MEETING MEERKAT'S SIGNAL PROCESSING CHALLENGES

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science and technology

Department:
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Outline

- Digitisation near the feed
- ADC selection
- The processing subsystem
- Choosing the right processing platform

KAT-7: RF Front-End

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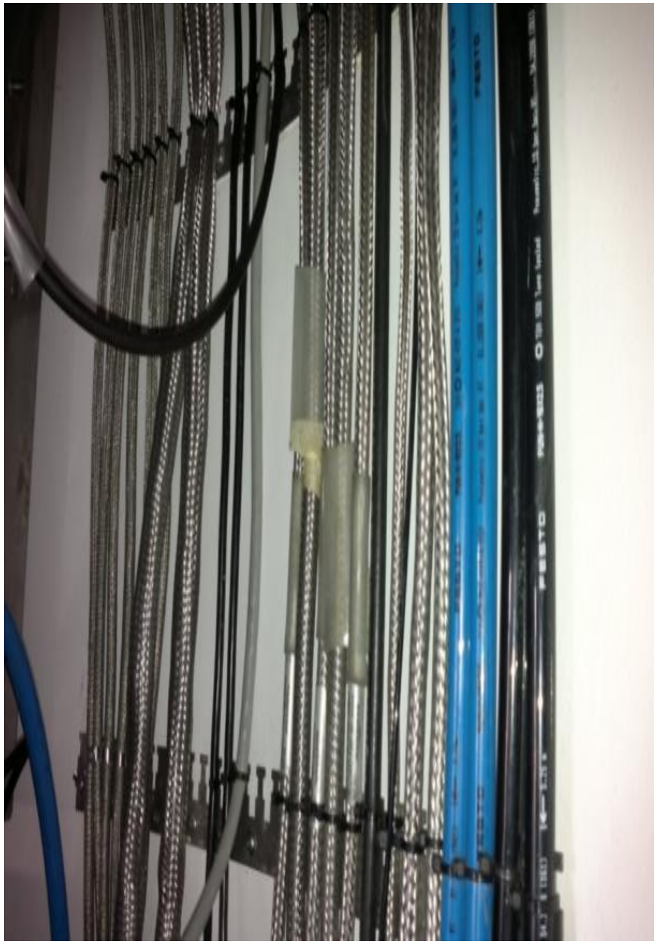
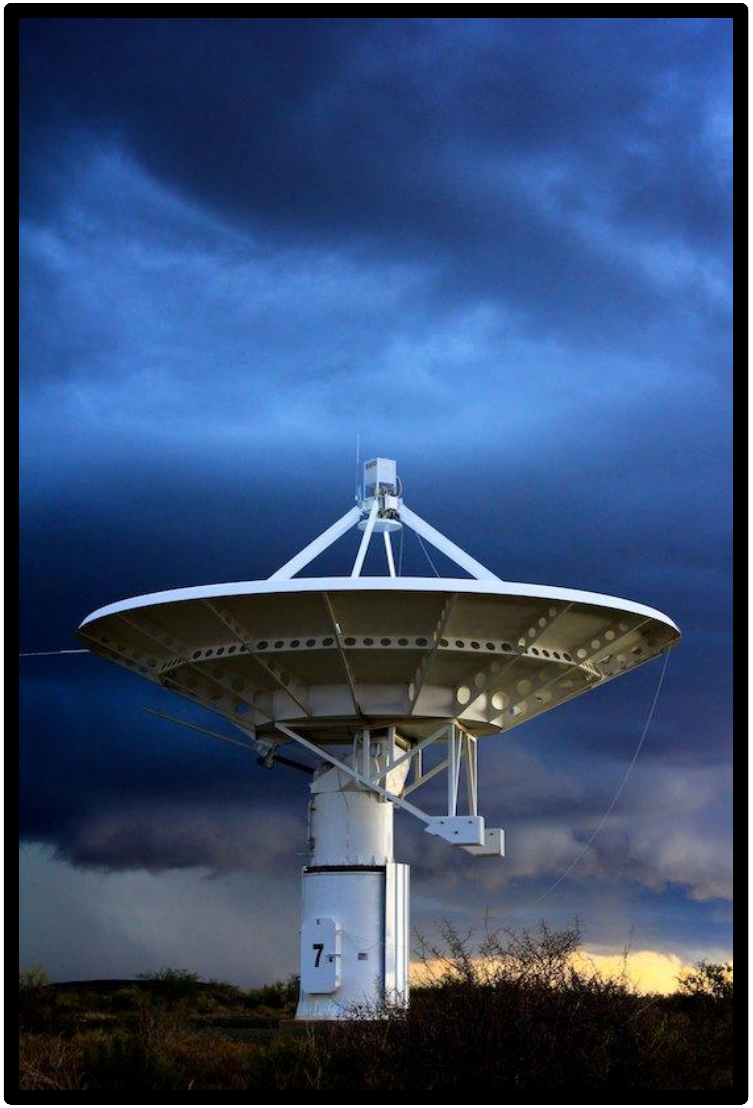
RF Cables





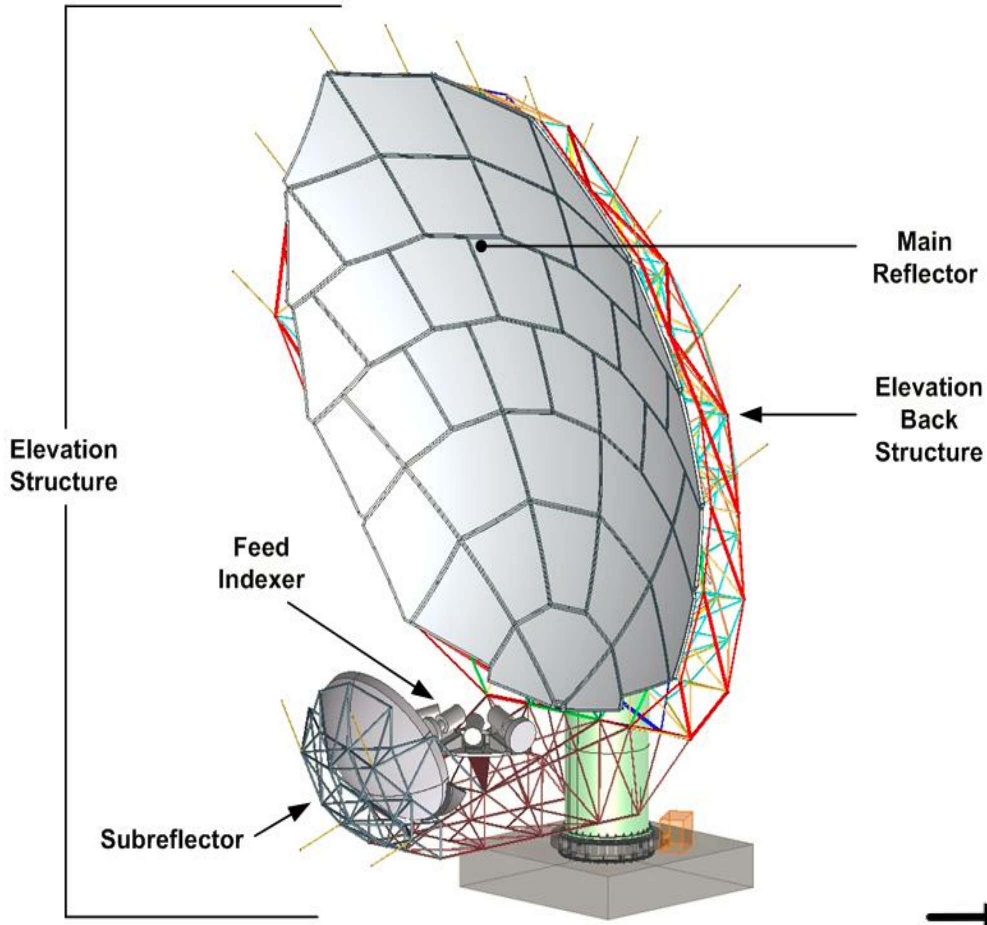
KAT-7: RF Front-End Stage 6

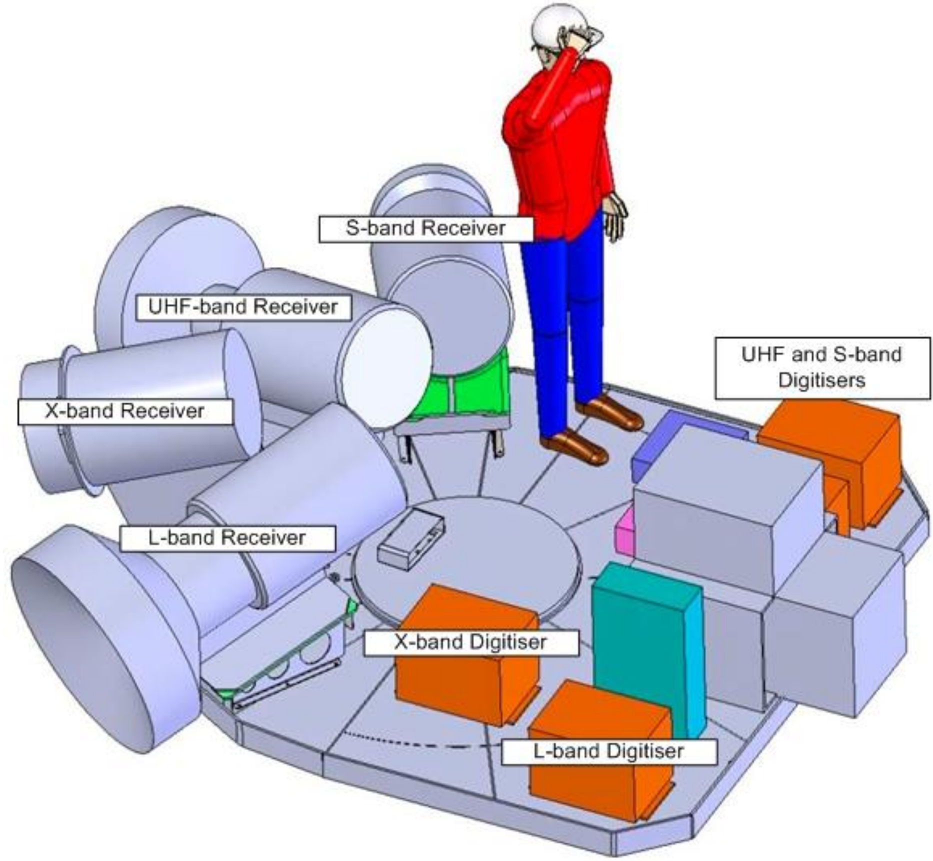
RF-to-Optical Conversion, Fibre Transportation, Optical-to-RF Conversion

