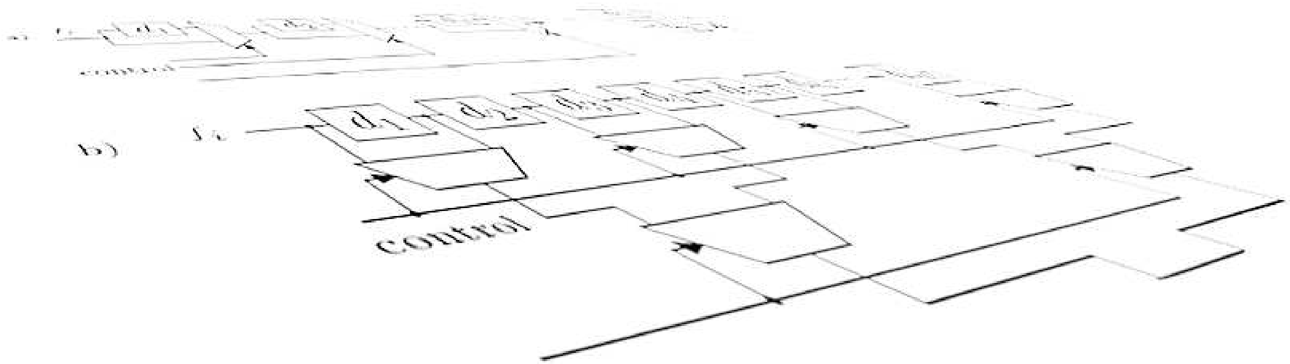


SERENUM a.s.

Electronics:

Inertial & Measurement Systems

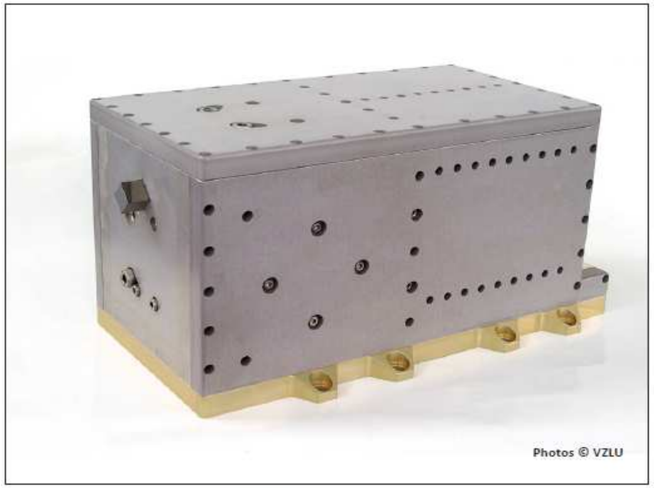
Time & Frequency Control

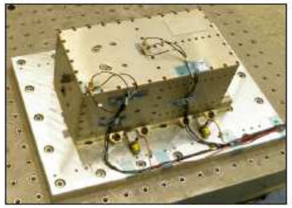
Custom Design and Development of Electronics

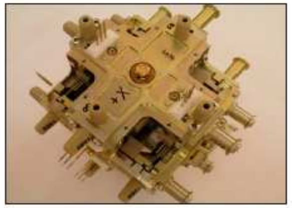
Outline

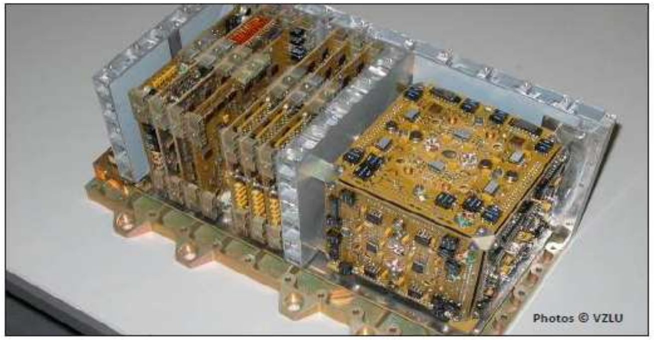
- Inertial & measurement systems
    - Capacitive micro-accelerometer
    - Inductive micro-accelerometer
    - Optimal estimator (Kalman filters) design for IMU
- Time & frequency control
    - Time-to-digit converter
    - Programmable delay controller
    - Direct RF signal generation DSP cores
    - Optimal clock ensembling algorithms
    - Single-photon counting detectors and timing
- Custom electronics design
- References

