Hes·so
Haute Ecole Spécialisée de Suisse occidentale
Fachhochschule Westschweiz
University of Applied Sciences Western Switzerland

HEIG VD
SCHOOL OF ENGINEERING AND MANAGEMENT

iICT
INSTITUTE OF INFORMATION AND COMMUNICATIONS TECHNOLOGIES

A presentation of HEIG-VD activities
centered on
Radio-astronomy
PAF2024/ASPFR20244
Brigham Young University, Salt Lake City

Dominique Bovey

Who are we?

- An applied R&D lab
  - Specialized in RF, microwave, IoT devices, low power embedded
  - Part of the Institute of Information and Communication Technologies
  - Part of the business and Engineering School Canton Vaud in Yverdon HEIG-VD, 20km north of Lausanne, Switzerland
  - Which is one campus of the University of Applied Sciences and Arts of Western Switzerland HES-SO (healthcare, business, agriculture, arts...)

- Our lab is scoping on long-term projects with industry and science partners
  - 12 employees (8 seniors)
  - Long-term employment contracts
  - Current core team active since 2011
  - No professor but a business manager, little teaching activities
  - ECSS-based project management and SysML on select projects
  - Microwave circuit design, implementation, testing, industrialisation
  - Design, implementation and testing of electromagnetic devices

    Tracking rhino and hornets, medical ultrasound, medical RF treatment, implants, measuring watches, SAR radar...

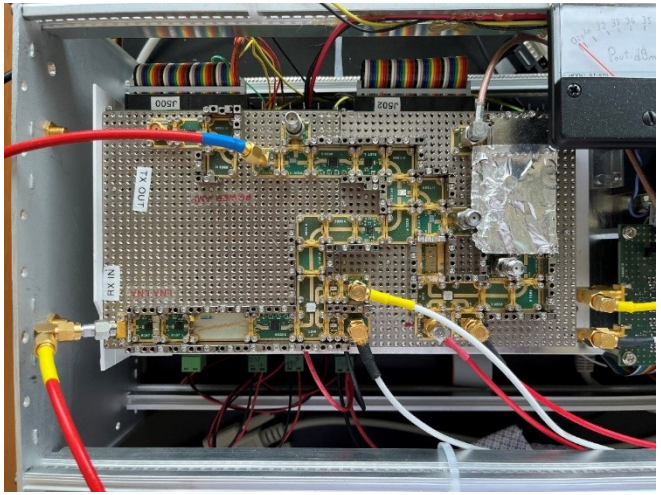
 In the following slides, a few relevant projects

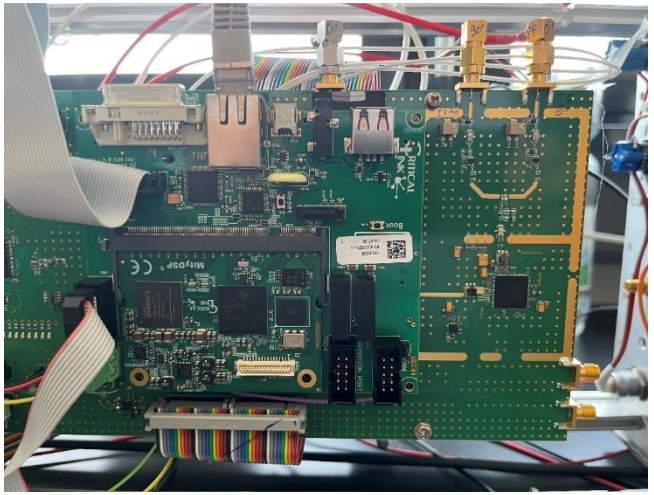
Navigation radar for Active Debris Removal spacecraft

X-band radar module (EBB) for Clearspace navigation system

2W RF, high-res target ranging at ~km to few m distance

- Digital chirp generator (DDS)
- 12-bit 80MHz ADC acquisition, low noiie TX+RX
- FPGA baseband
- Elegant breadboard (19’’ 3U rack) functionally validated, TRL4



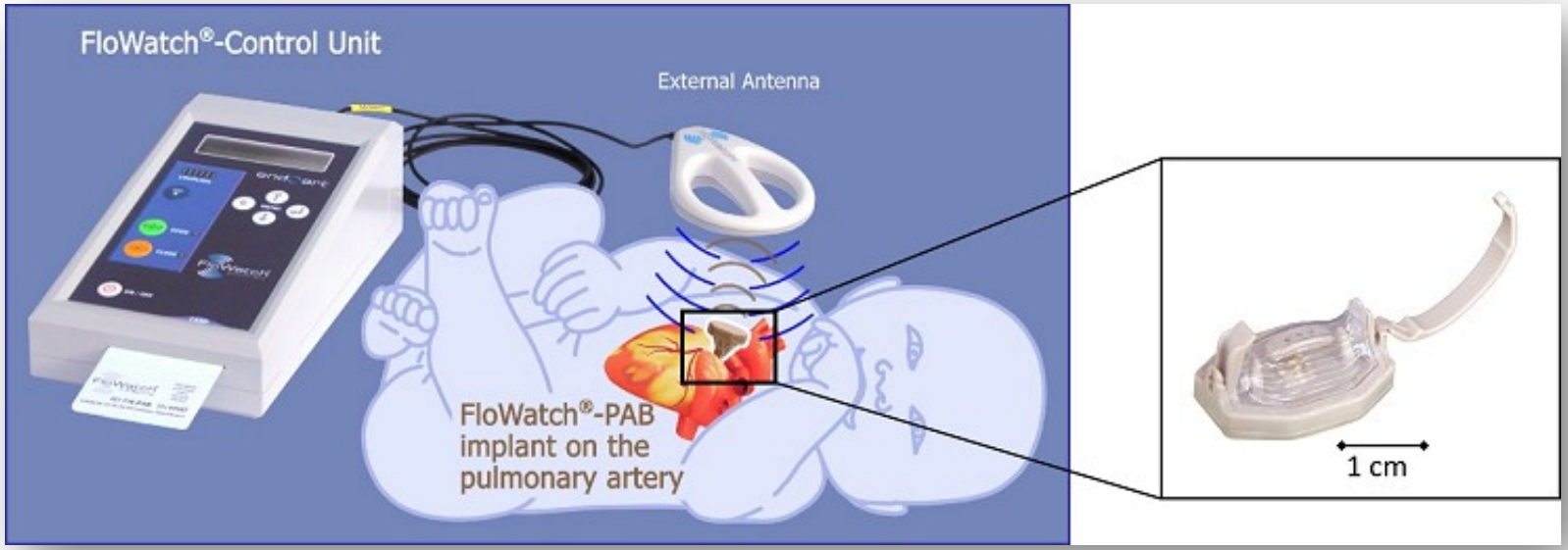


In design: EM with radhard FPGA, small size, low weight, **toward flight model**

And also… medical projects

Implant for infants suffering heart malfunction at birth

- Variable clamp for pulmonary artery
- Based on a «watch» micro-mechanical actuator
- Powered by induction from outside the body (no battery)
- Enables the pratician to adapt arterial pressure during growth of partient
- Ready for animal implantation (TRL 5)
- NeoCare project in collaboration with foundation for rare deseases EspeRare (Geneva, Switzerland)

