Wide Band Feeds for SKA

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MIDPREP meeting
20–21of April 2015
Instituto de Telecomunicações and Campus of University of Aveiro, Portugal

SQUARE KILOMETRE ARRAY
WIDE BAND SINGLE PIXEL FEEDS

Outline

- WBSPF Consortia
- Specifications
- Feed development progress
- Analysis in SKA optics
- LNAs
- Feed integration
- Receivers
- Future plans

SKA WBSPF Countries and Institutions

Sweden

- Onsala Onbservatory – Consortia lead, integration, system tests
- Chalmers/MEL – LNA design
- Low Noise Factory – LNA prototyping
- Chalmers/S2/Antenna group - feed design

China

- JLRAT – overall management
- NAOC – Feed and LNA design
- CETC54 – Feed design, integration and tests
- TIPC – WBSPF Cryostat design
- SHAO – LNA design
- Caltech – LNA design and Feed/Cryogenic consultancy

Netherlands

- ASTRON – cryogenics and system tests

Germany

- IAF – MMIC processing
- MPI – LNA design and testing

France

- University of Bordeaux / LAB – receivers

Earned value for the consortia 2.7MEuro

General Scope of Work

- Advanced Instrumentation Program for SKA Phase 2
- Derive functional and performance requirements for the WBSPF technology;
- Design and analysis of the WBSPF technology, with a view to meeting the required Aeff/Tys performance in SKA dish optics;
- Derive cost model and analyse how performance and costs changes with increasing fractional BW.
- Use the developed cost model to provide information to SKAO on construction, operation and schedule constraints.
- Optimize the design taking advantage of the most economic and efficient industrial methodologies and thereby ensuring competitive costs.

System and Operational advantages

- Capital costs- for any reasonable budget dish costs for SKA2 must be pressed down -> merge several SPF into one WBSPF package
- Fewer bands per dish will give less power consumption
- Maintenance costs- manpower in remote locations is expensive
- Reducing failure rates –fewer bands per dish
- Therefore extremely important to limit operations costs

WBSPF and technological chalanges

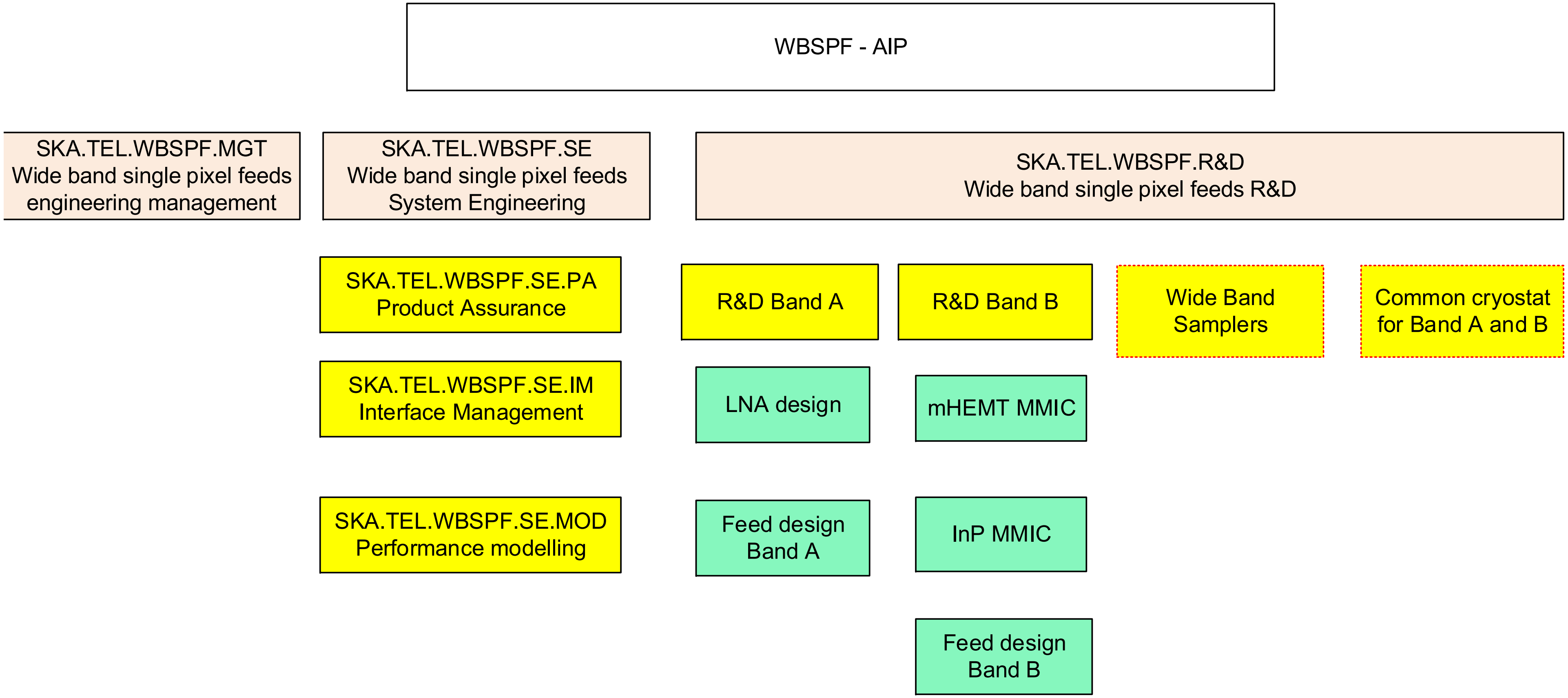
Performance issues

- Lower sensitivity than octave feed horn
- Some degradation in performance if they are made very wide band
- We believe the gap in performance can be narrowed given further R&D

Relative merits of octave horns versus WBSPF

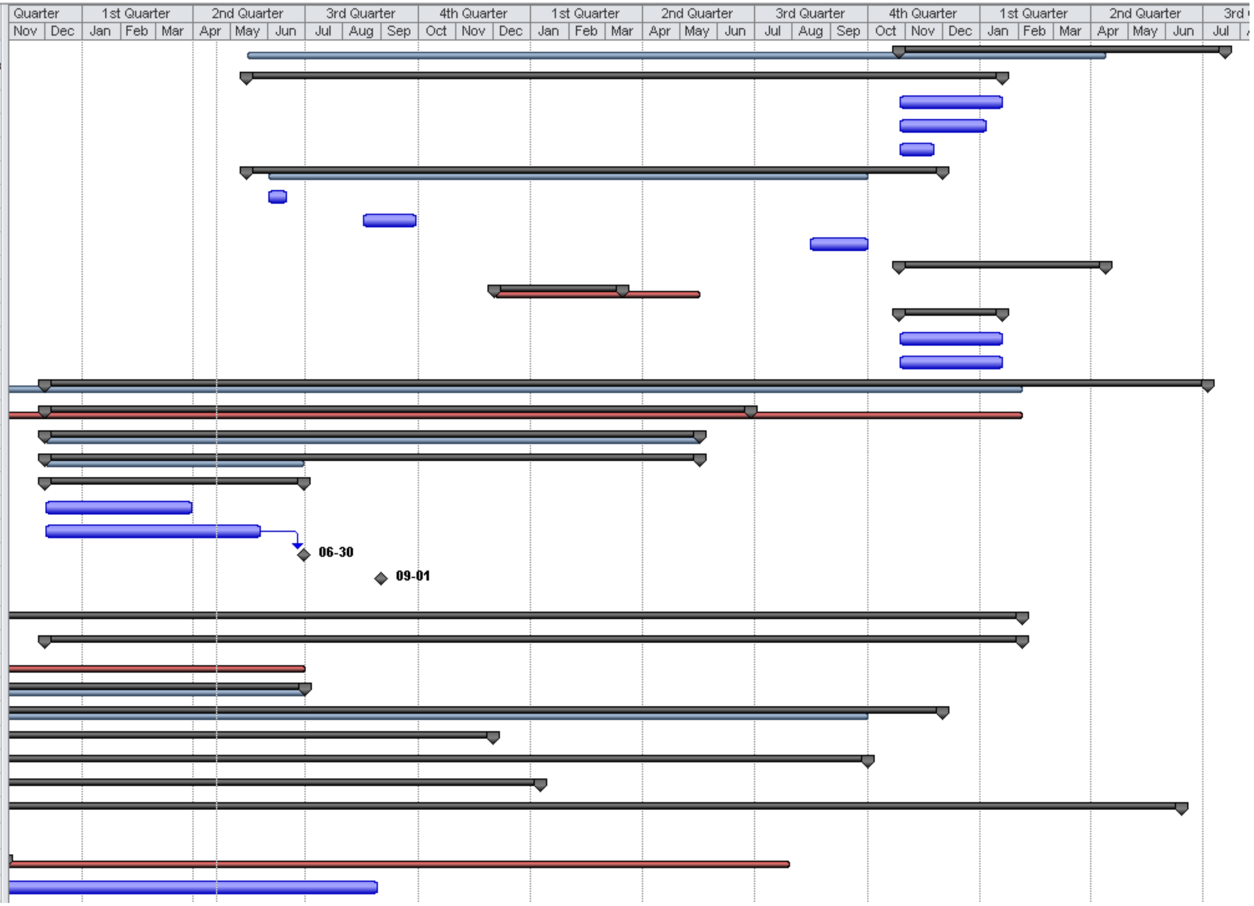
- Full 'cost of ownership' analysis including
- Initial investment
- Operations costs

WBS


WBSPF - AIP
SKA.TEL.WBSPF.MGT
Wide band single pixel feeds
engineering management
SKA.TEL.WBSPF.SE
Wide band single pixel feeds
System Engineering
SKA.TEL.WBSPF.R&D
Wide band single pixel feeds R&D
SKA.TEL.WBSPF.SE.PA
Product Assurance
SKA.TEL.WBSPF.SE.IM
Interface Management
SKA.TEL.WBSPF.SE.MOD
Performance modelling
R&D Band A
LNA design
Feed design
Band A
R&D Band B
mHEMT MMIC
InP MMIC
Feed design
Band B
Wide Band
Samplers
Common cryostat
for Band A and B

Schedule

ID		Task Name	Start	Finish
1		WBSPF	Thu 16-10-27	Tue 17-07-18
2		System Engineering	Thu 15-05-14	Wed 17-01-18
3		Evaluate feed performance in Dish	Thu 16-10-27	Wed 17-01-18
4		Cryostat Requirements Deffinition	Thu 16-10-27	Thu 17-01-05
5		System requirements definition	Thu 16-10-27	Wed 16-11-23
6		Reviews	Thu 15-05-14	Wed 16-11-30
7		SRR	Mon 15-06-01	Mon 15-06-15
8		CoDR	Mon 15-08-17	Mon 15-09-28
9		PDR	Mon 16-08-15	Fri 16-09-30
10		Verification Planning	Thu 16-10-27	Wed 17-04-12
13		Lab tests	Wed 15-12-02	Tue 16-03-15
17		WBSPF Qualification	Thu 16-10-27	Wed 17-01-18
18		Band A testing	Thu 16-10-27	Wed 17-01-18
19		Band B testing	Thu 16-10-27	Wed 17-01-18
20		WBSPF - Feed and LNAs	Mon 14-12-01	Tue 17-07-04
21		Band A	Mon 14-12-01	Mon 16-06-27
22		LNA	Mon 14-12-01	Mon 16-05-16
23		MMIC LNA	Mon 14-12-01	Mon 16-05-16
28		Band A Diescrete LNA	Mon 14-12-01	Tue 15-06-30
29		Design	Mon 14-12-01	Mon 15-03-30
30		LNA tests	Mon 14-12-01	Mon 15-05-25
31		LNAs availible for integration	Tue 15-06-30	Tue 15-06-30
32		LNA mass production report and cost estimation	Tue 15-09-01	Tue 15-09-01
33		Band A Feed	Mon 14-05-05	Fri 17-02-03
34		QRFH	Mon 14-12-01	Fri 17-02-03
40		Eleven Feed	Mon 14-05-05	Mon 14-05-05
44		Sinus Feed	Mon 14-05-05	Tue 15-06-30
48		Band B	Mon 13-11-04	Wed 16-11-30
49		Band B Feed	Mon 14-05-05	Mon 15-11-30
59		mHEMT - IAF	Mon 13-11-04	Fri 16-09-30
65		InP MMIC	Mon 14-05-05	Fri 16-01-08
71		Cryostat	Mon 14-10-27	Tue 17-06-13
77		Cooler	Fri 06-10-27	Fri 06-10-27
80		WBSPF Receiver	Thu 14-10-30	Thu 14-10-30
85		WBSPF controller	Mon 14-05-12	Fri 15-08-28



WBSPF Feed and LNA requirement

- Band A 1.6 – 5.2 GHz :
  - 6.5 m^2/K, **goal** 7 m2/K

  (assuming η ≈ 78%, Tsys ≈ 20 K)
- Band B 4.6 – 24 GHz :
  - 5.2 m^2/K, **goal** 6 m^2/K from 4.6 – 13.8 GHz (η ≈ 70%)
  - 4.7 m^2/K, **goal** 5.7 from 13.8 – 20 GHz (η ≈ 65%)
  - 4.3 m^2/K, **goal** 4.7 from 20.0 – 24 GHz (η ≈ 60%)

  (assuming Tsys ≈ 17- 24 K)
- Polarization – two linear, IXR better than 15 dB over HPBW

WBSPF Receiver Requirements

- Sampled Bandwidth with current technology
  - Band A: 1 x 2.5 GHz @ 5 GSPS for each pol.
  - Band B: 2 x 2.5 GHz @ 5 GSPS for each pol.
- RF Digitization
  - Band A: 6 bits
  - Band B: at least 2 streams of 3 bits.

WBSPF - Interfaces

SKA SQUARE KILOMETRE ARRAY — WIDE BAND SINGLE PIXEL FEEDS

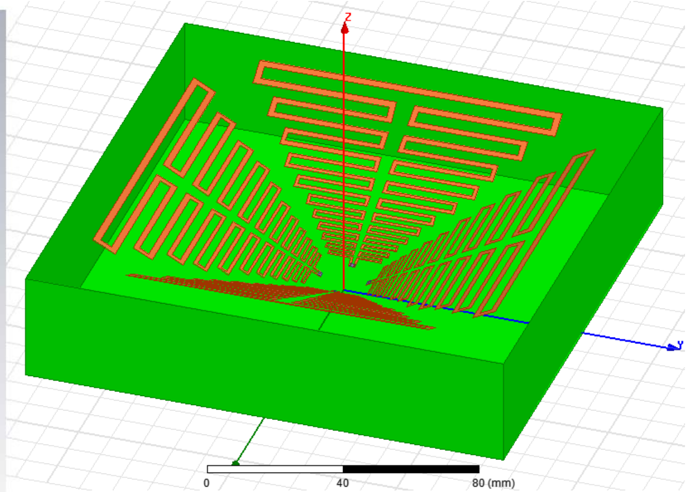
- WBSPF system shall be compatible with SKA DC in terms of:
  - Mechanical interface towards indexer (Accepted)
  - LMC system (Accepted)
  - Cryogenic system (TBC)
- Interfaces
  - External ICDs
    - WBSPF -> SKADC
    - WBSPF -> LMC
    - WBSPF -> SaDT
    - WBSPF -> TM