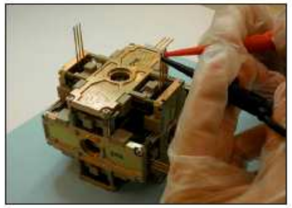
Capacitive micro-accelerometer for space #1











- High accuracy microaccelerometer measuring an influence of non-gravitational forces upon an artificial satellite

- Measurement of very small and slow accelerations in space

- Sensor based on a free-floating proofmass placed within a cavity of the same shape

Selected parameters:

- Measuring range – rotational +9.6e-3 $rads^{-2}$
- Measuring range – linear 2.1e-4 $m{\cdot}s^{-2}$
- Resolution – rotational 4.09e-7 $rads^{-2}$
- Resolution – linear 8.94e-9 $m{\cdot}s^{-2}$
- Frequency range from 1e-4 to 1e-1 Hz

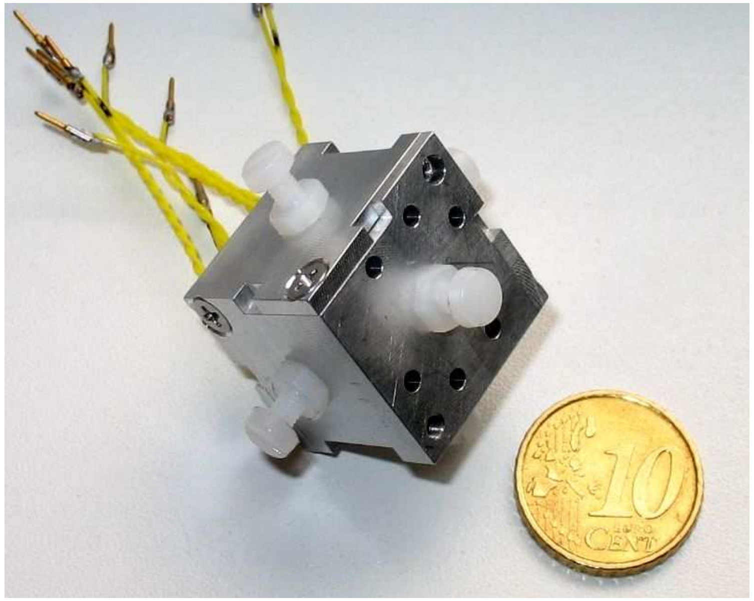
- Accuracy of acceleration measurement 0.2 %
- Dimensions 345 x 204 x 177 mm
- Weight 6.4 kg

Inductive micro-accelerometer for space

- Sensor using repulsive force on conductive materials in alternating magnetic field for proofmass stabilization

- Proofmass position derived from changes of magnetic field distribution inside the sensor

- Status: sensor design and detection principle verified on the development model in laboratory conditions



Selected parameters:

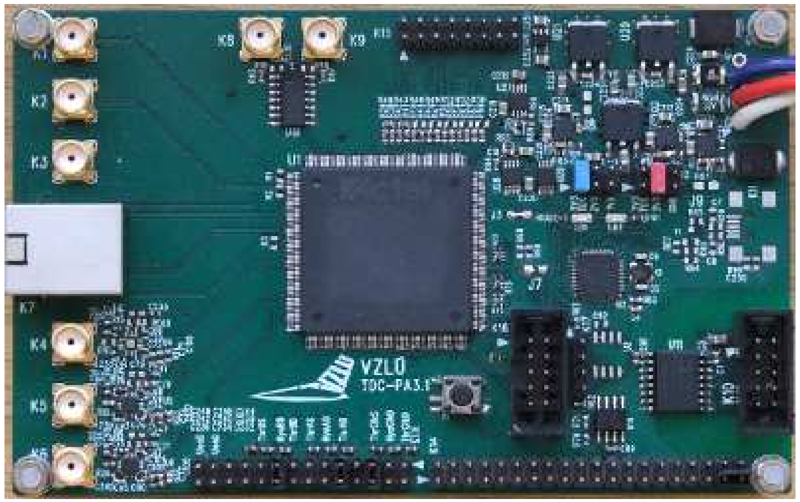
Three axial acceleration range cca - 1e-3 $m \cdot s^{-2}$ (1e-4 g)
- Frequency range - 0,1 - 100 mHz
- Resolution - 1e-7 $m \cdot s^{-2}$
- Accuracy - cca 1%
- Dimensions - cca 100x100x50 mm
- Mass - cca 200 g
- Consumption - cca 200 mW