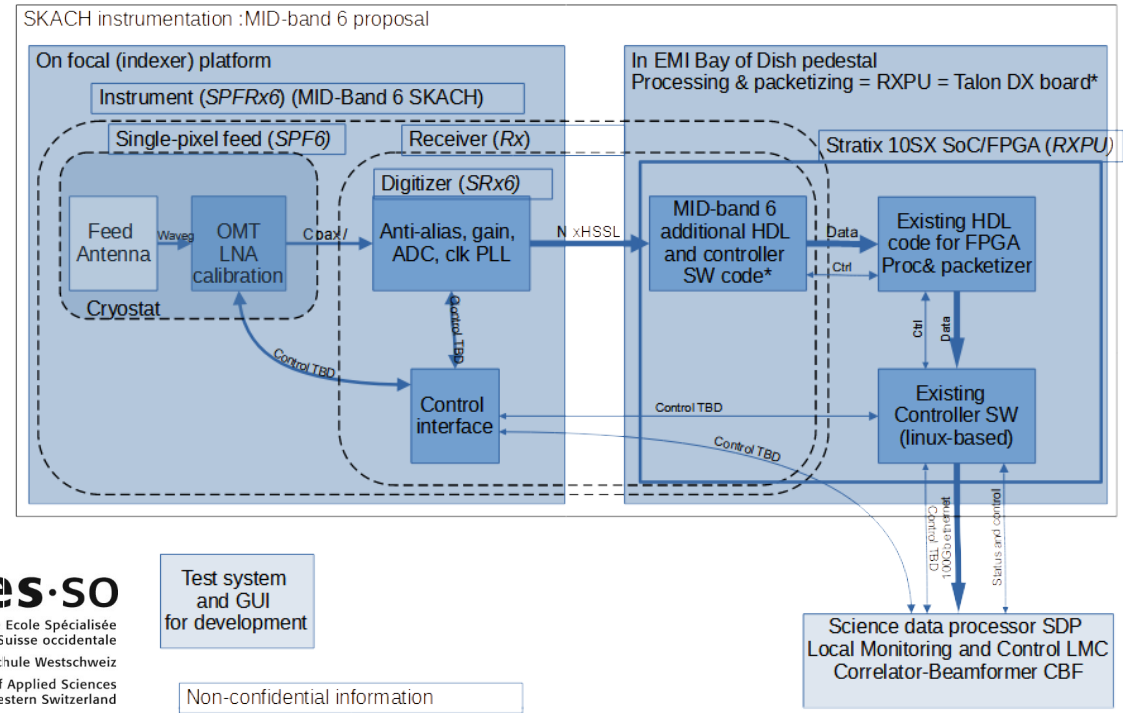


Radio-astronomy receiver for K-band

MID-band 6 receiver Proof of Concept/Elegant Breadboard (EBB)

https://skach.org and https://skao.int

- 15-25GHz, intended for future retrofitting on SKAO site in South Africa
- 10-bit undersamping ADC with 0-40GHz input range and 2.5-4GHz instant BW
- LNA based on https://www.diramics.com InP chips
- Front end designed with international collaboration
- In design: Elegant breadboard (EBB)
- Target: functional validation, TRL4-5



- Required to select ADC frequency band:
  - pass-band anti-alias filters
  - Tuning range 15-25GHz
  - 2.5GHz BW
  - Center frequency tuned with multiple micro-mechanical «watch» actuators from medical project

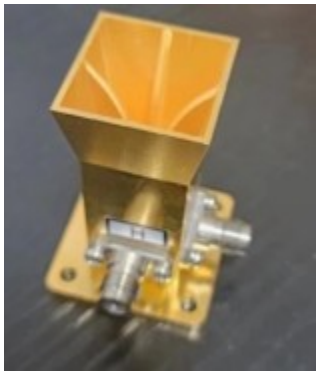
Mid-Band 6 Requirements evolution

- **Requirements**
  - Astronomical science needs have been taken into account for future EM (e.g. 40/50GHz)
  - Astronomy not really relevant for 15-25GHz EBB except as water vapour radiometer (IRAM collaboration in HE Radioblocks)
- **Action plan**
  - Design EBB to state of the art and using cutting edge technologies
  - EBB results will confirm requirements or define them more precisely
  - After PDR, final requirements for the EM in frame of future development projects
- **Roadmap to 50GHz MB6?**
  - 40GHz should be possible for digitizer (ADC specified, 5 bits)
  - 50GHz may be possible
    - requires measurement of state of the art ADC on state of the art PCB
  - Will require a complex “dual-path” front-end
    - no LNA/waveguides can cover 15-50GHz which is Ultrawideband (UWB)
    - e.g. 2 bands: 15-28GHz, 28-50GHz (WB)
      - either separate positions on indexer (bands 6+7), 2 horns
      - OR 2 bands combined into same output (band 6+)
  - band 6+ 015-50GHz feed horn
    - must have sufficient performance (constant aperture ratio)
    - tough project in itself (not SKACH)
  - some aspects covered in radioblocks project
  - **DISH quality?**
  - **Whole dish simulation on CSCS?**