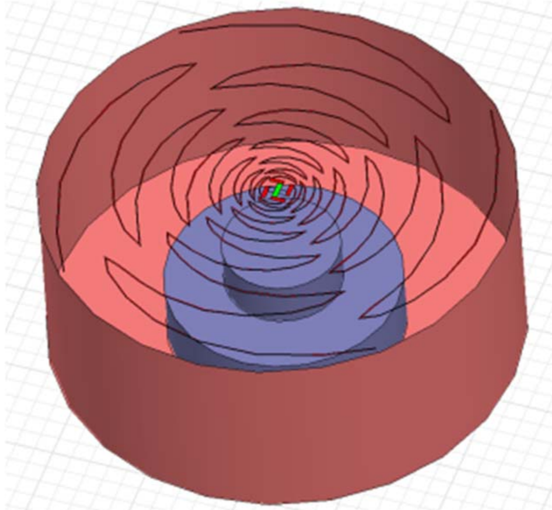
DEVELOPMENT PROGRESS

BAND A FEED

WP leader: Niu Chuanfeng, CETC 54

Comparison of three feeds





QRFH

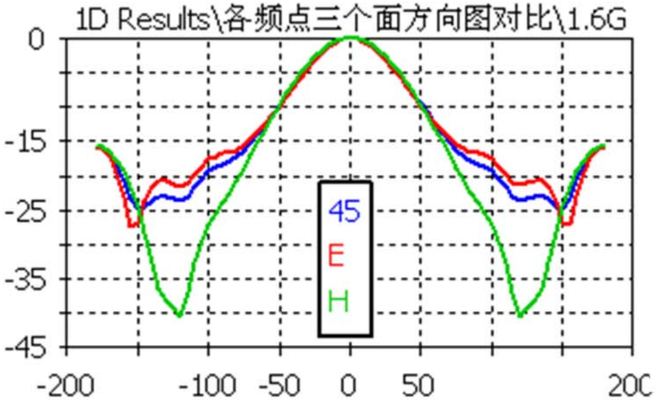
Eleven

Sinous

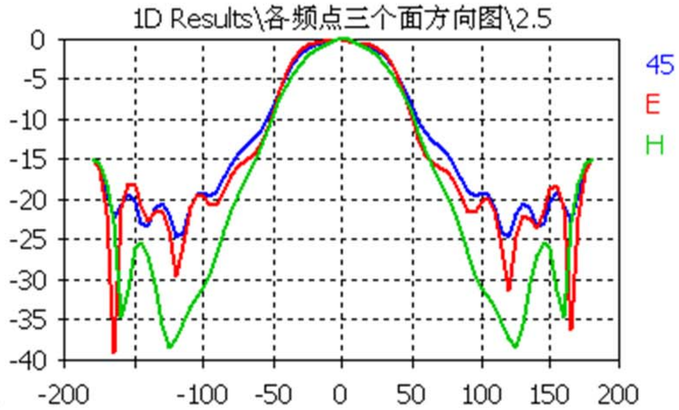
Comparison of QRFH/ Eleven/Sinous

WIDE BAND SINGLE PIXEL FEEDS

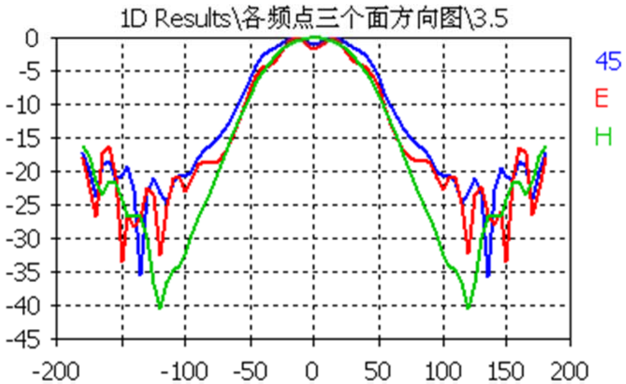
Comparison of three feeds



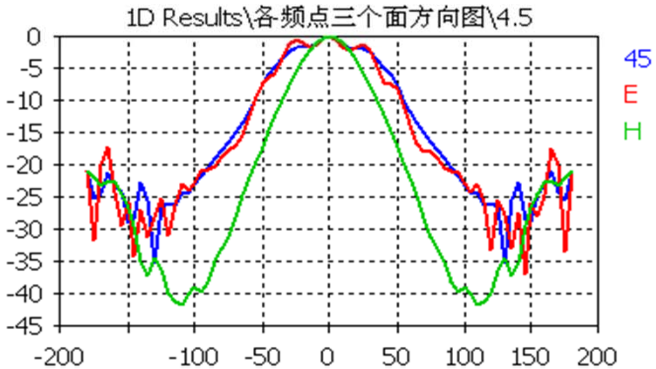
1.6GHz



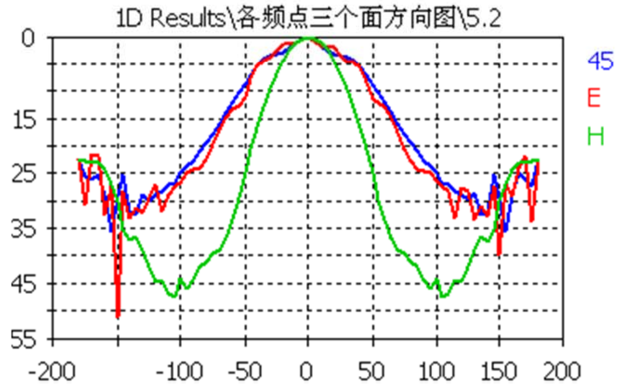
2.5GHZ



3.5GHz



4.5GHz

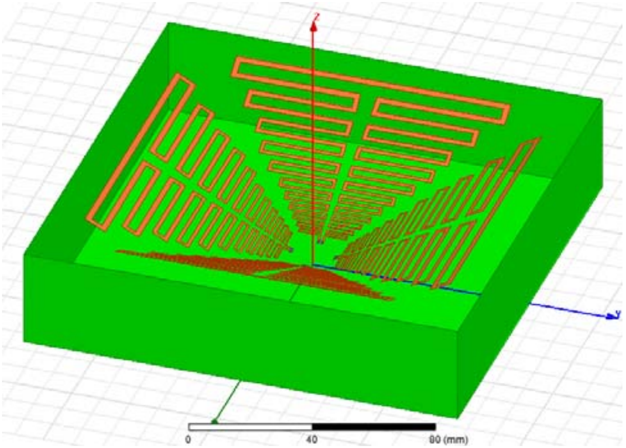


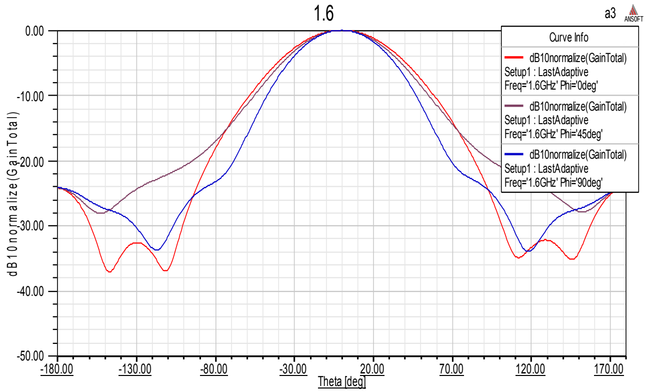
5.2GHz

Simulated Patterns of QRFH feed

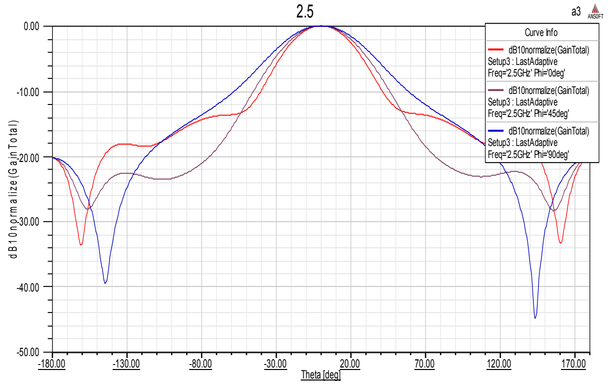
Comparison of QRFH/ Eleven/Sinous

WIDE BAND SINGLE PIXEL FEEDS

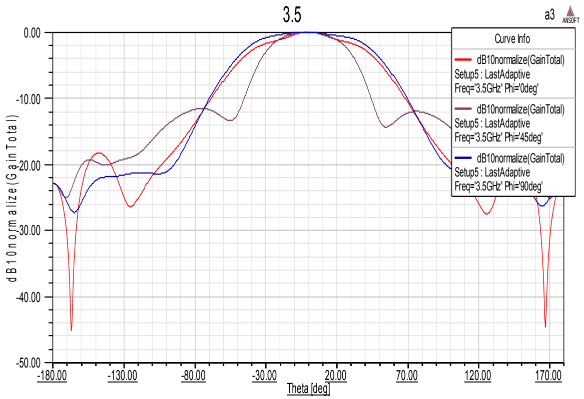




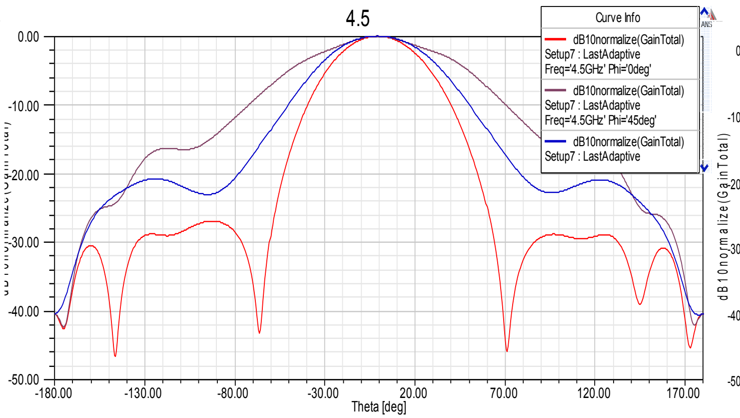
1.6GHz



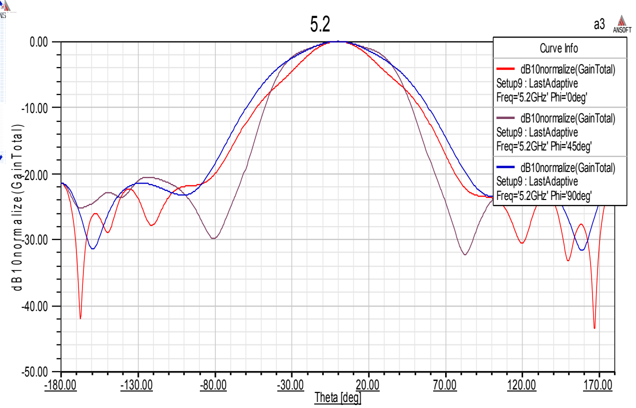
2.5GHZ



3.5GHz



4.5GHz



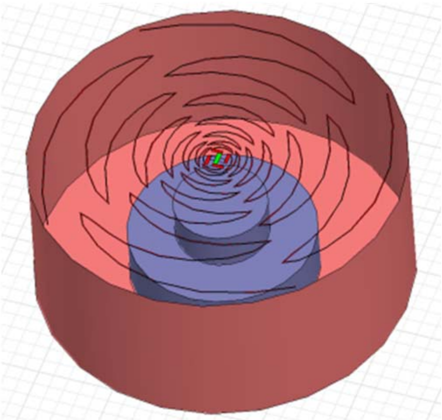
5.2GHz

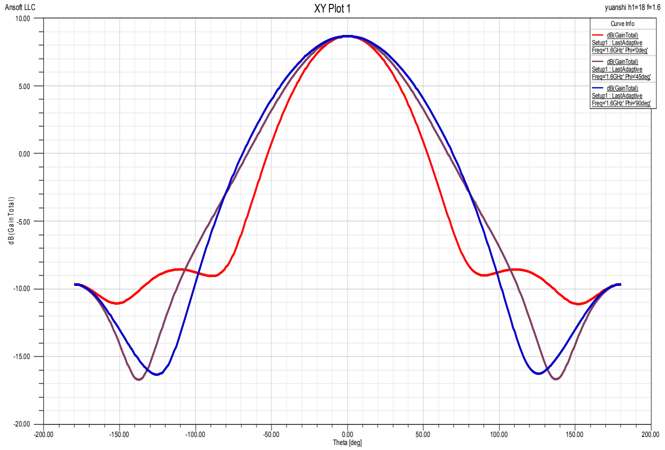
Simulated Patterns of Eleven feed

Comparison of QRFH/ Eleven/Sinous

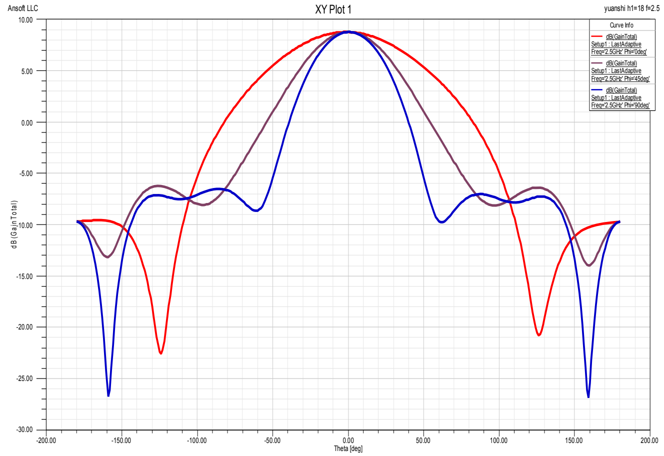
SKA SQUARE KILOMETRE ARRAY
WIDE BAND SINGLE PIXEL FEEDS

Comparison of three feeds

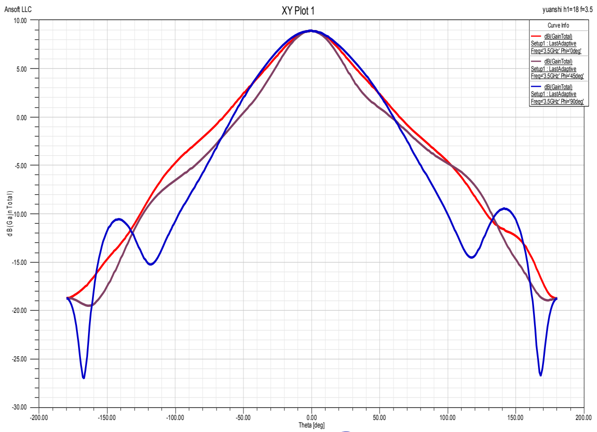




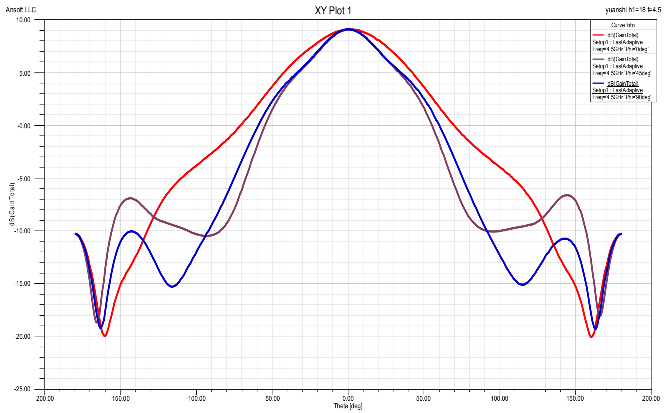
1.6GHz



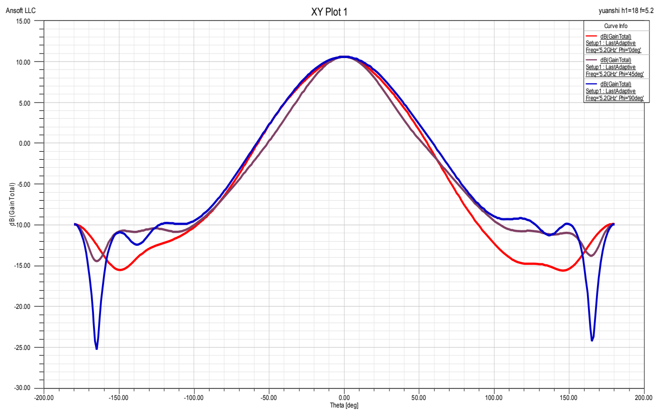
2.5GHZ



3.5GHz



4.5GHz



5.2GHz

Simulated Patterns of Sinous feed

Comparison of three feeds

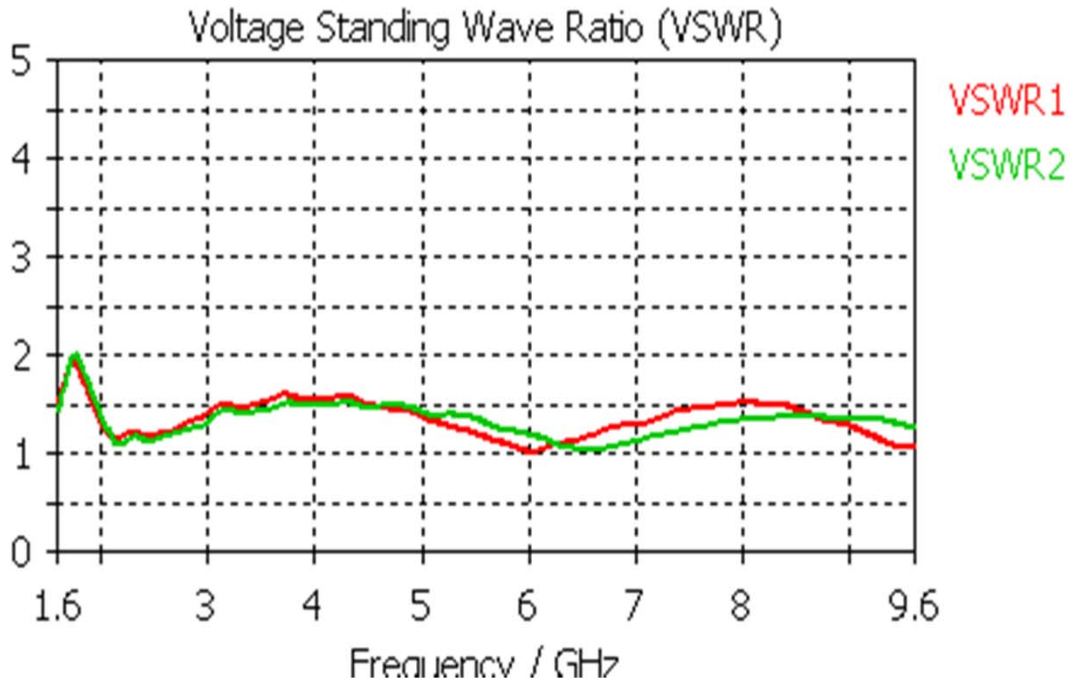
Table 1 Efficiency on 4.5m antenna with QRFH/ Eleven/Sinous feed

frequency (GHz)	QRFH		Eleven		Sinous	
	Gain(dB)	Efficiency (%)	Gain(dB)	Efficiency (%)	Gain(dB)	Efficiency (%)
1.6	35.81	67.03	37.16	74.09	36.67	66.19
2.0	37.76	67.21	38.75	68.38	----	----
2.5	39.71	67.40	40.43	64.43	39.9	57.03
3.0	40.51	56.27	42.46	71.41	42.46	71.41
3.5	42.08	59.34	43.55	67.43	41.56	42.64
4.0	43.05	56.81	44.82	69.16	43.64	52.71
4.5	44.01	55.99	45.69	66.77	44.91	55.79
5.0	44.74	53.65	46.22	61.10	42.81	27.82
5.2	45.14	54.39	46.89	65.92	46.2	56.23

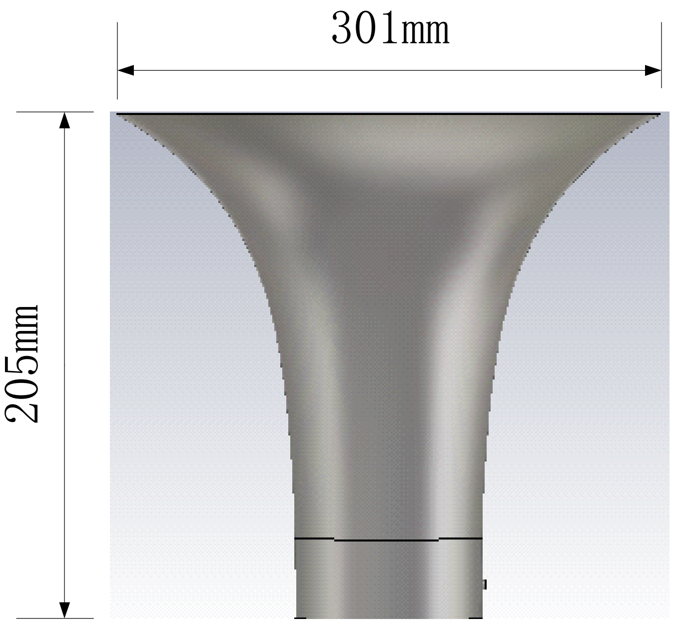
Efficiency of Sinous feed is sharp down at 5GHz

Detailed Design of Band A 1.6~5.2GHz feed (UP to 9.6GHz)

Designed a QRFH feed for SKA Band A



Simulated VSWR of feed

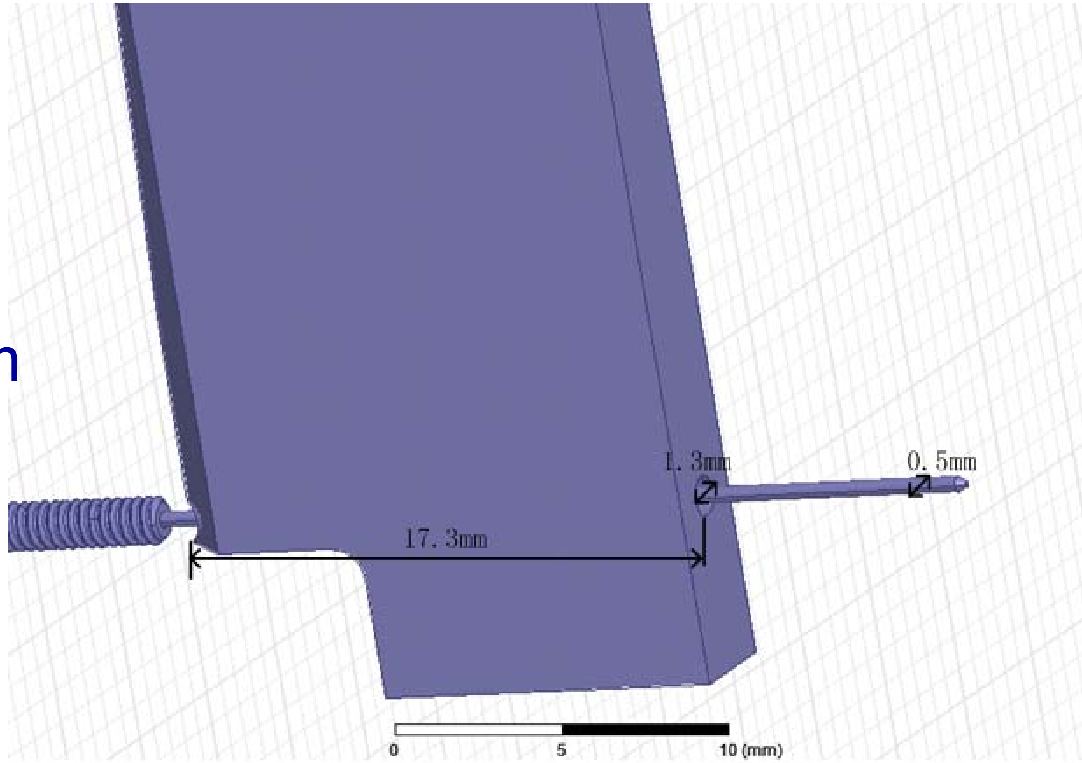


Dimensions of feed

Design of probe

Designed Specifications

- Inner diameter:0.5mm
- Out hole diameter:1.3mm



Dimensions of probe

BAND B FEED

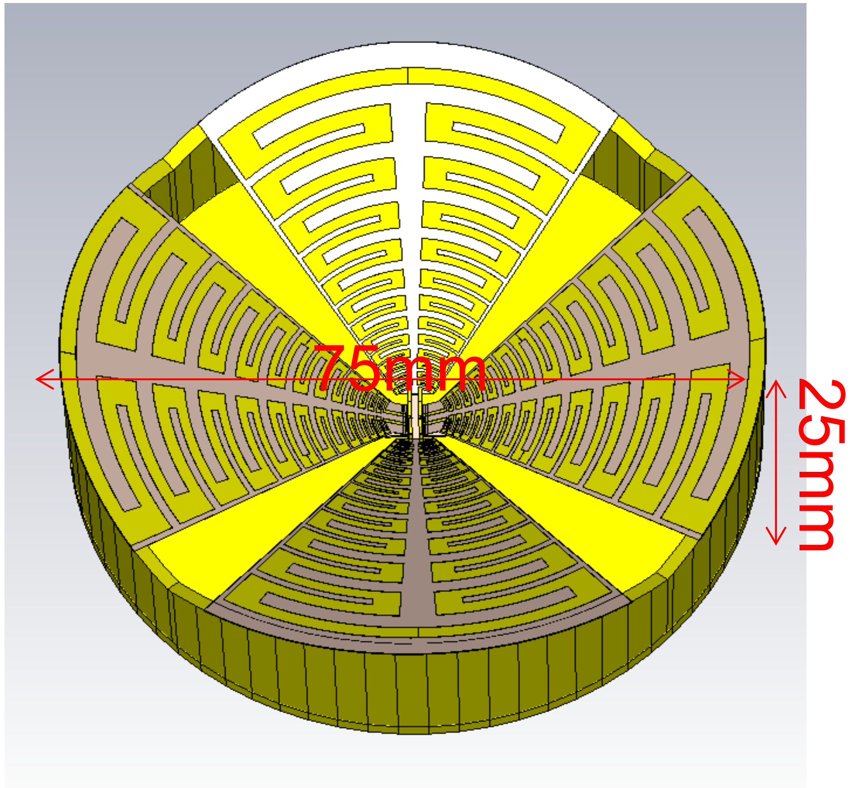
WP leader: Jian Yang, Chalmers University of Technology