- RF-over-Fibre for ~5 km distance
- ~40 dB dynamic range

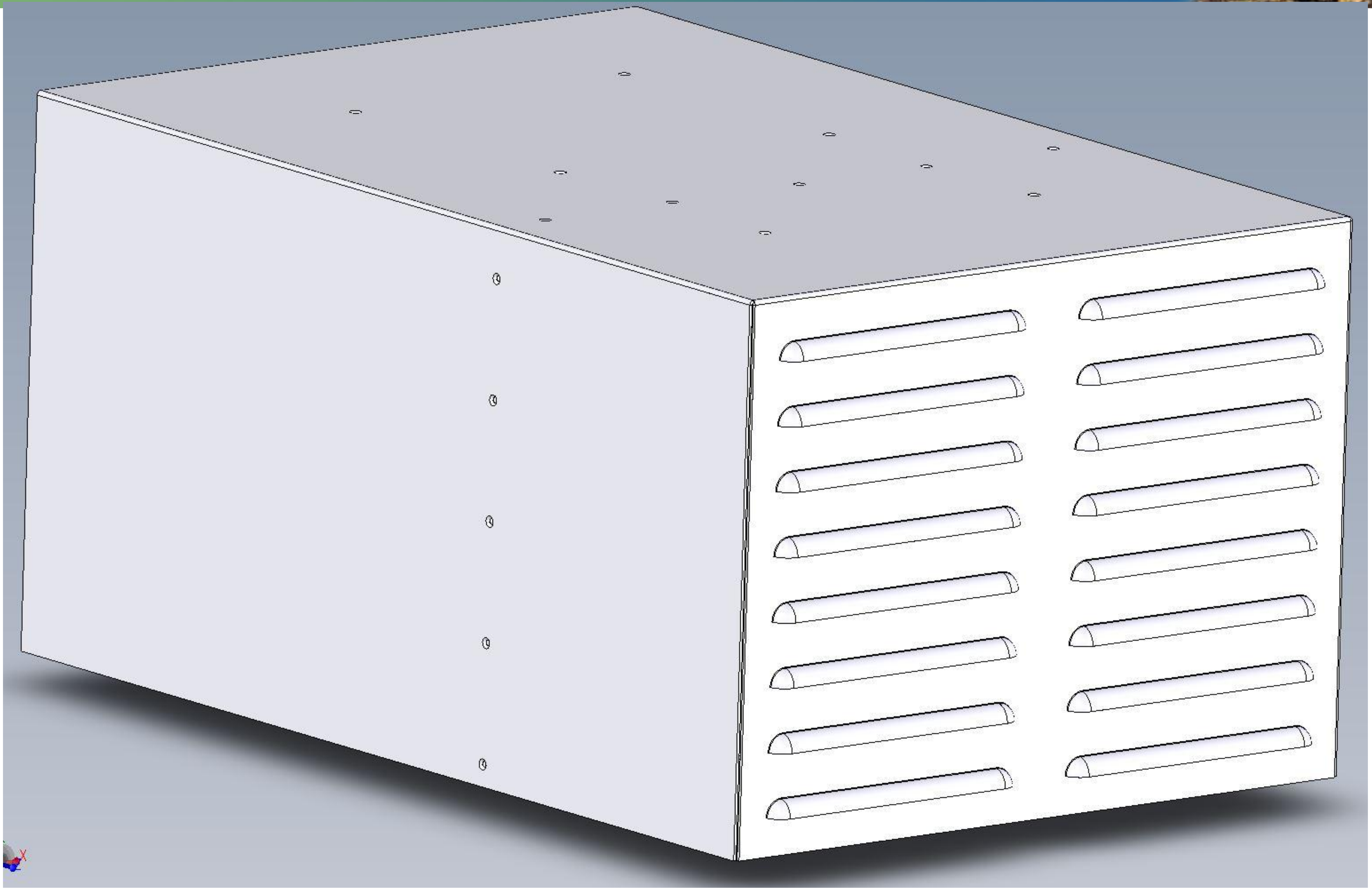
Optical Transmitter

Digitiser context: MeerKAT Receptor

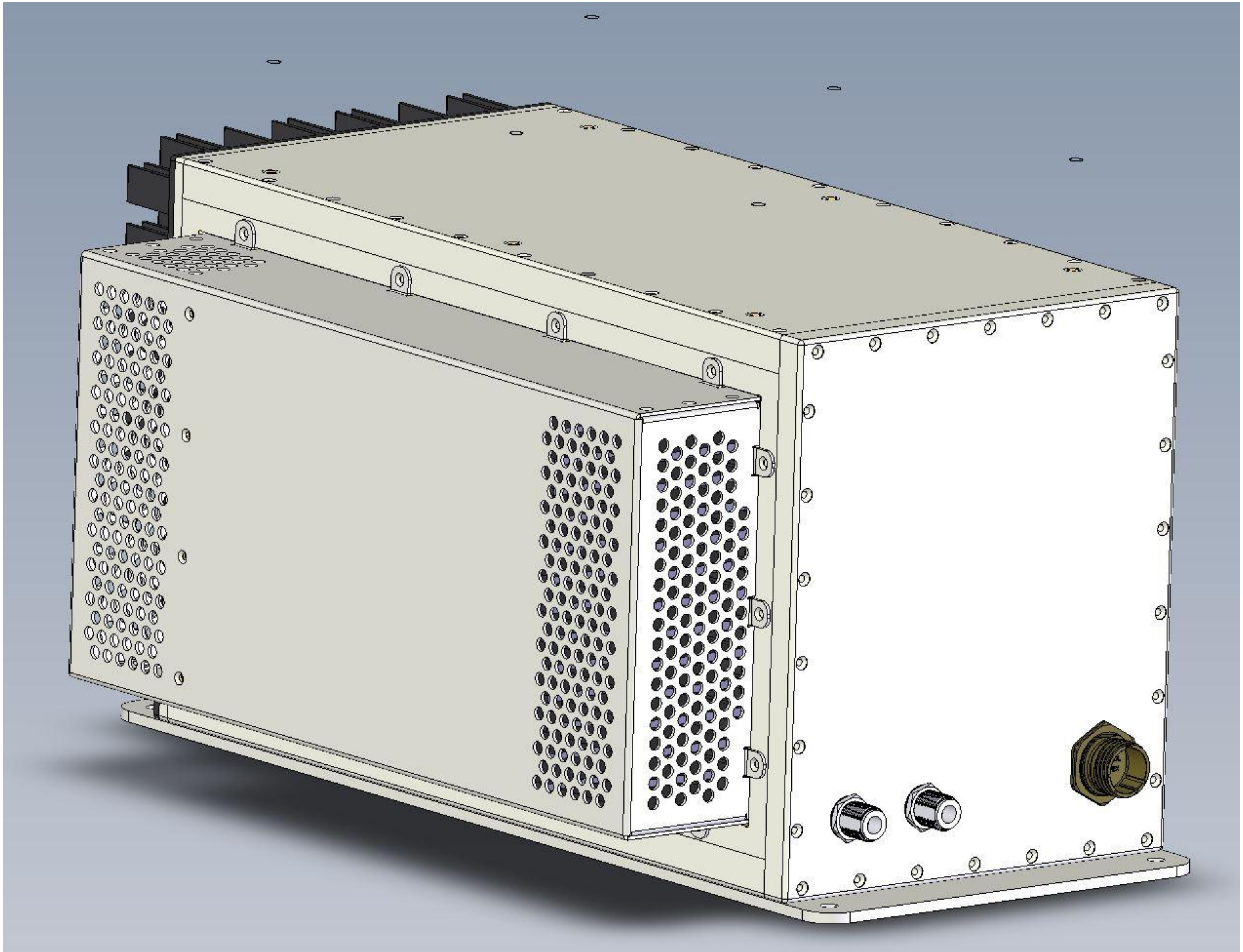




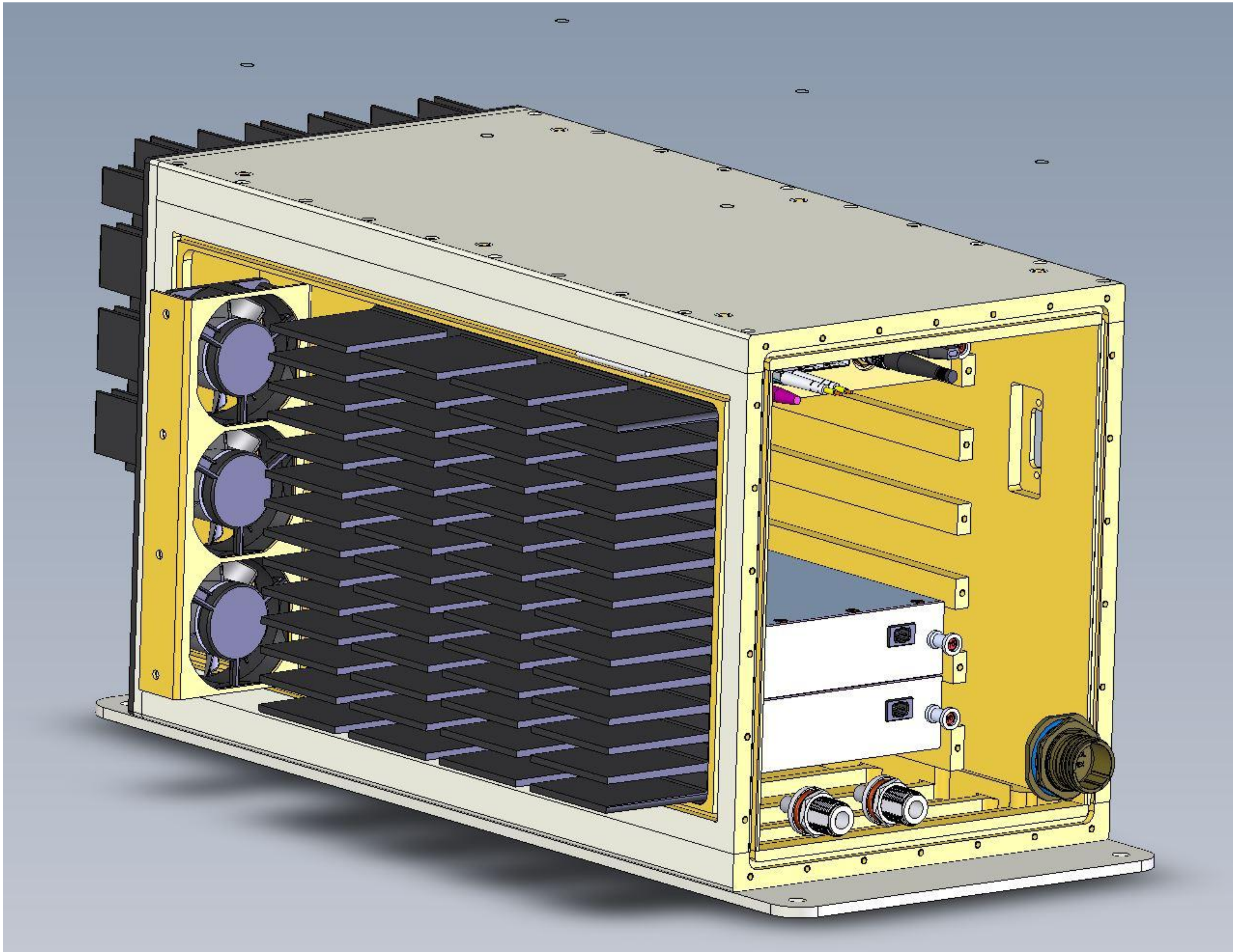
Mechanical design



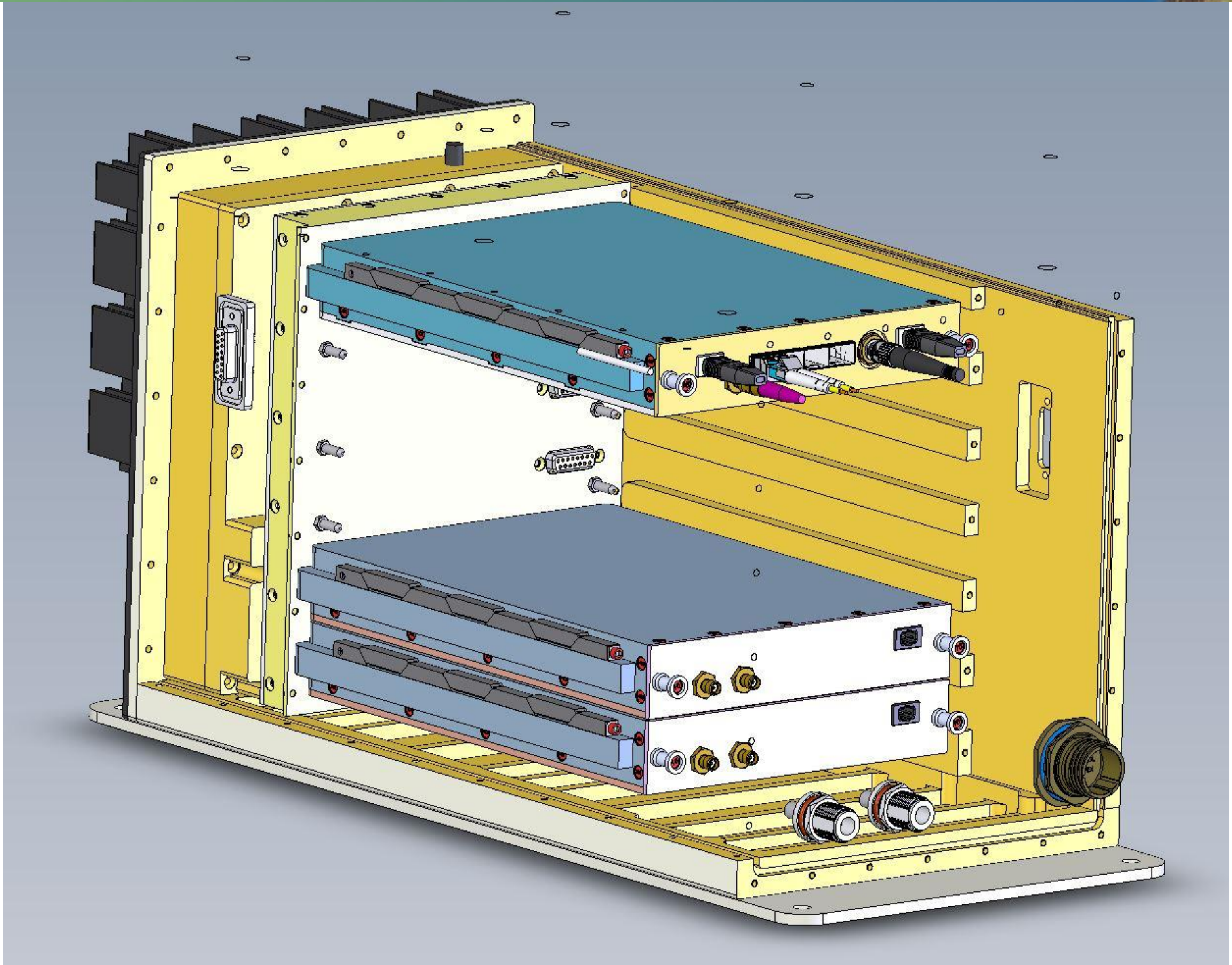
Mechanical design



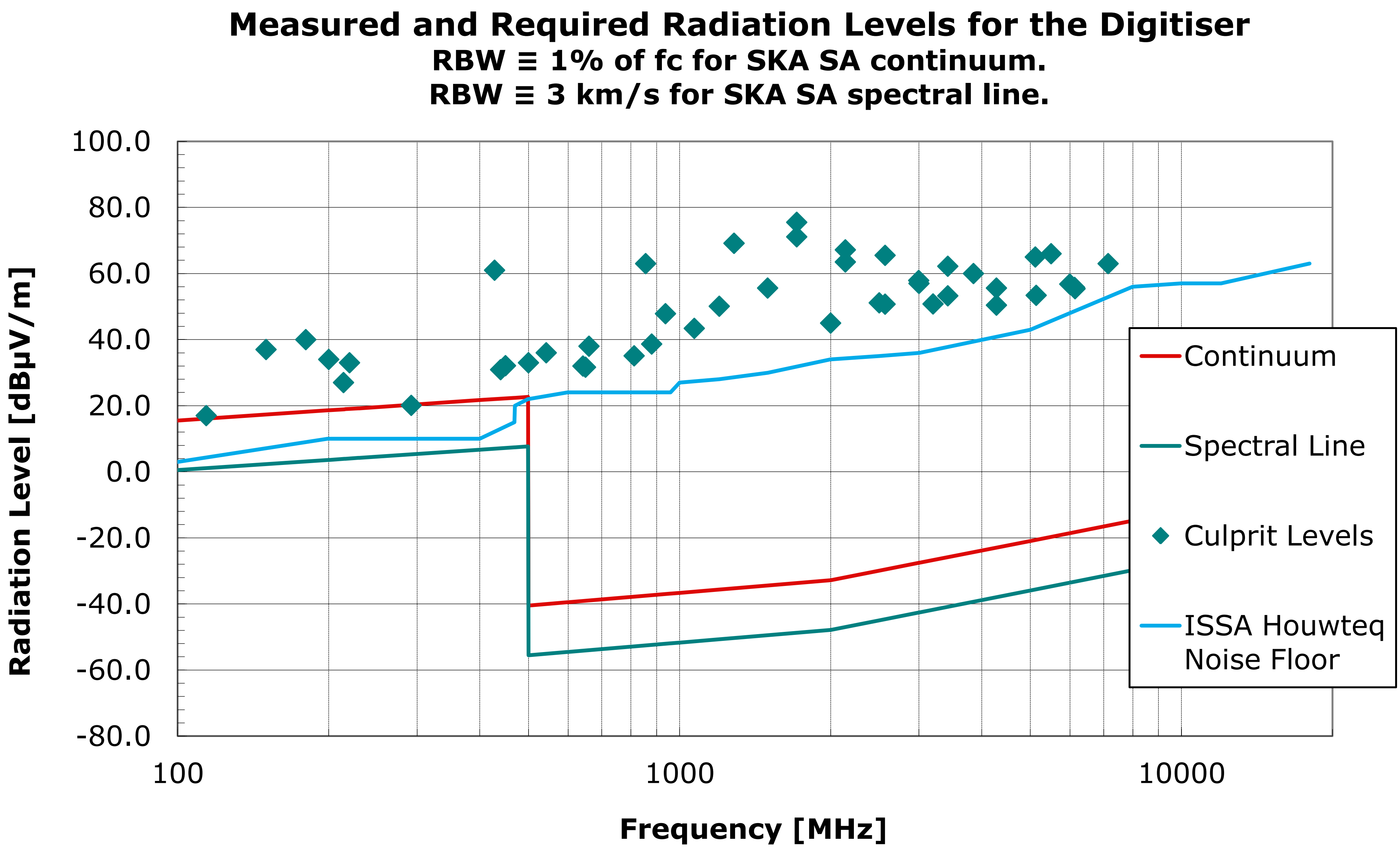
Mechanical design



Mechanical design

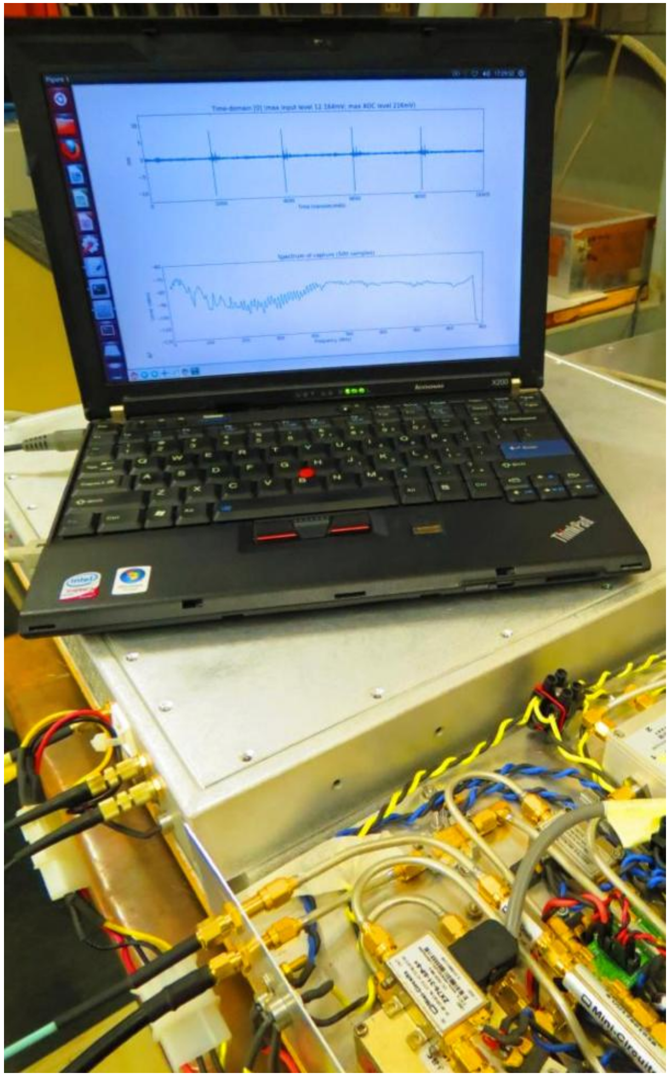


Key specifications: RFI



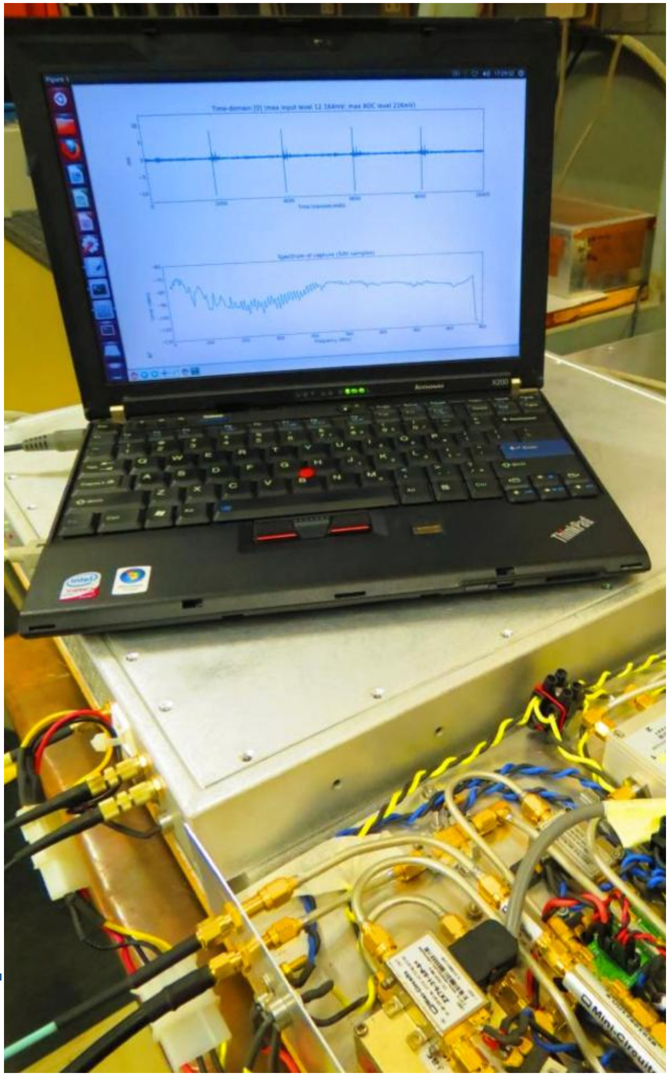
ReAlTime Transient analYser (RATTY)

- A real-time, radio frequency measurement system.
- Time-domain capture or integrating spectrometer on ROACH2.
- Broadband, high sensitivity.
- Powered by battery DC (field use) or mains AC (lab instrument).
- “Low” cost, suitable for university use.
- Developed in collaboration with MESA and University of Stellenbosch.



ReAlTime Transient analYser (RATTY)