Radio-astronomy digitizer

- **Current work**
  - ADC-100GbE data handling (A. Dassatti & team)
    - Reached 97Gbps (Stratix FPGA)
    - Raw data transfer
  - Bandpass anti-aliasing filter
    - 7-cavity fixed filters, adustable by «manual algorithm» for anti-aliasing
      - Bandpass adjustable 1.65:1 center frequency ratio (15-25GHz)
      - Being built (watchmaking technology)
  - Single-cavity 18-24GHz «notch» filter for WP2 (IRAM, Radioblocks)
    - Prototyped as 1:8 scaled model 2-3GHz cavity in SKACH
    - For Water Vapour Radiometer, RFI filtering
    - Base unit cell
- **Future work (Radioblocks)**
  - Based on the above unit cell, motorised multipole filter (5 to 7 cavity) for «any frequency/any response» anti-aliasing of Multiband ADC
  - AI-supported tuning algorithm (better than classical responses)

Front end components



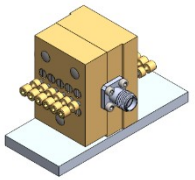
- ☑ 10-**50**GHz QRFH Feed antenna (Acura Microwave)
- ☑ 2-40GHz splitter (Mini-Circuits or HEIG-VD design)
- ☑ 10-40GHz high ENR noise source (Noisewave) **ordered**

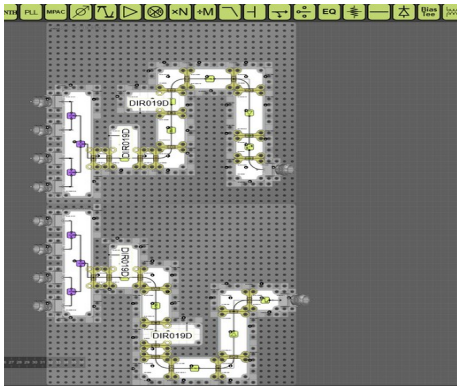
- ⚠ coaxial relays: **ordered**
- ⚠ Circulators: **Custom** 15-25GHz **ordered** (Acura)

- ⚠ Coaxial cables, adapters **in order** etc (Mini-Circuits et al.)

Digitizer 2/3 analog design (WP2310+20)

8x BPAF-F filter
(WP2320)





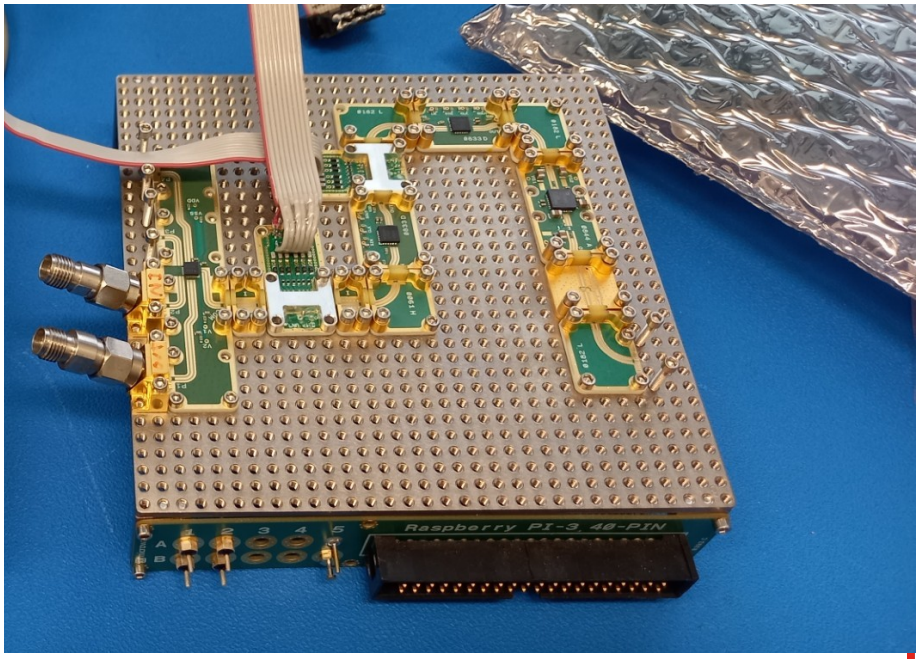
X-Microwave prototyping

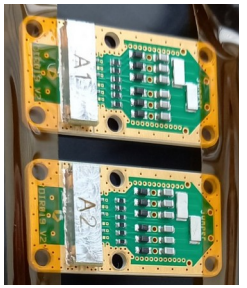
Switching of BP filters

large variable gain

Diramics amplifiers

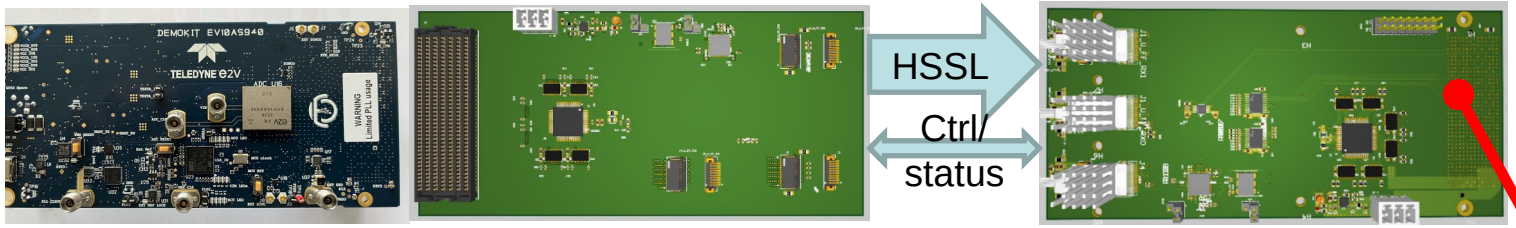
2x 4:1 relay
(WP2310)





Digitizer conv+digital part (WP2330,40,50)

H

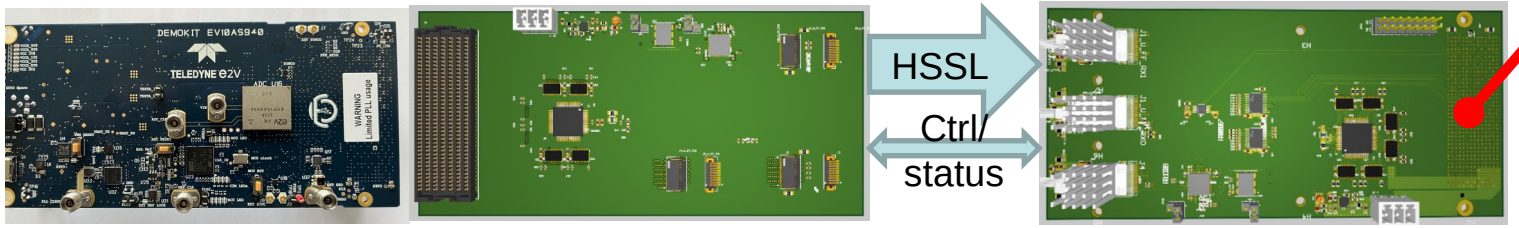


MonoCAN ADC board (WP2330):
Integrating 2x single ADC eval board in system, distributing 1 CLK 2 channels, phase compensation, uC FW adaptation

