ReRaNP

Re-configurable Radio Network Platform

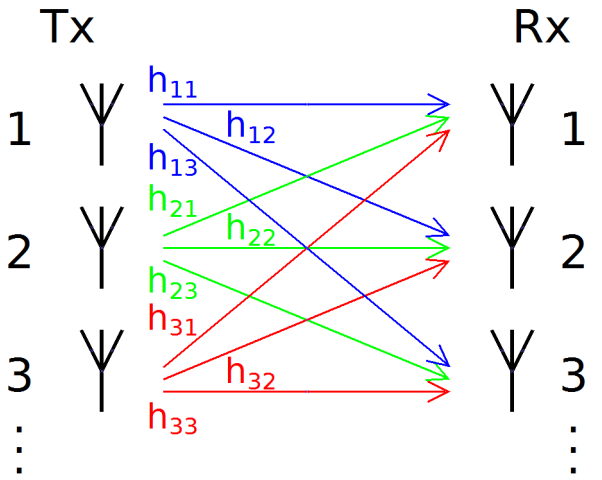
128 antenna
Massive MIMO
Software Defined Radio

...from an engineers point of view

Challenges of going from n=1 to n=128

What is massive MIMO?

- A MIMO system with a large number of antennas.



MIMO principle

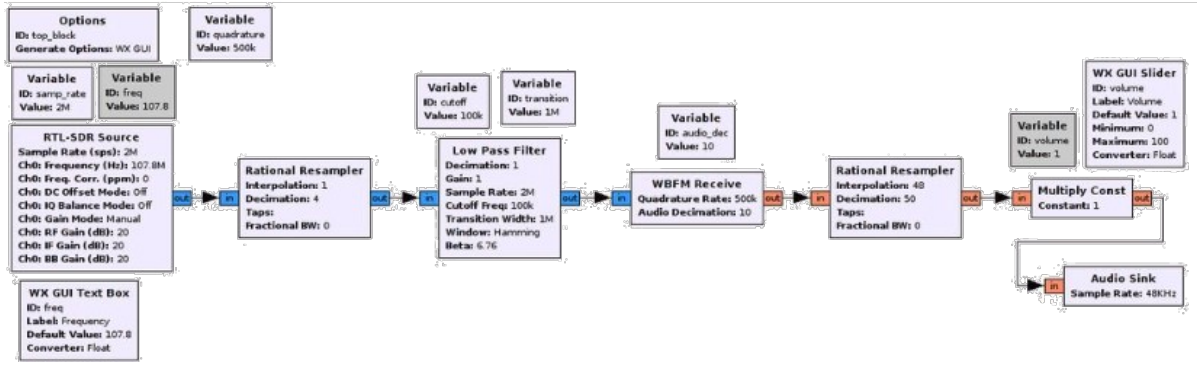
What is MIMO?

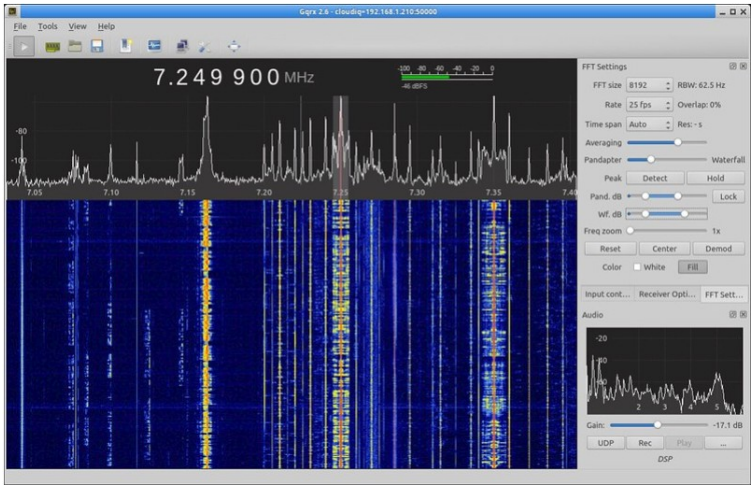
- **Multiple-input multiple-output**
  A wireless network allowing transmission and reception of more than one simultaneous data stream over the same radio channel.

Mid-range wireless router

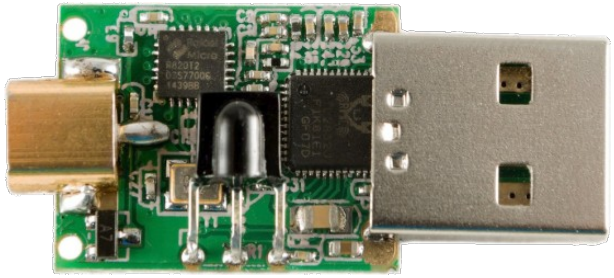
What is SDR
Software Defined Radio

- A radio system that use real-time re-configurable digital calculations, to do what analog hardware used to.





$ 10
Micro-controller based



$ 10’000
FPGA based

ReRaNP Requirement

- We want a flexible mobile massive MIMO software defined radio platform that we can use for field measurements (city, roofs, along roads, coast, in a vehicle...) that also can be split into separate stations. With portable battery operated user terminals

The impossible while you wait,
miracles takes a bit longer.

Where we started

….from scratch.

The result

… a miracle or two later

“Non-scientific” challenges

of going from n=1 to n=128

Power
Heat
Weather and water proofing
Mechanical strength
Transportation / Vibrations
Expansions
Cost
Data handling
Service friendly
Re-configurable (128, 64, 32..)
Cable management
Symmetrical design – phase coherence
Design / wow-factor
...Documentation

Power

ReRaNP power estimates

128 x USRP @ 40W	5000	W
7 x UT @ 100W	700	W
6 PXIe + 2 controllers + FPGAs	1200	W
6 x rack support system @ 200W	1000	W
6 fans x 6 racks x 30W	1000	W
UPS power loss (8900W /0,9 efficiency)	988	W
Cooling (air condition)	3000	W
Total	**12888**	W

Annual consumption 113 MWh

(Annual power consumption of 6 residences or 13 apartments.)

Annual cost 50 – 100 kNOK / 5 - 10 kUSD

Power

Inrush

- Approx 110 switching power supplies.
- 10A inrush => 1110A, **30A in-rush => 3300A.**

Power glitches / spikes

- Power outages (3-5 annually)
- Line noise (harmonics / distant lightning strike)
- Too low / too high voltage (rural location)
- Generator power (sites with insufficient power available)

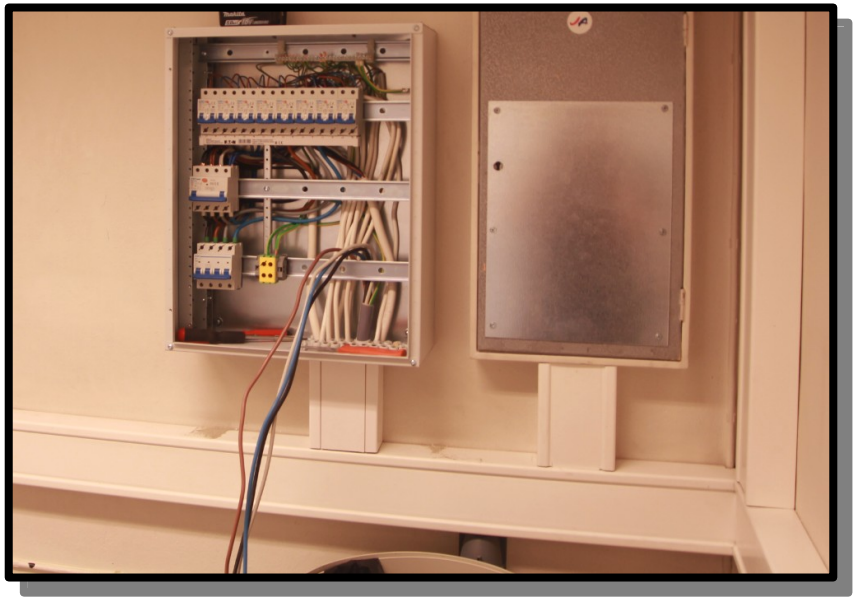
Different power grids

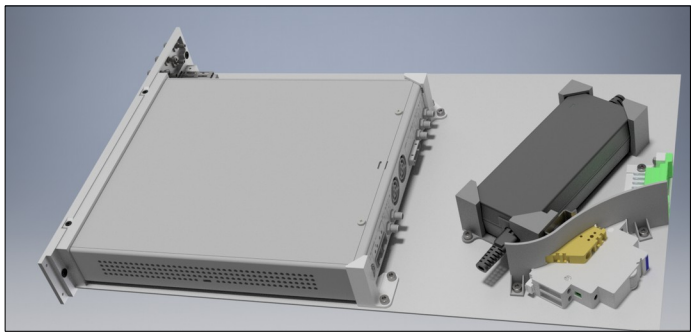
- 230 V single phase multi circuit (ground loop!!)
- 230 V three phase
- 400 V three phase

Power

Infrastructure improvements take time!