- SKA on-site RF interference (RFI) monitoring system. On-going, long-term.
- SKA subsystems verification.
- Electric fence measurements.
- Reverb chamber characterisation and instrumentation.
- On-site characterisation and validation of RFI counter-measures.
- EMSS using derived system for feed compliance testing.

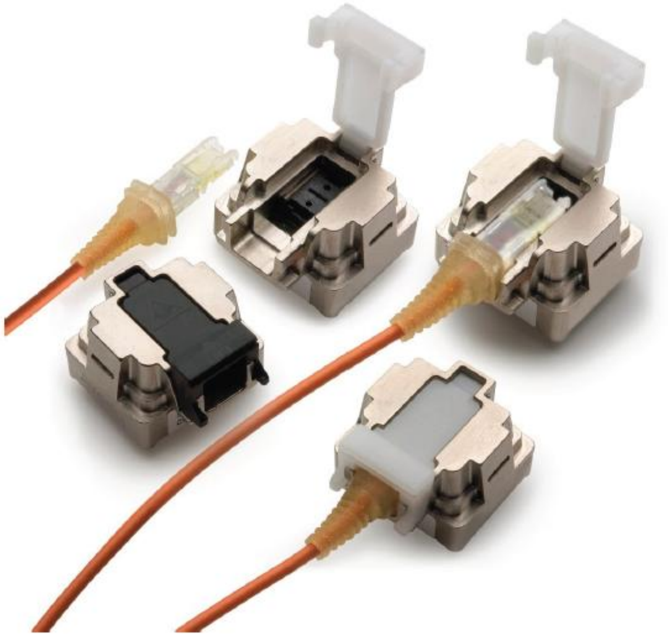


5 papers published already (that I know of).

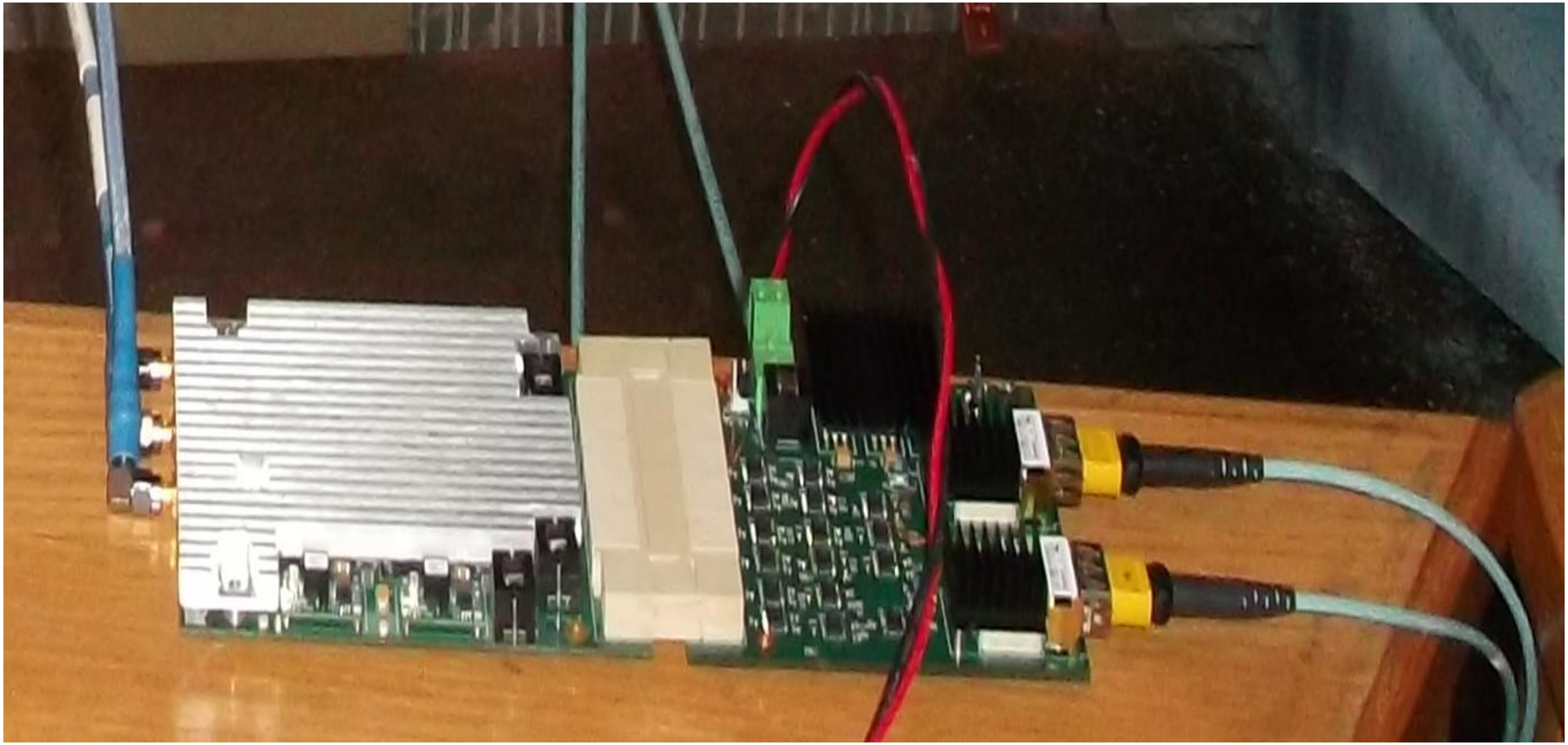
5 masters students. 1 undergrad project.

RE and CE mitigation

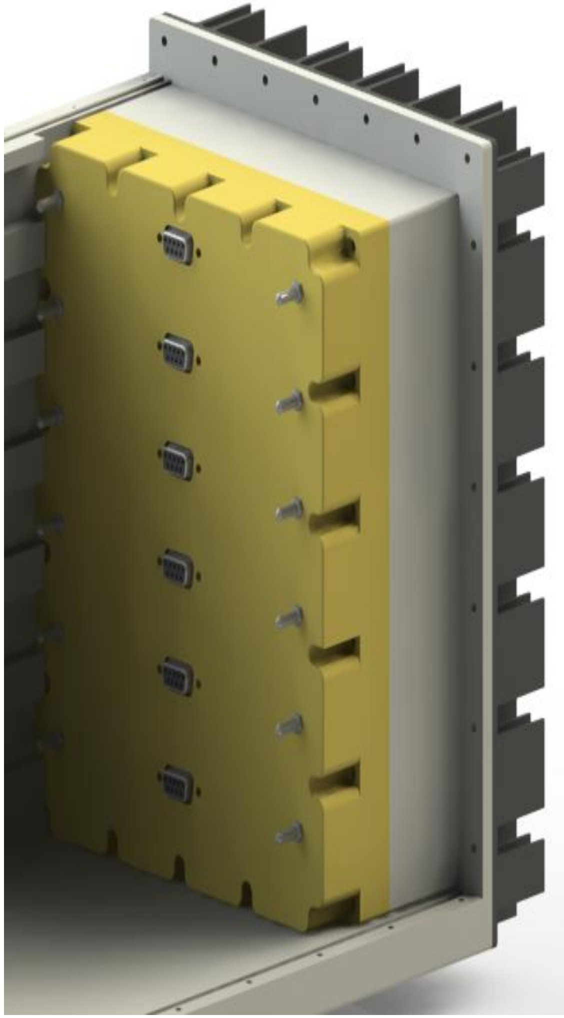
- Minimise the number of switching circuits.
- Ensure that there is no ringing at the transition of digital signals – proper termination critical.
- Lock all clocks to the same reference.
- Modular, individually shielded units.
- Minimise enclosure aperture counts and sizes.
- Apply filtering on galvanic interfaces.
- Use optical cables where possible.