Electrical-optical-electrical boards (WP2340): enabling HS data transfer and control of digitizer and front end **through optical fibre**

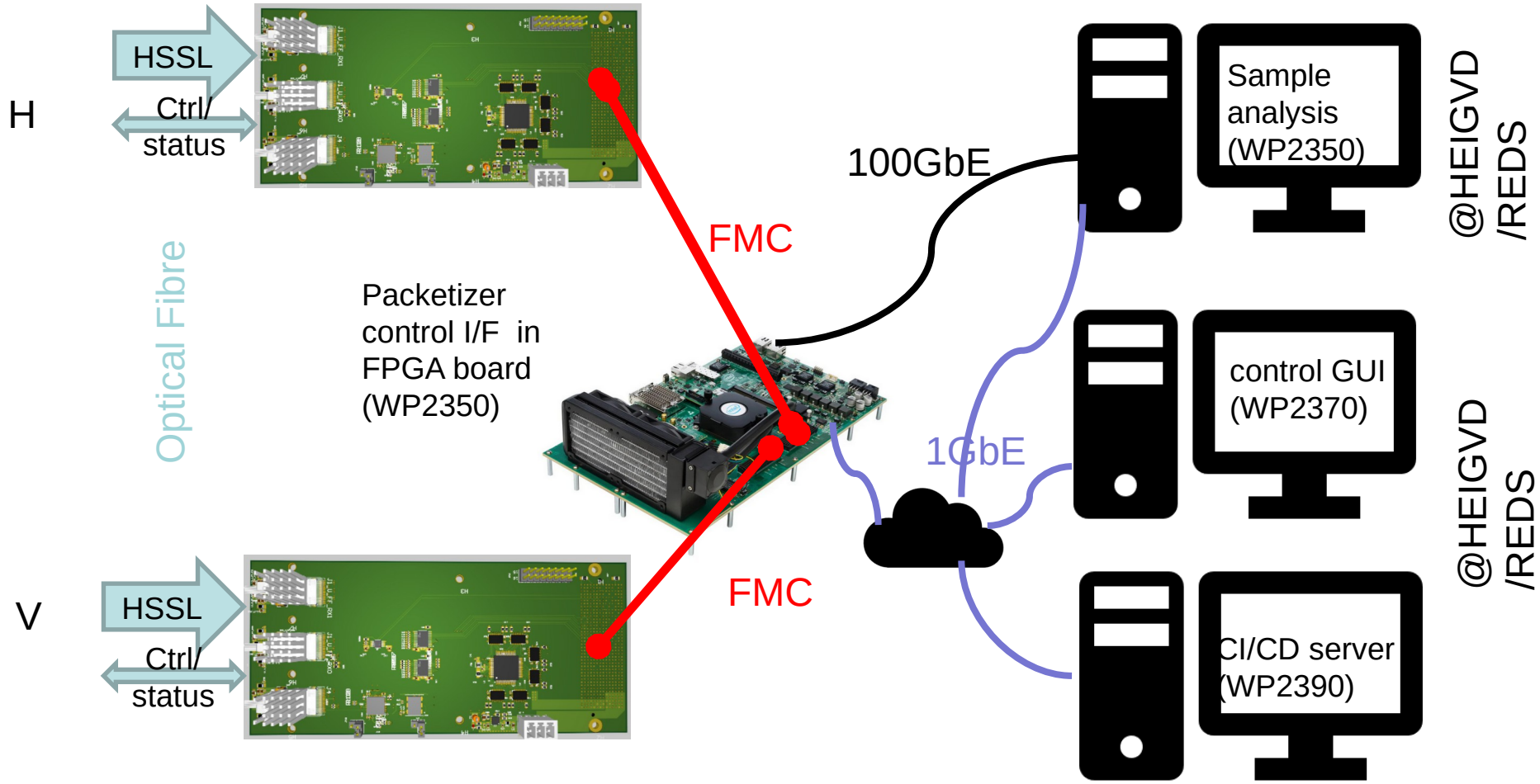
Packetizer control I/F in FPGA board (WP2350)

V



Optical Fibre

Digitizer digital + test part (W2340,50,70,90)



ADC-FPGA integration test @REDS (WP2350)

MonoCAN ADC board

FMC

100GbE

Sample analysis (WP2350)

control GUI (TBD)

1GbE

Packetizer and control I/F in FPGA board (WP2350)

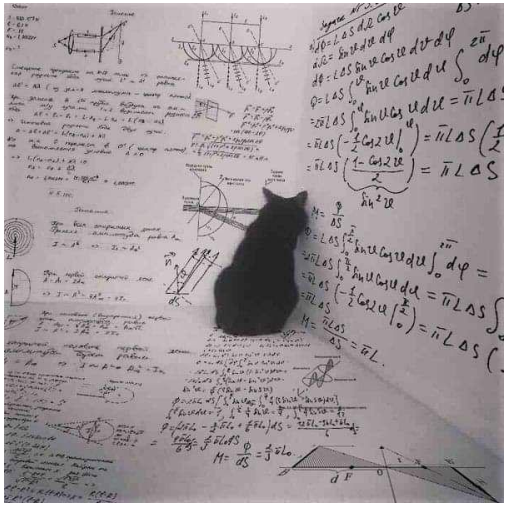
Digitizer for RADIOBLOCKS WP3

- **Use case: wideband direct conversion «narrow band digitizer»**
  - Goal specs:
  - 1-40 GHz frequency range (?up to 50GHz)
    - 2.5GHz (-60dB~) bandwidth per ADC channel (H+V or LHCP/LHCP): 2 ADC at any center frequency (variable sampling frequency, high Nyquist zones)
    - Needs fixed or variable bandpass filter for anti-alias
    - 10 bits ADC, 6-8bits ENOB typical, 5-6 bits at 40GHz
    - On-chip 4xDDC enable extraction of narrow(er) bands
    - On the market from 2025 (COTS), + dual channel FMC eval board *developed by HEIG-VD*
    - HES-SO gets early samples (partnership with manufacturer)
    - Few watts, low power digital low EMI (compatible with focal platform noise requirements)