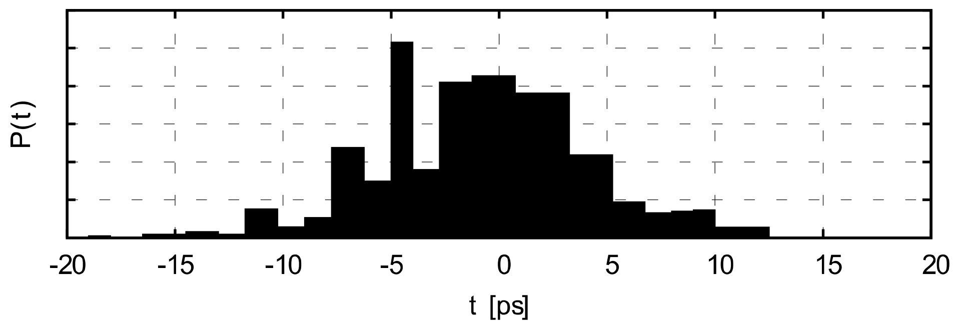
Extended Kalman Filter for Inertial Measurement Unit

- Extended Kalman Filter for Inertial Measurement Unit (3× acc., opt. 3× gyro, opt. 3× magnetometer)
- original Extended Kalman Filter
  - unique covariance treatment, tailored for attitude quaternion
  - efficient, robust, fixed-point ready UDU-factored sqrt-EKF implementation
    - based on heritage of V. Peterka, Czechoslovak Academy of Sciences, 1970s
    - beneficial over QR-based sqrt algorithms
- UAV-rotorcraft flight-proven (autopilot)

Time-to-Digit Converter (TDC)

- All-digital (FPGA = Field Programmable Gate Array), delay-line based TDC
  - inherent self-compensation of slope drift
  - accurate stochastic calibration
  - SEU-tolerant design branch
- 20.7 ps abs. max. deterministic error
- 6 ps RMS random jitter
  - may complement phasemeter within CMCU; 2 orders of magnitude time reading improvement

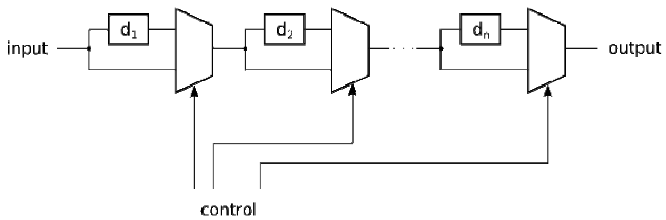


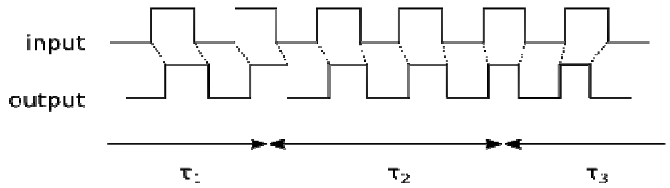


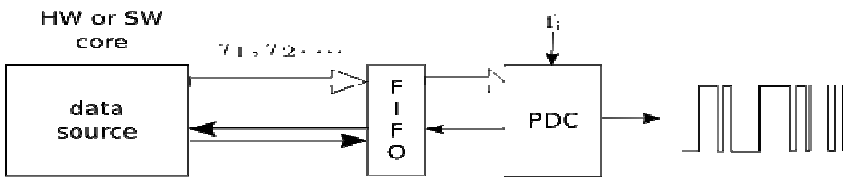
Single shot measurement histogram of the developed TDC

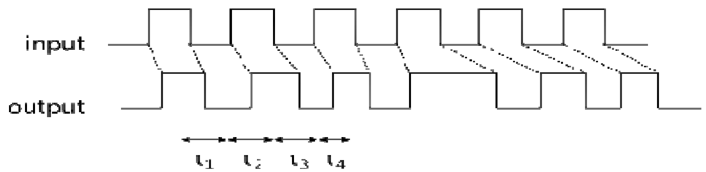
Programmable Delay Controller

- currently known PDCs: fs << fo
- our concept: fs ≈ 2fo
- generation of arbitrary binary waveform, subject to the only constraint: edge-to-edge time tee ≥ tmin
- fs ≈ 2fo   number to time-domain converter
- edge-to-edge times data-flow $t_k \longrightarrow$ waveform
- low jitter: no edge created by MUX
  - jitter defined solely by input clock & delay-line jitter
- frequency synthesis possible, even to higher f
  - without local oscillator!
- modulation (BPSK, n-PSK, FM, PM) possible