WP contributors:
Jonas Flygare – Onsala Observatory
Bhushan Billade – Onsala Observatory
Magnus Dahlgren – Onsala Observatory

Design and optimisation approaches

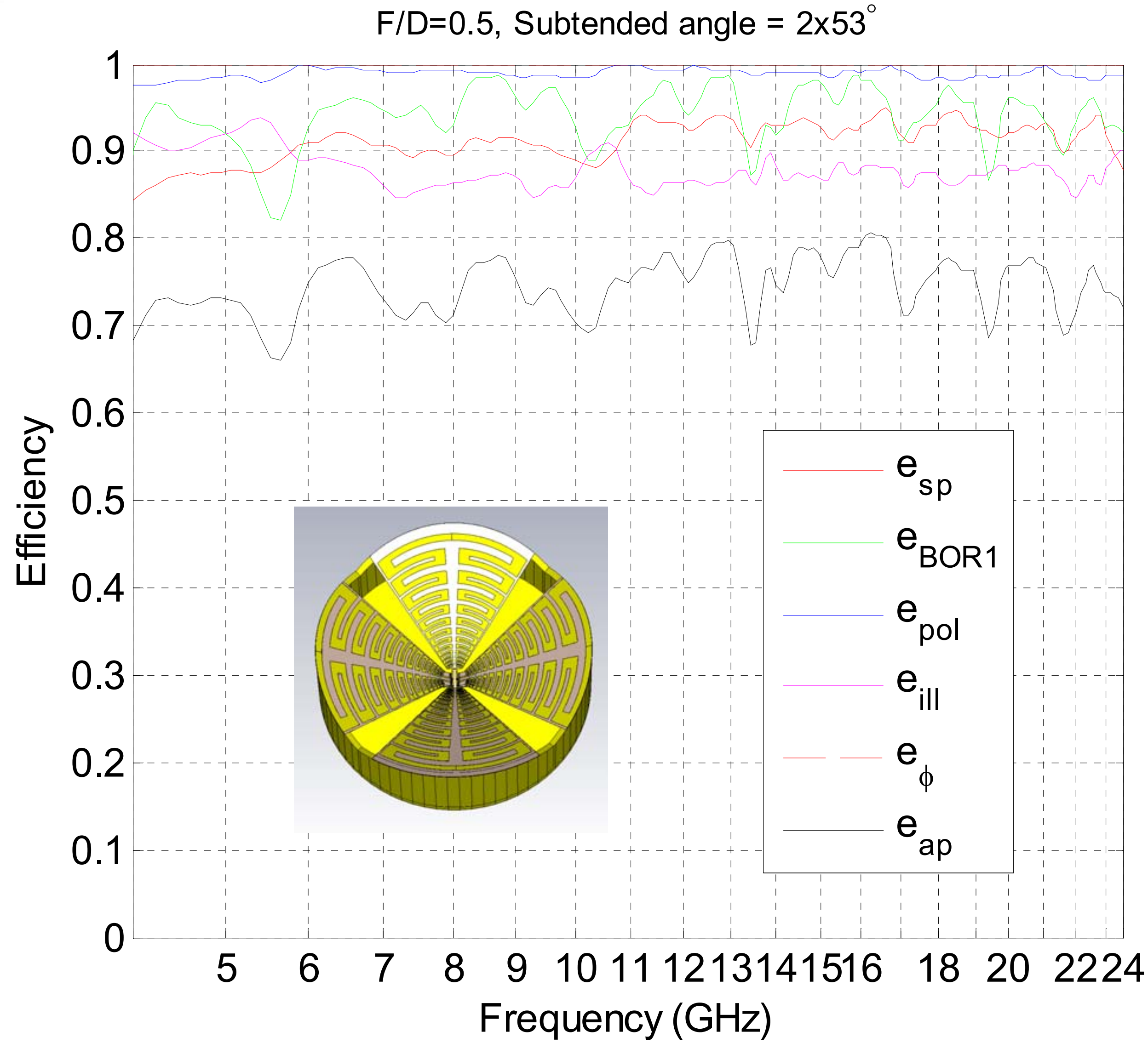
- Eleven Feed
  - Explore design options to tune the beam width
    - The 10 dB beamwidth of straight eleven feed can be tuned down to 2x47.5=95 degrees, compared to the previous one of 2x57=114 degrees.
    - Further decrease of the beam was done by increasing the spacing between the pairs of folded dipoles. But the grating lobes start to come.
    - The H-plane beam width is narrower than that in E-plane.
  - Scale of existing design and calculate Aeff/Tsys
  - Explore options for manufacturing
- QRFH
  - Scale of existing design and calculate Aeff/Tsys
  - Look for options to keep ridges relatively thick

Eleven Feed for Band B

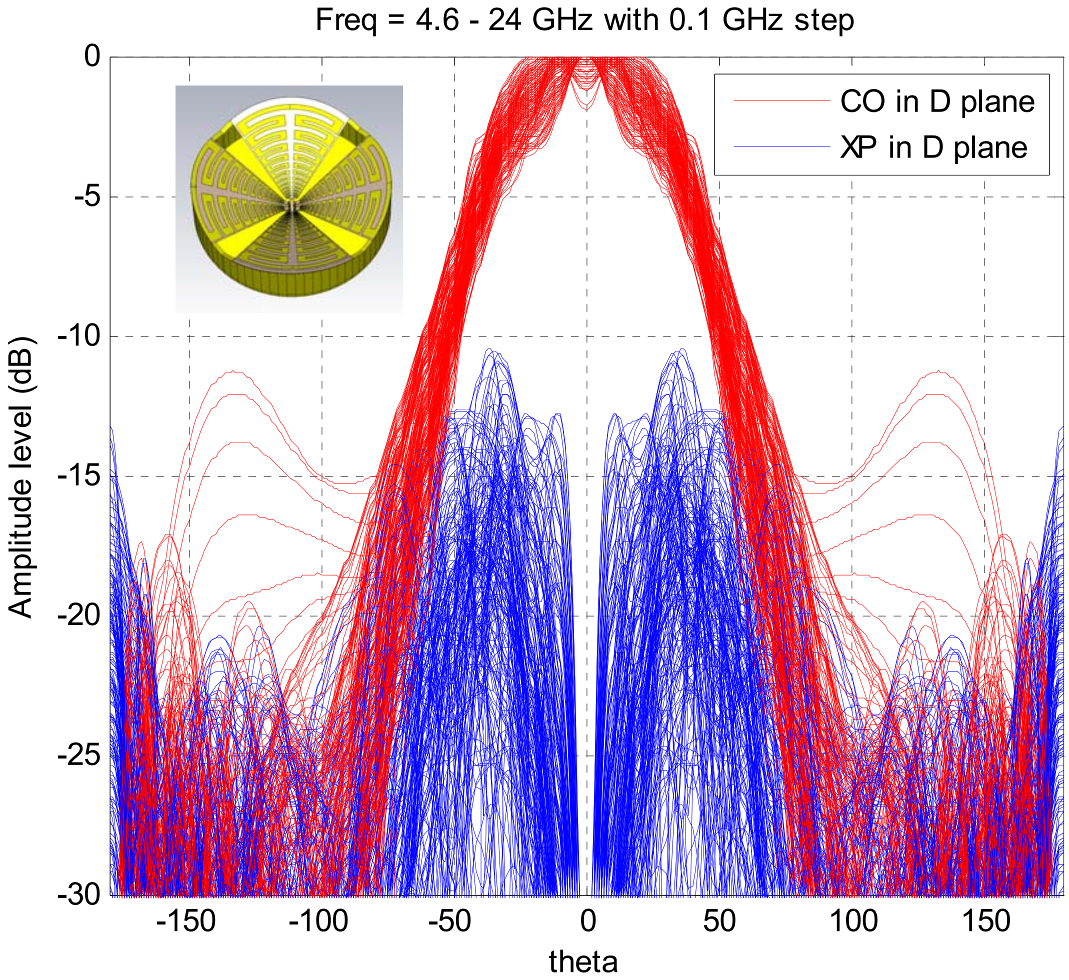


- The size has not been decided yet but will be within the size of 75 mm diametre and height of 25 mm.
- The narrowest line width of dipoles is larger than 0.2 mm
- Petals will be etched on the 0.1mm thick Rogers PCB
- Input ports are of 4 coaxial cables for the dual polarization.
- The feed is feasible to manufacture via 3D printing and stadard PCB etching.

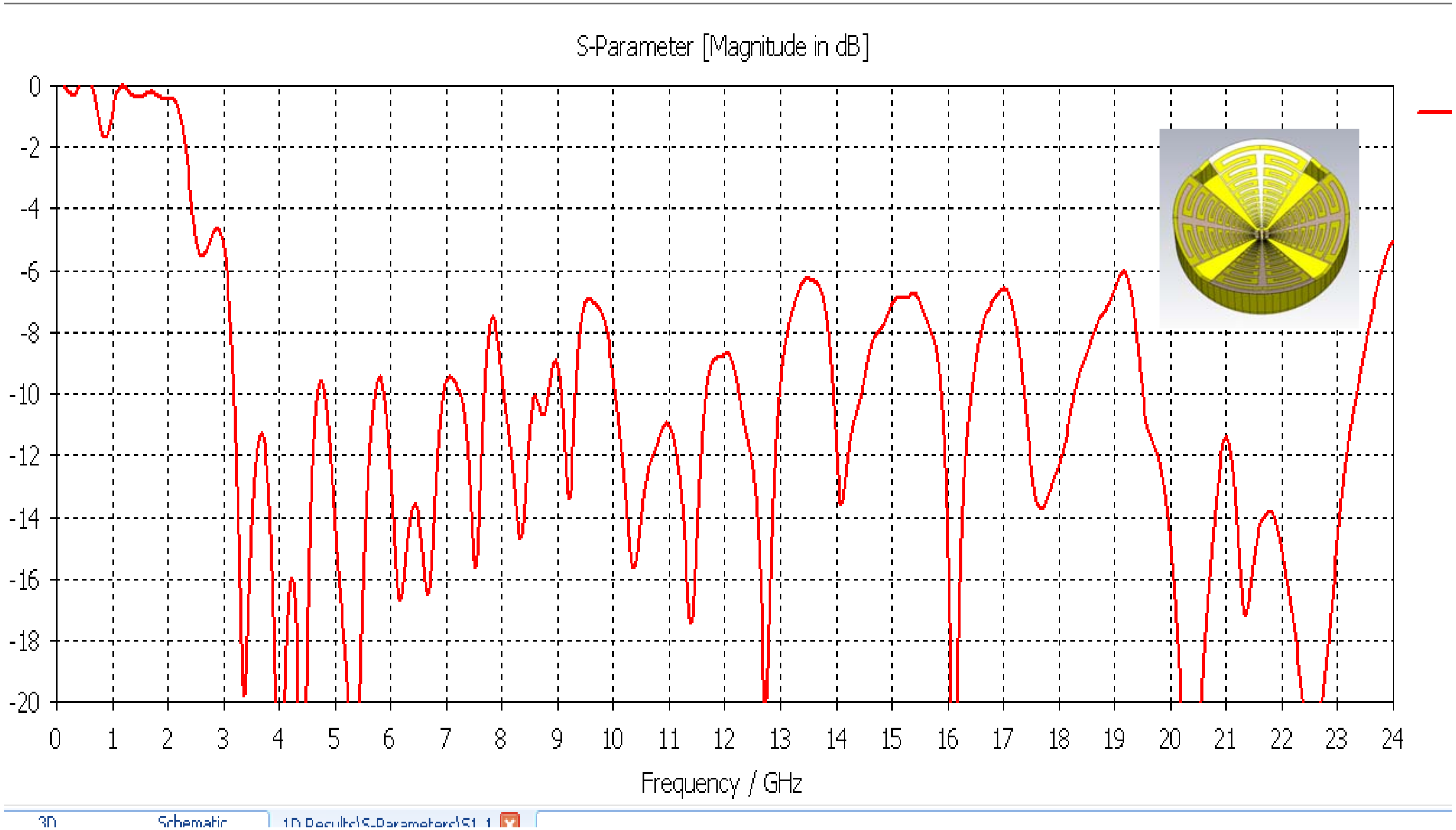
Eleven Feed for Band B in primary reflector



Radiation patterns in 45 deg plane



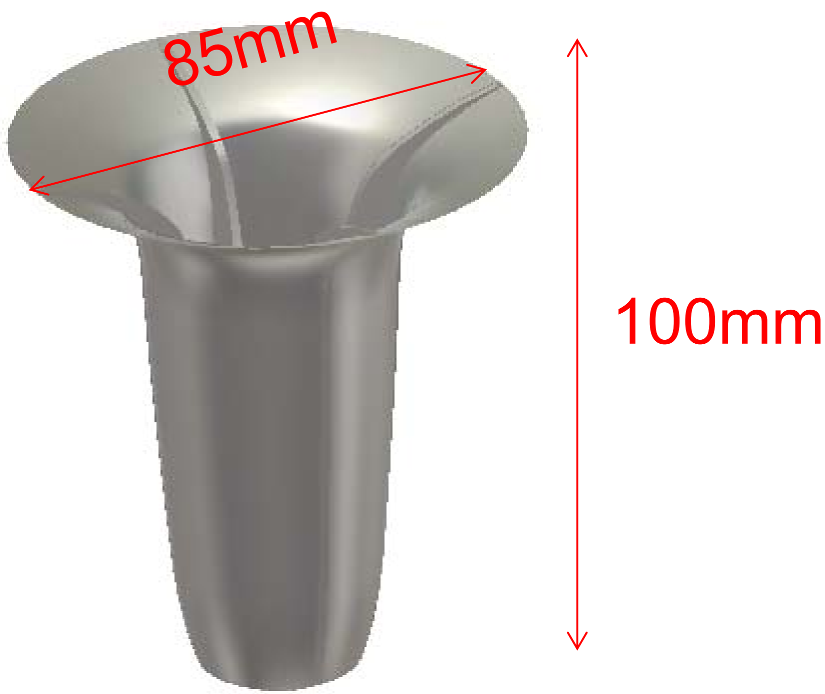
Reflection coefficient



Conclusions – Eleven Feed

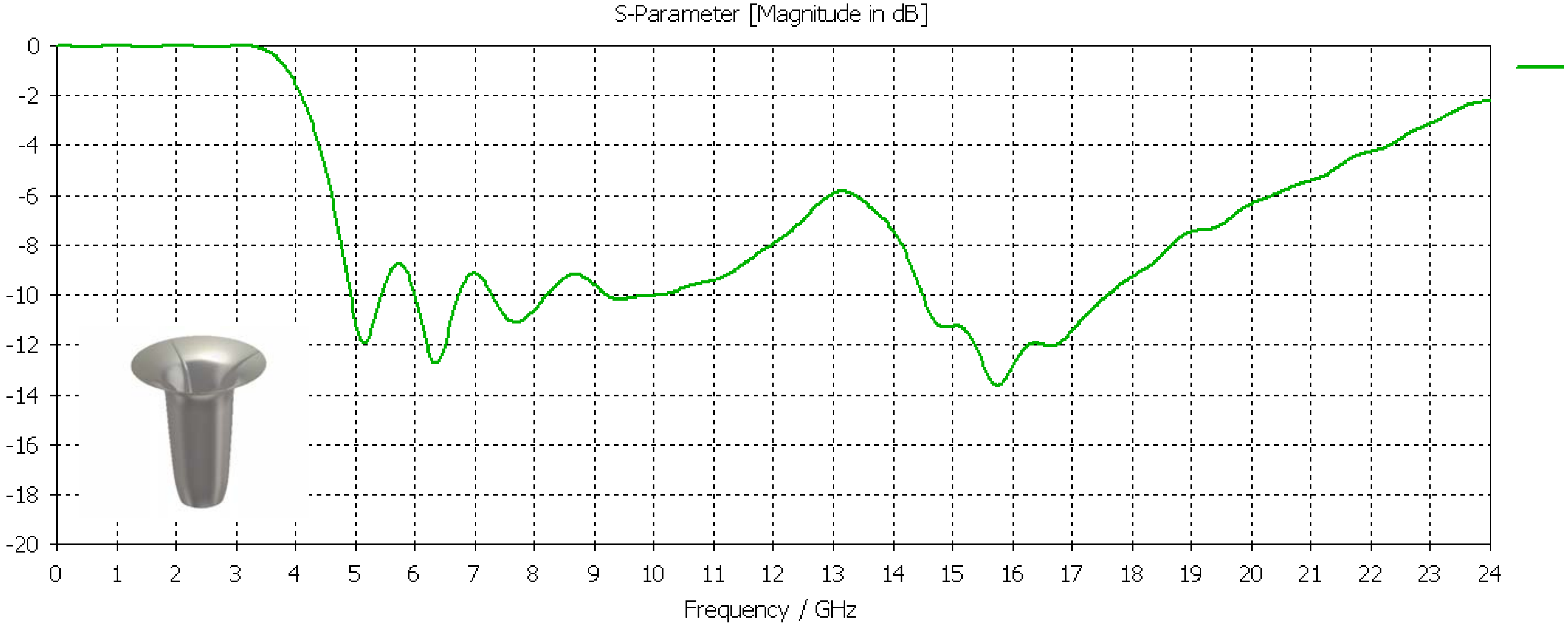
- Eleven Feed
  - Radiation performance is very promising
    - Good aperture efficiency
    - Good cross-polar performance
  - Reflection coefficient needs optimization
  - Manufacture: the petals has the minimum width of 0.2 mm so it is not very difficult for manufacture by using PCB etching. The support can be manufactured by 3D printing technology. We have had a try and it is very promising