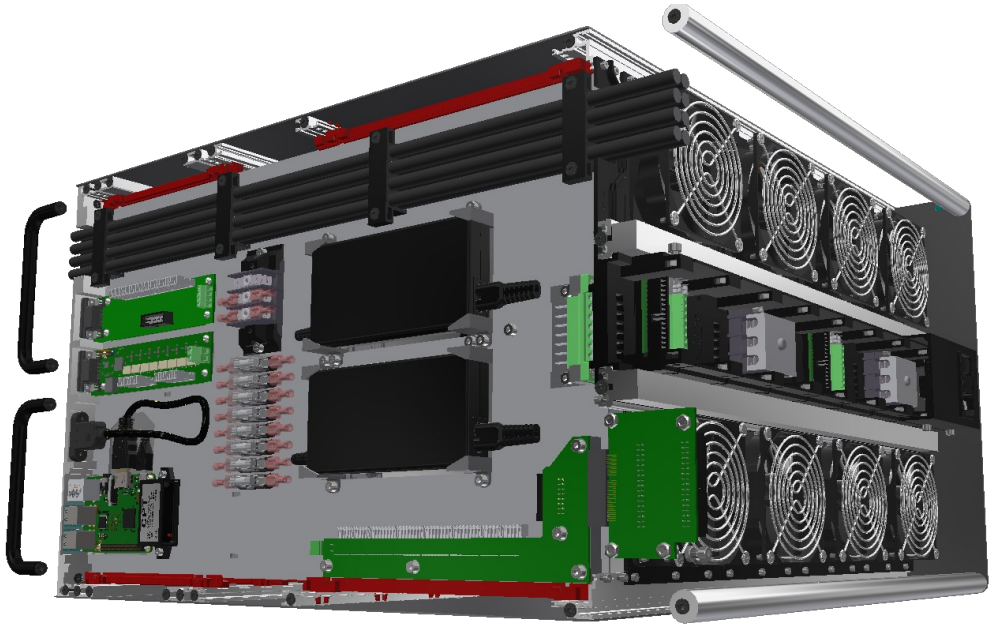
- Start the process in good time before campaign
- Choose sites with power available





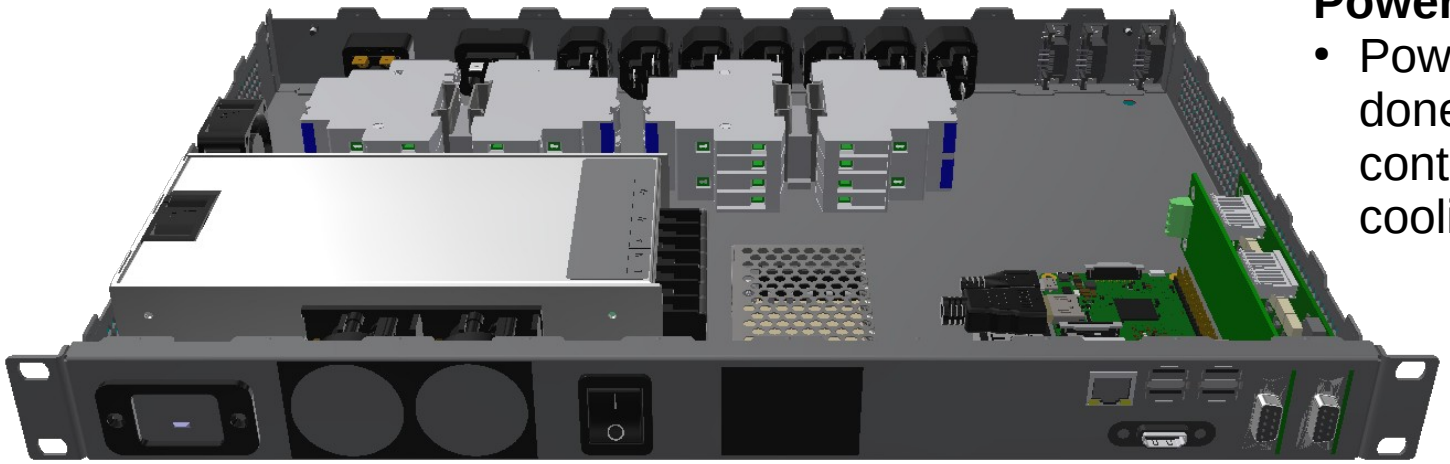
Power

Implementation



Control module (sub-rack)

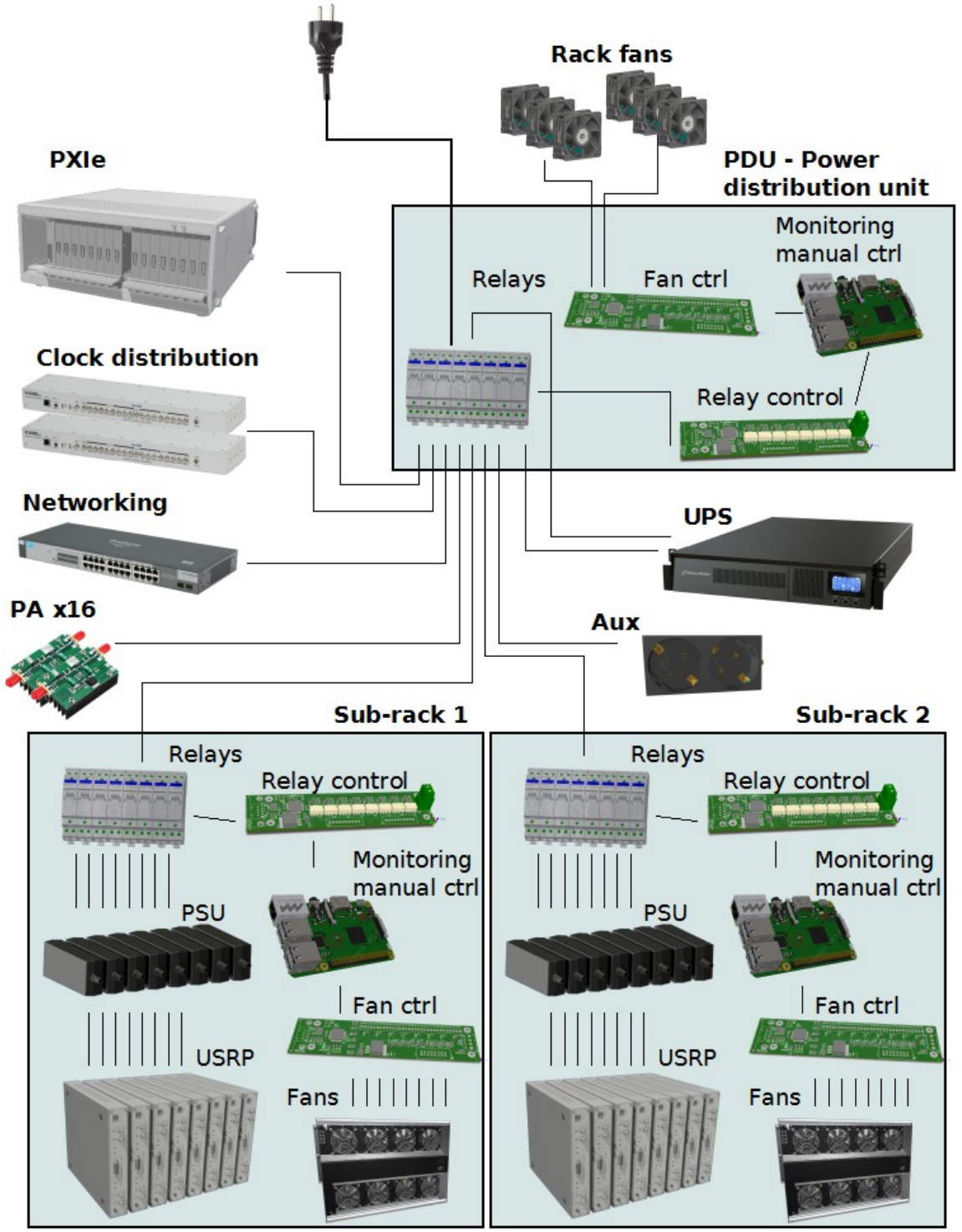
- Power control for the sub-rack is integrated on a control module inside the sub-rack.
- Power distribution and control signals are distributed through a backplane conduit.
- Raspberry Pi are used for network connectivity and manual override.



Power Distribution Unit

- Power control for the rack is done through a 1U PDU, controlling both power and cooling.

Rack power overview



- Each function is controlled individually.
- All USRPs have individual power control
- Planed for PA
- AUX for e.g. heating or cooling
- Controller cards operate autonomously, but can be overridden.
- Full remote control
- Modular design with focus on reuse.
- Can operate independently from 10A / 16A outlet.
- UPS can be centrally controlled for soft generator start.
- Startup delay and interval fully programmable

Heat

Challenges

Stability of oscillators

- Sensitive to temperature variations

Operational range

- -20 to +30ºC environment temperature.
- Aims at 40ºC USRP temperature

13kW consumed converted into heat (44000 BTU)

- Typical 1:3 cooling efficiency, adds 3-4 kW for cooling on top of the 10kW consumed.

Heat

Challenges

Solution:

- Unique solution with uniform temperature on all USRPs.
- Two USRPs share one cooling zone.
- Each zone has separate fan speed regulation
- Airfoil guide cool outside air to regulate intake air on USRP sub-racks.
- Air gap and air flow between USRPs ensure cooling from both fan and USRP case.