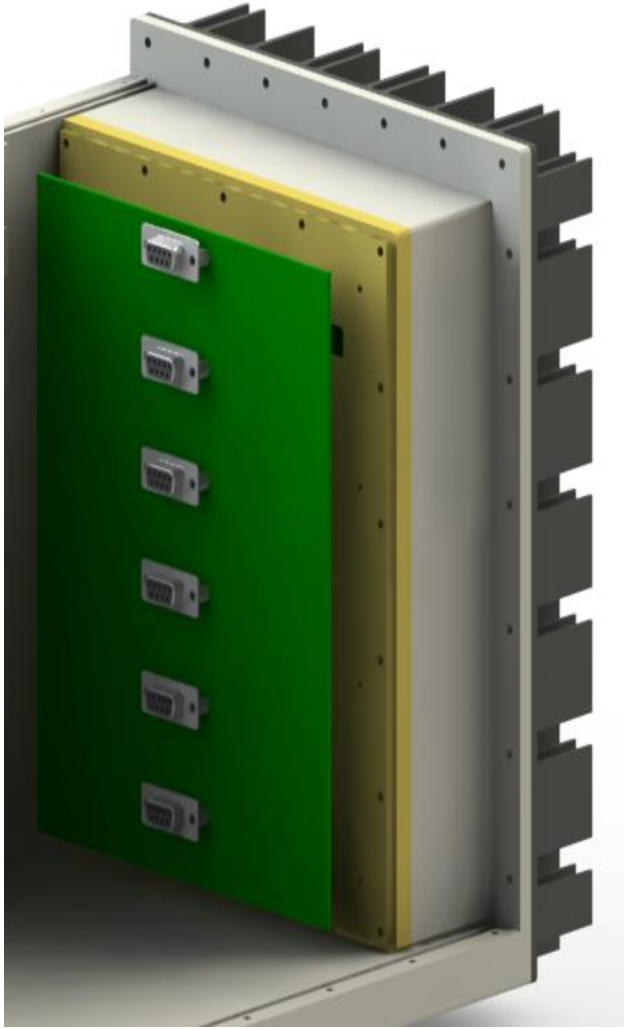


ADC Optical Transmission



Digitiser PSU design





Digitiser fibre connectors

MXL38999
Circular Optical Connectors

106386

Key specifications: environmental

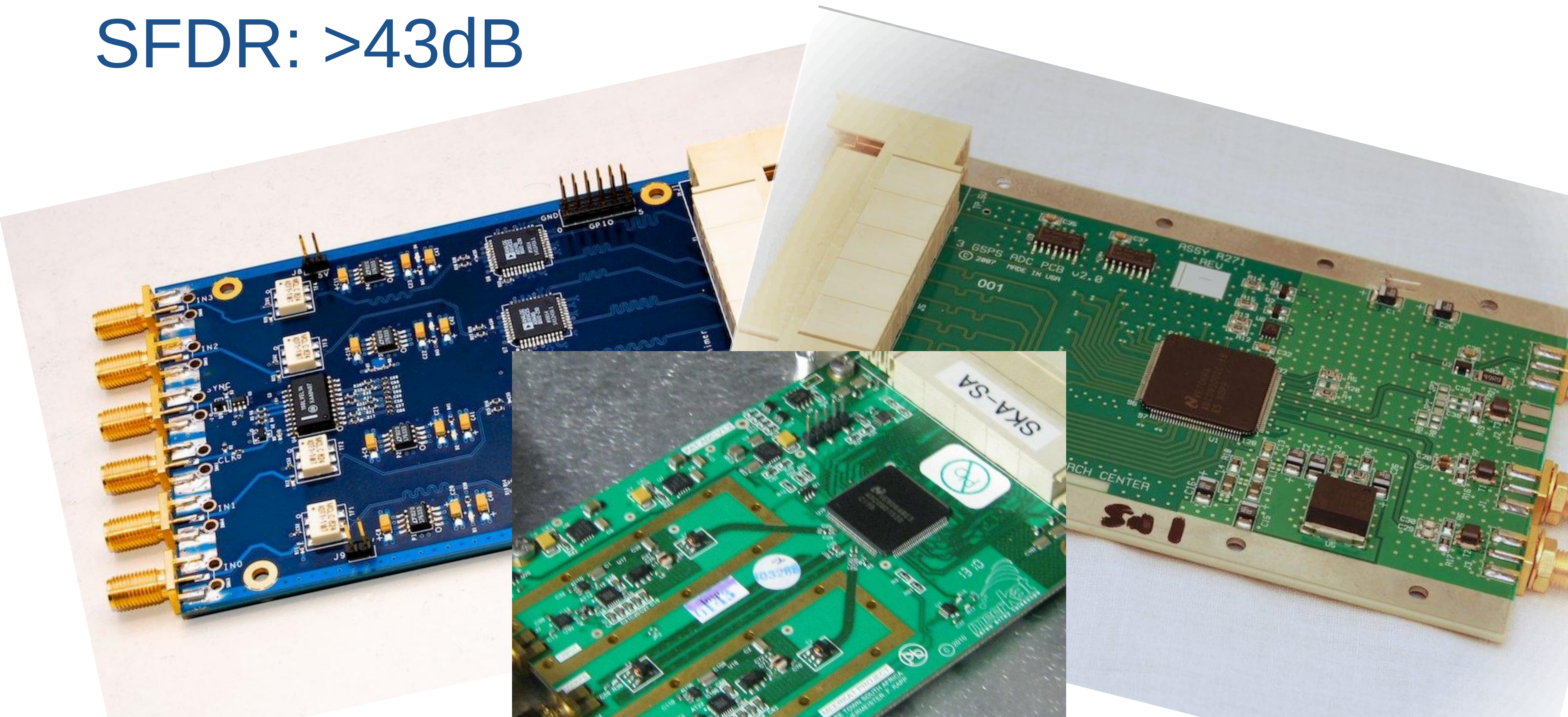
Environmental parameter	Description
Air temperature	Digitiser ambient conditions • Temperature change (R.D.E.5): -5 to +40ºC • Rate of change (R.D.E.6): 3ºC in 20min and 2ºC in 10min • Survival (R.D.E.1): -20 to +55 ºC
Humidity	• Relative: 93% at 40 ºC • Condensation: 90-100% at 30 ºC
Precipitation	• Submersed in 0.4m head of water for 30min
Solar radiation	• 1120W/m^2
Mechanically active substances	• Dust • Sand
Vibration and shock	This is defined in detail by table 5 of ETSI EN 300019-2-4 V2.2.2 (2003-04)