QRFH - scaled from SKA band1 feed

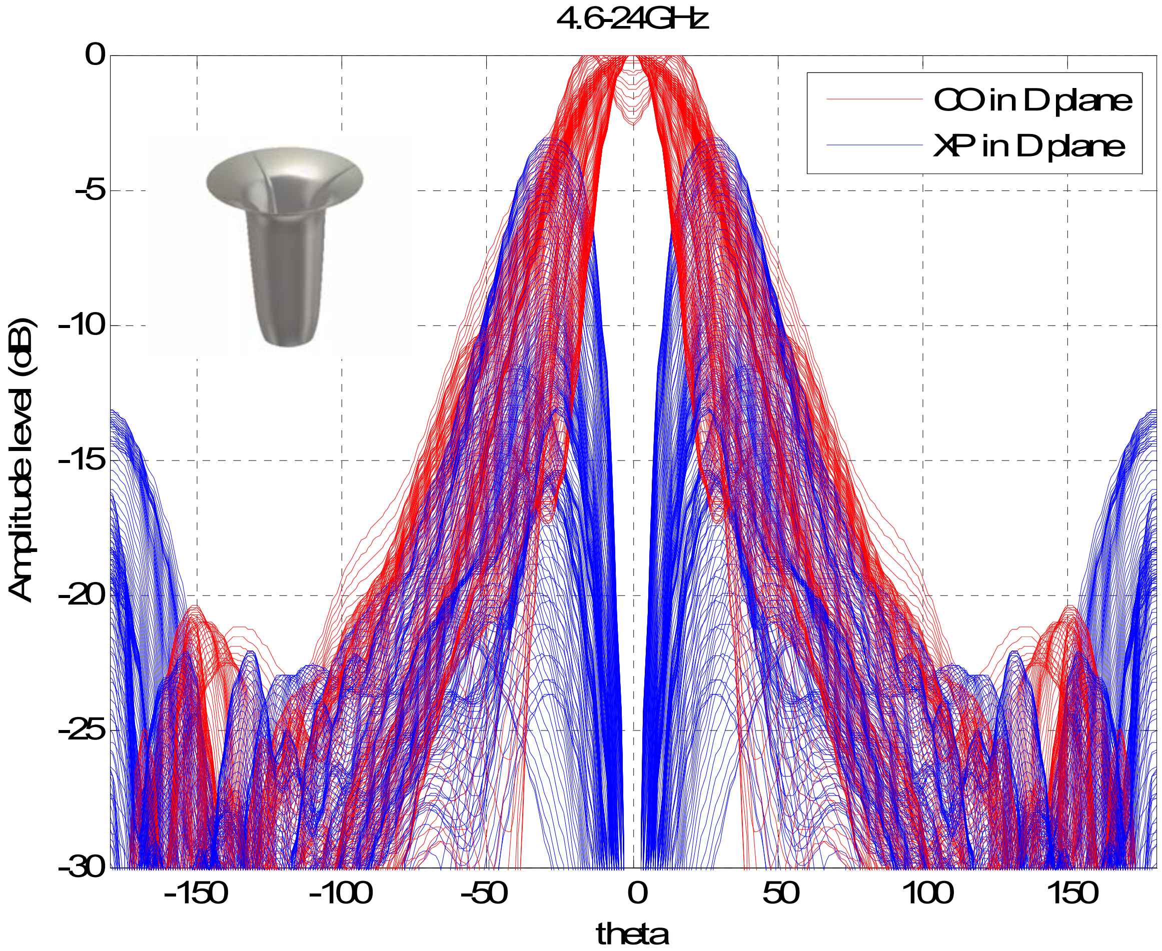


Band 1 QRFH with spline ridge profile was provided from EMSS and then further optimised and scaled

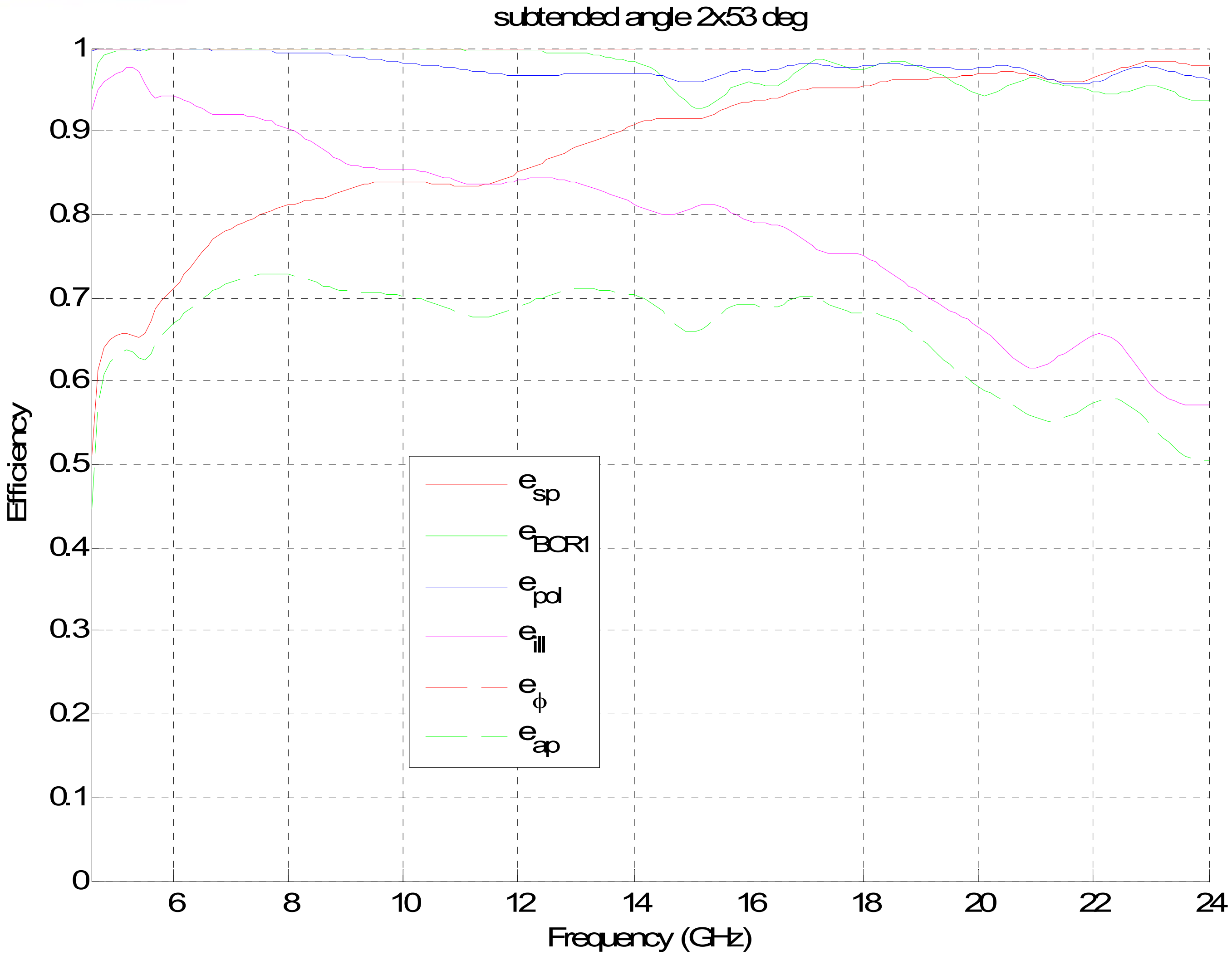
Reflection coefficient



Radiation patterns in 45 deg plane



Aperture efficiency for primary reflector



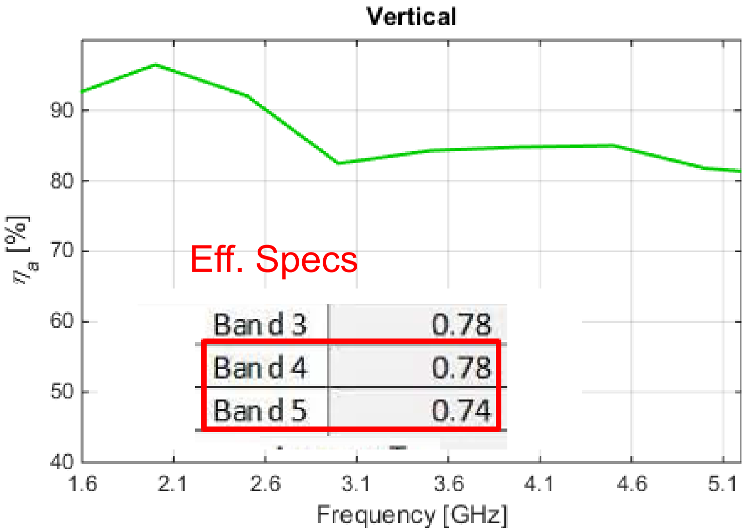
- The design work is undergoing
- There are some challenges to be solved
- The width of the ridge is 1.4 mm for manufacture reason. We may change this for better performance

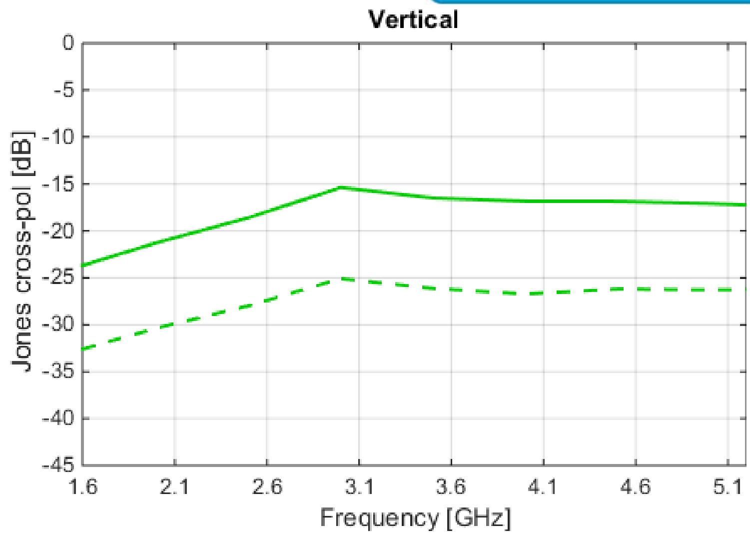
BAND A AND B FEED IN SKA REFLECTOR OPTICS

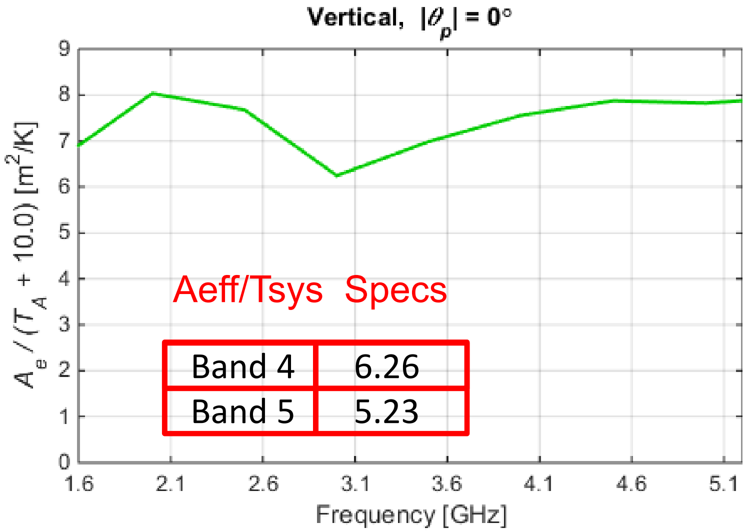
Jonas Flygare – Onsala Observatory
Bhushan Billade – Onsala Observatory

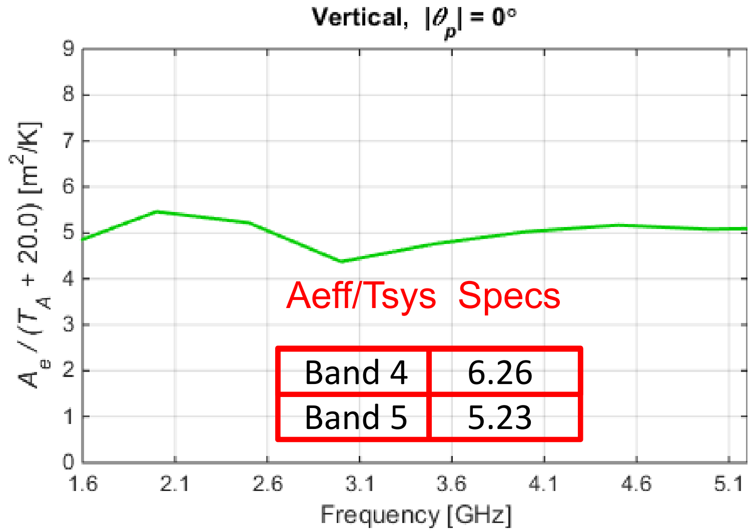
System simulator developed and provided by Marianna Ivashina and Oleg Yupikov