Weather and water proofing

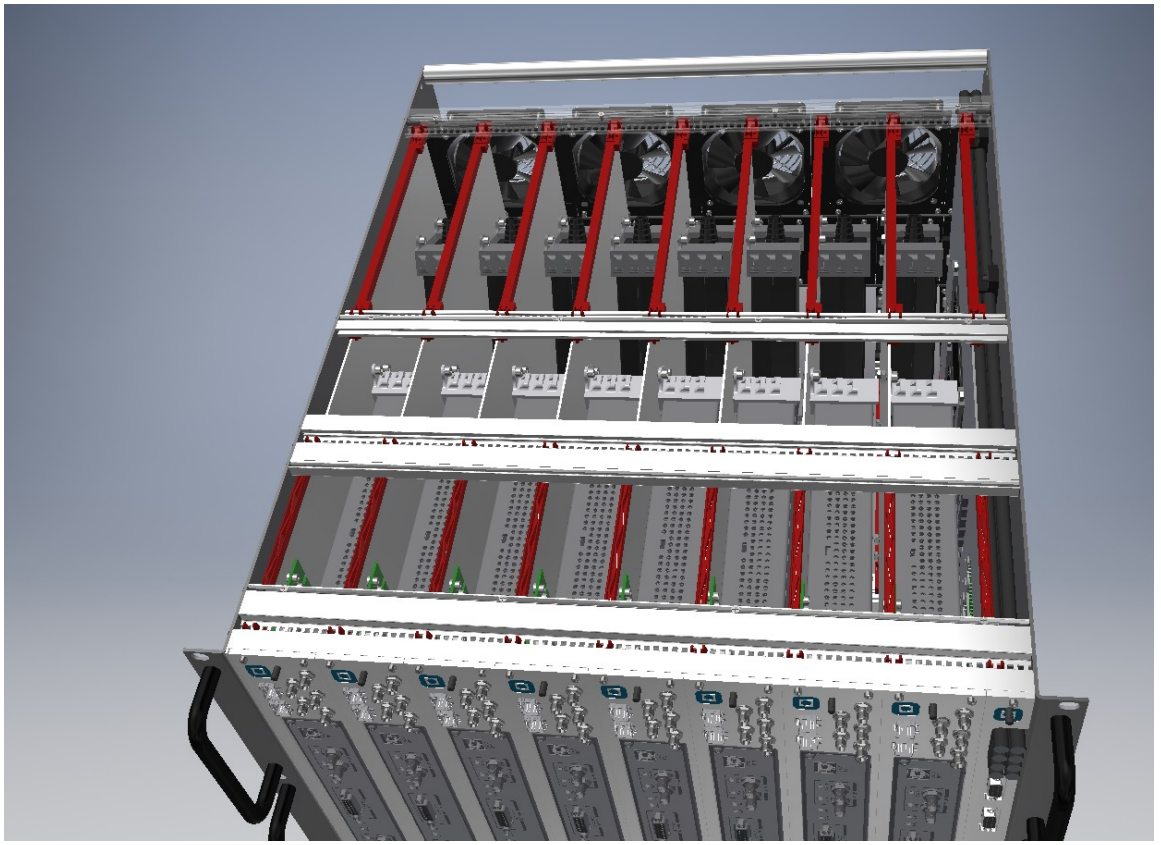
ReRaNP is meant to be placed outside, in all kind of weather, to do real life measurements.

Ingress Protection (IP) IP44 as a minimum.

- 128 antenna cables, and a few handful system cables needs to be IP-ed in a way that allows for easy disassembly and assembly.
- **Filtering of all airflow. Approx 600 m^3h (21 200 ft^3h)**
- Weather proofing of all access areas.

Heat - airflow

USRP sub-rack



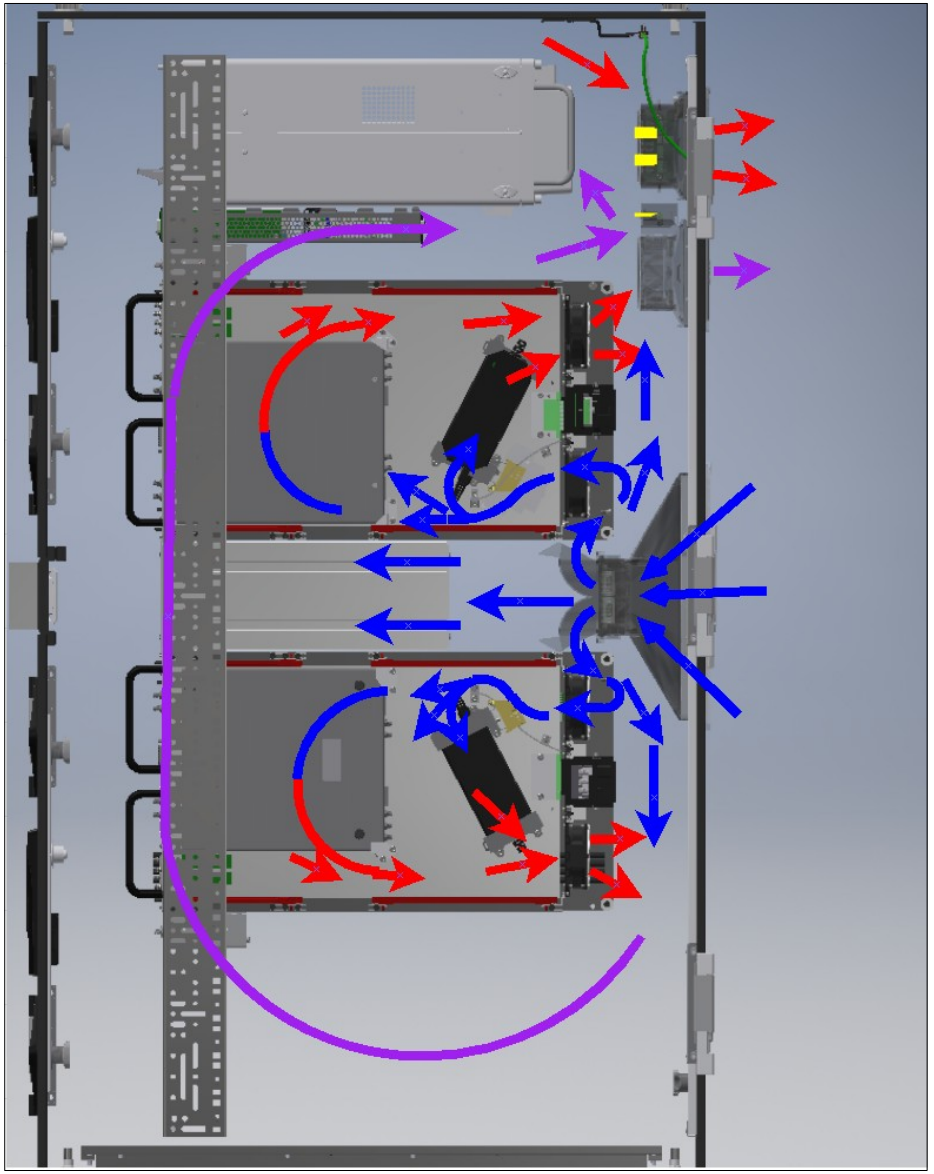
USRP sub-racks

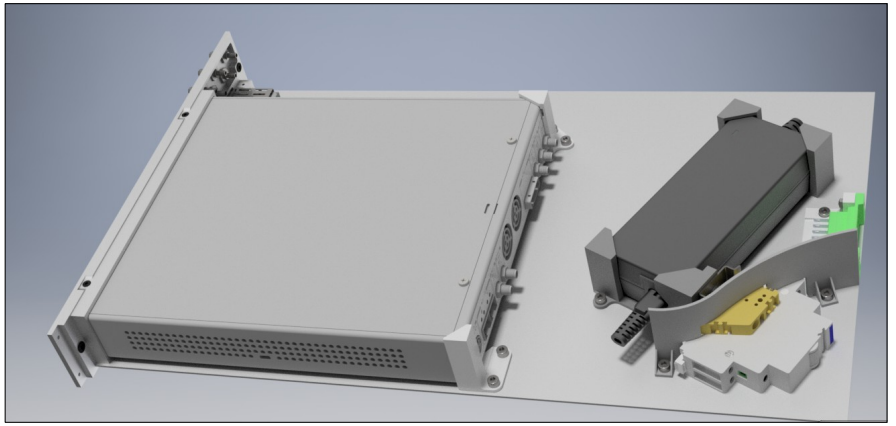
- 4 in fans
- 4 out fans
- The sub-rack allows for original USRP cooling to operate
- Fan controllers with speed regulation and monitoring for each fan.

The system contains a total of 278 cooling fans.

Heat - airflow

Rack



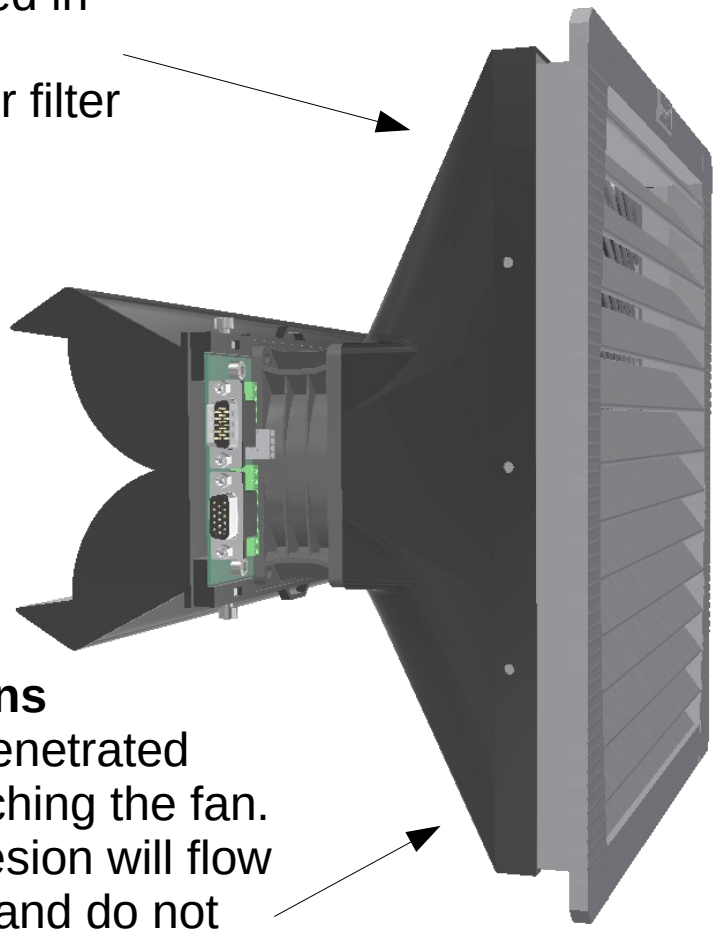


- Airflow inside both the USRP sub-racks and the rack is controlled
- During warm up, air-flow is reduced for rapid heat-up and stabilization
- Individual control of all fans allow for setting over pressure to prevent dust and water ingression.
- Air guides to control air flow
- Preheating optional