Meerkat L-band ADC requirements

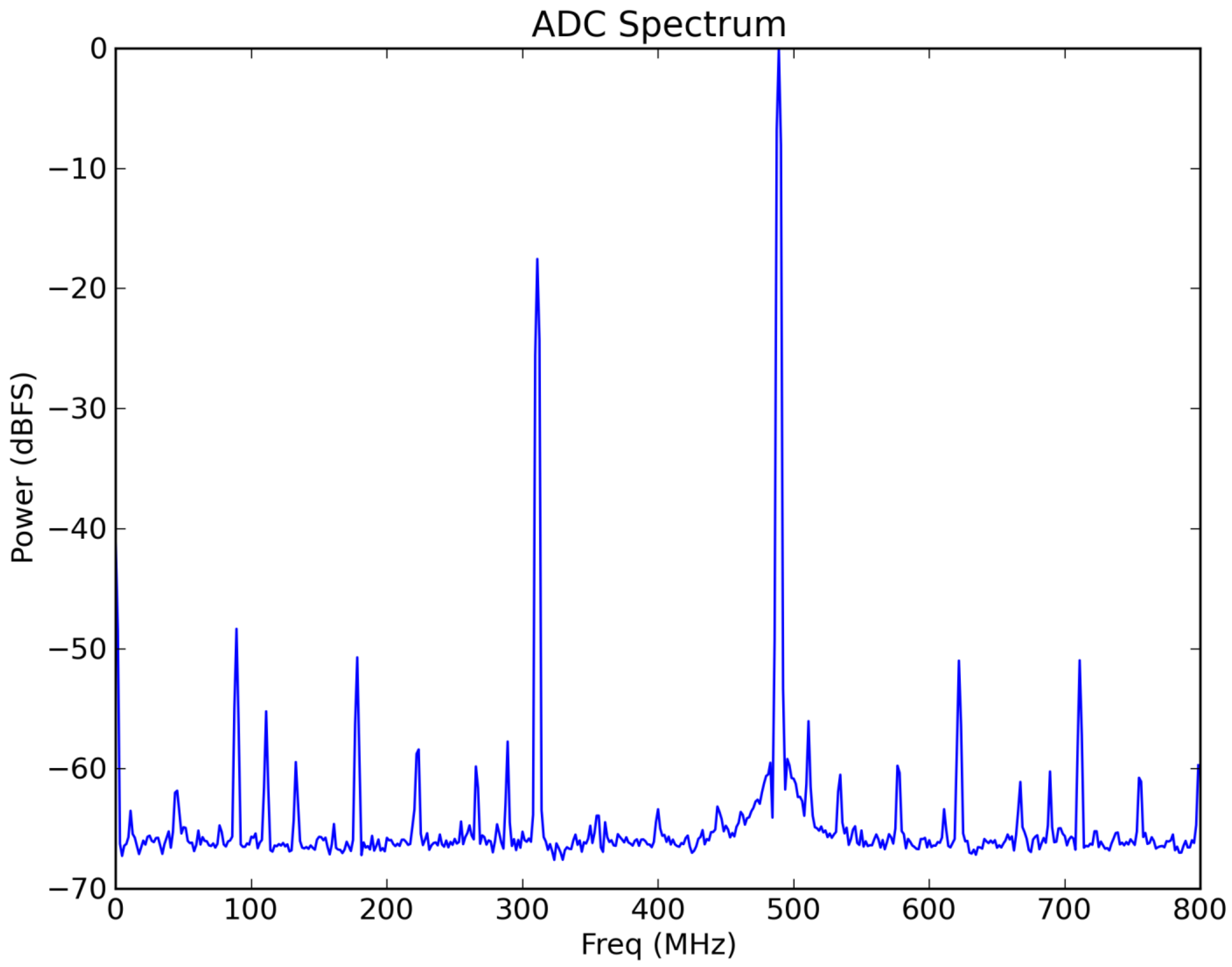
Analogue band: 900MHz – 1.67GHz

ENOB: >8b

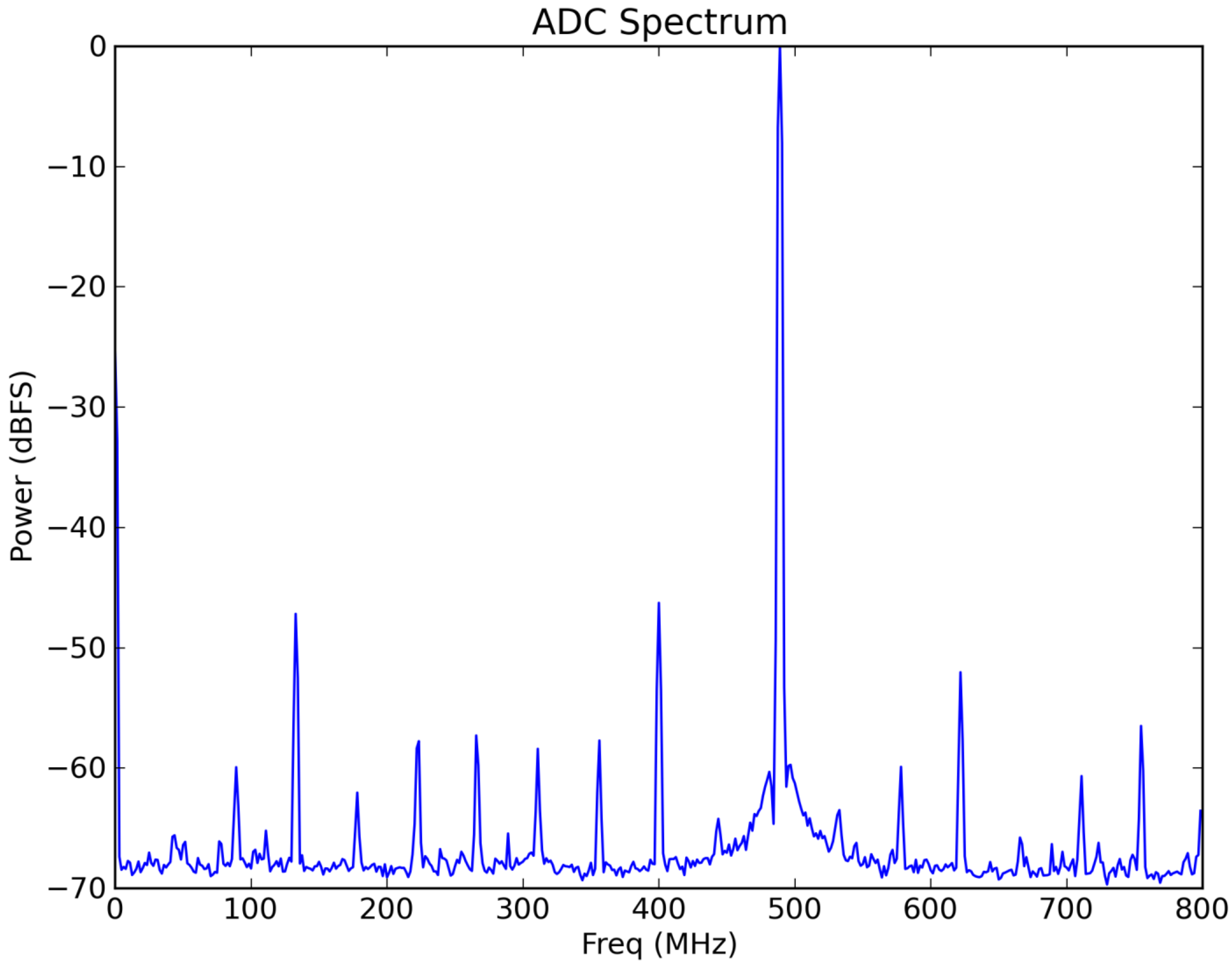
SFDR: >43dB



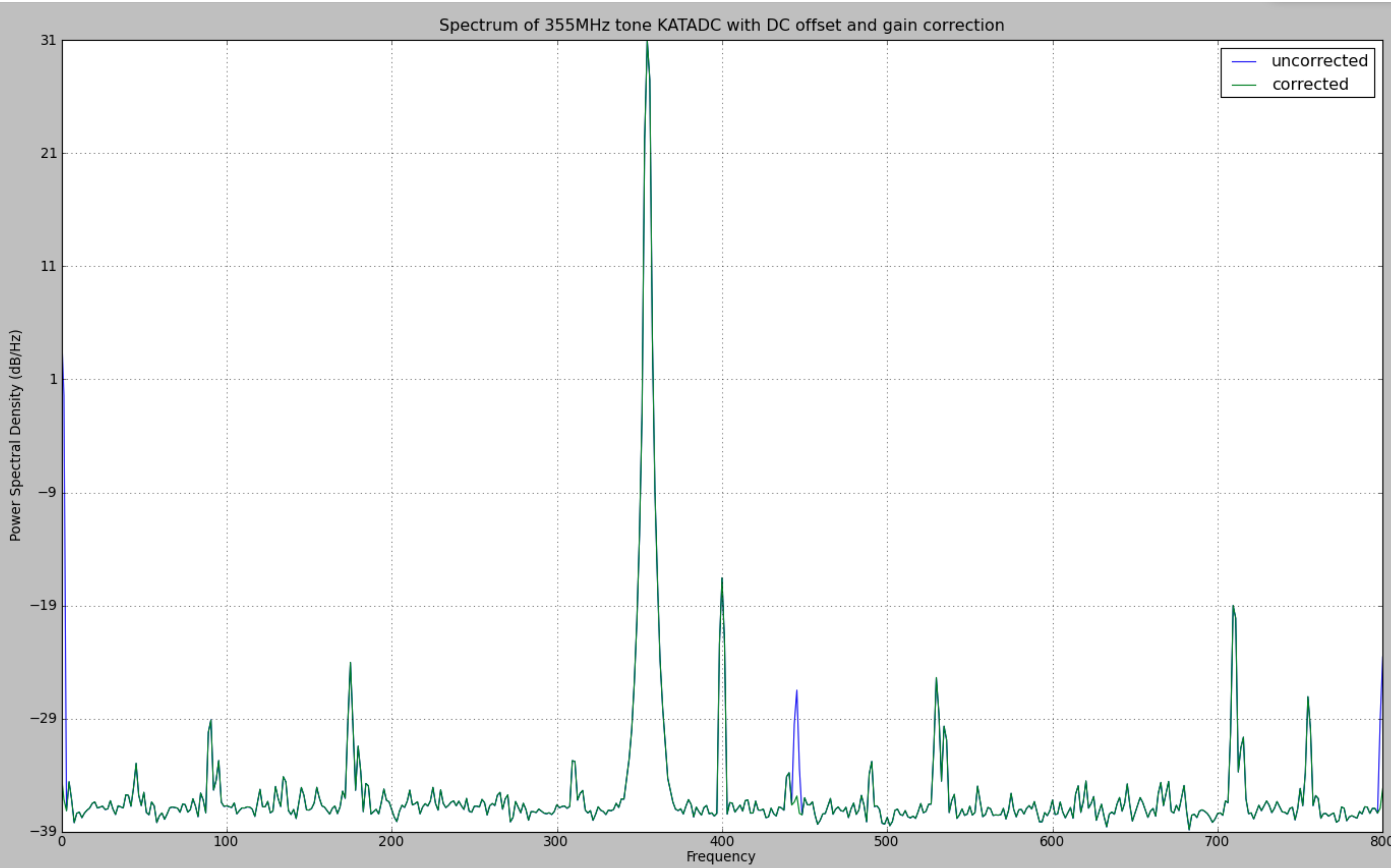
Interleaved ADCs – 2 way



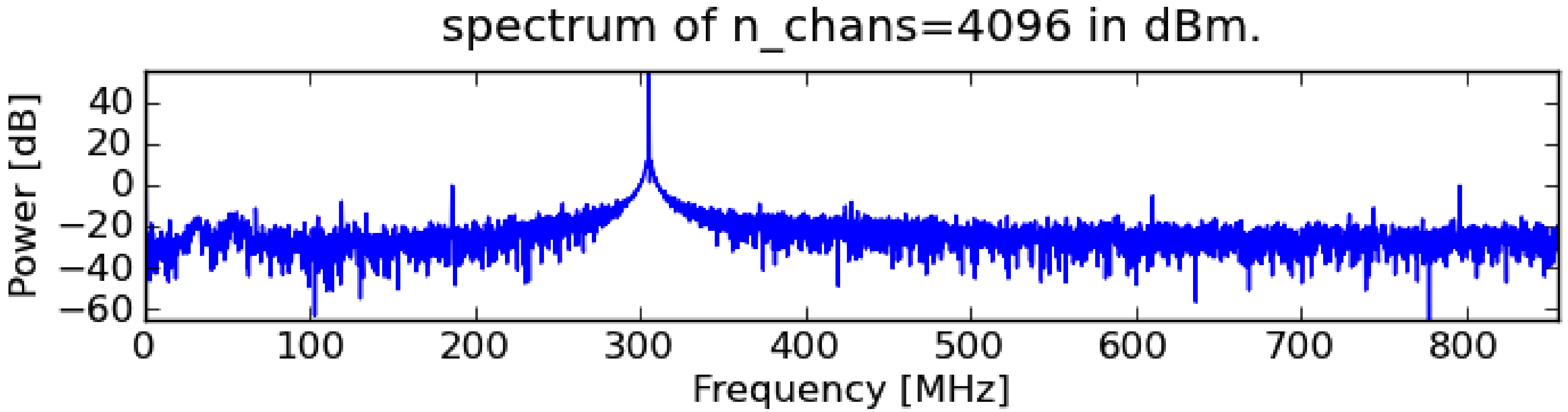
Interleaved ADCs – 4way

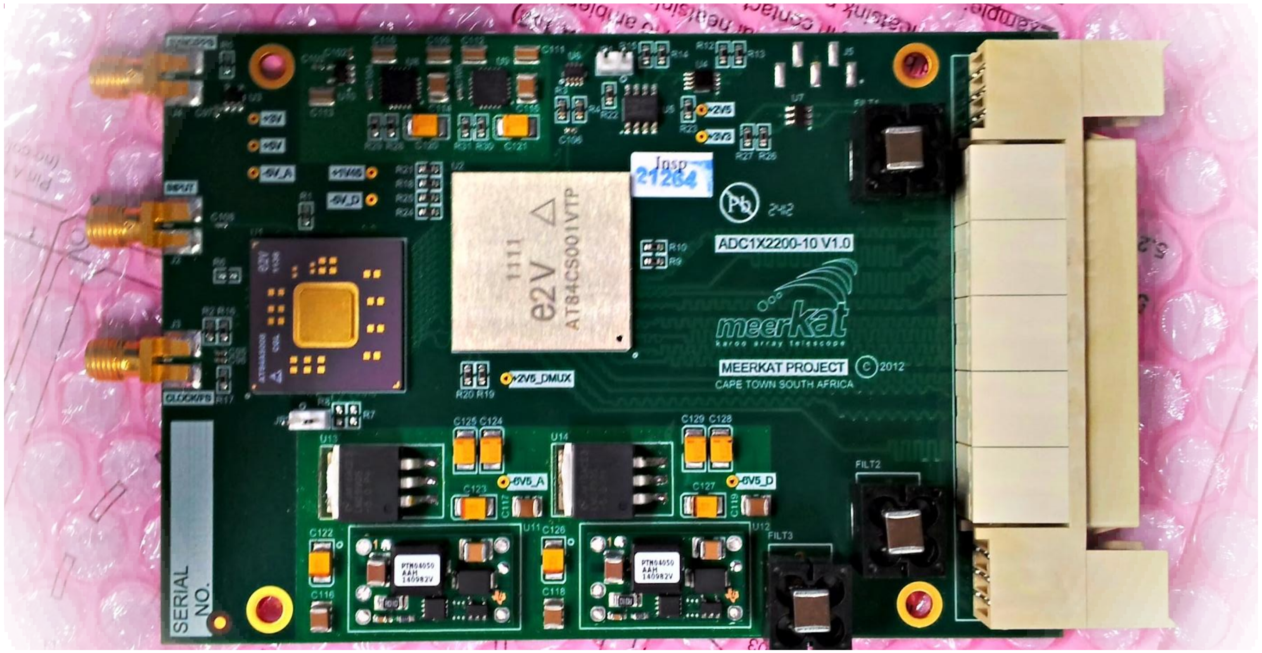


Correcting interleaved ADCs



MeerKAT ADC prototype

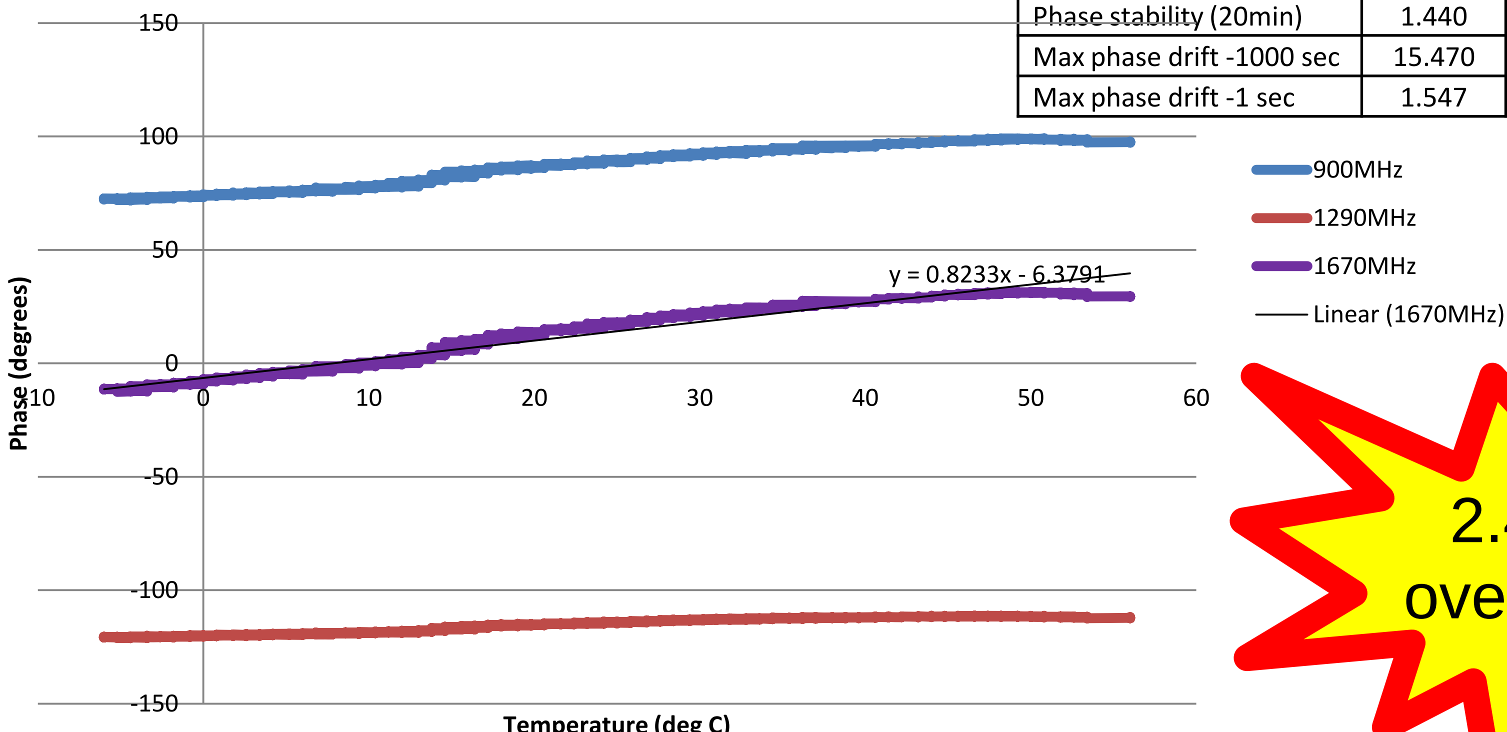




Gain and phase stability

Parameter	Doc PUID	Value
Gain stability (20 min)	R.D.P.21	<0.7 % RMS
Gain stability (5 s)	R.D.P.36	<0.5 % RMS sampled at 20ms intervals and removing a linear fit
Phase stability (20min)	R.D.P.23	<1.6 °RMS after subtracting a linear interpolation
Max phase drift	R.D.P.24	• 0.3 radians over a time period of • 0.03 radians over a time period o

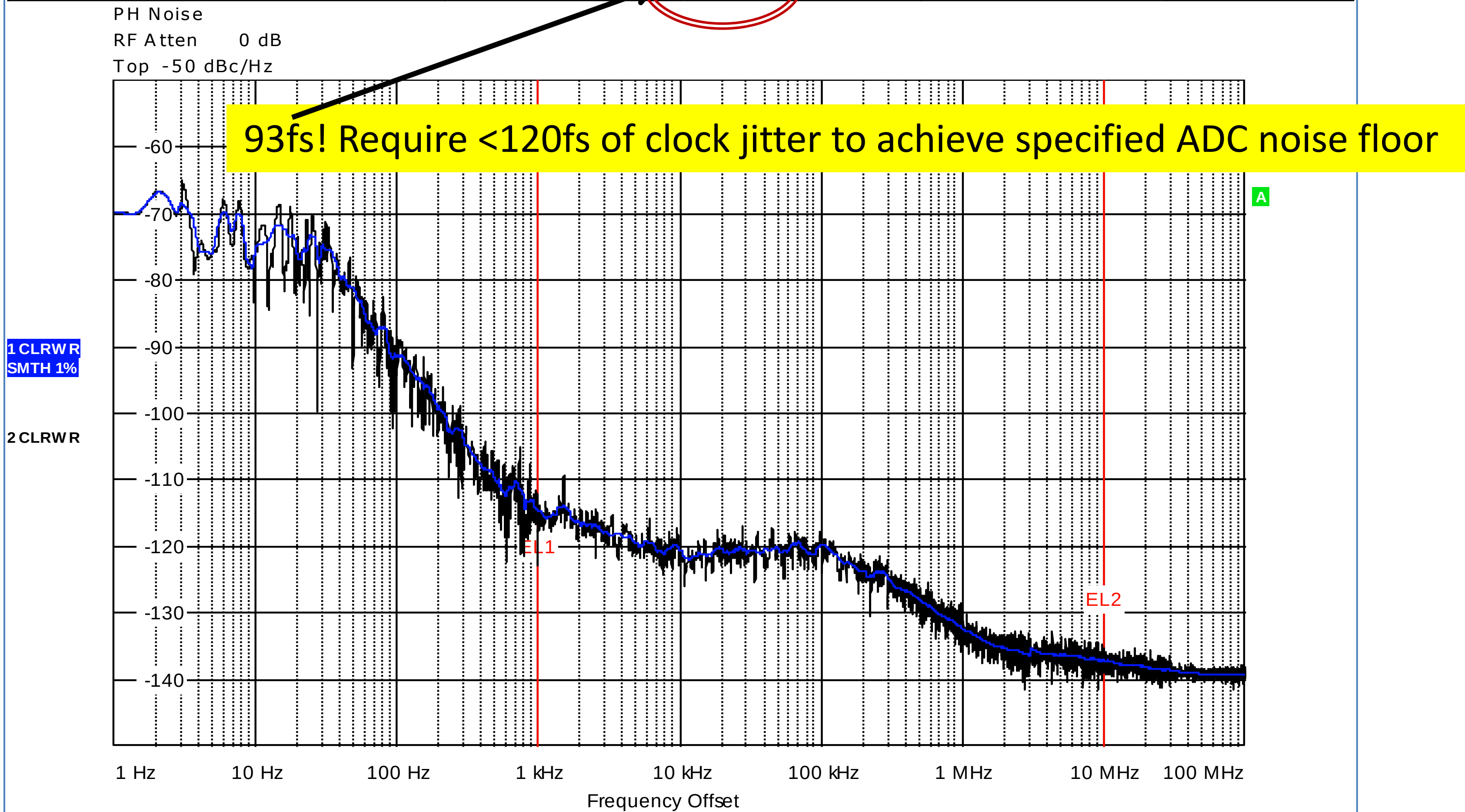
Parameter	RFCU	ADC+Clock	Total
Gain stability (20 min)	0.630	0.070	0.700
Gain stability (5 s)	0.045	0.005	0.050
Phase stability (20min)	1.440	0.160	1.600
Max phase drift -1000 sec	15.470	1.719	17.189
Max phase drift -1 sec	1.547	0.172	1.719