QRFH JLRAT 1.6-5.2 GHz Band A
SKA Dish 58^0

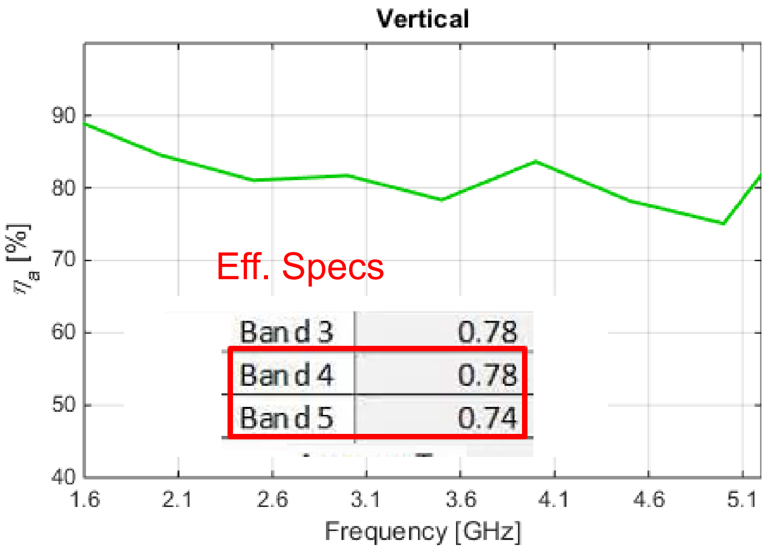


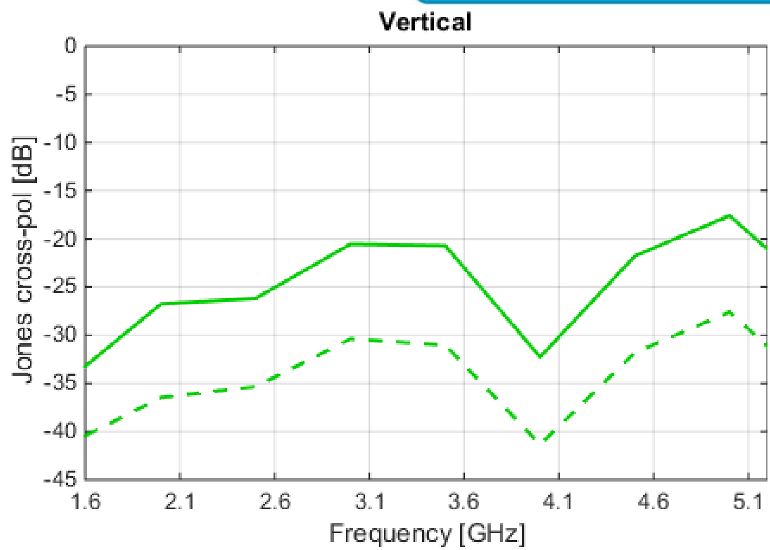


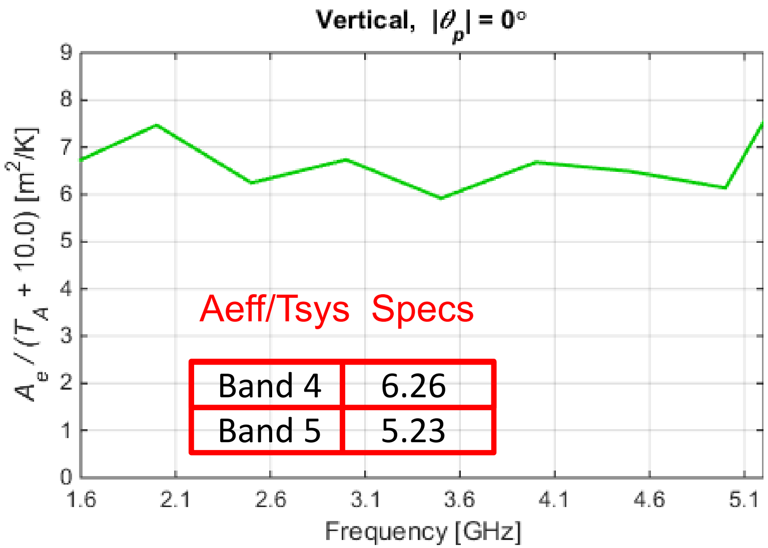


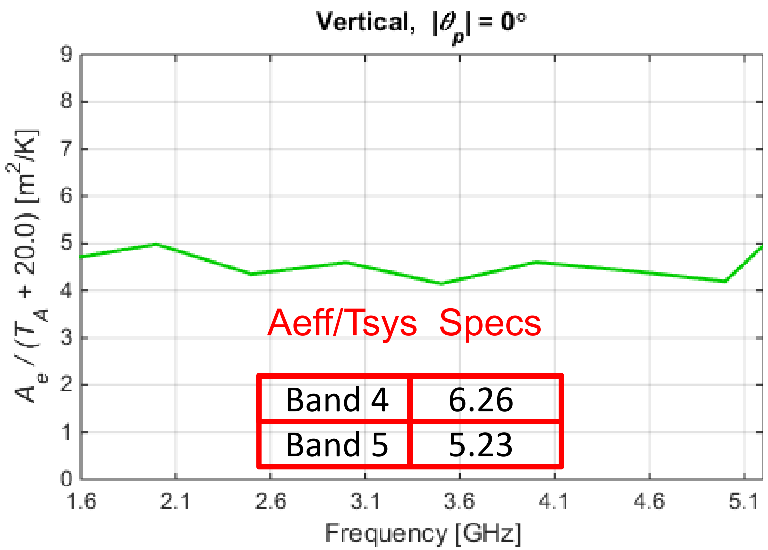


Eleven Feed JLRAT 1.6-5.2 GHz Band A SKA Dish 58^0

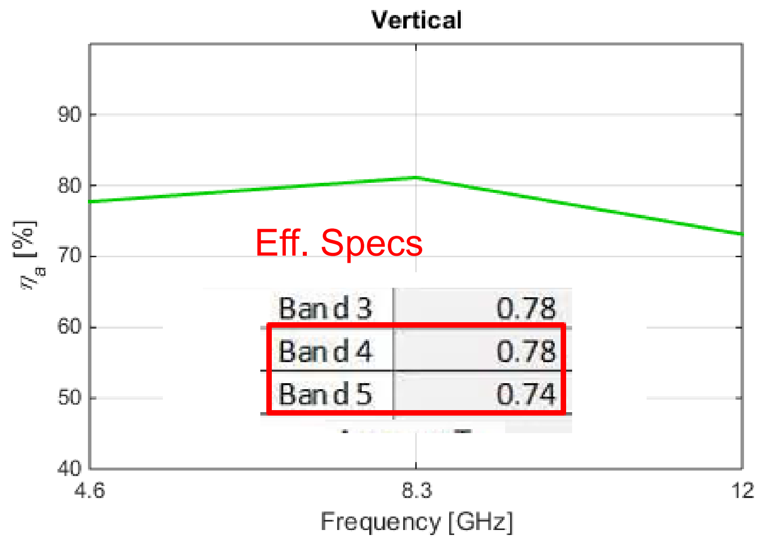


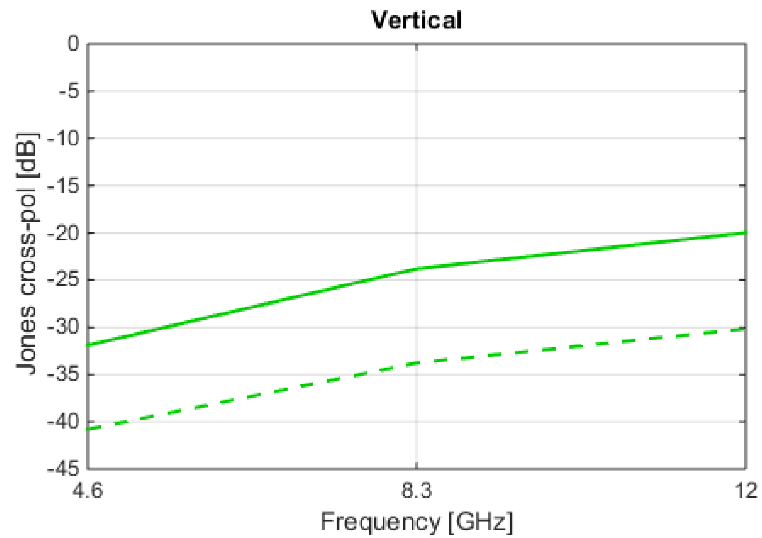


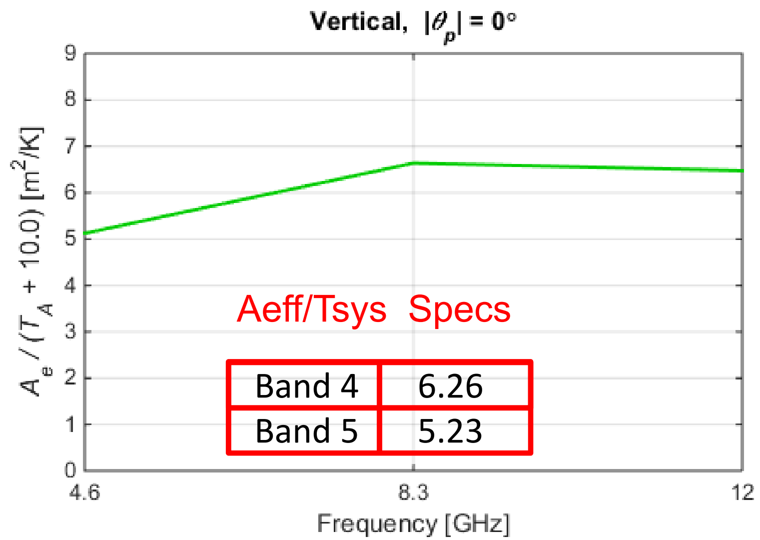


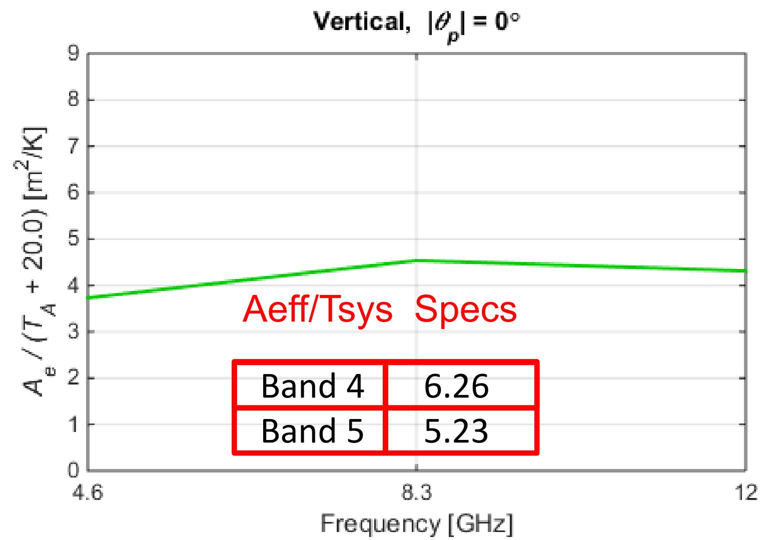


QRFH OSO 4.6-24 GHz Band B
SKA Dish 58^0 - (Up to 12GHz Evaluated)



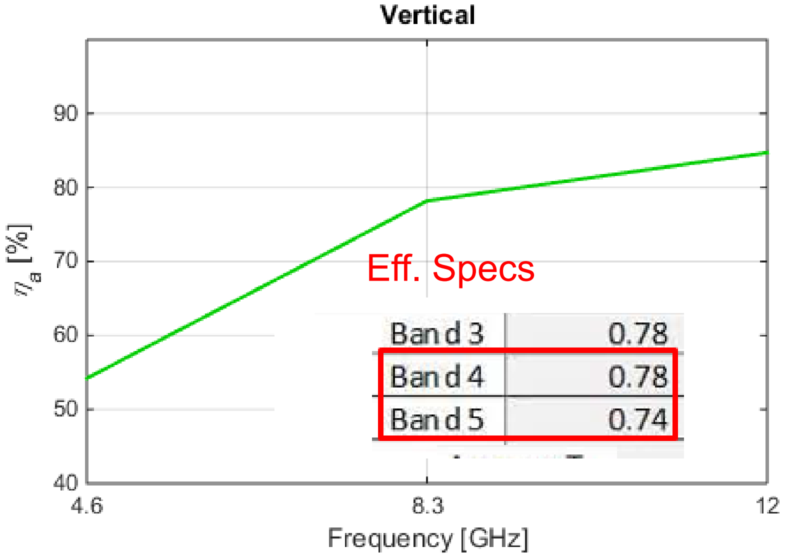




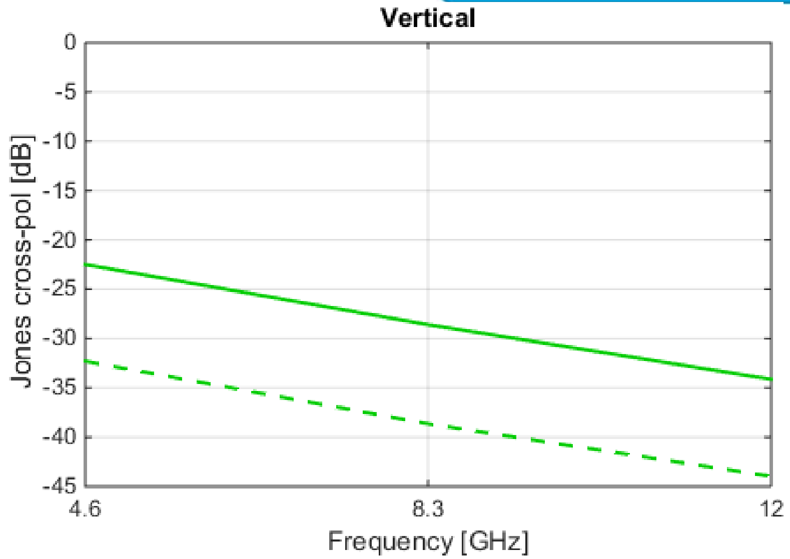


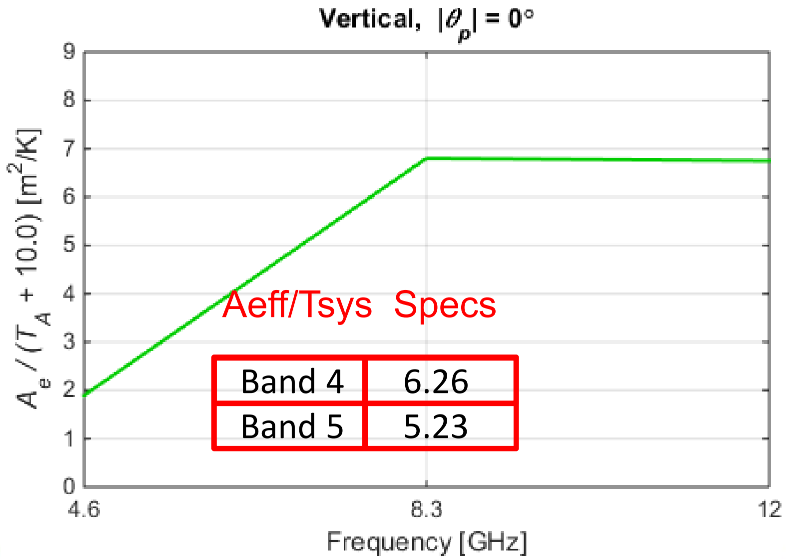
Eleven Feed OSO 4.6-24 GHz Band B SKA Dish 58^0 (Up to 12GHz Evaluated)

SKA SQUARE KILOMETRE ARRAY
WIDE BAND SINGLE PIXEL FEEDS

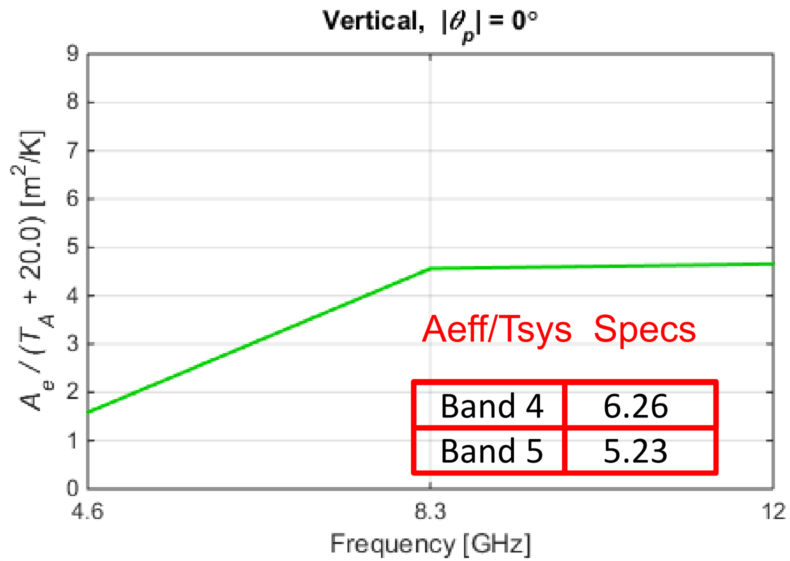


Band 3	0.78
Band 4	0.78
Band 5	0.74



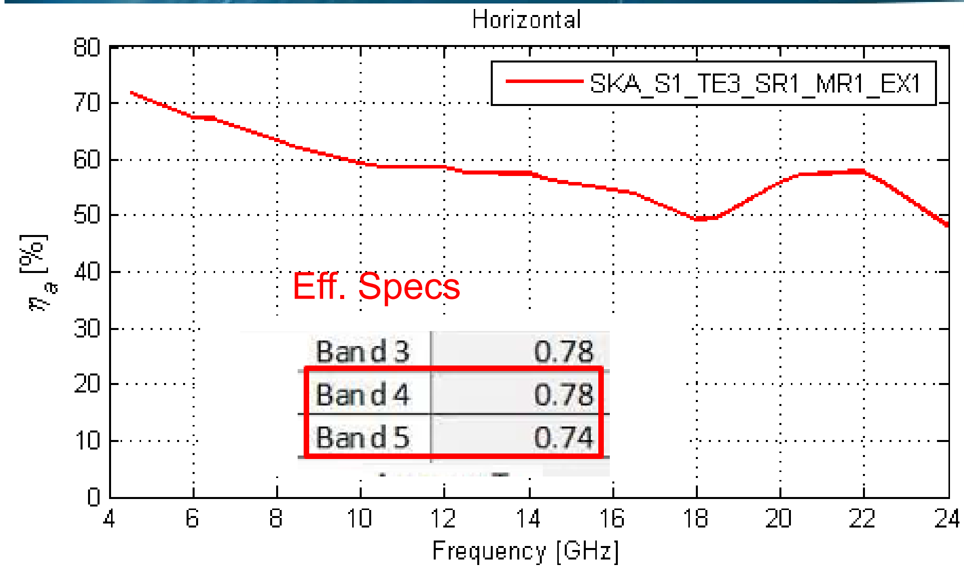


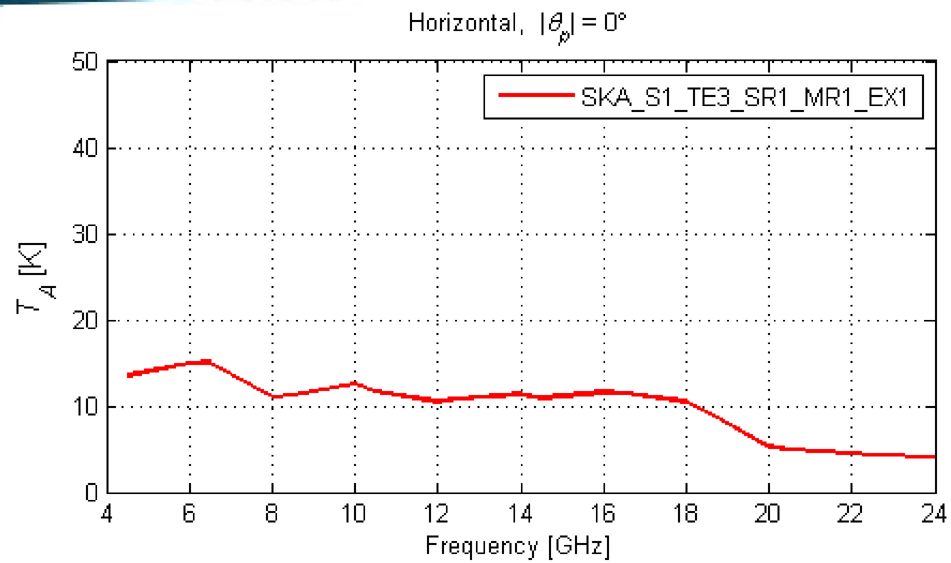
Band 4	6.26
Band 5	5.23

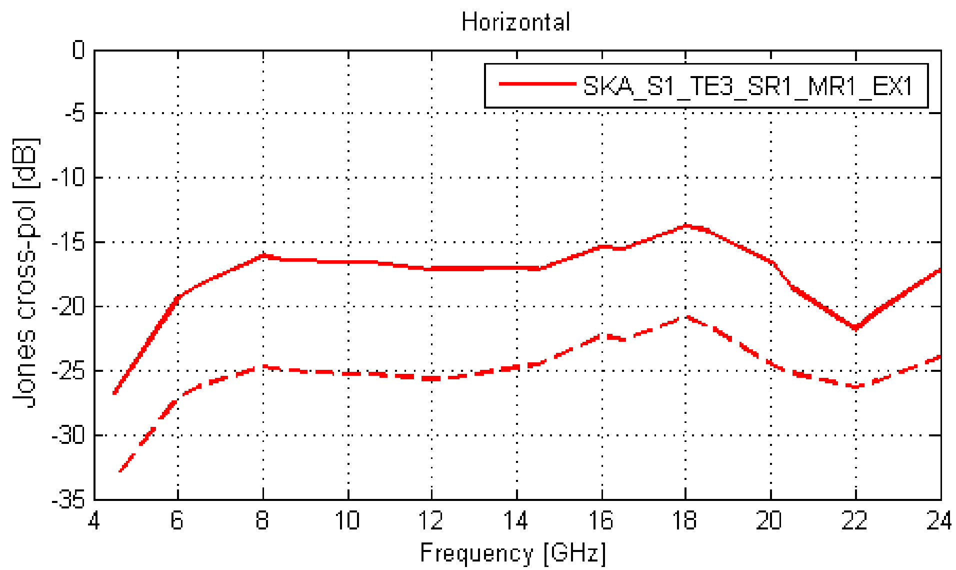


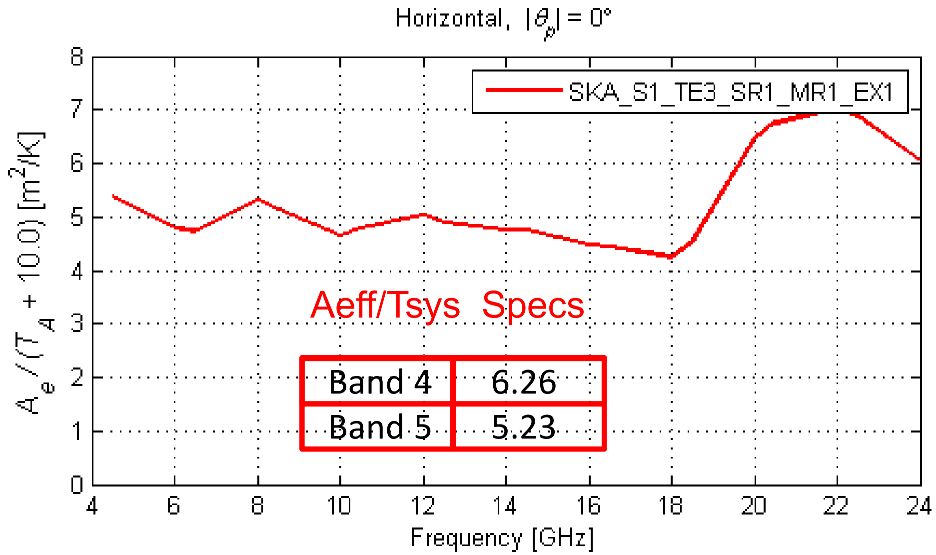
Band 4	6.26
Band 5	5.23

Preliminary QRFH design for Band B 4.6-24GHz in SR1 MR1 reflector





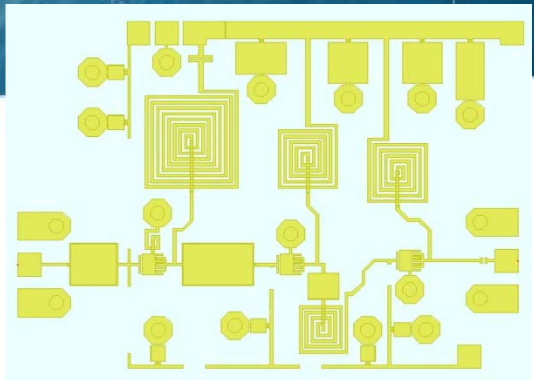




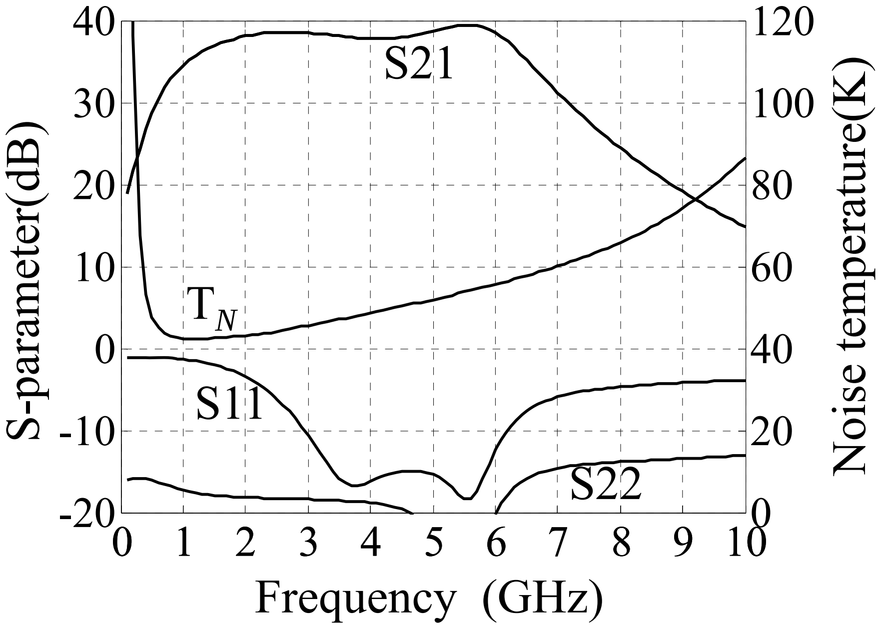
BAND A LNAs

WP leaders:
MMIC - Li Bin (SHAO)
Discrete components - Sander Weinreb (Caltech)

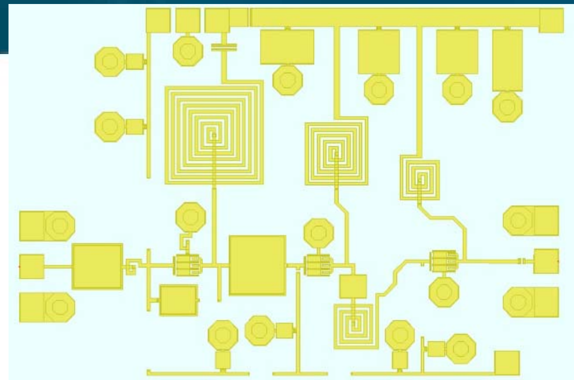
1.6~5.2GHz LNA Design using OMMIC 70nm mHEMT