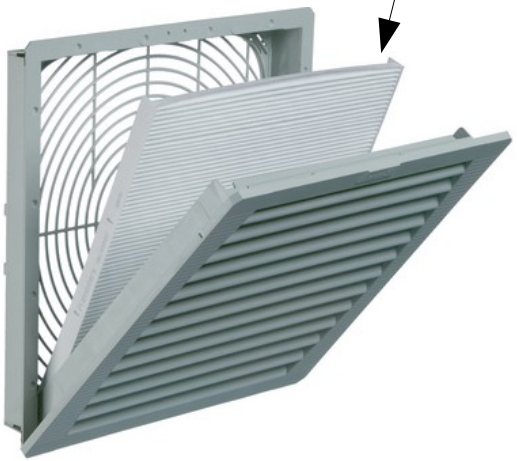
Weather and water proofing

Air funnel
Lowers air speed in intake filter.
Allows for larger filter that last longer

Air intake



IP55 (or IP54) filter
Filters dust, rain and snow



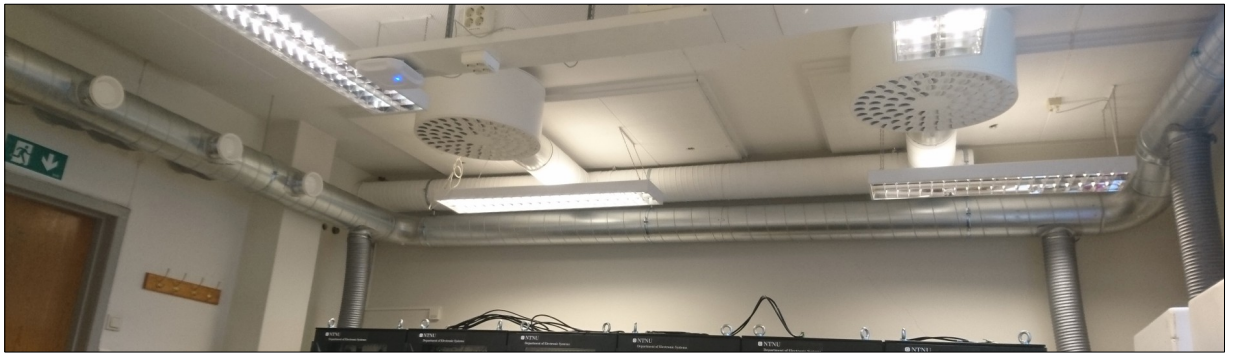
Angled air “grades”
Prevents heavy rain from direct contact with air filter.

Mechanically protects the filter

Slope up to fans
prevents any penetrated water from reaching the fan.
Any water ingresion will flow along the door and do not come in contact with the equipment

Heat - airflow

Location



Mobile air condition units

- Transfer heat into building HVAC
- Recycles heat energy centrally
- Easy to implement into HVAC compared to ice water
- Mobile – can be used at other sites.
- Replaceable

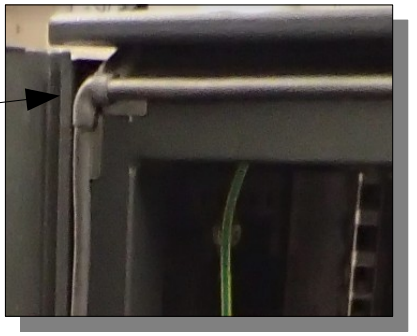
35ºC into HVAC
10ºC into room
18-22 ºC room temperature

3 units 4050W consumed,
10,5kW cooling (+ consumed power)

Weather and water proofing

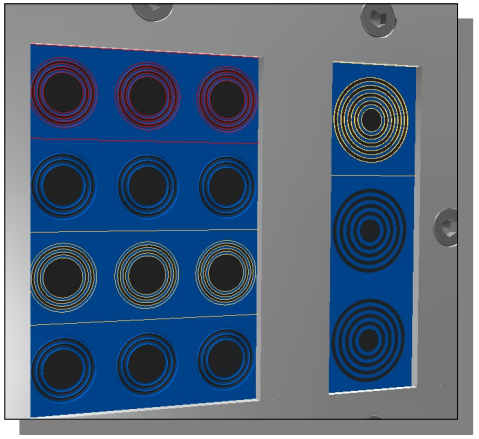
Rack

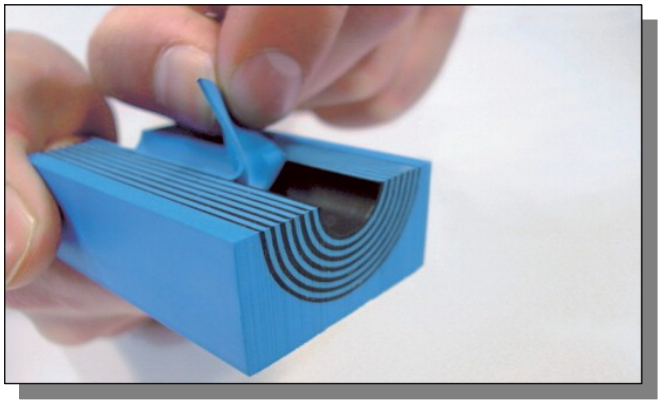
Rubber seal on all doors



Modular rubber seal for cable transits

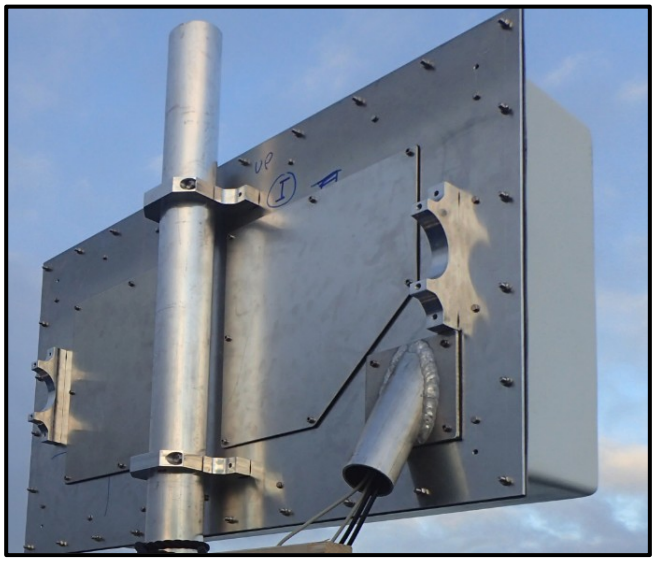
- Allows for terminated cable to be installed.
- Reconfigurable according to needs.





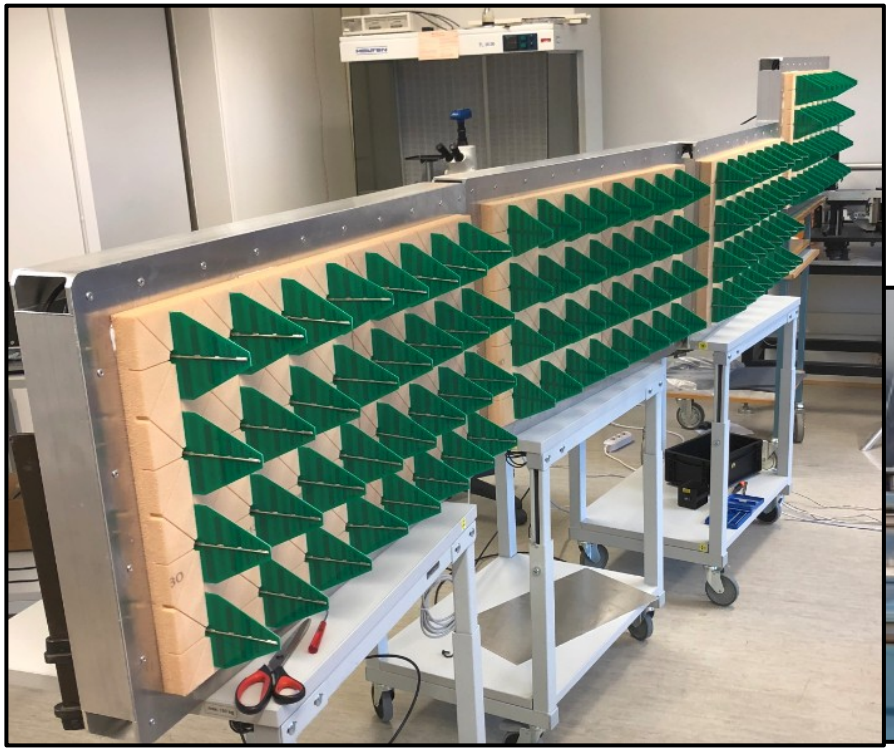
Weather and water proofing

Antennas



Water proof glass fiber domes for antennas

- Allows for horizontal and vertical mounting
- Cable transit pipe allows re-cabling and water ingress protection.