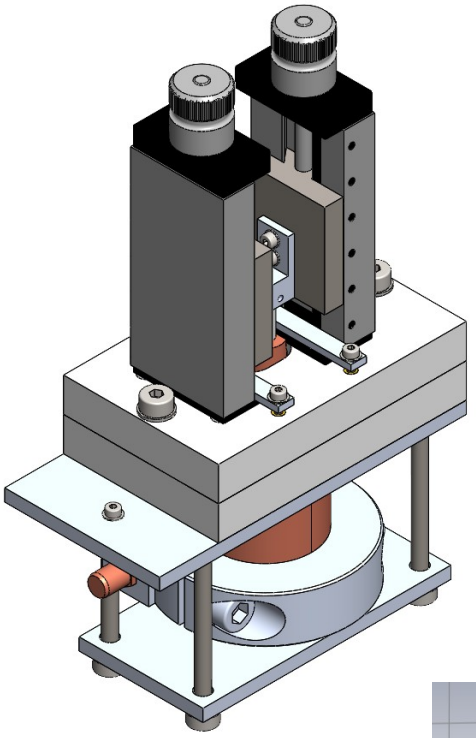
      digitizer on platform, enables digital PAF cost-effectively
    - Optical Fibre digital transmission to «FPGA mainframe» in dish pedestal or (much) further away
  - Demonstrator System:
    - Output: (H+V channels) x 4 bits x 2 streams in 100GBe (<12GS/S)
    - Digital Optical lines into Intel Stratix-10SX FPGA

Digitizer technology development

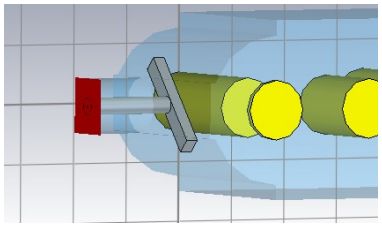
- Possible new design: direct conversion optical output digitizer module
  - **Ideal for scaling up PAF**
    - Low power (2.5W ADC + use low power MMIC as gain blocks)
    - Small size
    - SPI control through fibre
    - Vacuum compatible
  - All building blocks can be put on single PCB
  - Use optical fibre multiplexer/demultiplexer if required
  - **Need mecanical specification**
  - More generally, define interfaces that are useful for several projects
- Refactor for quantum computing?
  -



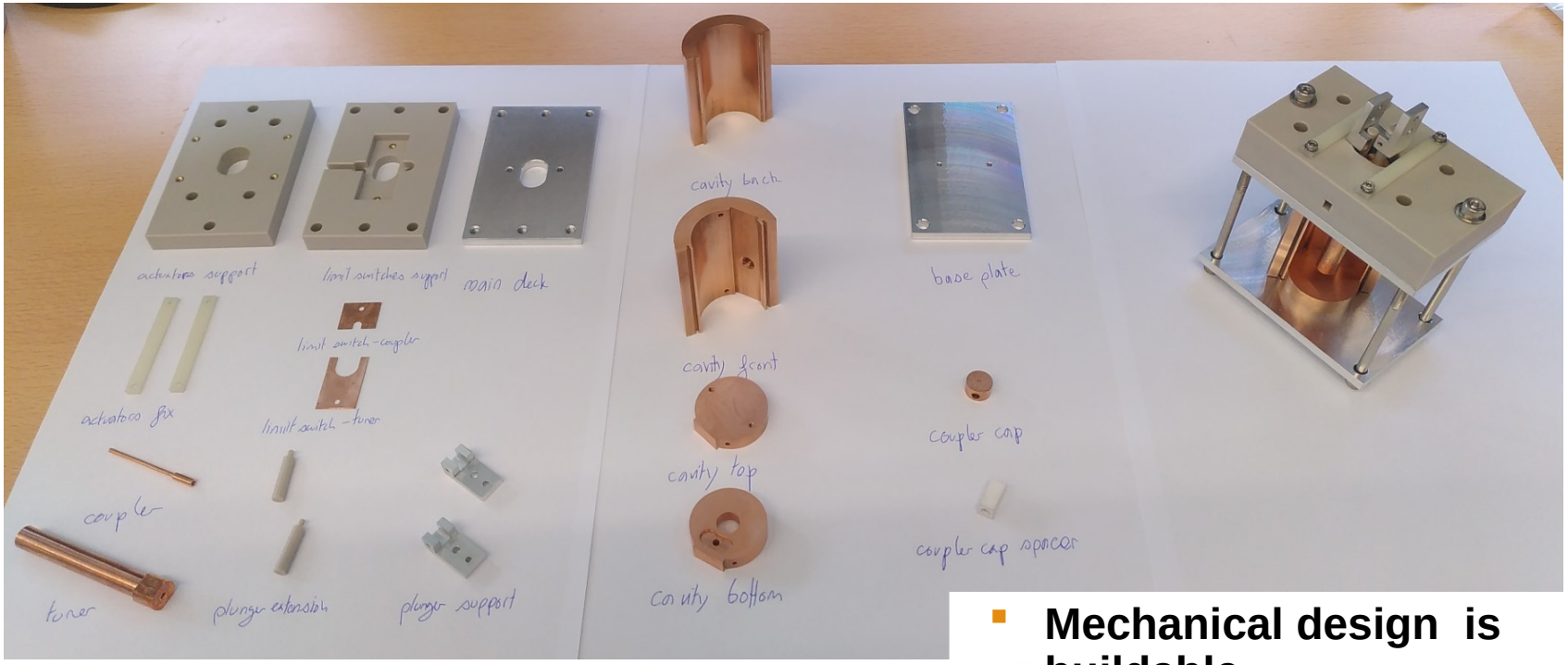
Filter developments : 1 cavity PoC (8:1 size)



- **Single cavity PoC as preparatory work for future «notch» filter (Proof of Concept)**
  - Done within Swiss SKA project (https://skach.org) for MID-band 6
  - ~2-3 GHz center frequncy variation range
  - Single cell resonator
  - Being built
  - Can be scaled to other frequency range
  - Actuators for frequency and coupling factor are:
    - Currently: commercial micrometric screws
    - Coupler shape is quite complex (difficult to scale down)