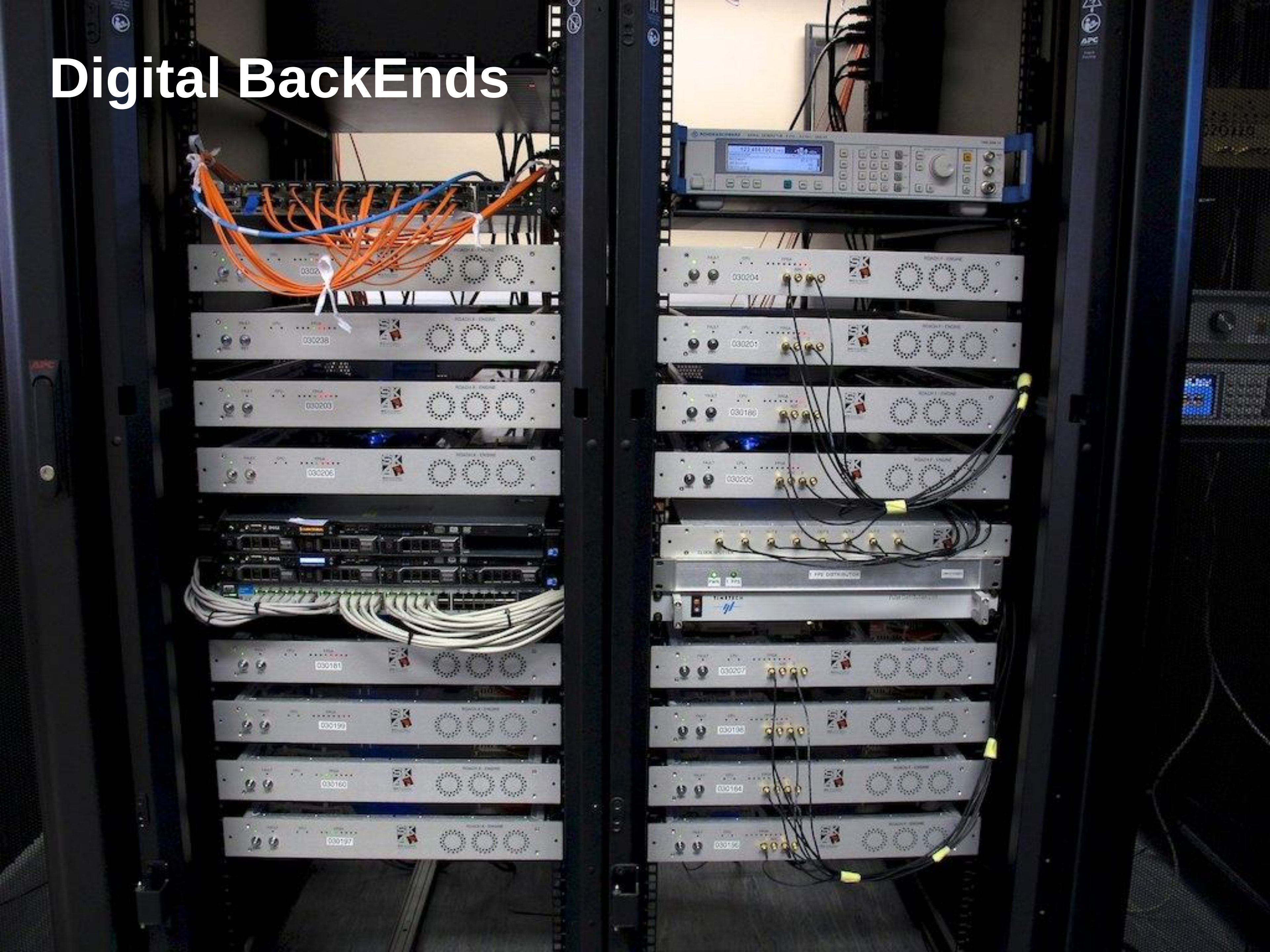
2.499˚
over 20min

RF signal efficiency

PHASE NOISE					
Settings		Residual Noise		Spot Noise [T1]	
Signal Freq:	1.711999 GHz	Evaluation from 1 kHz to 10 MHz		1 kHz	-114.79 dBc/Hz
Signal Level:	-4.84 dBm	Residual PM	57.396 m°	10 kHz	-120.53 dBc/Hz
Signal Freq Δ:	-21.61 Hz	Residual FM	3.757 kHz	100 kHz	-119.83 dBc/Hz
Signal Level Δ:	0.02 dBm	RMS Jitter	0.0931 ps	1 MHz	-132.45 dBc/Hz



Digital BackEnds



CBF design philosophy

- Standardised, array-wide communication protocols…

  SPEAD and KATCP

- Commercial interconnects...

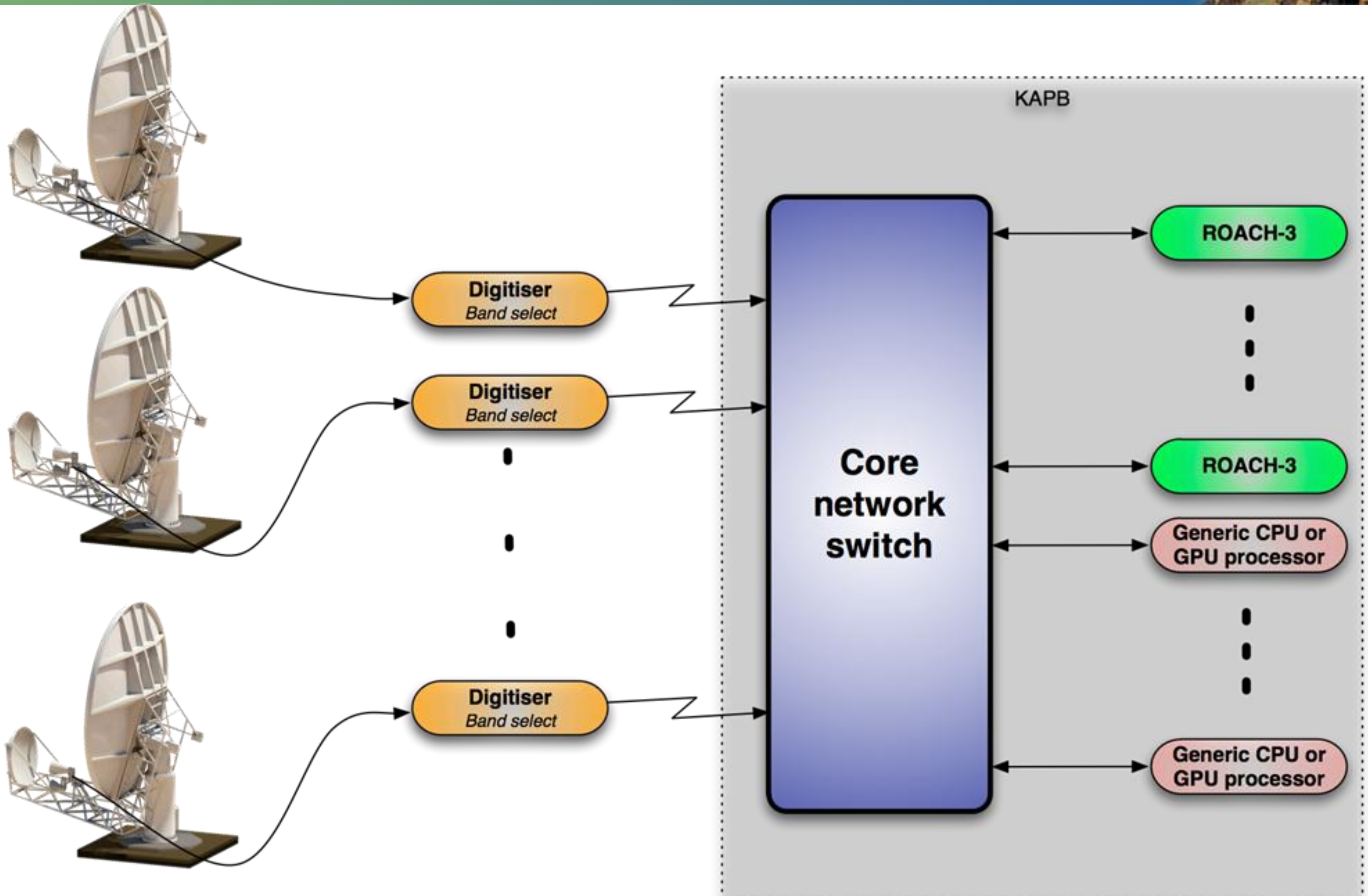
  Multicasting Ethernet

- Standardised processing hardware...

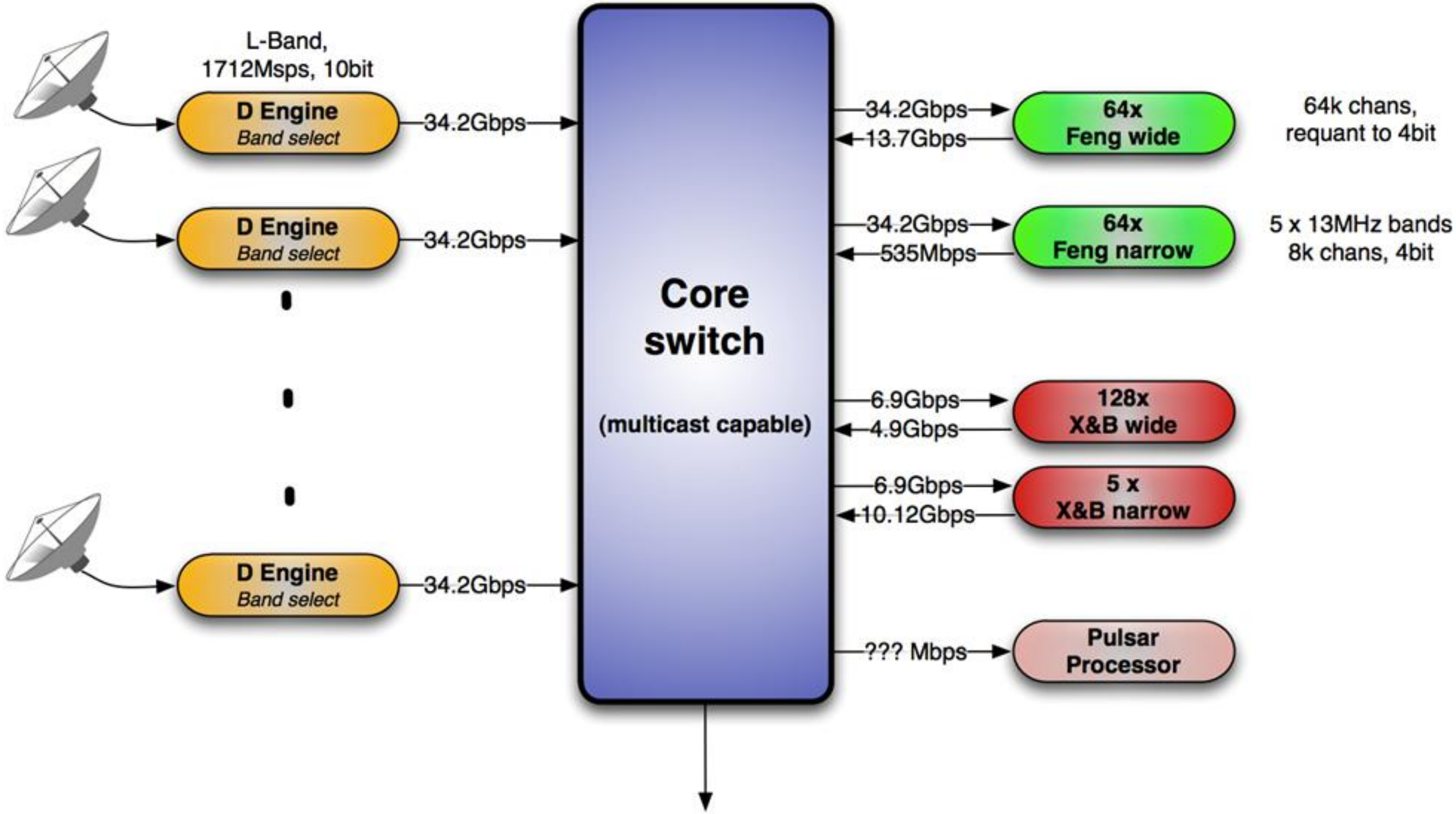
  ROACH1/2/3, CPUs/GPUs

- Portable, shared, open-source IP... shared risk.
- Asynchronous processing hardware

MeerKAT DBE physical overview



MeerKAT L-band datarates



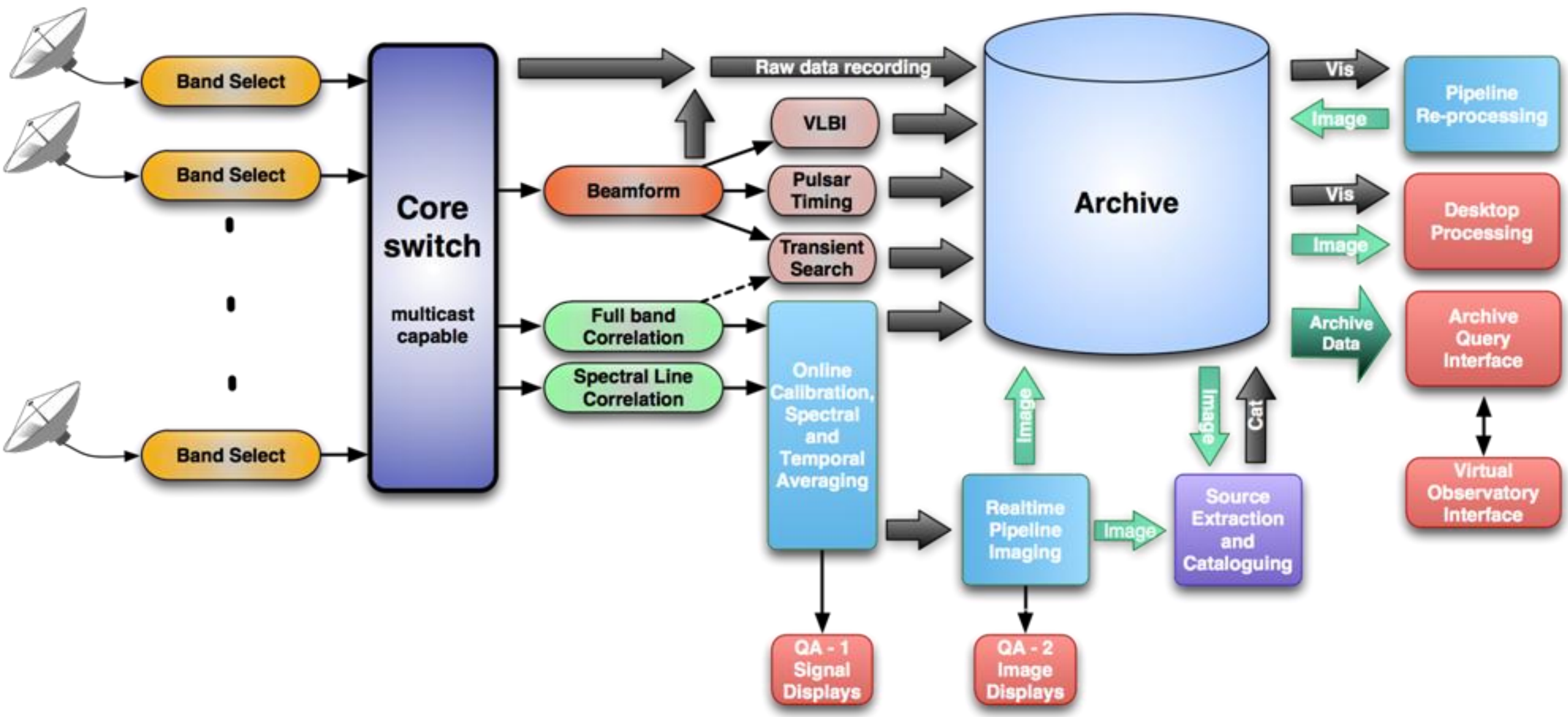
Beamformer wide: 55Gbps per beam (4) = 220Gbps
Beamformer narrow: 0.45Gbps per beam (4) per band (5) = 9Gbps
Beamformer time-averaged (100 beams): 78Gbps
Correlator wide (100ms dumps): 325Gbps
Correlator narrow: 32Gbps (256ms dumps) per band (5): 42Gbps

NB: Add SPEAD overhead

L-band: number of switch ports

	10GbE, ROACH2	40GbE, ROACH3
Deng	(4x64) = 256	64
Feng wide	(4x64) = 256	64
Feng narrow	(4x64)=256	64
Xeng wide	(1x128) = 128	64
Xeng narrow	(4x10)=40	10
Output	50	25
Totals	**986**	**291**

