS
- memory interfaces
- timers
- 2 USART
- IT controller
- 32 parallel I/O
- PCI interface
- 1 W / 100 MHz
- AMBA Advanced Microcontroller Bus Architecture
- EDAC and Parity protection

TMR (Triple Modular Redundancy) logic:



Memory selection

- ❑ ***PROM***
- ❑ ***DRAM/SDRAM***
- ❑ ***SRAM***
- ❑ ***Flash/EEPROM***
- ❑ ***SUROM***



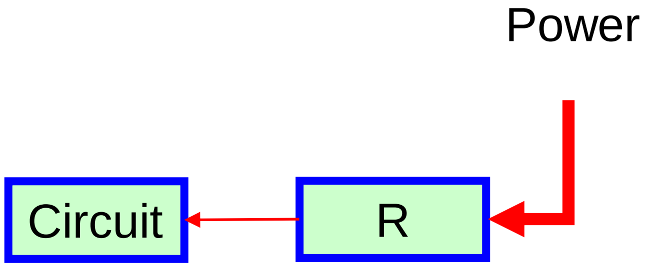
512*32 RADIATION-HARDENED SRAM
(www.ti.com)

- TID ≥300 kRAD
- SER < 5e-17 upsets/bit-day
- Latch up immune to LET 110 MeV
- Built-in error detection and correction (EDAC)
- Built-in scrub engine for autonomous correction

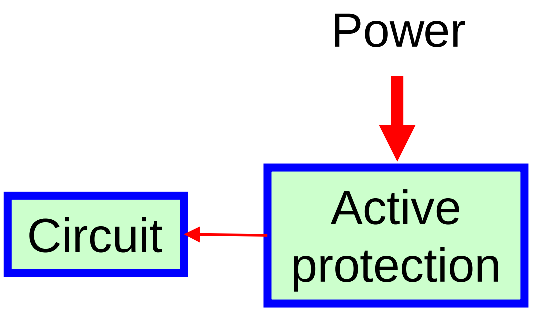
Cassini

Radiation protection

- applying rad-hard components
- using bipolar semiconductors
- shielding (aluminium)
- electronic latch-up protection
- protection with serial resistor



Passive



Active: current monitoring
switch-off within 1ms

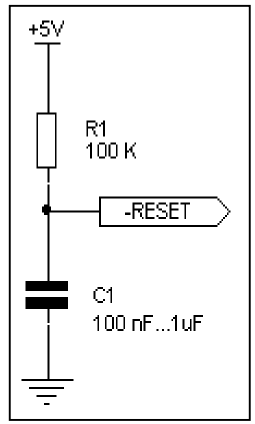
Digital design – reliability questions

- ❑Reset
- ❑Watch-dog
- ❑Clock
- ❑Layout
- ❑Hazard-free design

Digital design– reliability 1.

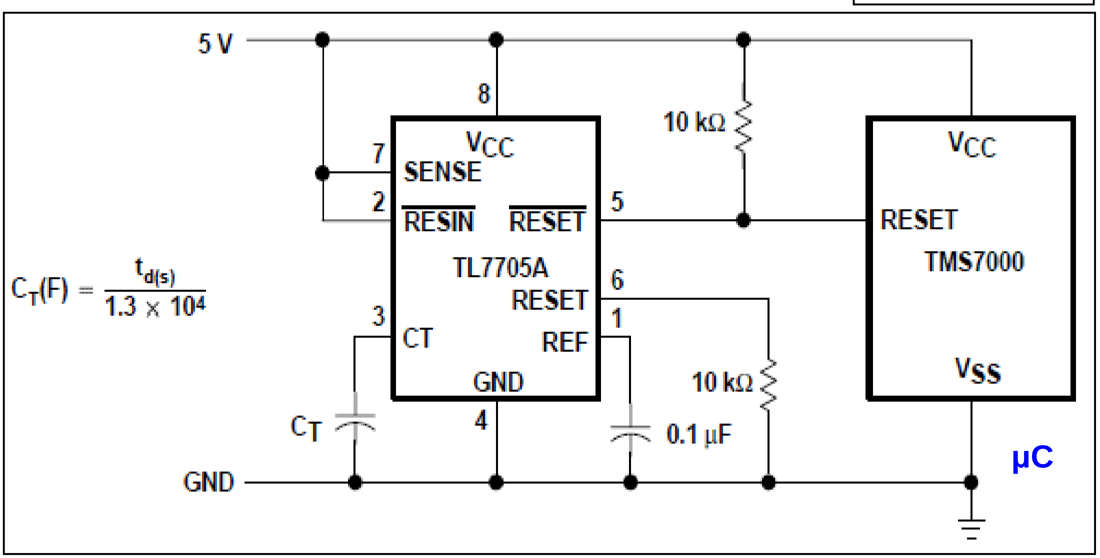
Reset: process after power-on
processors/DSPs may have further hardware inicialization
power voltage change/decrease may cause reset