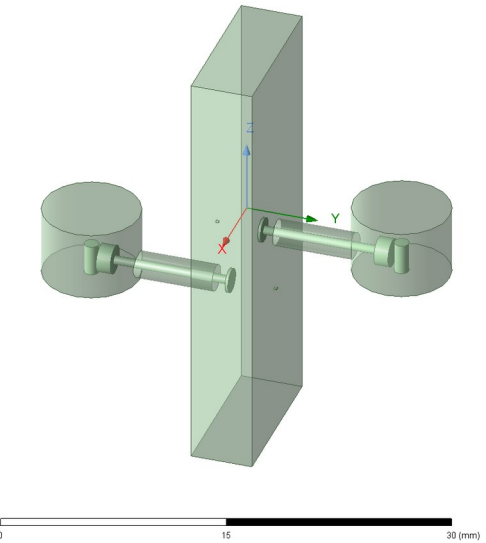


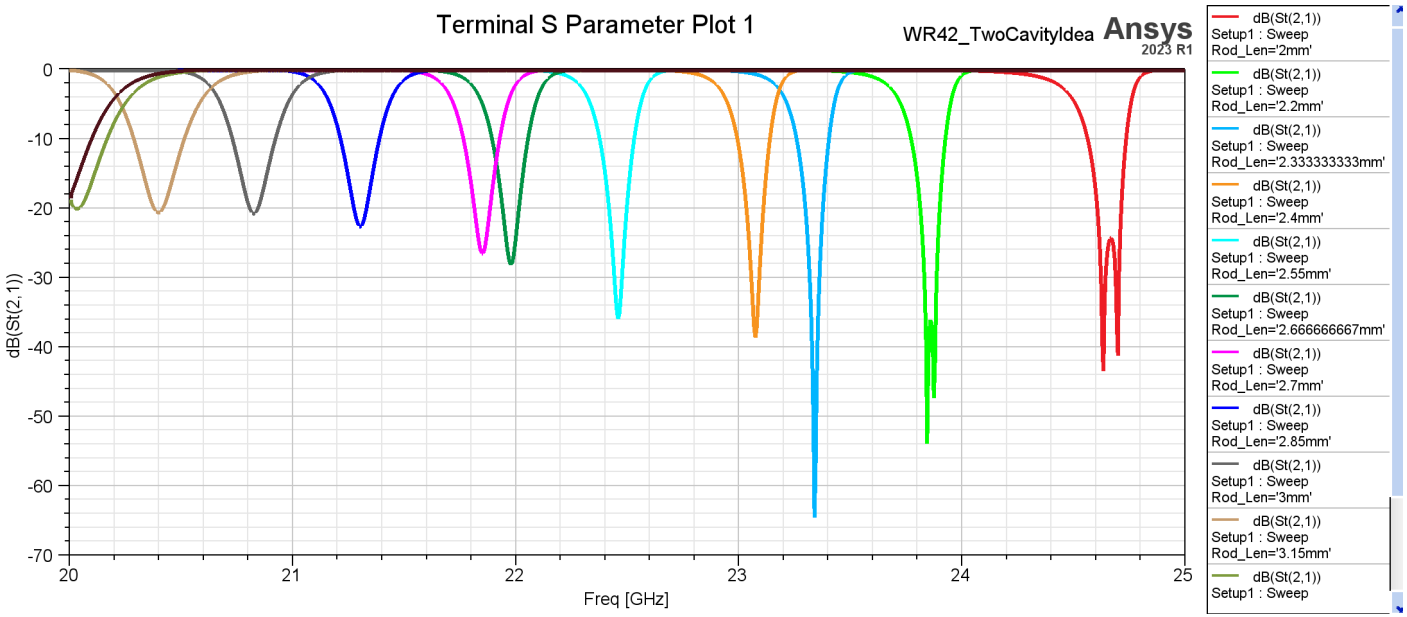
8:1 single-cavity PoC



- **Mechanical design is buildable.**
- except one part which must be re-fabbed (gold plating tolerances)
- needs gold plating
- to be RF tested