MeerKAT DBE dataflow



DBE design philosophy

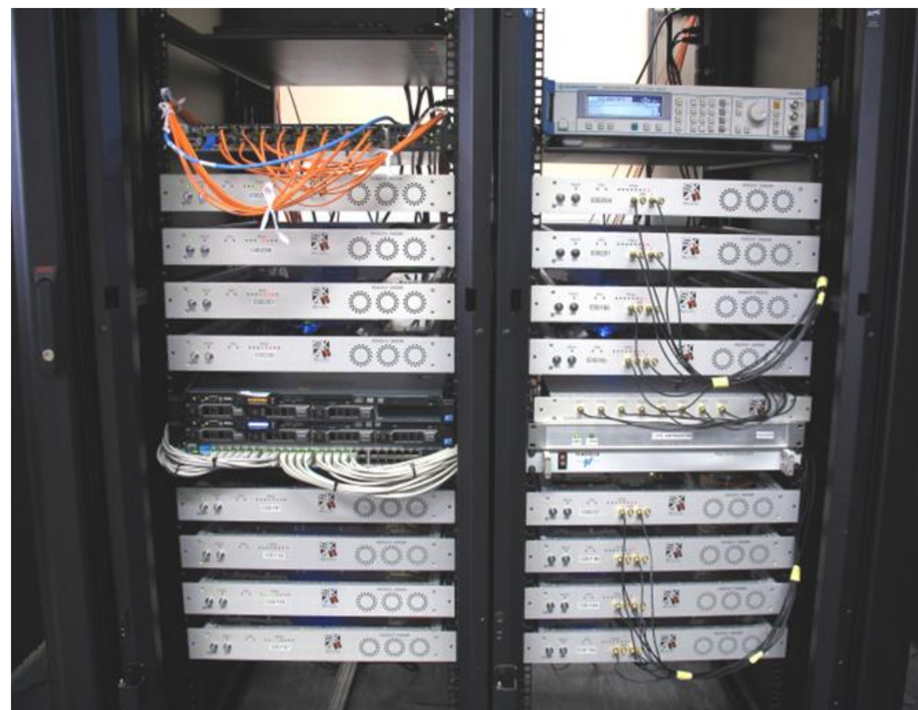
- Standardised, array-wide communication protocols: SPEAD and KATCP
- Commercial interconnects... Multicasting Ethernet
- Standardised processing hardware... ROACH1/2/3, CPUs/GPUs
- Portable, shared, open-source IP... shared risk.
- Asynchronous processing hardware

Digitiser and Correlator: ROACH

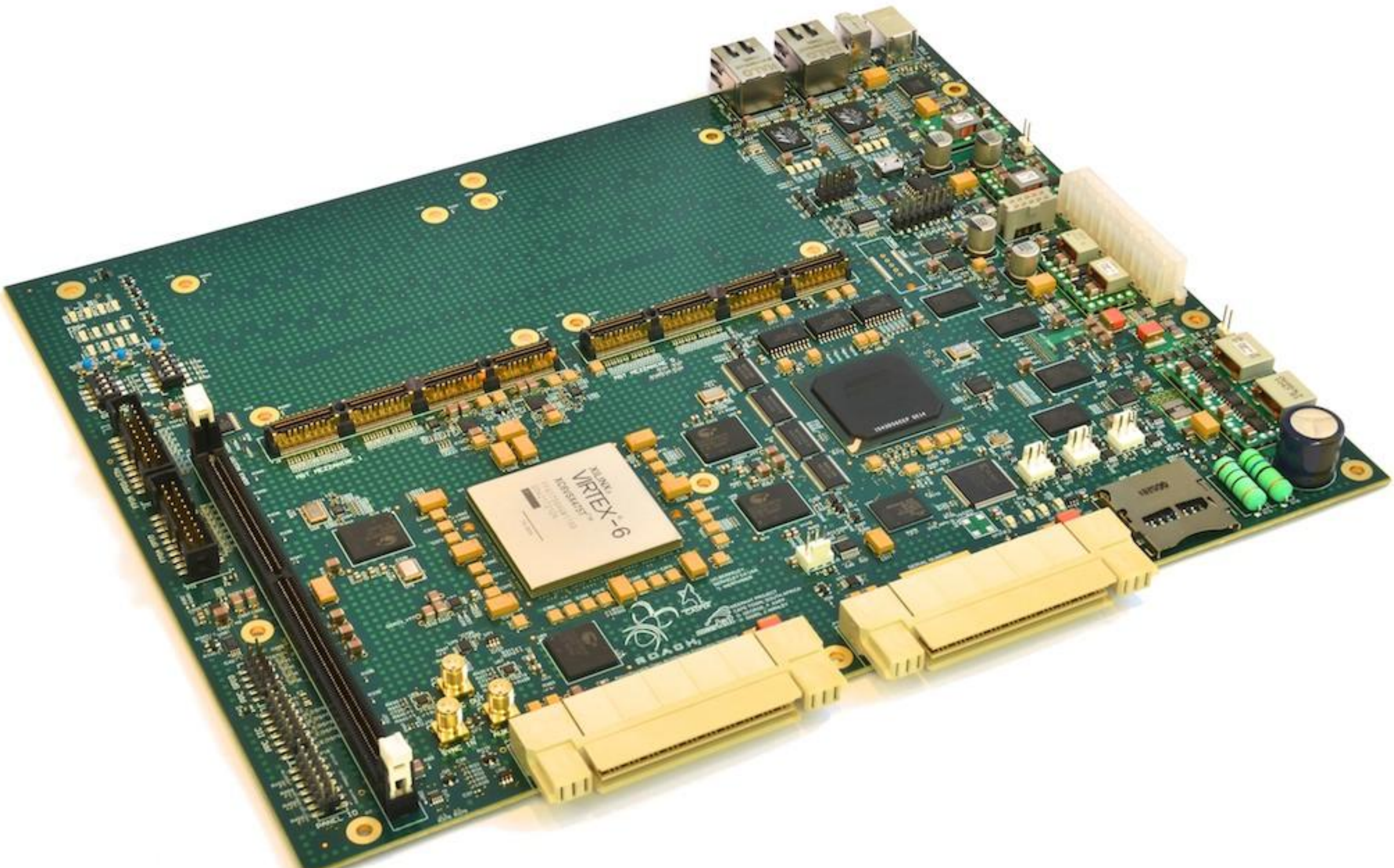
ROACH (**R**econfigurable **O**pen **A**rchitecture **C**omputing **H**ardware) is a standalone FPGA (**F**ield **P**rogrammable **G**ate **A**rrays) processing board.

- CASPER collaboration, started at U.C. Berkeley, driven by SKA-SA

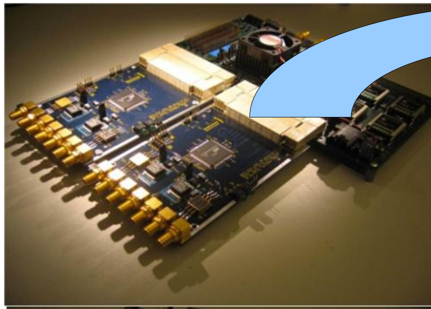
ROACH

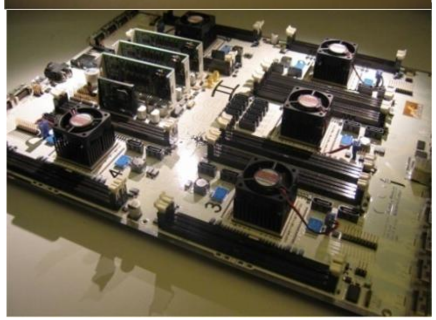


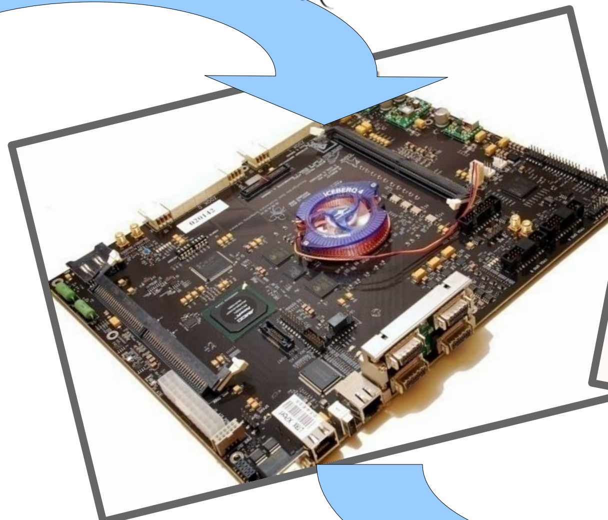
ROACH-2

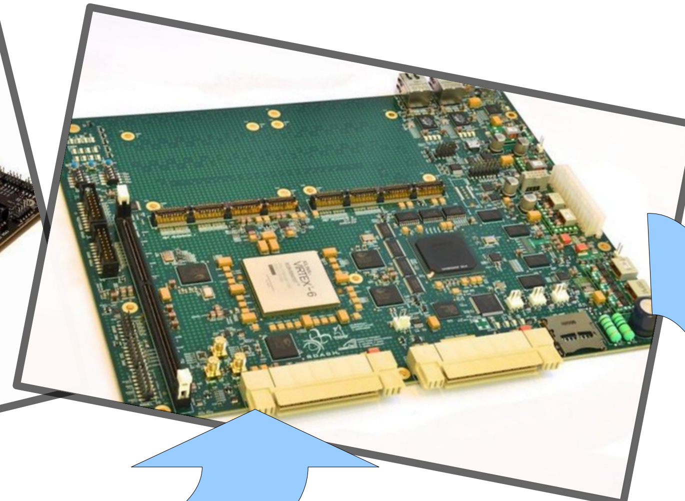


Technology: ROACH3









- Designed for MeerKAT
- Suitable for SKA-1 F/X/B engines
- 28nm FPGA technology
- 40 Gbps Ethernet
- 20Gsps ADCs and faster

ROACH

Reconfigurable Open Architecture Computing Hardware

DBE design philosophy

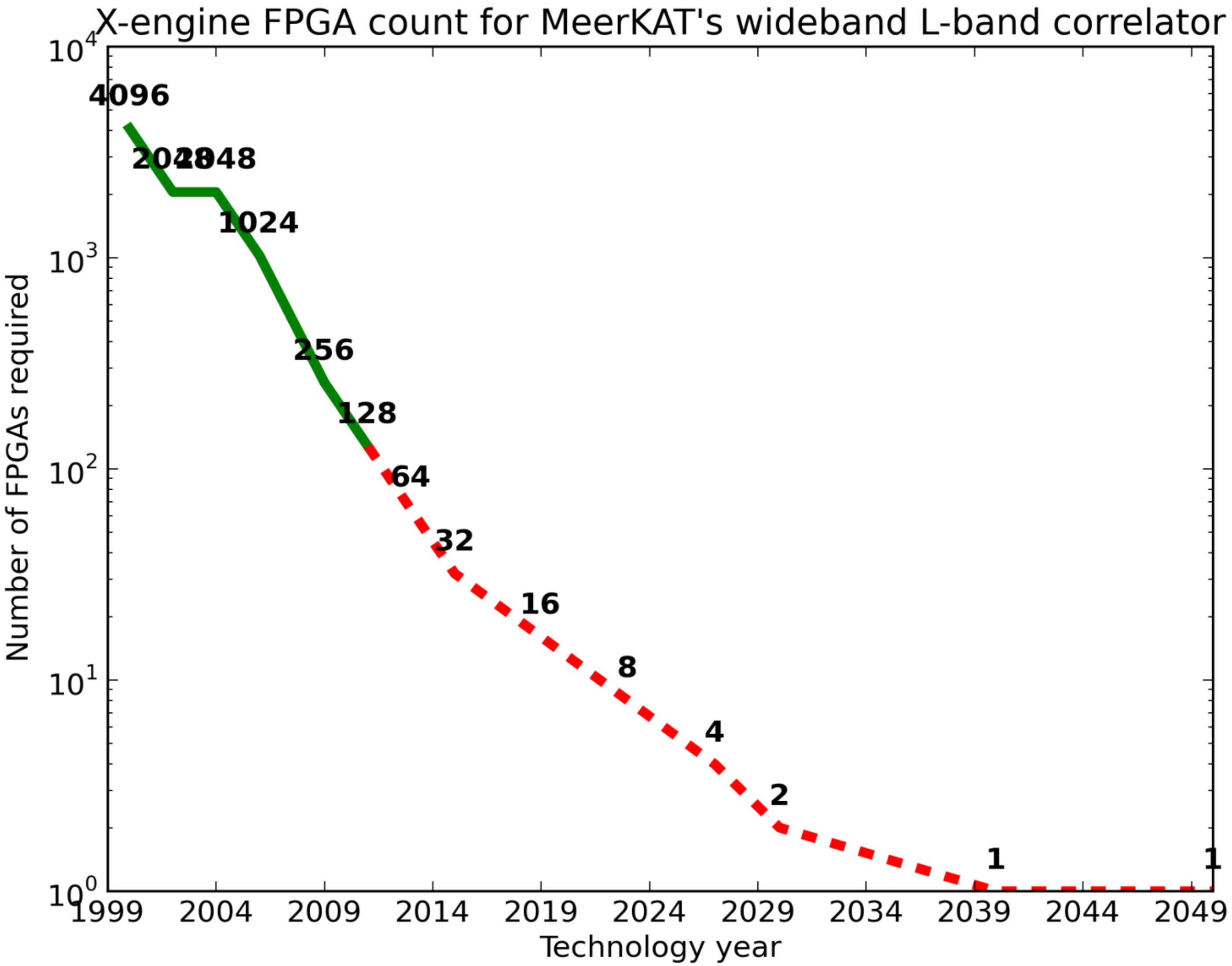
- Standardised, array-wide communication protocols: SPEAD and KATCP
- Commercial interconnects... Multicasting Ethernet
- Standardised processing hardware... ROACH1/2/3, CPUs/GPUs
- Portable, shared, open-source IP... shared risk.
- Asynchronous processing hardware
- “Disposable” hardware... Investment in IP, not short-lived hardware

GPUs for MeerKAT?

- Definitely for pulsar timing and searching
- Probably for multiply-accumulate engines

  (X in FX correlator)
- Possibly for F engines
- FPGAs still unbeatable for high-bandwidth, computationally simple problems like beamforming.
- GPUs good for computationally dense problems.
- N=64, GPUs just start getting interesting for X.

How often should I replace?