Service friendly

Measurement campaigns are expensive. Downtime must be kept as short as possible.

The nature of experimental equipment require constant tweaks and reconfigurations.

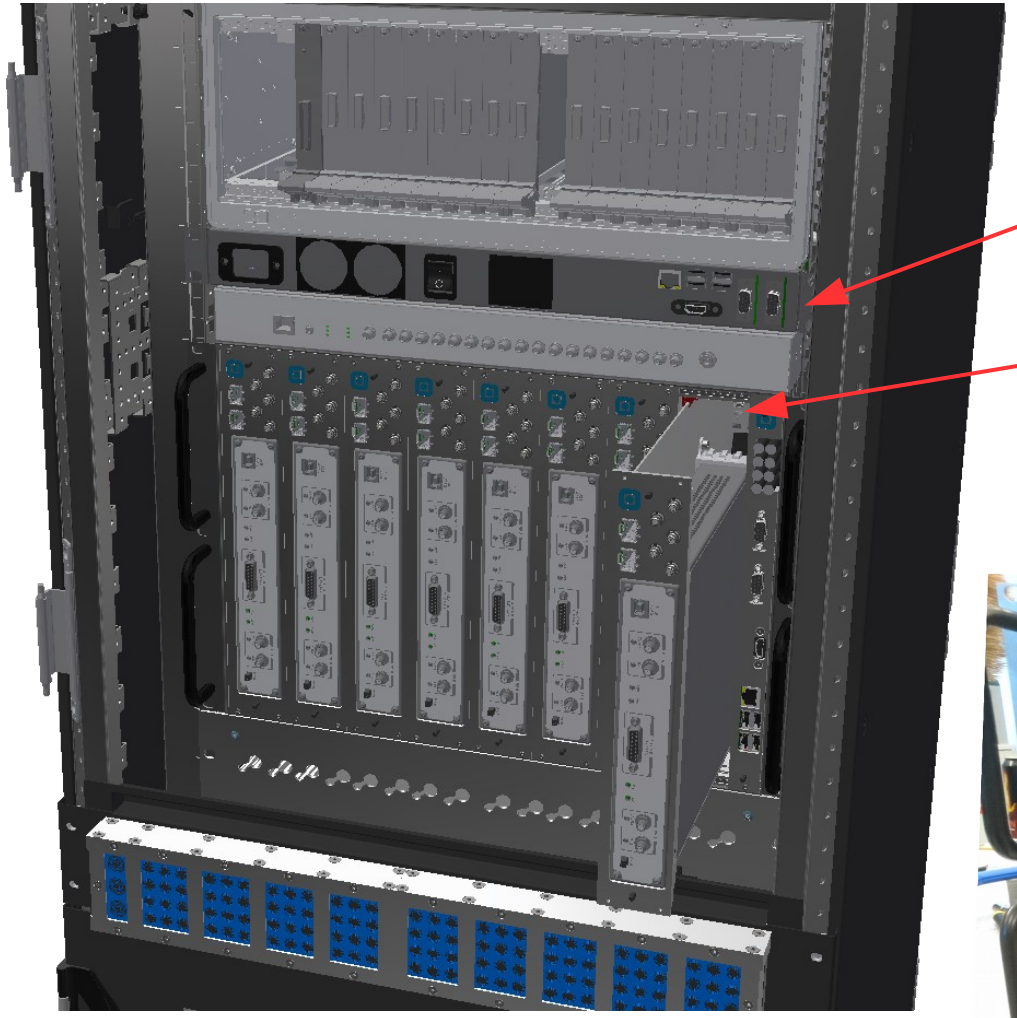
- The goal is that any failure should take less than an hour to fix / replace. (Given availability of spare parts)

Measures taken:

- Modular design and reuse of parts.
- Spare parts made

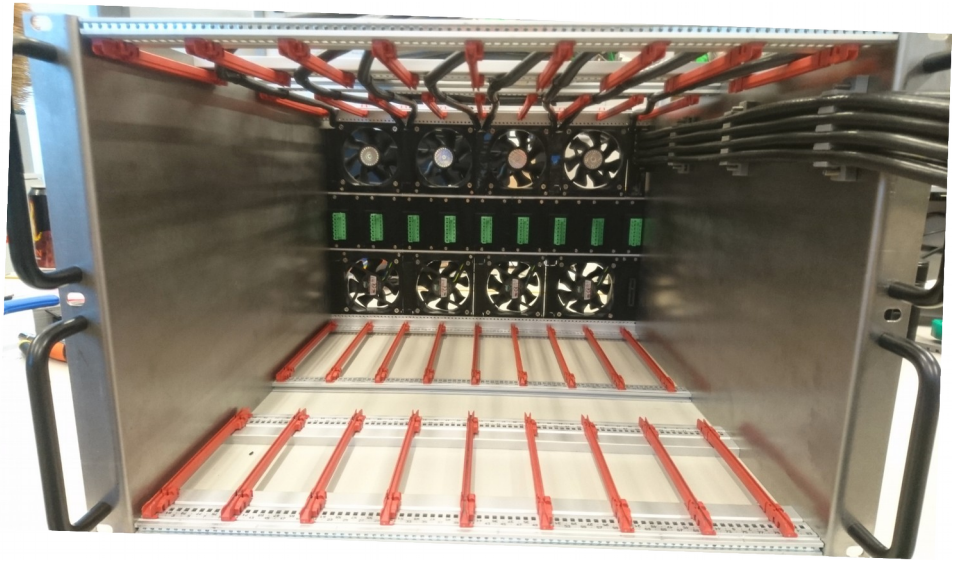
Service friendly

Module design



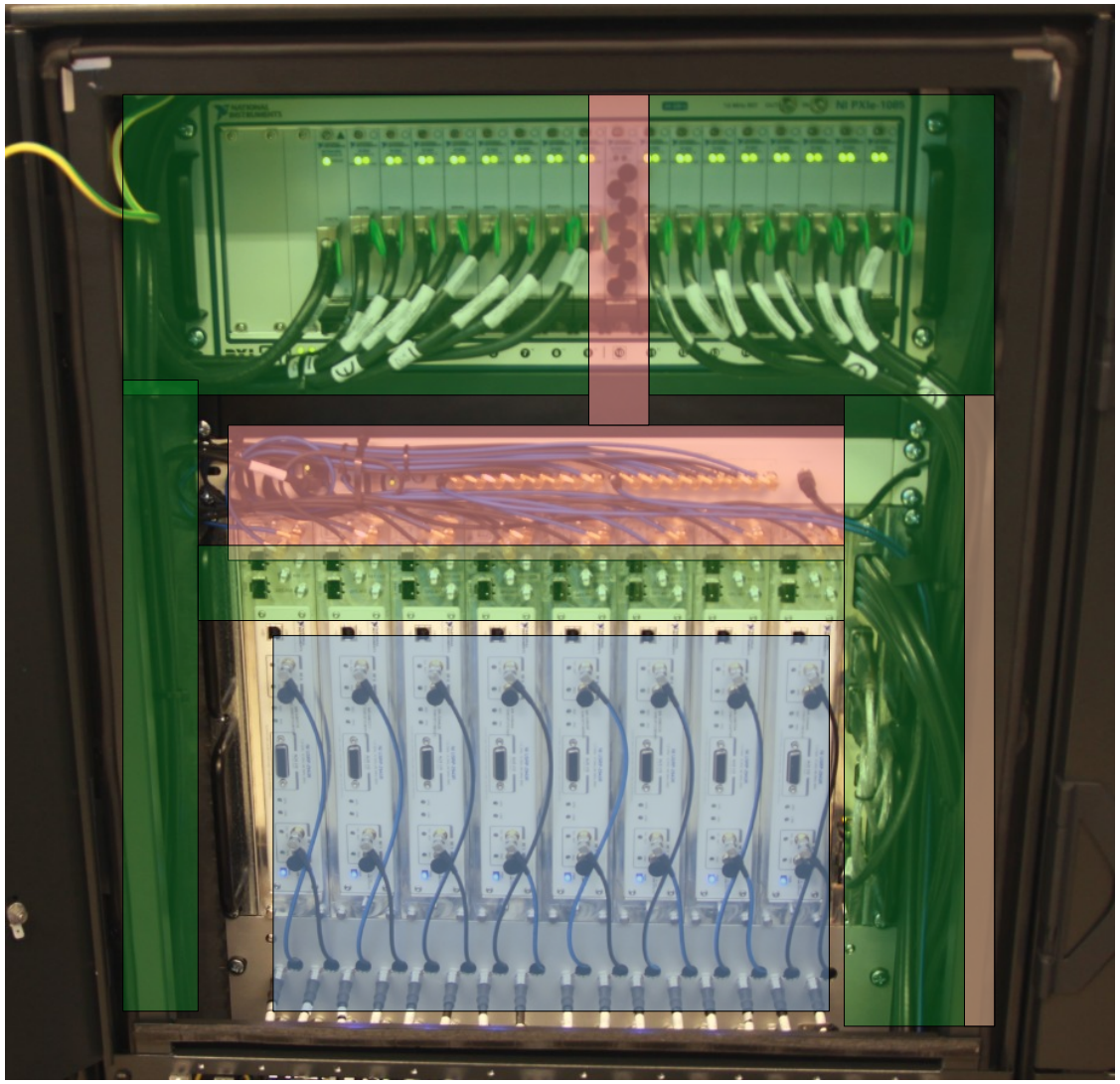
Measures taken:

- All units are rack mounted.
- All USRPs are sub-rack mounted.