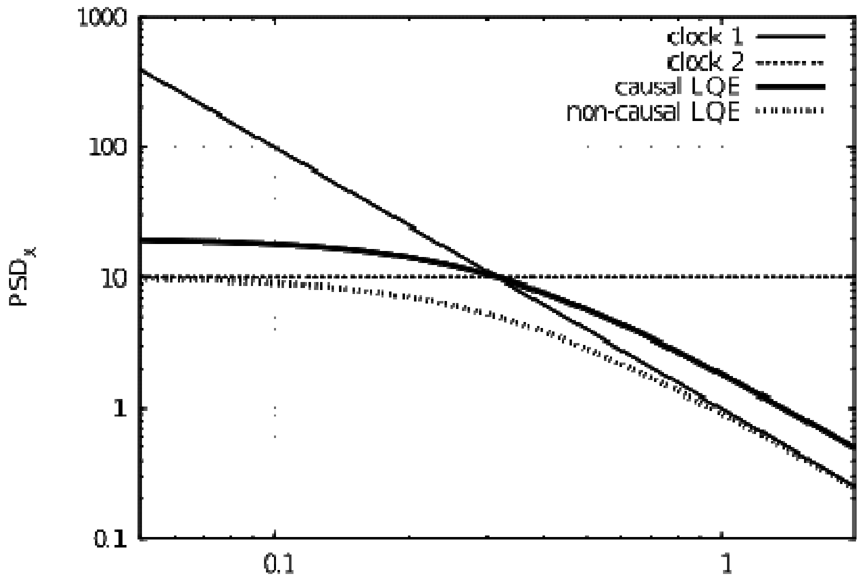
Direct RF Signal Generation DSP Cores

- pure sinewave DDS
    - 200Msps, up to 2GHz BW with appropriate DAC
    - strongest observed spur: -65dB (without dithering)
- precise pulse generator (DAC-based)
    - 100MHz BW
    - <0.1ps resolution
    - allows low-jitter phase stepping
- PN code CDMA modulator
    - including fine tuning of code and carrier phase/frequency

Optimal Clock Ensembling

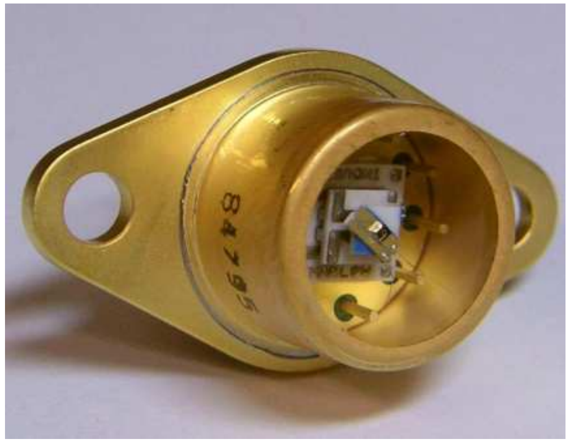
- clock ensembling problem
  - each single clock drifts (marginally stable process)
  - ensemble of N clocks ≡ N – 1 measurements → not completely observable
- unbounded error
  - estimation non-trivial by means of classic control engineering
  - → Kalman ensembling still discussed today

- robust, integer arithmetic-based implementation
  - V. Peterka's UDU for sqrt-Kalman filter
  - only + - * / → no FPU, cross-platform identical behaviour, rational-number variants possible



Single-Photon Counting

- cooperation: Czech Tech. Univ., Prof. B. Sopko, Prof. I. Procházka
    - 40 years of G/S↔S/C photon counting
    - 25 years of radiation-hard, Si solid-state detector
- broad S/C and SLR experience (well received in geodesy, ILRS)
- suitable for GNSS laser links, EO missions
    - simultaneous ranging and picosecond time transfer



Custom Instrumentation #1

- Digital signal processing, data acquisition systems, and real-time process control

- FPGA (Field Programmable Gate Array) design, IP core development, high-throughput real-time data processing, including alternative industrial and aerospace versions (e.g. Actel/MicroSemi & Xilinx)

- Localization systems based on inertial-, camera- and beacon-based measurements

- Analysis, calculation and implementation of controllers and estimators; implementation of measurement and control in real-time as well as offline processing, digital signal processing, algorithm implementation or stand-alone hardware solutions

Custom Instrumentation #2

- Delay compensation and adjustment for use in telecommunications, satellite technology, and navigation

- Precision time metrology, custom built equipment, event time, interval and phase measurement (10^{-12}…10^{-10} s RMS single-shot jitter), accurate frequency/phase synthesis; distribution and synchronization of time in the industrial and computer networks, electro-optical devices calibration