Reset circuits



RC

+ simple
+ cheap
- temperature ans voltage dependent
- slow signal transitions

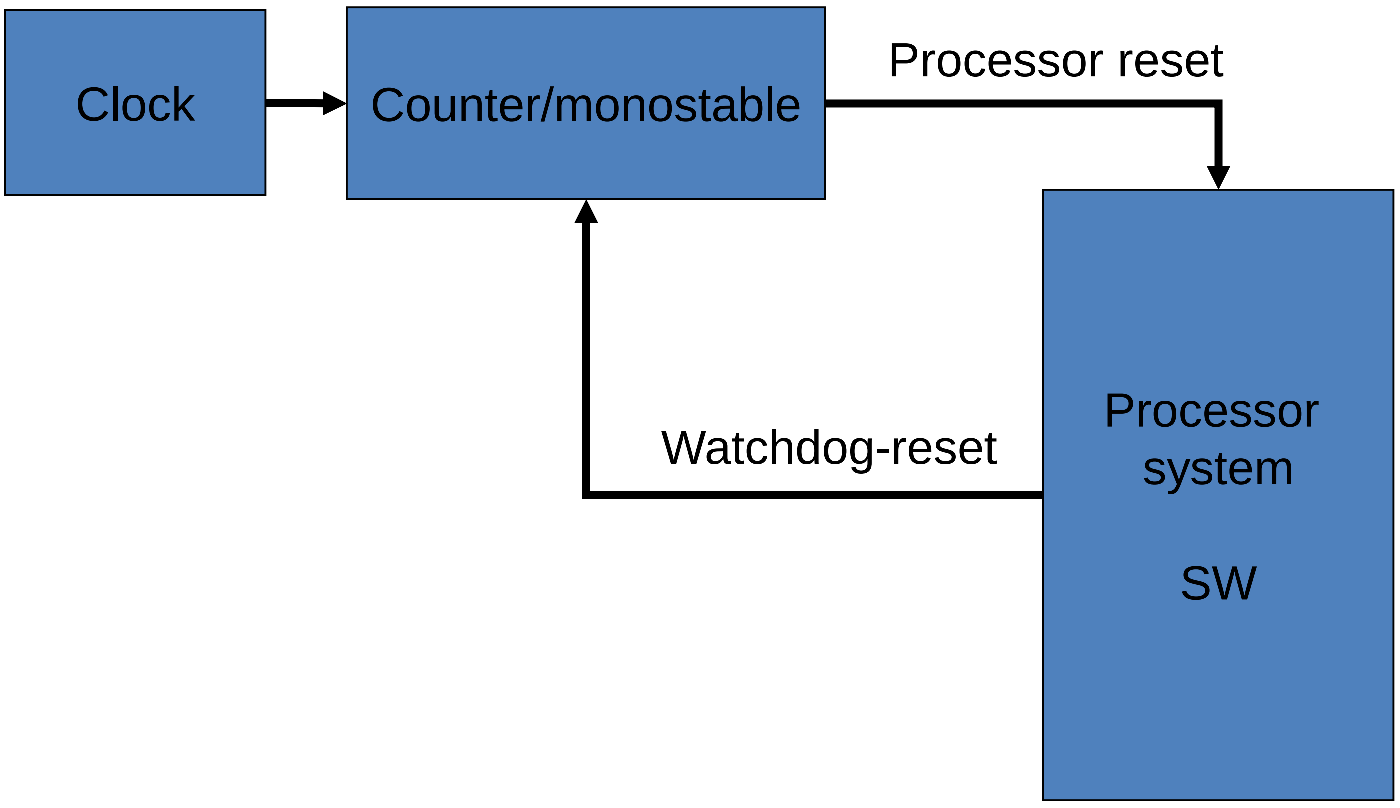


ACTIVE

+ temperature compensated
+ exact voltage detection
+ tuneable reset-time
- complicated

Digital design– reliability 2.

Watch-dog: **resolve software failures**
parameter: reaction time