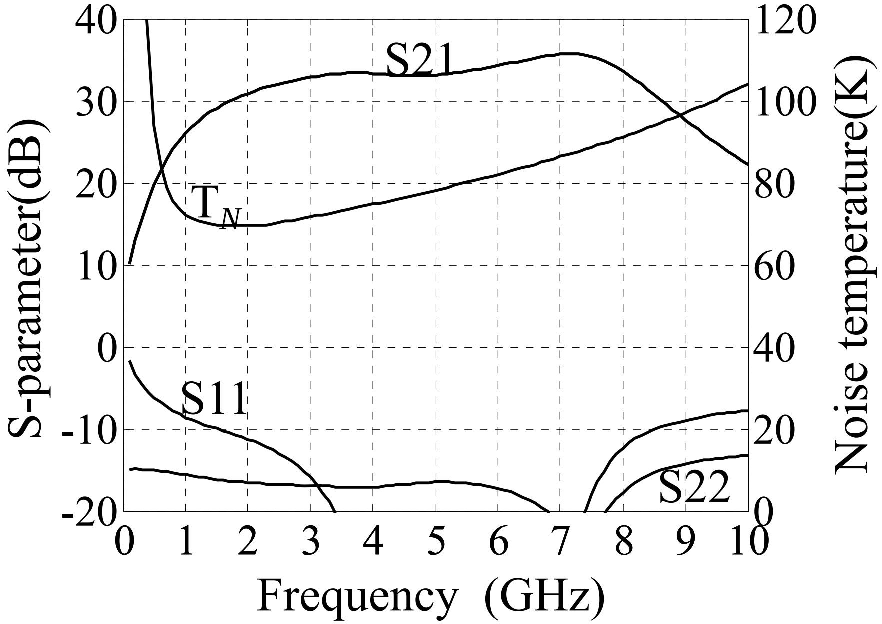
1.6~5.2GHz LNA, for the lowest noise
Area:2000 μm ×1500μm
processing: OMMIC 70nm mHEMT



Gain≈40dB T_N <50K



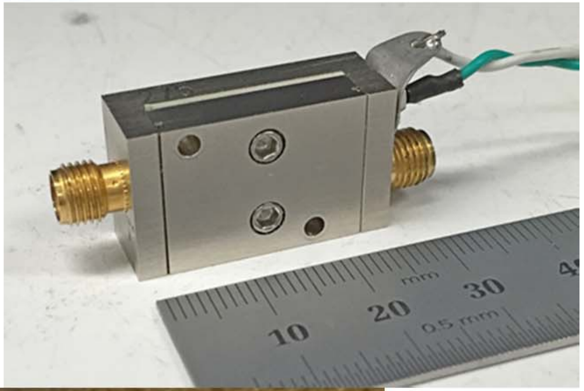
1.6~5.2GHz LNA, for the best input matching
Area:2000 μm ×1500μm
processing: OMMIC 70nm mHEMT

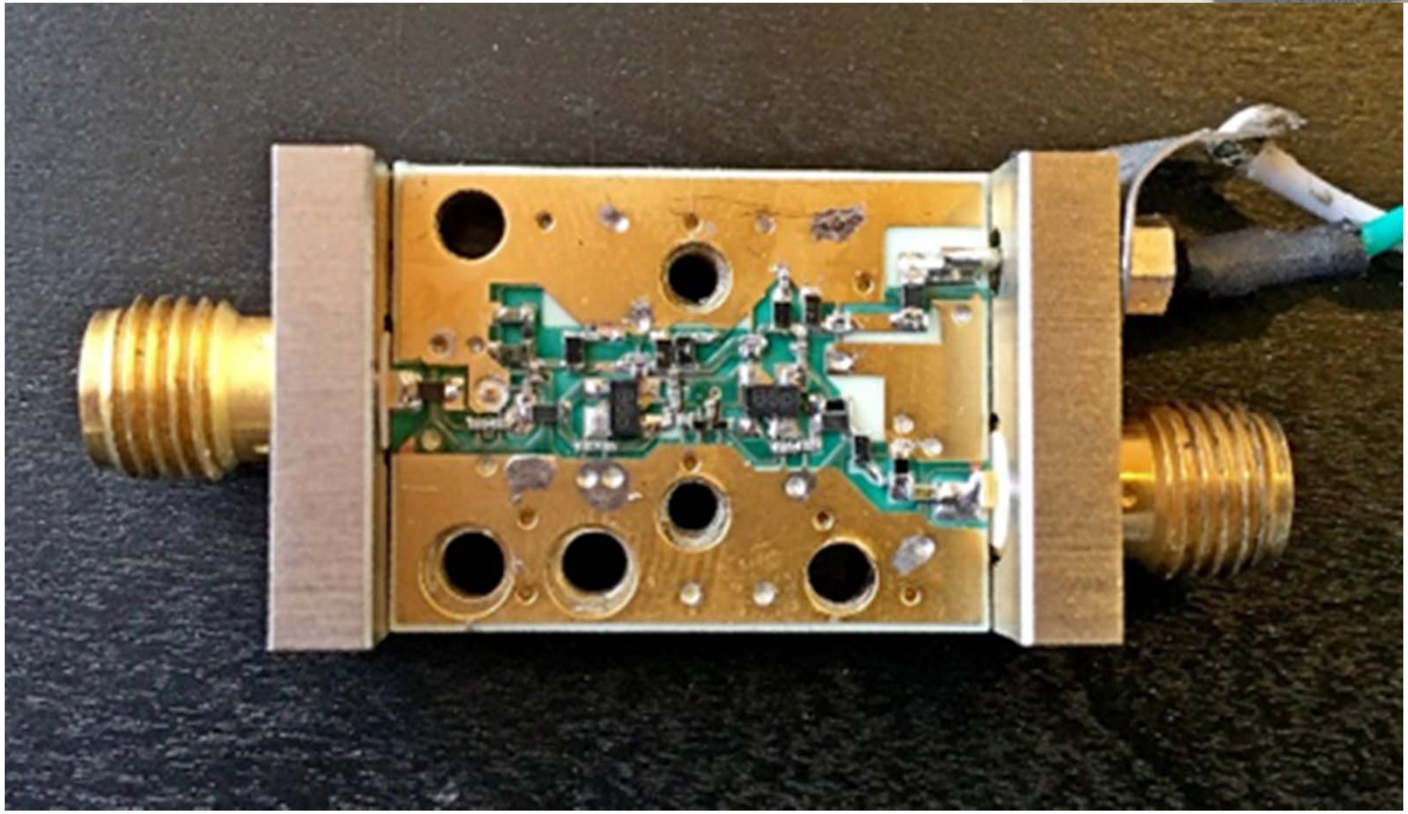


Gain>30dB T_N <80K

SiGe Low Noise Amplifier for Band A @ Caltech

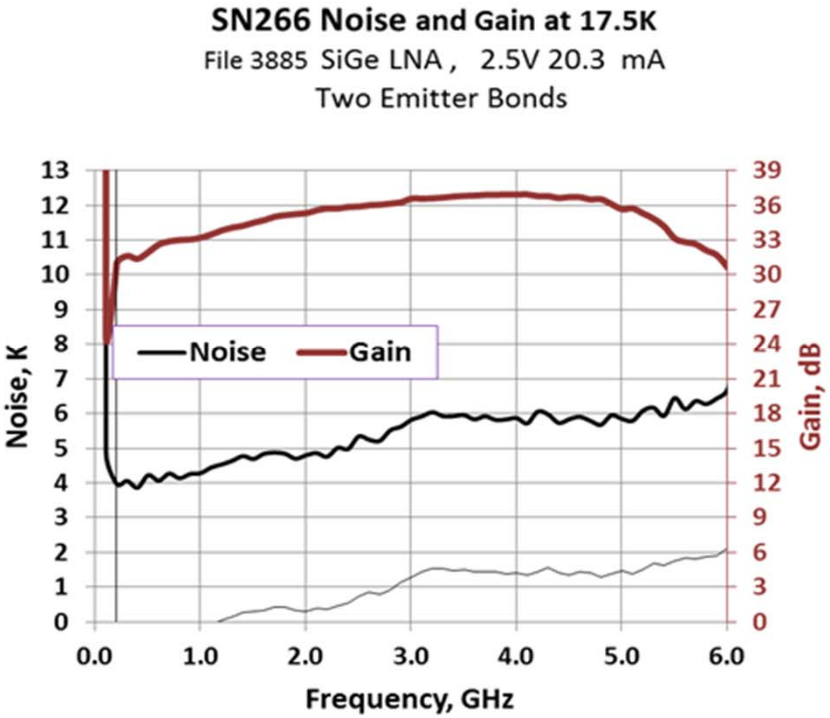
- Highly repeatable discrete bipolar transistor design
- Constructed with surface mount components on microwave circuit board
- Easily manufacturable in quantity

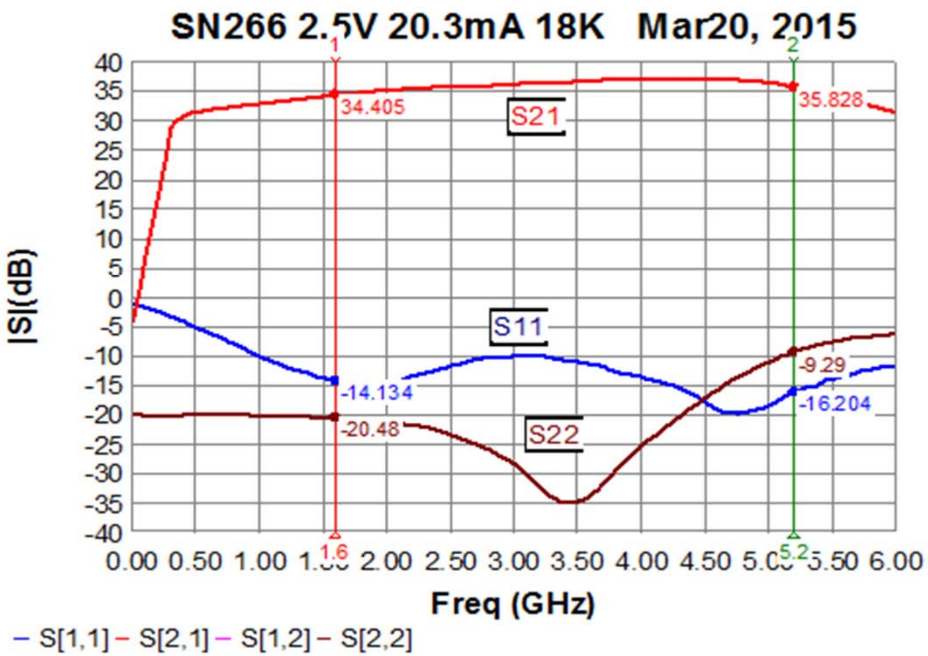




SiGe LNA Test Results at 18K

- Noise is 4K to 6K from 0.4 to 5.5 GHz
- Gain is 32 to 37 dB from 0.4 to 5.5 GHz
- Input return loss is <-10 dB from 1 to 6 GHz
- Output return loss is -20 dB from 0 to 4.3 GHz; -9dB at 5.2 GHz
- Two units tested with near identical results
- Operates from single 2.5V, 20mA bias supply





BAND B mHEMT LNA

WP leader: Mikko Kotiranta

WP contributors: Giuseppe Moschetti, Fabian Thome

Fraunhofer Institute for Applied Solid State Physics IAF, Freiburg, Germany

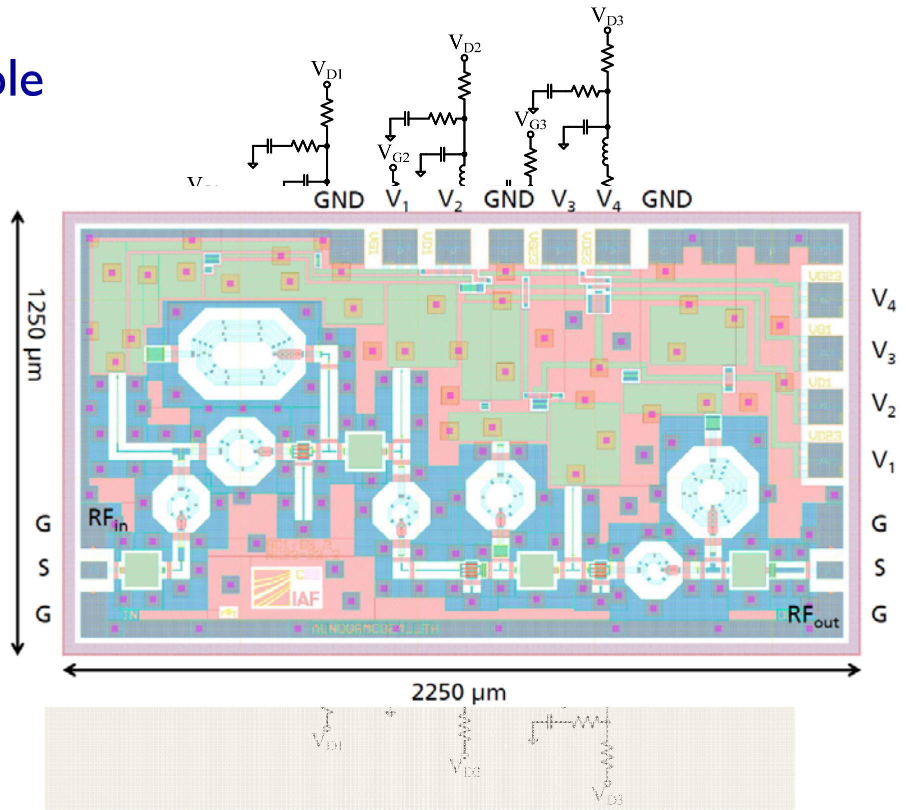
Tasks and Goals

- Tasks
  - Design of LNA for band B (IAF)
    - Differential-to-single-ended (eleven feed) version
    - Single-ended (quadridge feed) version
  - Fabrication of in-house MMICs (IAF)
  - MMIC on-wafer characterization of S-parameters and noise figure
    - Room temperature (IAF) and cryogenic (MPIfR)
  - LNA package design and assembly (MPIfR)
  - Room temperature and cryogenic test of the packaged LNA (MPIfR)
- Goals
  - Fully integrated amplifier – including input matching network
    - Cost reasons
    - Simplicity of packaging

Single Ended LNA design

- One half of the differential amp
- 50 Ω single-ended
- Performance comparable with differential amplifier
- Redundant DC-pads (V_1-V_4) for flexible feed integration

	Specification	Simulation	Comment
Frequency	4.6 – 24 GHz	4.6 – 24 GHz	
Input impedance	50 Ohm single-ended	50 Ohm single-ended	
Output impedance	50 Ohm single-ended	50 Ohm single-ended	
Gain	25 dB	> 30 dB	
Noise temperature (300 K)	Not specified	< 75 K	
Noise temperature (25 K)	20 K	< 10 K	based on an estimated improvement factor of 7 - 10 compared to RT
Power consumption (300 K)	150 mW	280 mW	
Power Consumption (25 K)	150 mW	< 60 mW	

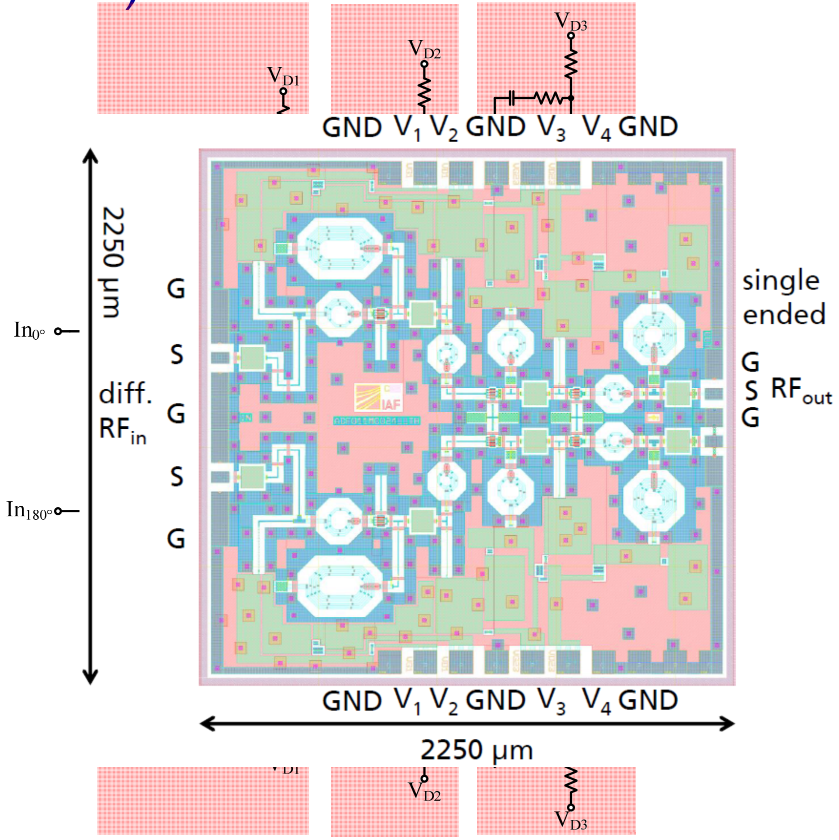


Differential LNA design

- 3 stage fully-differential LNA
- 1. stage common source with ind. source deg.
- 2. and 3. stage common source with source line as differential amp.