Service friendly

Cable management



- “All” cabling in front
- Cables crossing modules kept to a minimum.
- Each cable type mainly kept in its dedicated area
- Preferred use of connectors

Data cables

Synchronization cables

Radio cables

Service friendly

Patch panel

Patch panel

- Easy connect and disconnect
- No mechanical stress on USRP connectors
- Aligned with cable transit modules.
- Saves SMA connectors for wear.
- Easy replacement of patch cable

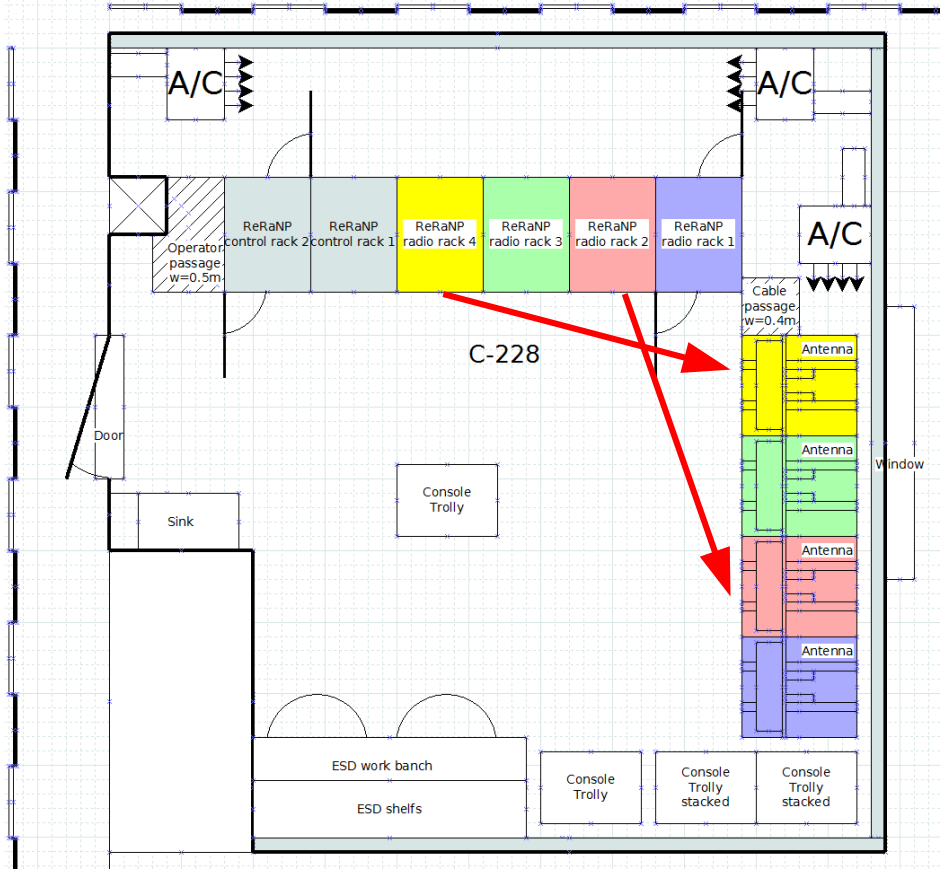
QMA connectors

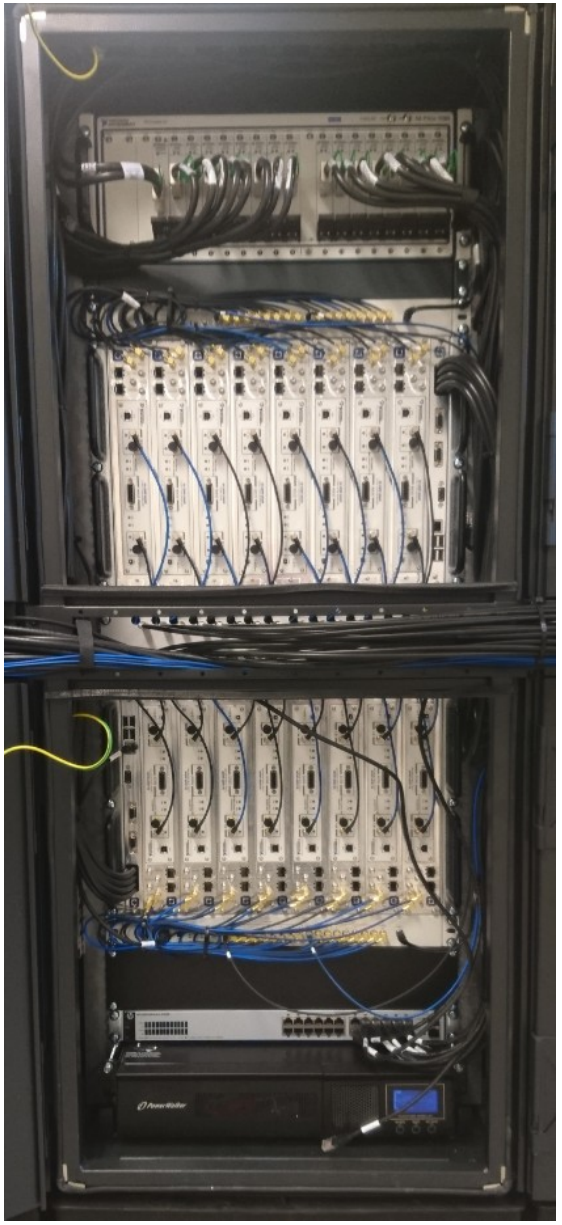
- Push – click – locked
- Mechanically rigid

Symetrical design

Cable management

- All cable groups are the same length
- Mirrored design around patch panel inside rack





Mechanical

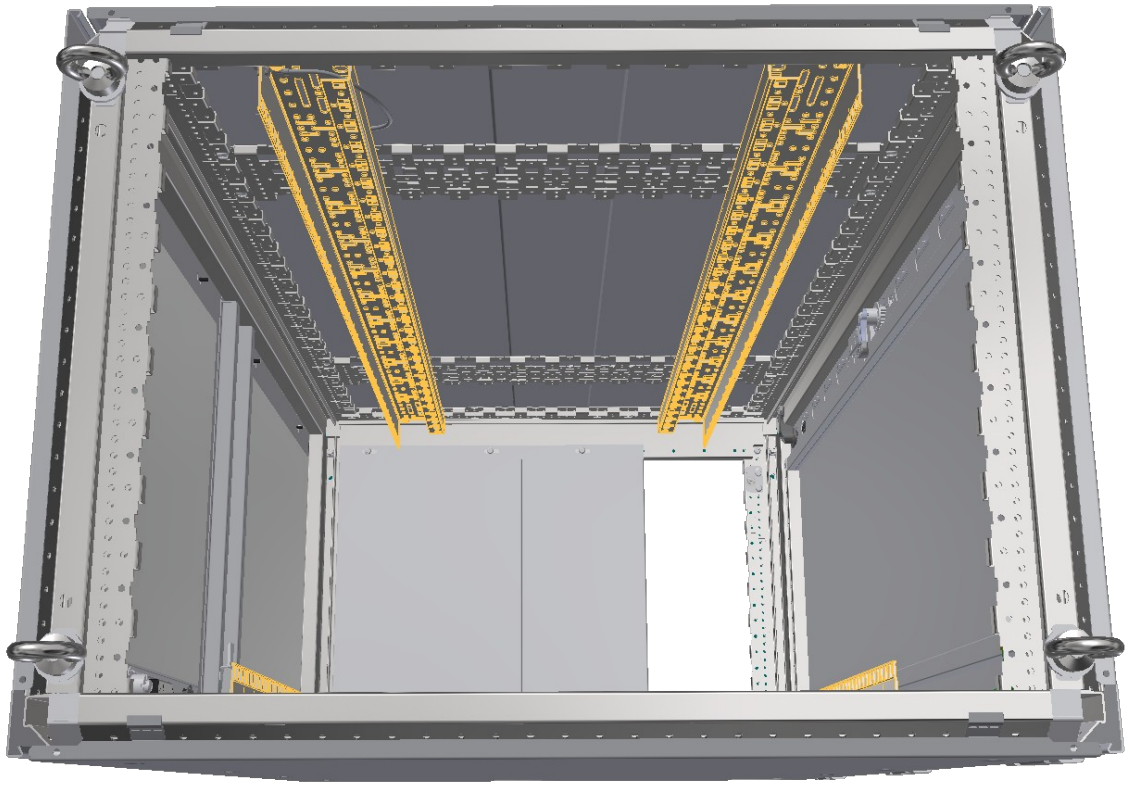
Challenges include

- Stable mounting for USRPs, controllers and support equipment.
- Secure cable mounts.
- Approx 200-300kg pr rack.
- Vibration and resonance in transport.
- Crane lifting
- Compact design