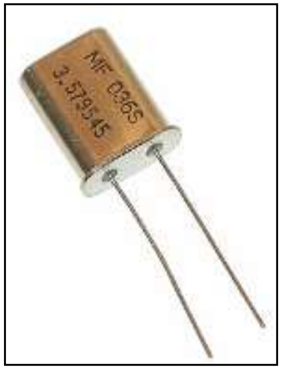


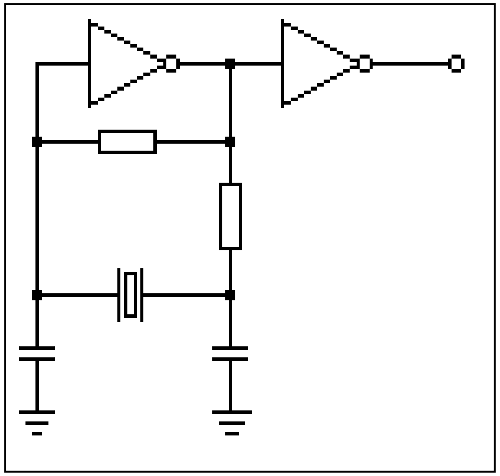
Digital design– reliability 3.

Clock generation: **quartz-oscillators**

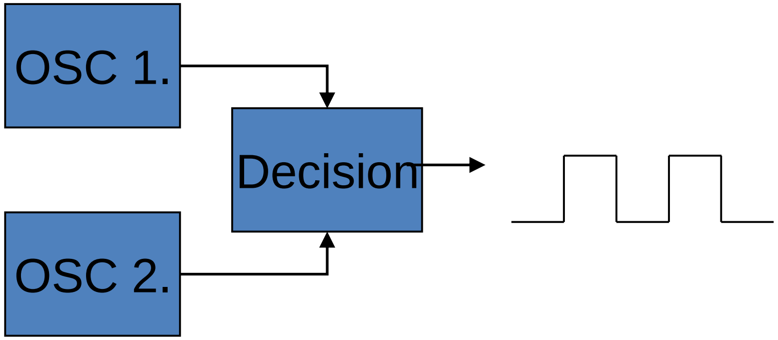
serial or parallel resonance

+ high precision
+ low temperature dependence (improveable with thermostat)
- mechanically sensible