	Specification	Simulation	Comment
Frequency	4.6 – 24 GHz	4.6 – 24 GHz	
Input impedance	100 Ω differential	100 Ω differential	Deviation from [1] as decided by the consortium: initially 200 Ω differential
Output impedance	50 Ohm single-ended	50 Ohm single-ended	
Gain	30 dB	> 27 dB	G < 30 dB only when f > 21 GHz
Noise temperature (300 K)	100 K	80 K	
Noise temperature (25 K)	20 K	< 10 K	based on an estimated improvement factor of 7 - 10 compared to RT
Power consumption (300 K)	300 mW	380 mW	
Power Consumption (25 K)	150 mW	< 80 mW	
CMRR	25 dB	> 29 dB	

- Input impedance: 100 Ω diff. (50 Ω single-ended)
- output: single-ended accessible (active balun / second output terminated on-wafer)

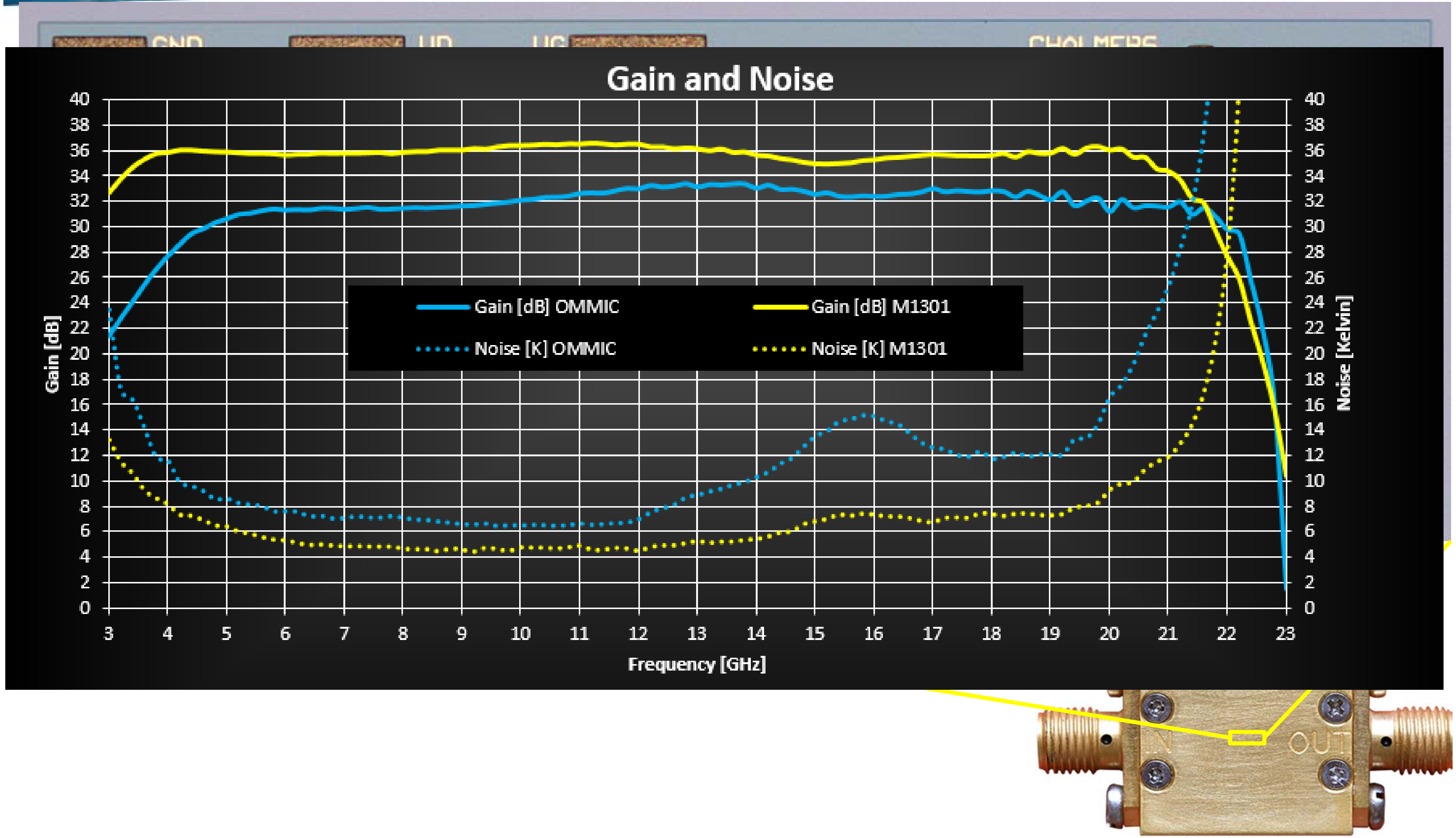


BAND B InP LNAs

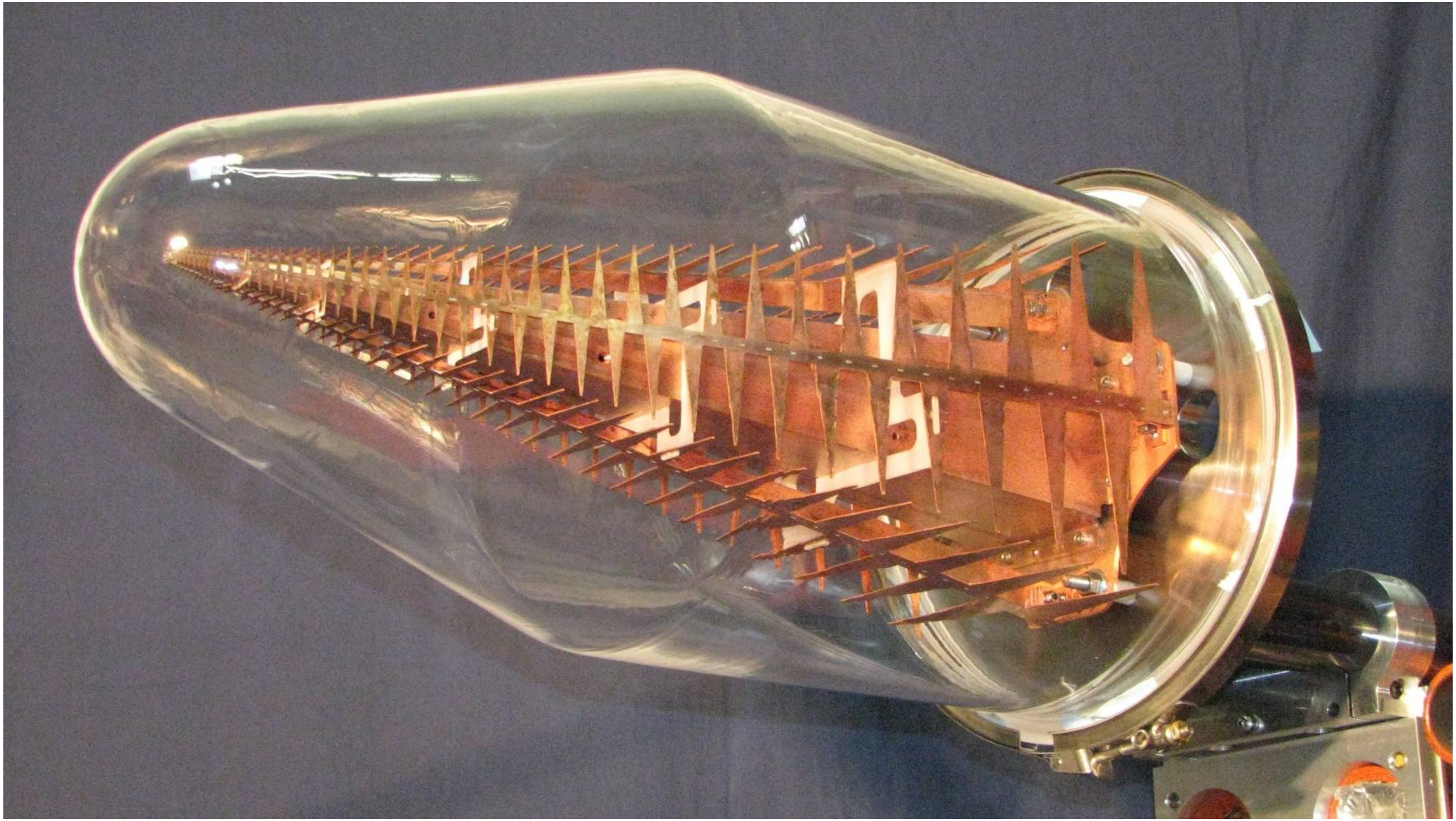
WP leader: Jan Ghran, Chalmers University of Technology

WP industrial partner: Low Noise Factory
Niklas Wadefalk, Joel Schleeh, Ann Shen, Peter Malmberg

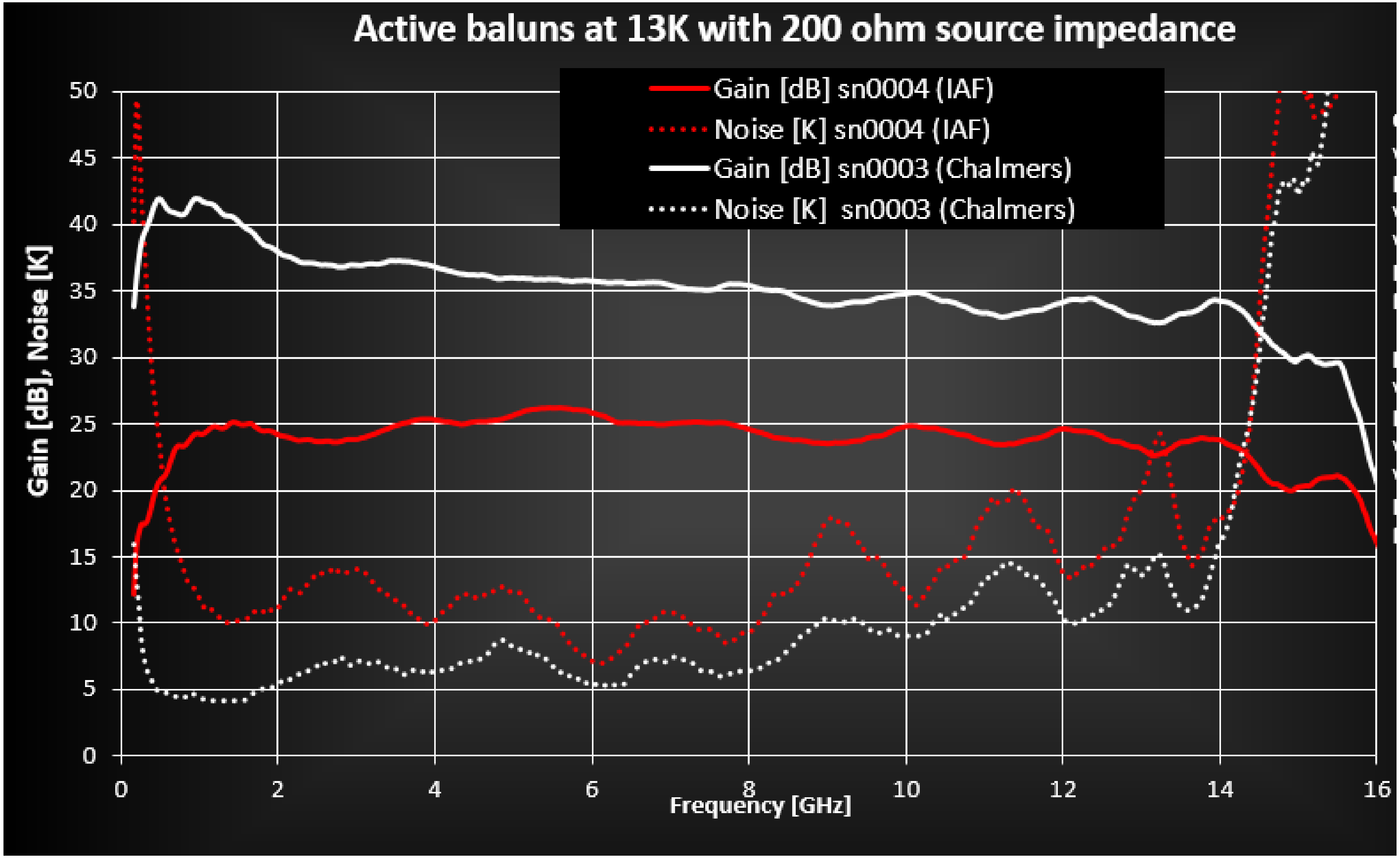
Example performance 6-20GHz



ATA upgrade



ATA upgrade test results



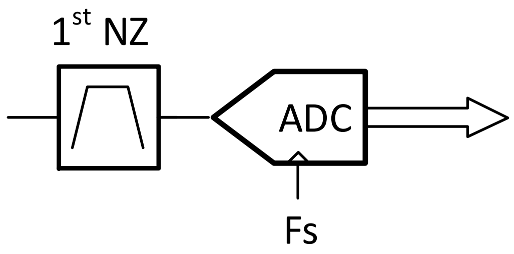
RECEIVERS

WP leader:Stéphane GAUFFRE, University of Bordeaux

Benjamin Quertier, Marina Studniareck, Herve Soulie, Willy d'Anna, Ahroundin Salim, Antsa Randriamanantena

Sampling concepts

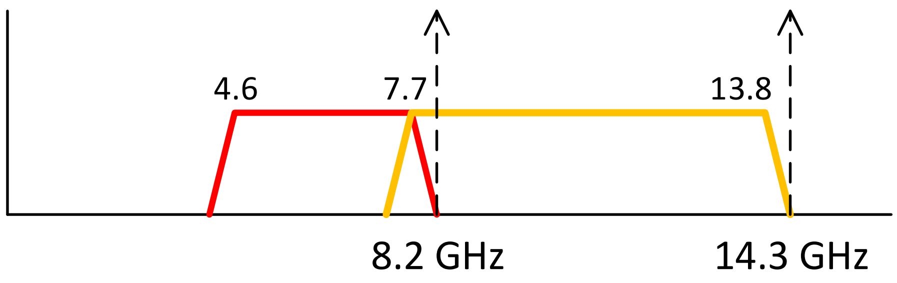
- **Wide band direct sampling in one go**
  - Band A: 6-bit at 12 GSps (U. of Calgary, Micram, Alphacore)
  - Band B: 6-bit at 50 GSps (or 40 GSps?) – interleaved (Alphacore or Micram)

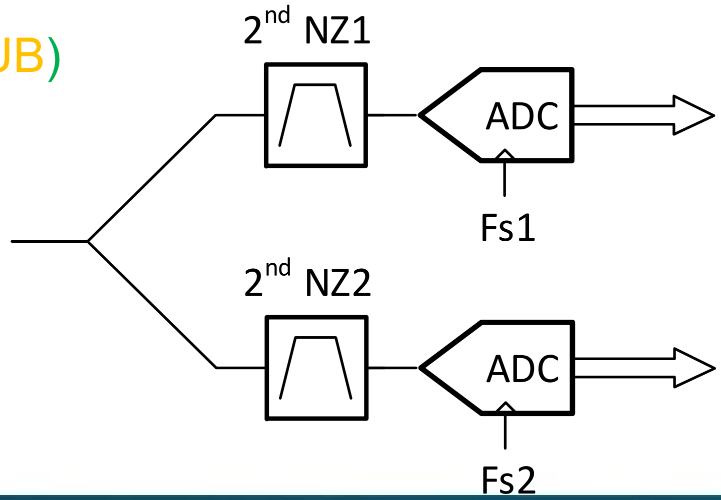


  - Band 5: 6-bit at 30 GSps (Micram)
  - Band 5: 3-bit at 30GSps (Hittite) – Interleaved

- **Band 5: Multi window sampling in 2nd Nyquist zone**
  - 3-bit ADC at 14.3 GSps (Hittite or UB)
  - 3-bit or 4-bit ADC at 8.2 GSps (Hittite or UB)

  or 4-bit at 8.2 GSps (Adsantec)





Sampling concepts

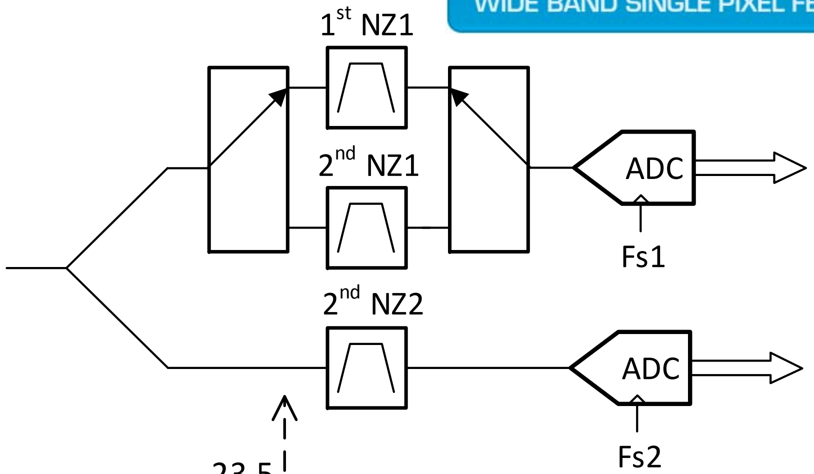
- **Band B: Multi window sampling**

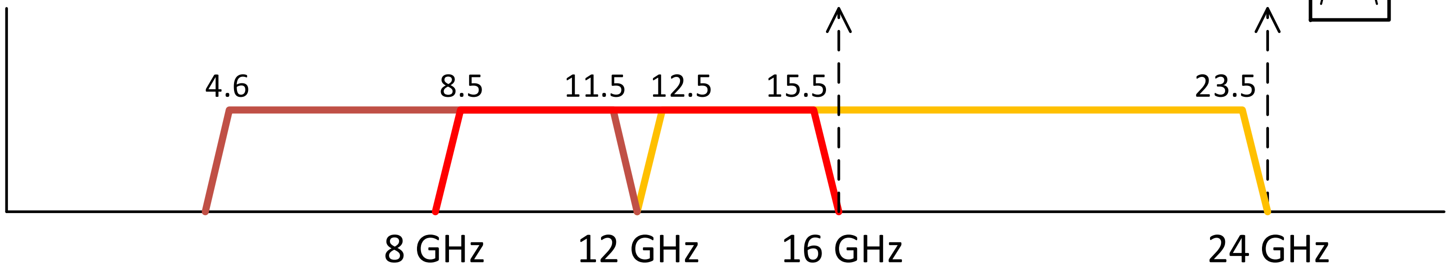
  Goal:

  – 6-bit at 24 GSps (Alphacore)

  – 3-bit at 16 GSps (Hittite)

  or 6-bit at 16 GSps (Micram)

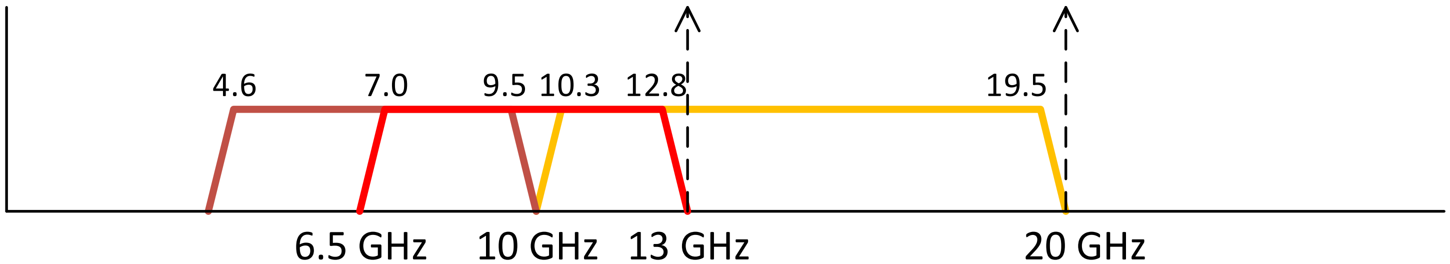




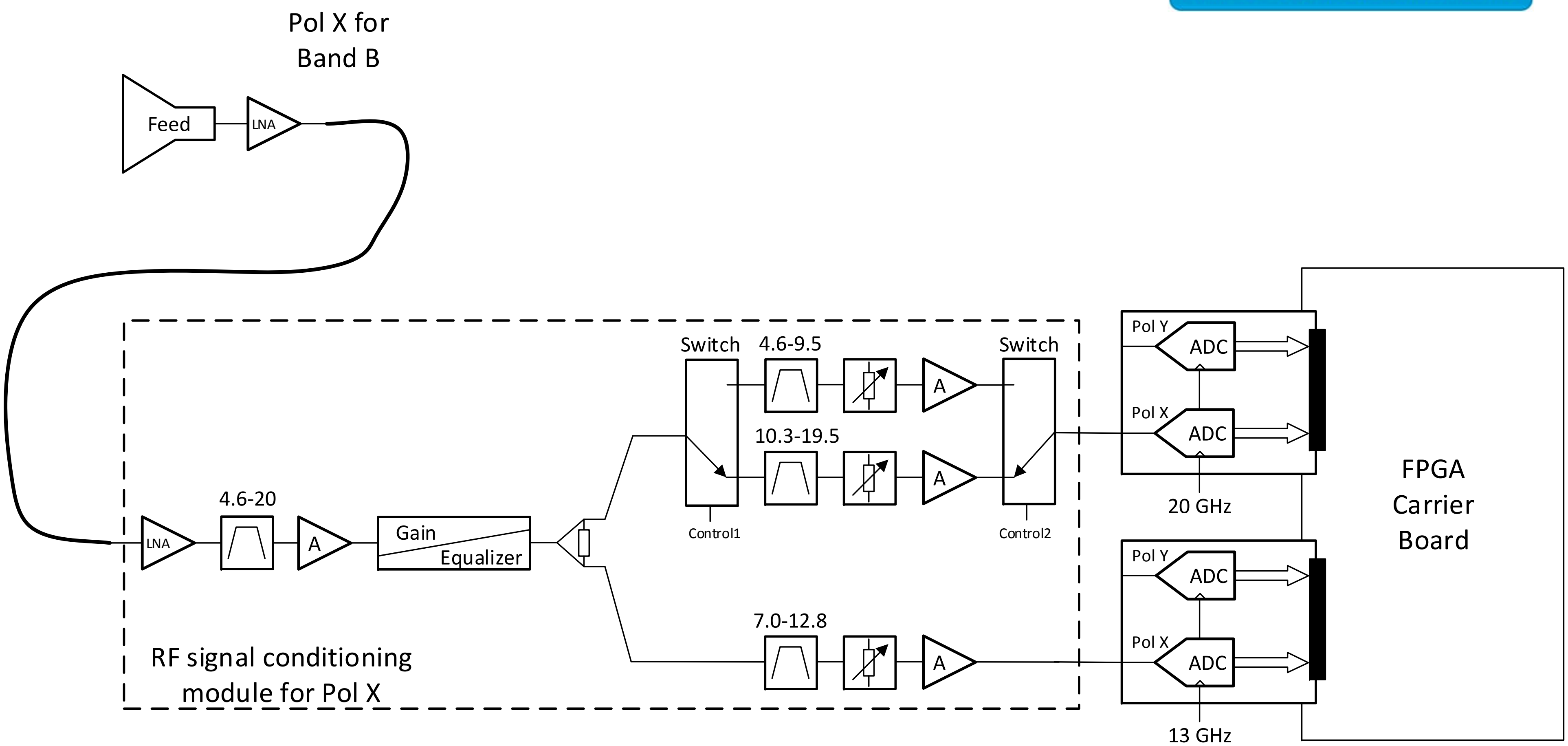
First prototyping: (To be discussed)