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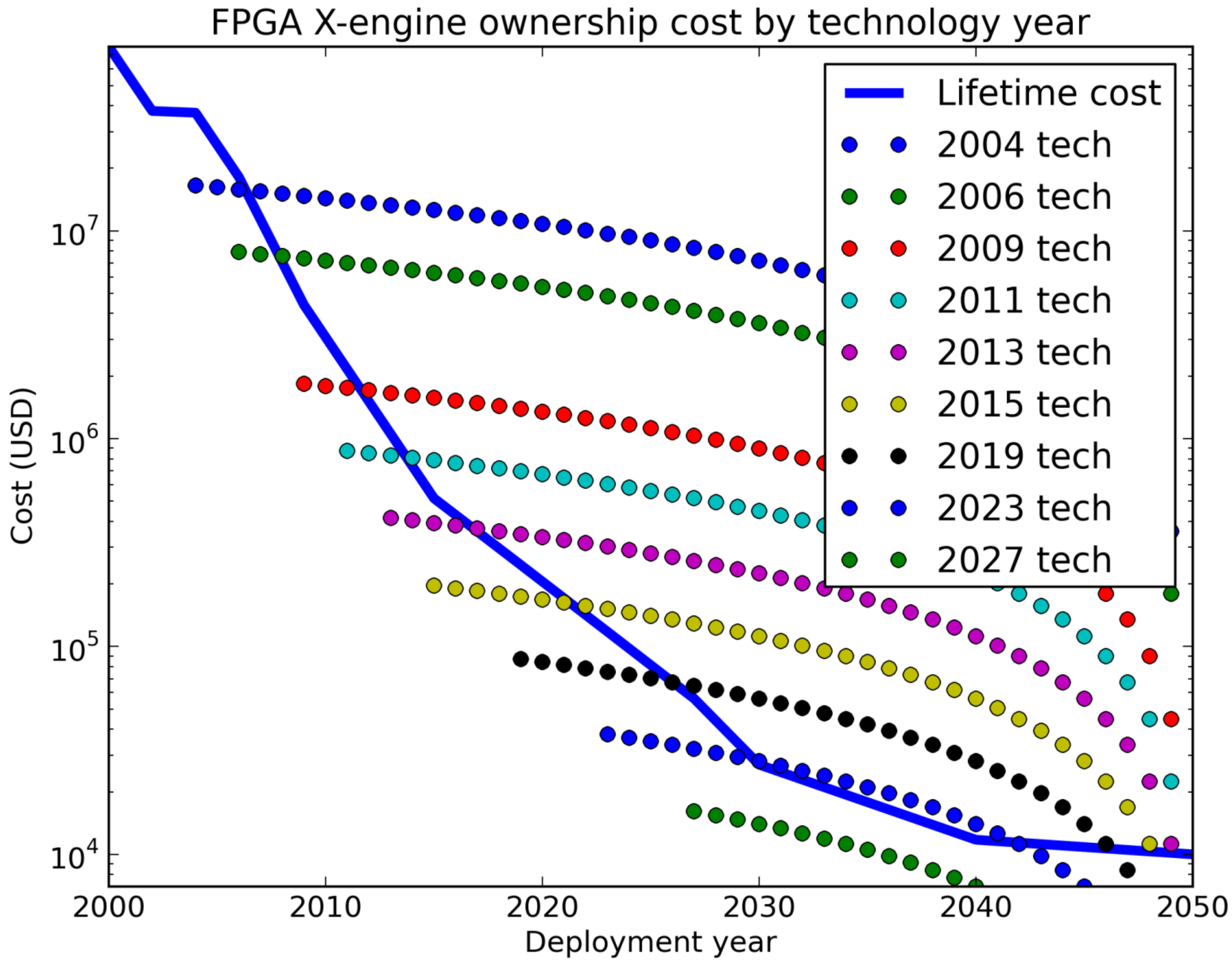
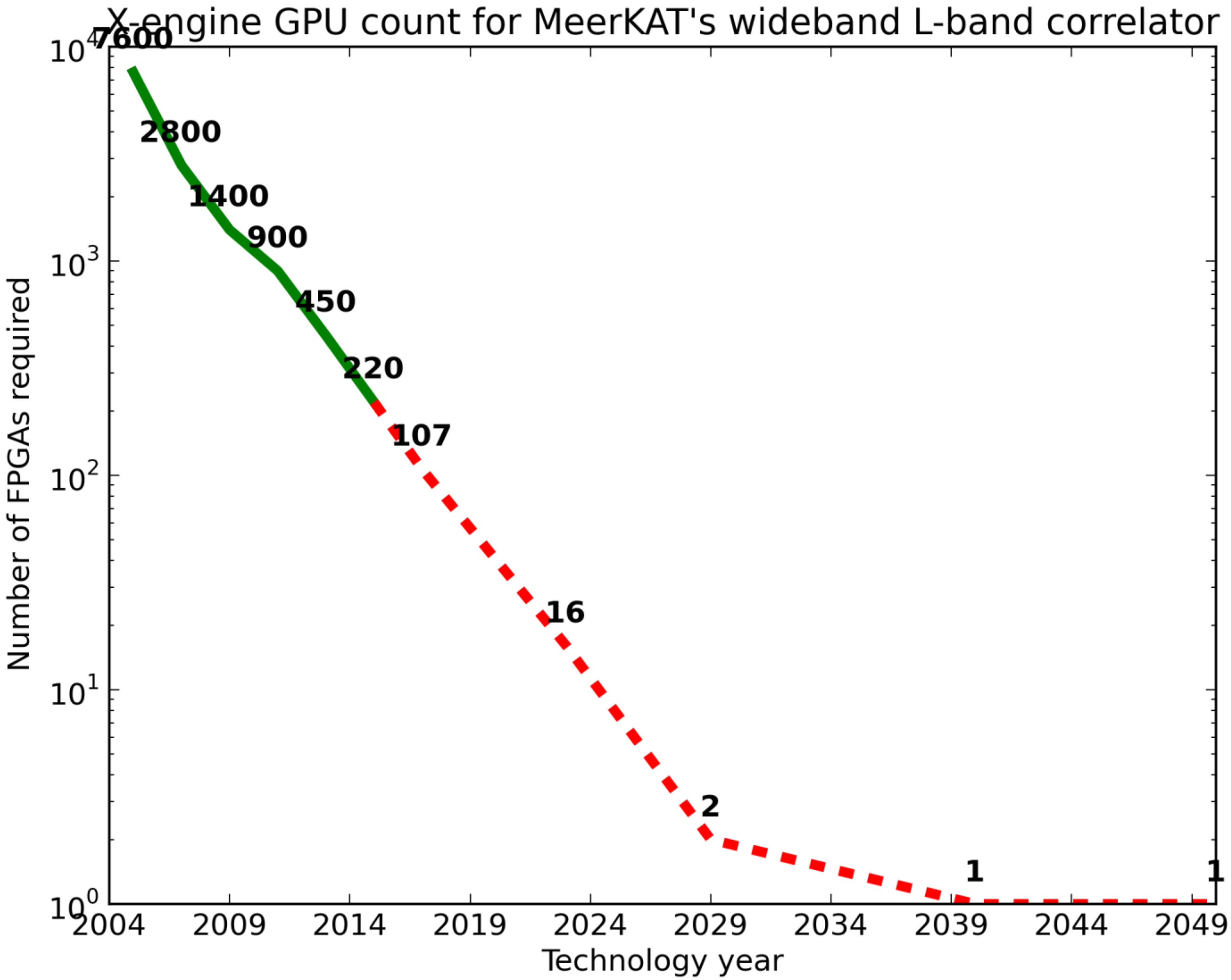


Assuming:

- USD 0.15/KWh
- Cooling 3W requires 1W
- FPGA boards cost USD10k
- FPGA boards consume 100W

How often should I replace?



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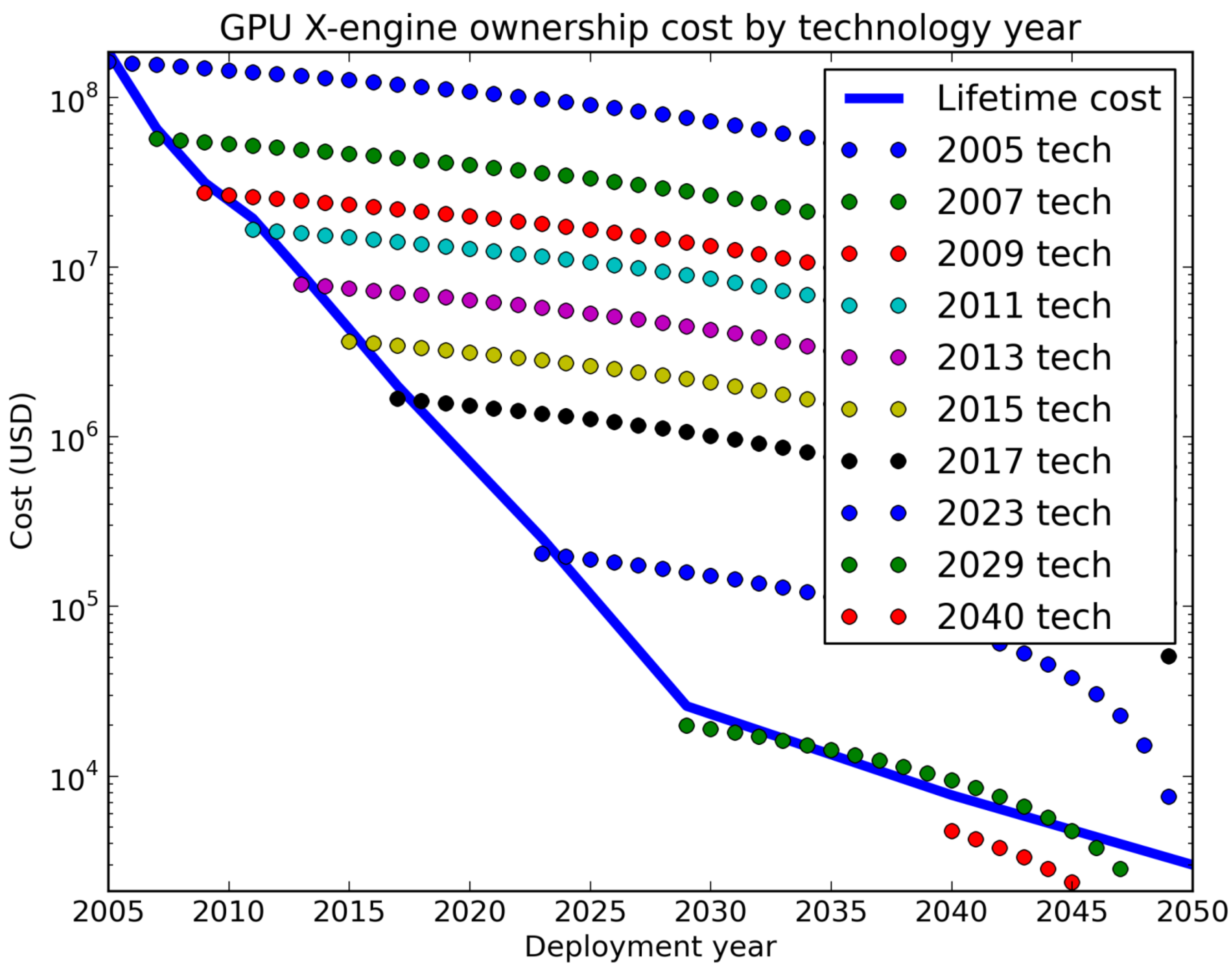
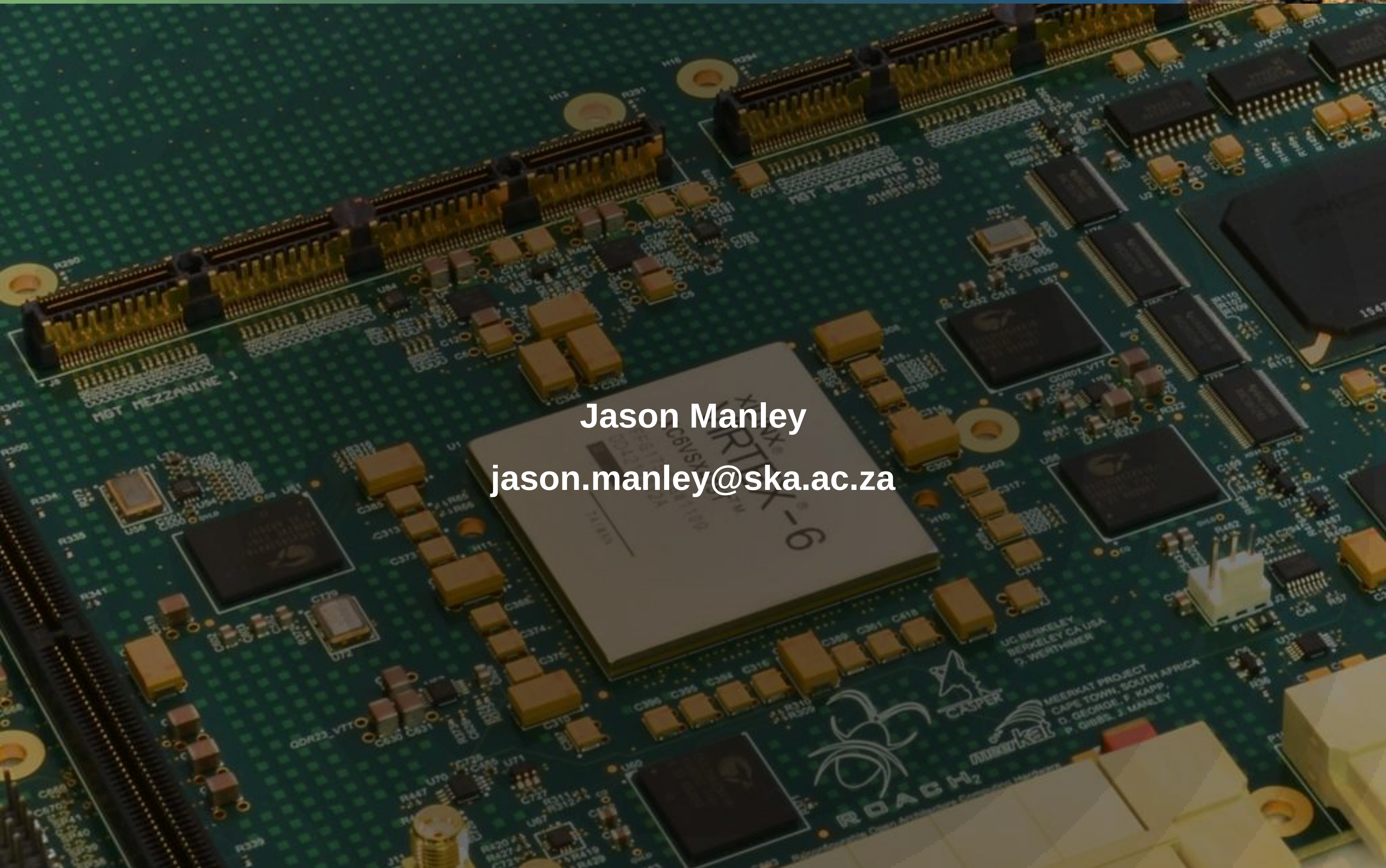


Assuming:

- USD0.15/KWh
- Cooling 3KW requires 1KW
- GPU with host computer costs USD3000
- GPU with host computer consumes 270W

Questions & Comments



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