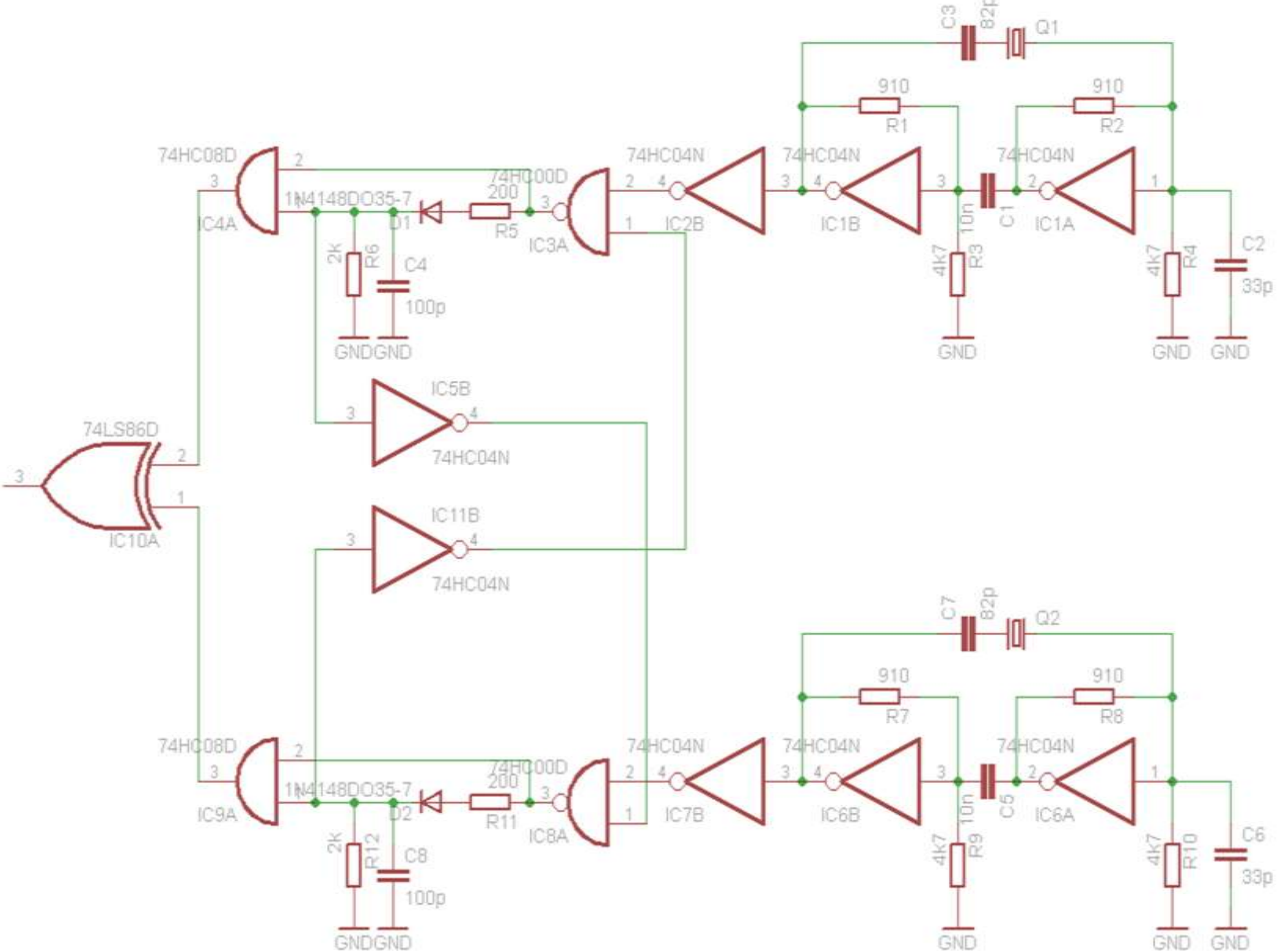


The onboard clock generation is always redundant



[Quartz for space missions]

Redundant clock generation



Digital design– reliability 4.

- **PCB design considerations**
  - **0/1 signals transferred: high curren peaks are generated**
    filtering capacitors
    wide power lines (using inner layer)
  - **digital and analog circuits must be separated**
  - **upper and lower PCB layer can be used for EMC protection**
  - **using as short wires as possible**
  - **at high frequencies: PCB acts a waveguide**
  - **pull up/down the unused CMOS inputs**

Main topics / questions

- ❑ Bipolar vs. CMOS circuits in space applications
- ❑ RadHard and RadTolerant components
- ❑ SEL and SEU
- ❑ Radiation dose accumulation and its effects
- ❑ Microprocessors vs. microcontrollers
- ❑ The watchdog