Mechanical

Custom made Schroff rack

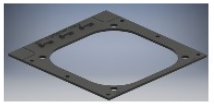
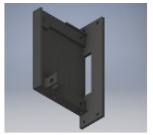
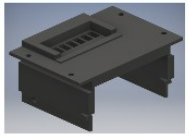
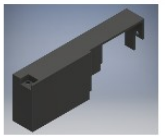
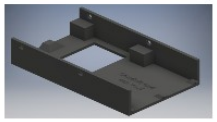
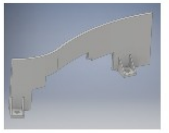
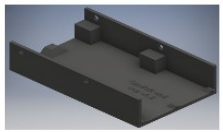
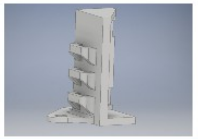
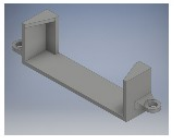
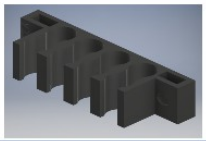
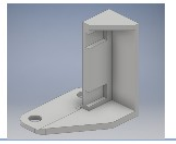
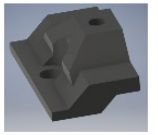
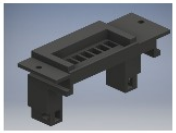
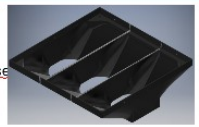
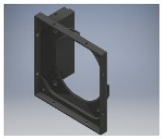
- Rigid rack design with hoisting lug
- Double rail design
- Compact short design



Extra back mounts on heavy units

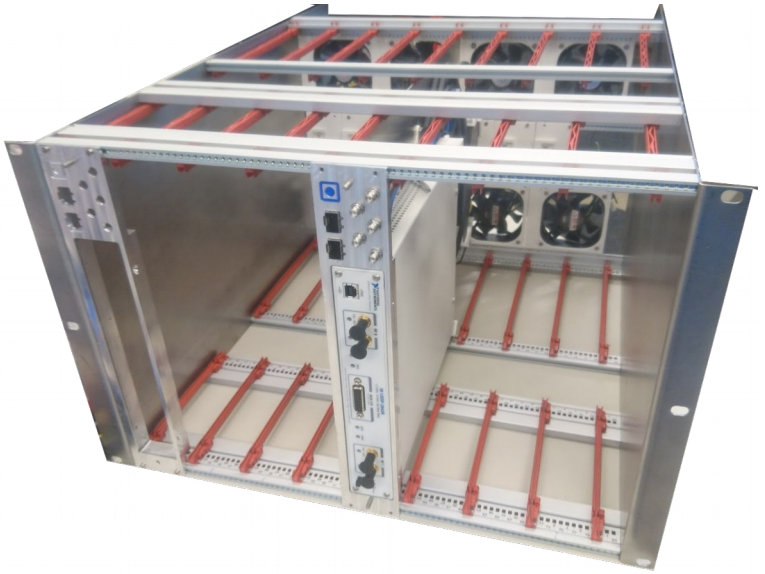
Mechanical

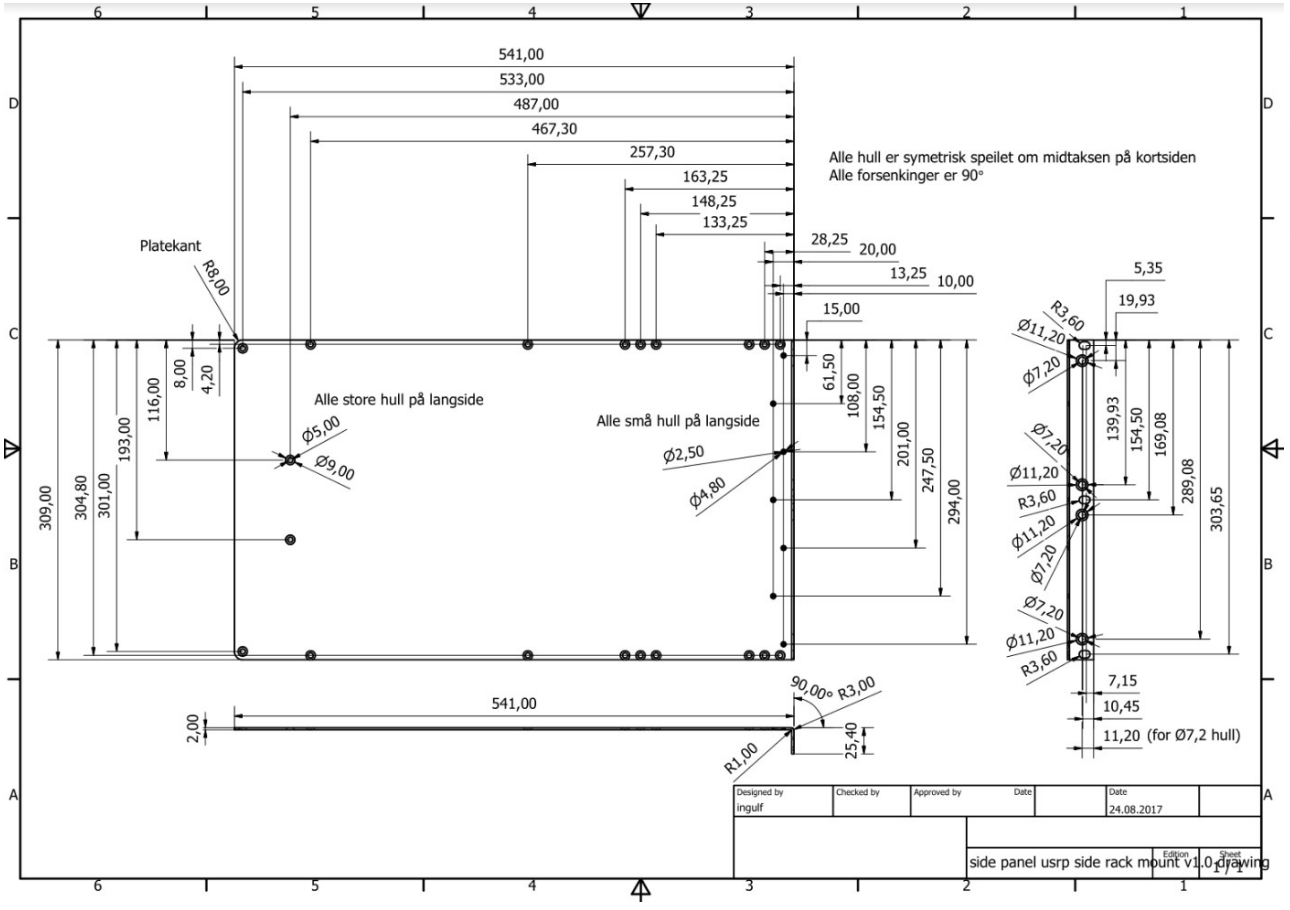
3D printed parts

Fan Holder		Backplane Control Module Interface holder v1.1		PSU-Bracket	
Terminalblockholder backplane		Backplane Control Module Interface holder lid v1.1		PSU-Bracket wDIN	
Conduit lid C14		MXI-cable transit backplane v1.2		Fan airflow guide	
Conduit lid		USRP holder top back		CU-PSU-holder	
MXI-Cable holder		USRP holder bottom back		Terminal tab block holder v1.1	
		Terminalblockplugholder 1v4		Control module backplane interface holder v1.4	
289mm ti 92mm adapter one-piece asse		Intake fan air flow guide v1.1		123mm to 92mm fan adapter v1.1	

Mechanical

Structural critical parts made of metal.
Production drawings for external manufacturing.





Data handling

Main challenges

- 2 GB/s measurement data
  7.2 TB/h, 16Gb/s streaming

- Error handling storage system
  No storage system is error free. Confidence of stored data

- Access and post processing
  In-house HPC. External user and HPC.

- Data archive, 10 years after publications
  Data loss, hacking, ransomeware. 0.1 – 1 PB throughout lifetime.

Data handling

Reliability of storage media

Media	(U)BER	Errors pr PB read
LTO-7/8	1E-19	0,0008
Intel 480GB SSD	1E-16	0,8
Samsung NVMe	1E-15	8
HDD 2.5'' 5TB	1E-14	80
HDD 3.5'' 12TB	1E-16	0,8

Data handling

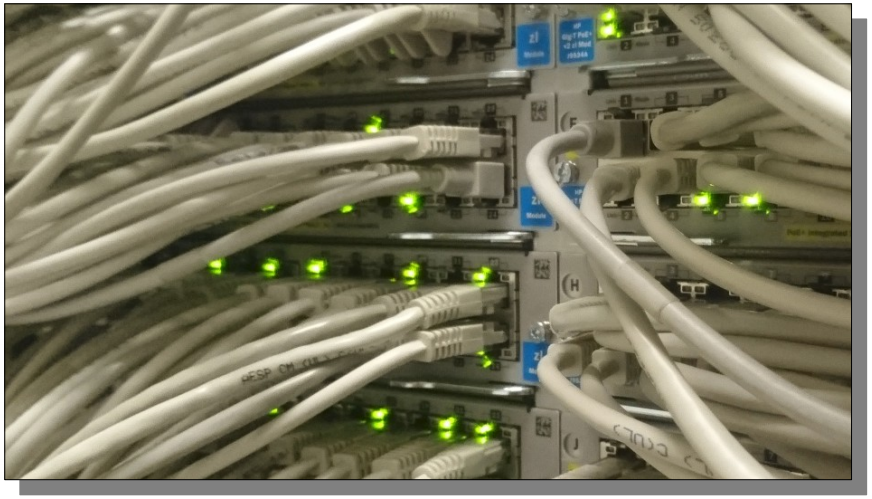
Speed of storage media

Disc datarate	Capacity 1 hour	Capacity 16 hour	
300 MB/s	1.1 TB/h	17,6 TB	Tape drive
880 MB/s	3.2 TB/h	51,2 TB	6 HDD RAID6 write speed
3 GB/s	10 TB/h	160 TB	SSD in PXI RAID0
6 GB/s	20 TB/h	320 TB	NVMe in server