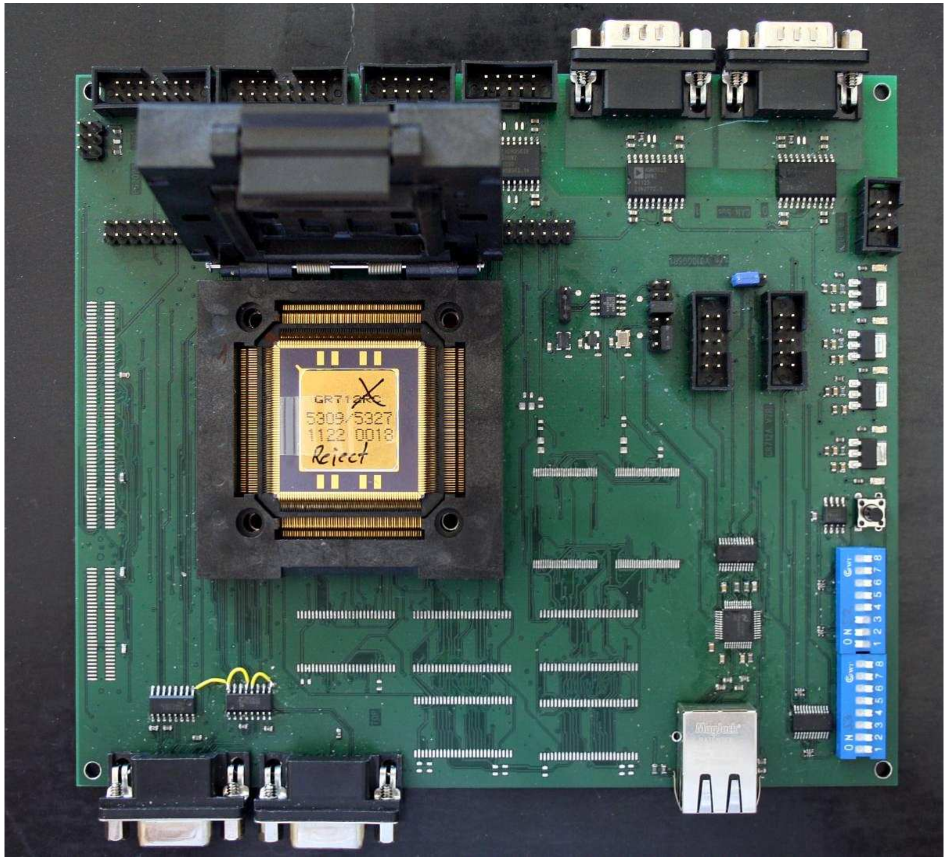
- Measurement, generation and distribution of precise time and timestamps, systems based on radiation-tolerant FPGA

- Numerical simulation of timing and photonic devices

- Electronic and electromechanical system audit, optimization and prototyping (including production documentation)

Custom Instrumentation #3

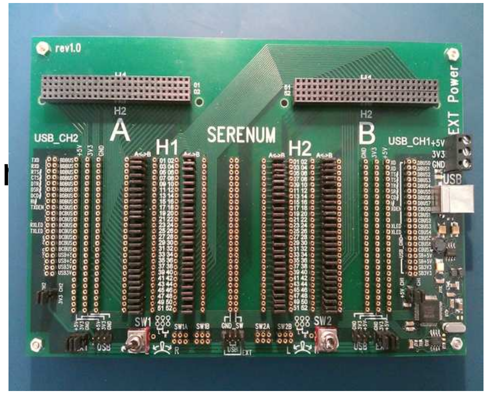
- In-house SPARC LEON board
- Gaisler GR712RC SPARC LEON3-FT development boards
- Open-source toolchain, no need of GRMON



References

- **OCEARI** (2014-now) - Optimal clock ensembling algorithms with robust implementation for ESA
- **TT III-TX** (2014-now) – Digital version, both transmit and receive, of TimeTech's modem for ranging and time transfer.
- **SWARM** (2005 -2011) - Three flight units of capacitive microaccelerometer including ground segment equipment were developed and delivered for three satellites of SWARM mission.
- **TEASER** (2004-2009) - Flight verification of microaccelerometer during orbit operation, launched on Russian satellite TATIANA 2.

SNM-H201 is low phase noise programmable frequency synthesizer



SNM-CD10 CubeSat debug tool for measurements and experiments on standard main 104 pin CubeSat connector