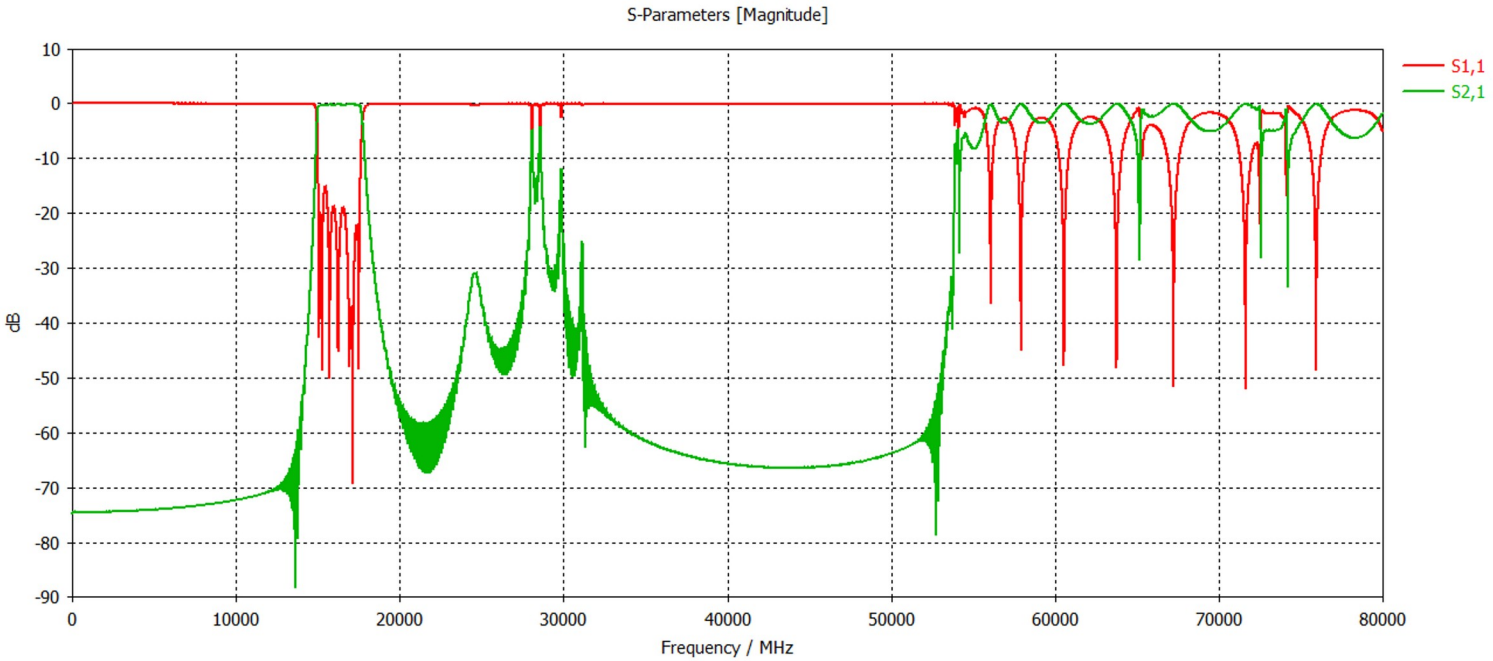
Dual cavity notch 1:1 size



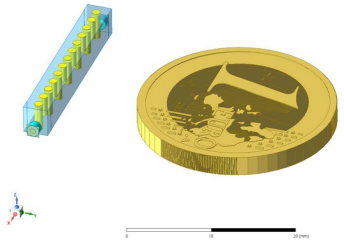


WR42 waveguide
Coaxial cable coupling (fixed coupling, can be varied by changing couplers)

Using higher cavity modes



scaling down dimension is difficult, therefore



- Using upper cavity resonance modes to synthetise filter
- To allow using existing filter at 3-4x higher frequency
- Different approximation algorithm (genetic/AI)

Contacts

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And also… medical projects

Implant for infants suffering heart malfunction at birth

- Variable clamp for pulmonary artery
- Based on a «watch» micro-mechanical actuator
- Powered by induction from outside the body (no battery)
- Enables the pratician to adapt arterial pressure during growth of partient
- Ready for animal implantation (TRL 5)
- NeoCare project in collaboration with foundation for rare deseases EspeRare (Geneva, Switzerland)

Ultrasound generator for prostate cancer treatment with HIFU

- High-Intensity Focused Ultrasound
- 16-channel MHz ultrasound generator (300W)
- Beamforming, enables «pinpointing» the tumor for very little side effects
- Heart of Focal one treatment machine
- More than 100 3U racks in as many machines sold since 2013 (TRL9)
- Design transferred and produced by customer EDAP-TMS (Lyon, France)
- New medical indications are currently explored in an EU project with INSERM and French companies

Medical projects

Implant for persons suffering urinary incontinence ARTUS

- Artificial Urinary Sphincter restores control of patient on his/her bladder
- Redundant Battery lasts 7 years of typical use, implant module replaceable in minimally invasive way
- «cuff» stays on urethra
- Total redesign of original implant design by HEIG-VD
- Developed in collaboration with MyoPowers start-up
- In clinical tests

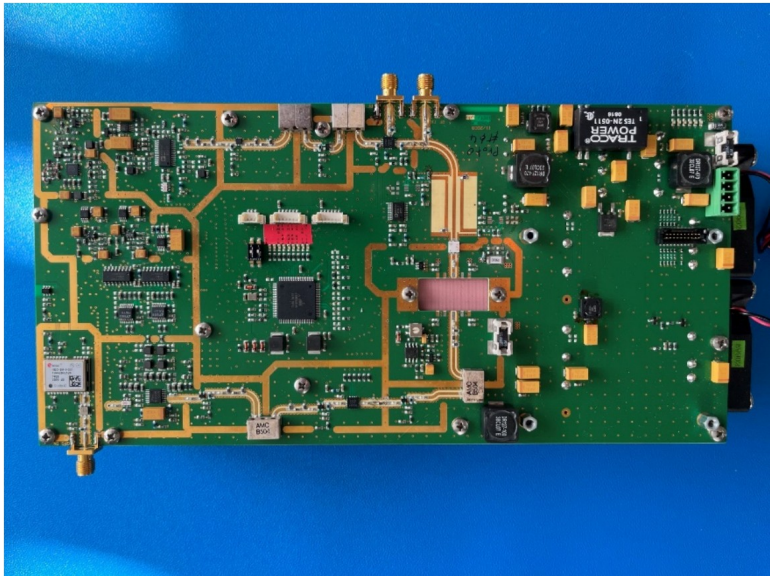
Hyperthermia cancer (co-)treatment machine

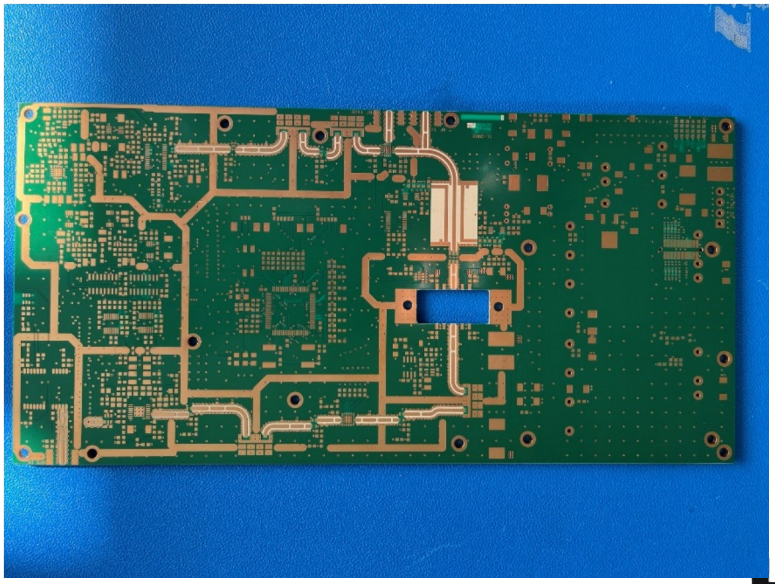
- High power UHF (434MHz ISM band, 200W)
- Innovative antenna and cooling system allows concentrating the heating effect several cm under skin
- Miniature dielectrically tuned and loaded antenna (applicator)
- As a co-treatment of radio- and chemotherapy, could allow dividing toxic doses by factor 3 to 4
- Demonstrator, developed with non-profit, TRL4
- Waiting for further development and certification

L-band Satellite communication system

Ground terminal for automotive application (long-distance trucks).