** Real-time 2GB/s

Data handling

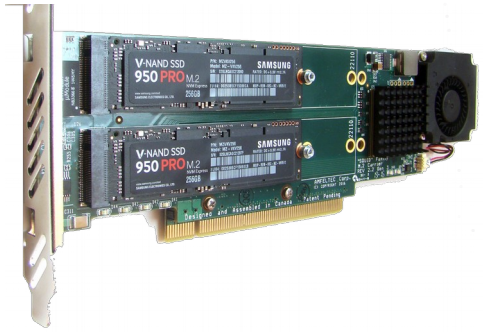
Network transfer speed



Link speed	Capacity 1 hour	Capacity 16 hour	
1 Gb/s	0,43 TB/h	6,88 TB	Standard high speed network
4 Gb/s	1,73 TB/h	27,7 TB	Quad link gigabit
10 Gb/s	4.3 TB/h	68,8 TB	Backbone speed
40 Gb/s	17.3 TB/h	276 TB	Server grade link

Data handling

Cost of storage media



Storage level	Name	Price (NOK ex)	Capacity TB	Price pr hour	Max speed	Copy time rate
L0D	NI HDD-8261	55233	3	132559	3000	1,5
L1	NVMe	39600	6	47520	7500	3,8
L2	HDD 3.5''	54000	96	4050	1260	0,6
L2 expansion	DAS-HDD 3.5''	79000	132	4309	2100	1,1
L3 low speed	HDD 2.5''	22500	40	4050	1120	0,6
L3 medium speed	SSD 2.5''	104990	40	18898	4160	2,1
L3 high speed	NVMe	39600	6	47520	7500	3,8
L3 expansion	DAS-HDD 3.5	79000	132	4309	2100	1,1
L4	LTO-8M Tape	96163	423	1637	300	0,2
L4 expansion	LTO-8M Tape	86752	432	1446	300	0,2

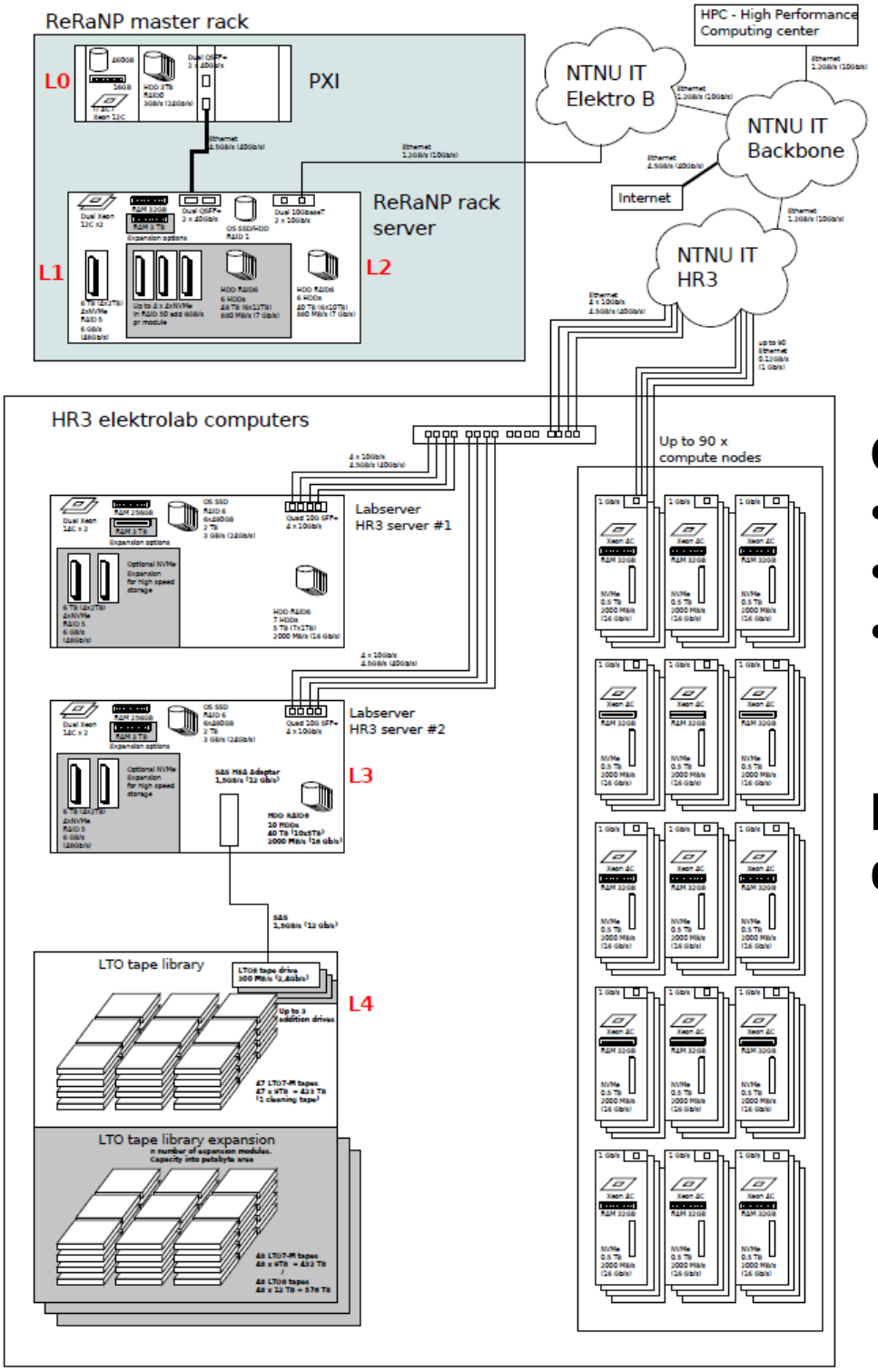


Illustration 1: ReReNP data handling diagram

Data handling

Data flow

Our solution

- Level based data storage
- In house for security (GDPR, etc.)
- Re-use of exiting computing solution

Each level solve a specific part of the data handling

L1 – Measurement streaming
L2 – Campaign storage
L3 – Post processing / pre-archiving
L4 – Archiving

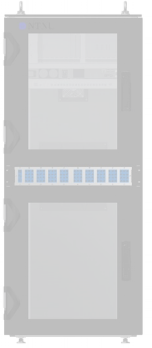
ReRaNP configurations

Rack setups

4 x 32 (28) antenna

2 x 64 antenna

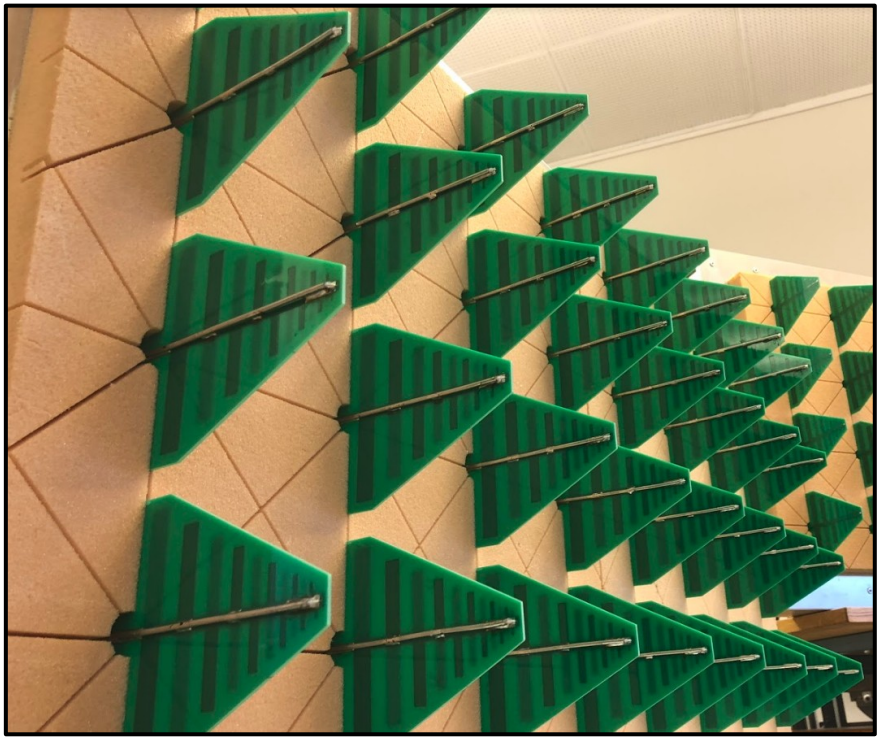
1 x 128 antenna



ReRaNP configurations

Antenna

Antenna polarization selectable in 45º increments.
Log periodical 1.4 – 6 GHz operation
3-6 dB gain



Portable nodes

...still to be designed

Laptops

- Huge challenge with PC-card interface.
- Bought second hand used 12” laptops
- Upgraded 12” to out perform most new 2017 15”
  - Core i7 3840QM, 1TB SSD, 16 GB RAM

Other features:

- 2-4 hours battery time
- Of the shelf power tool battery and charges
- Water / weather proof
- Backpack style
- 10-20W RF power amplifier

ReRaNP fun-facts

560 3D printed parts
655 hours of continuous printing (given no breakdowns)
Total about 20kg of plastic.
124 custom made metal parts.
30 different 3D printed designs.
7728 bolts and nuts for the sub-racks only.
1216 self-made wires and cables. 597 bought cables.
50 self-made circuit boards.
13 kW consumed to generate 13W of RF power.
272 cooling fans.
7041 technical design files. (522 GB)
70 FPGAs for data processing. 5.5M LUTs, 27k DSP modules
Capable of generating 1.4Tb/s of network traffic