– 3-bit ADC at 20 GSps (Hittite)

– 3-bit ADC at 13 GSps (Hittite or UB)



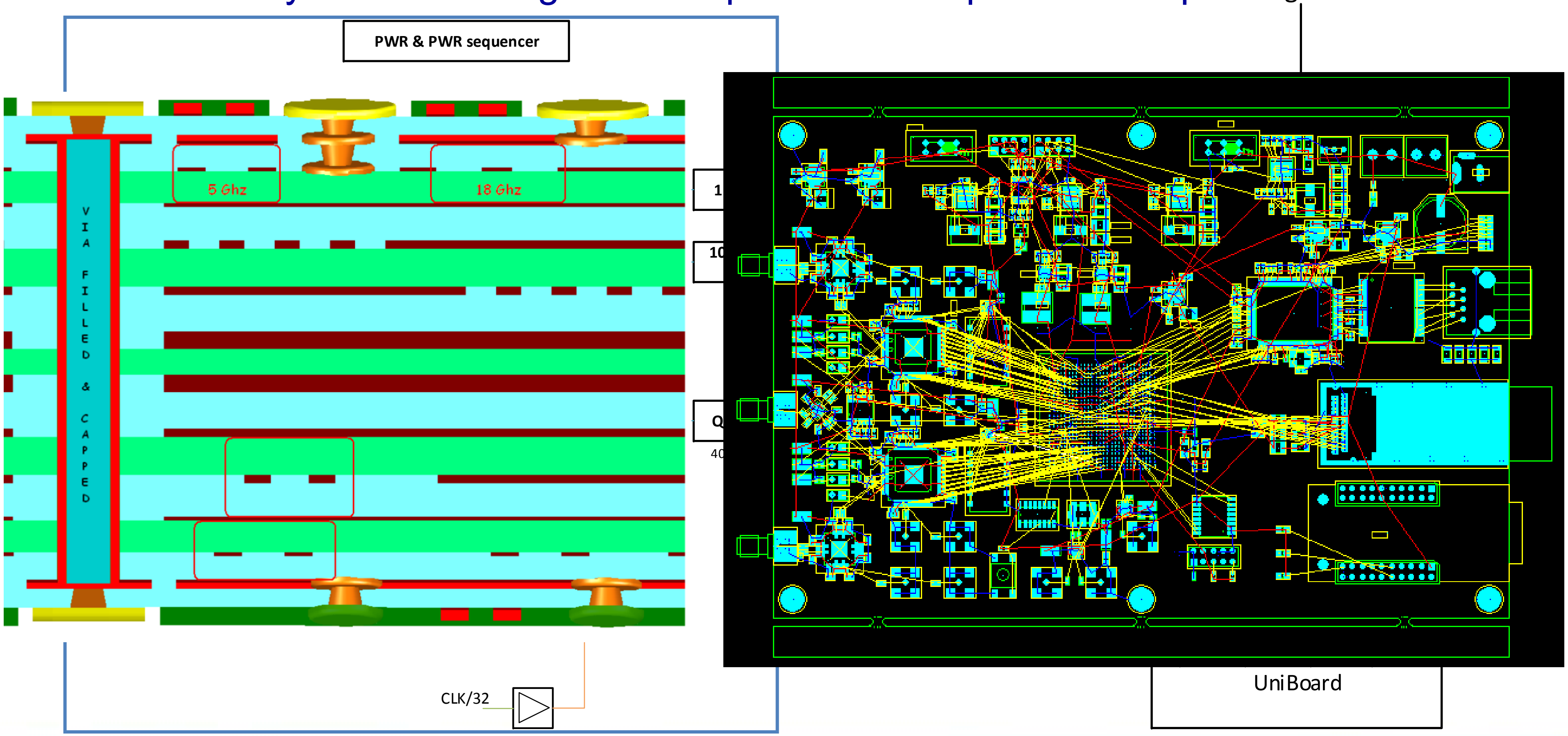
Band B prototyping



First lab demonstrator

The first lab demonstrator for SKA WBSPF uses the 4-bit ADC at 5 GSps from Adsantec for testing of complete WBSPF receiver:

- Low cost solution (substrate, ADC)
- Possibility of interleaving at 10 GSps and 20 GSps for backup solution

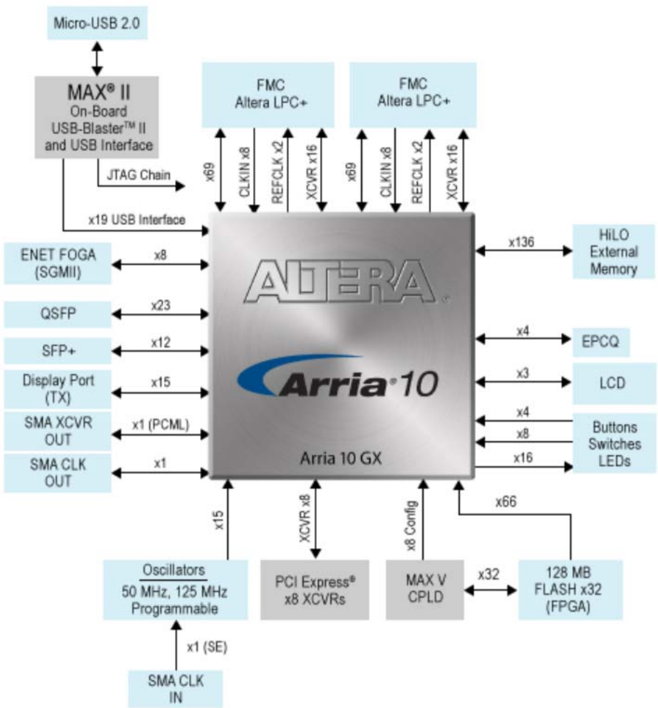


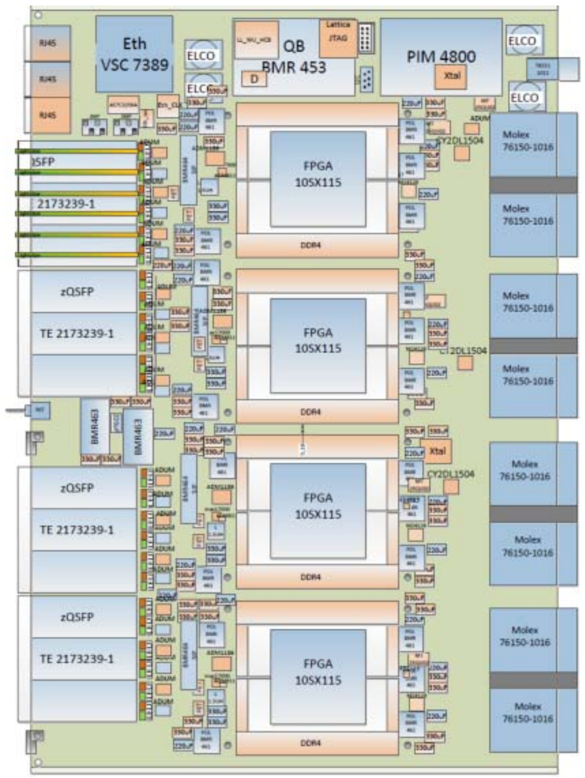
Test facility

Test facility and firmware design:

- An Arria 10 evaluation kit from Altera has been ordered to simulate the FPGA carrier board during the design and characterization of the ADC boards. (May 2015)

- A Uniboard² board will be, also, available at LAB in Bordeaux (early 2016).



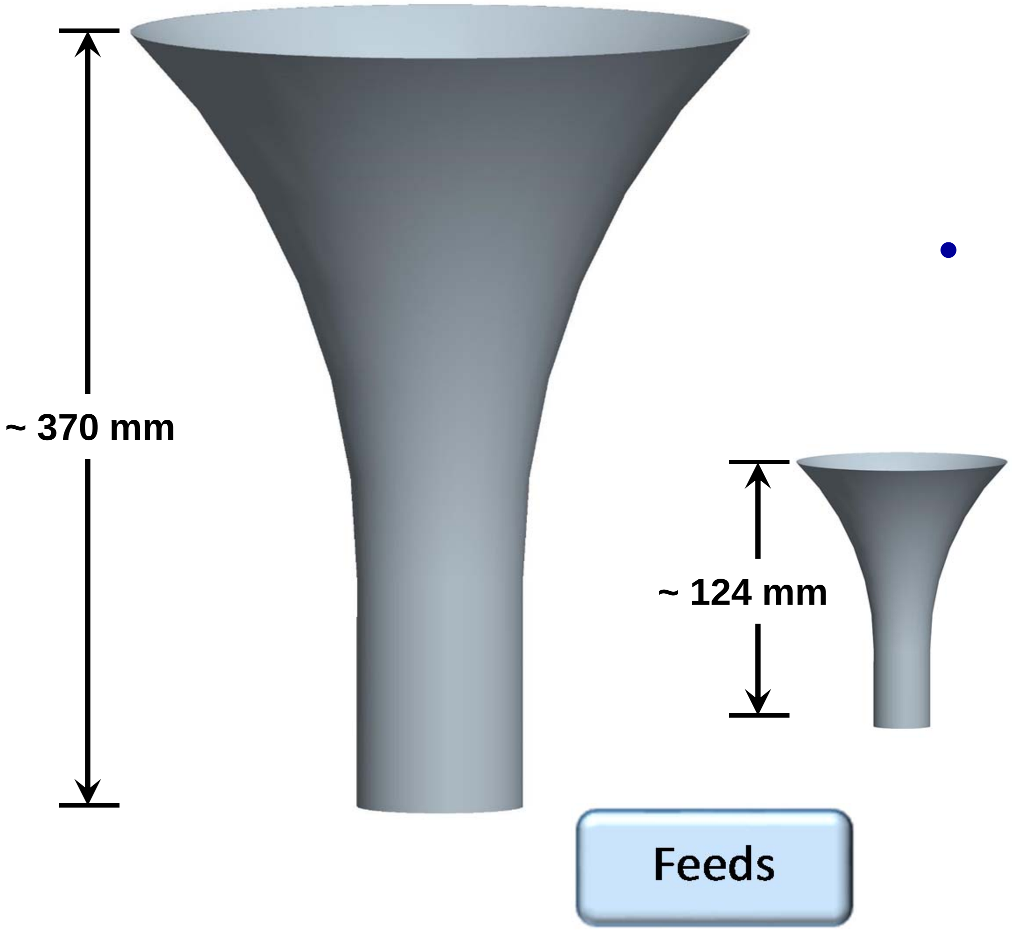


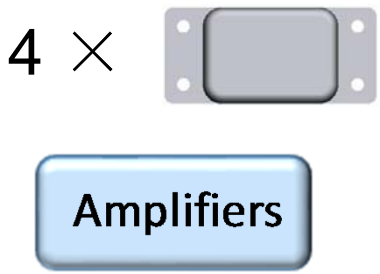
WBSPF CRYOSTAT

WP leader: Nan PENG, TIPC

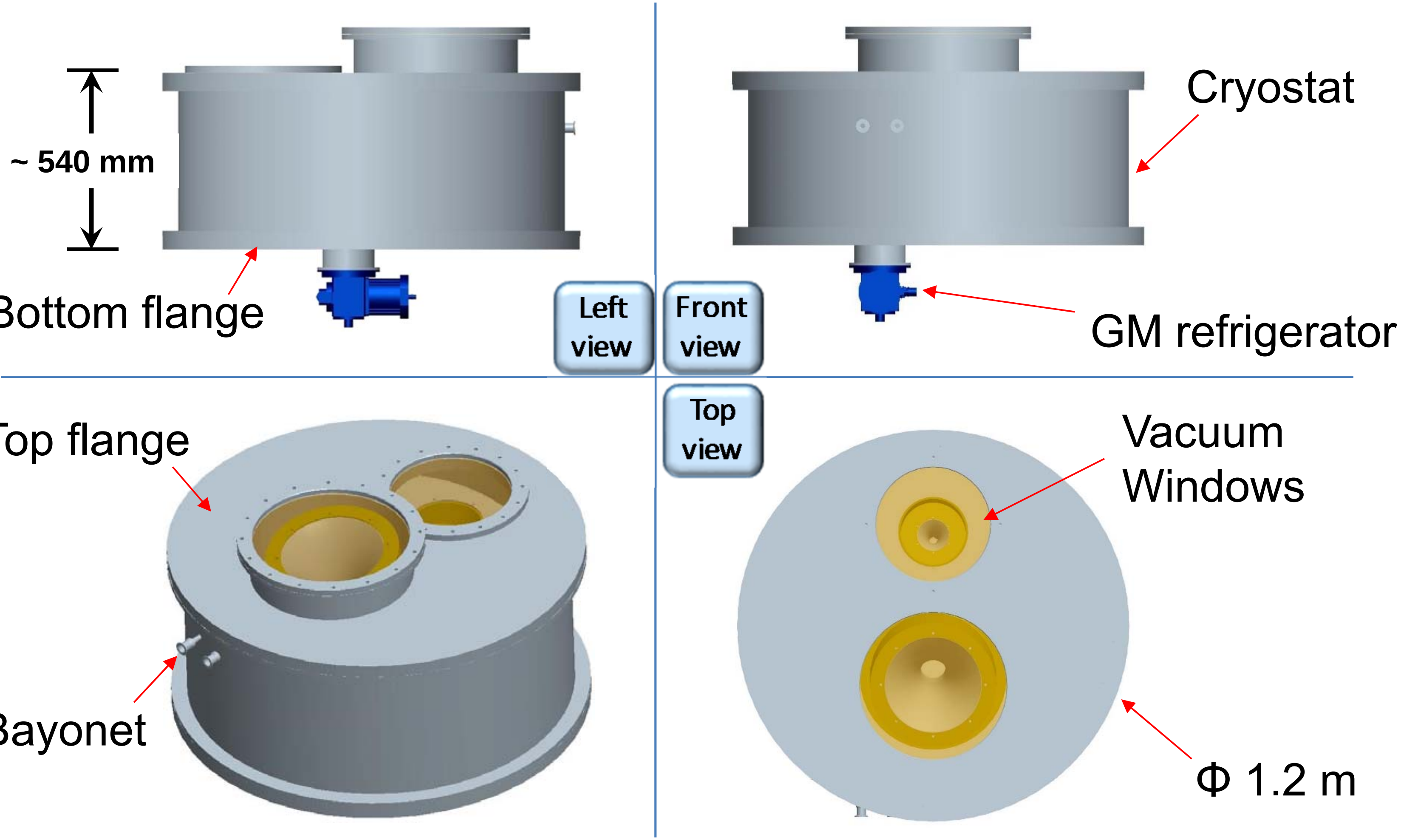
Requirements

- Target:
  - Cool bottom of two feeds lower then 20 K
  - Cool Four Amplifiers lower then 20 K
- Refrigerator:
  - GM refrigerator
  - Small Brayton refrigerator

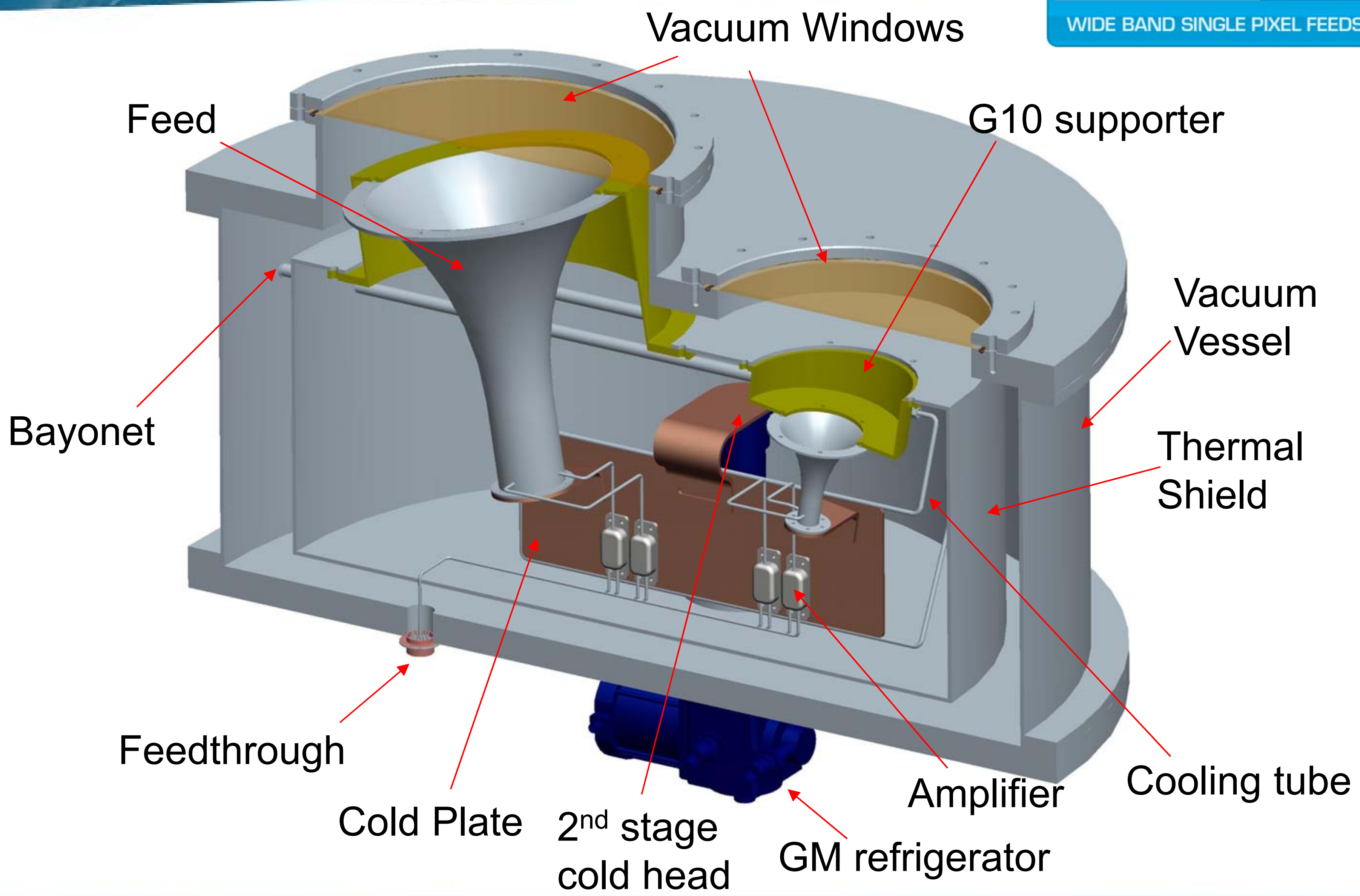




Conceptual design of Cryostat



Section View



Future work

- Complete Feed Design
- Demonstrate performance with prototypes

- Establish link to SKA-DC for considering WBSPF Band B as alternative to SKA-DC Band 5

SKA SQUARE KILOMETRE ARRAY

WIDE BAND SINGLE PIXEL FEEDS

THANK YOU

QUESTIONS?