- 5W TX, 30kbit/s bidirectional via geostationary satellite
- 3 patch az-el antenna,
- Zero-IF receiver, analog bandwidth setting
- RF and mixed signal design with DSP + FPGA module intégration.
- Fully functional, tested on satellite simulator, TRL4-5
- Successful ESA/Artes without follow-up (discontinued by industrial partner)

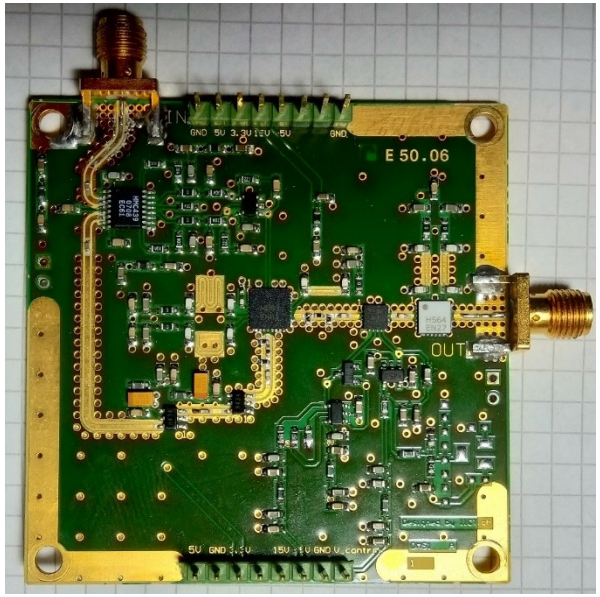


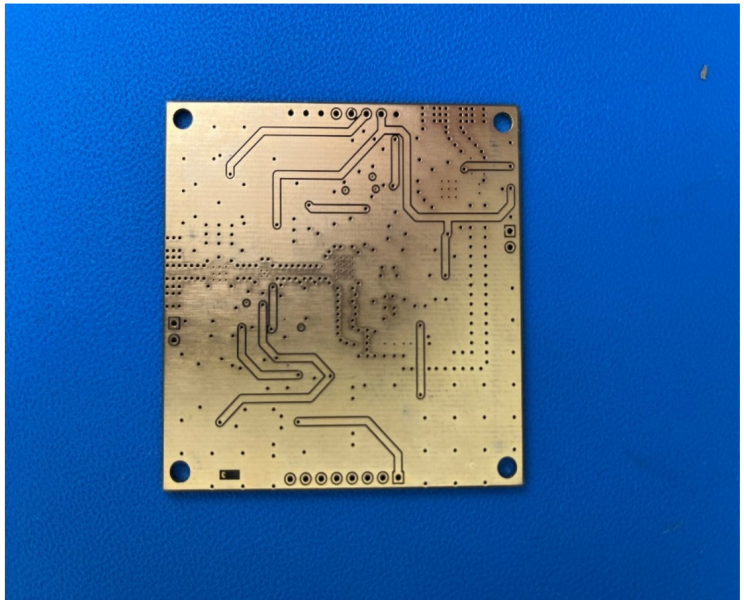


PLL for Optical Fiber Sensing

Brillouin-effect-based strain/temperature measurement

- Output frequency 10.0-13GHz
- Variable output levels from -16..+14dBm (voltage control)
- Typical phase noise -90dBc/Hz to 1MHz
- Reference for PLL: DDS~100MHz
- Power consumption 3.6W
- Implemented in several hundred instruments, TRL9

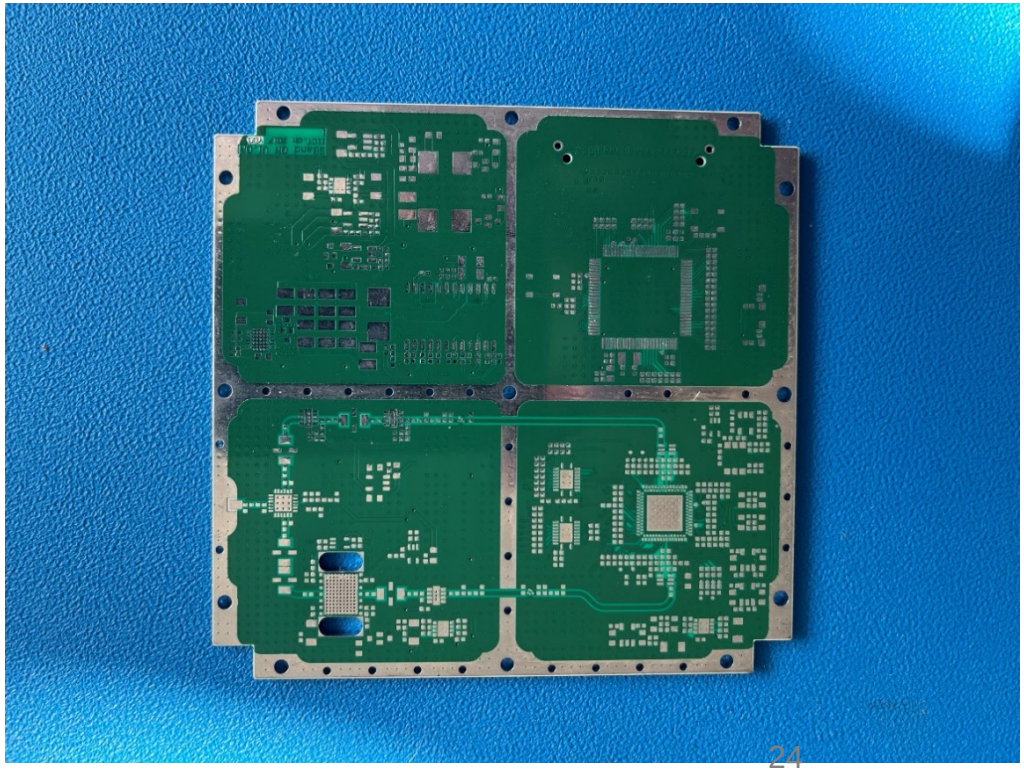




Satellite communication system

RF payload module for Astrocast precursors (3U cubesat)

- S-Band 2400-2500 MHZ transceiver
- 3W RF
- Based on SDR chipset
- FPGA baseband 1Mbps
- Radiation tested to 10kRad
- In-orbit demonstration, TRL7-8



100x100 mm format