SQUARE KILOMETRE ARRAY

SKA WBSPF-AIP

www.skatelescope.org

Exploring the Universe with the world's largest radio telescope

Host Countries · Members of SKA Organisation · African partner Countries · Associate Member Countries

Agenda

- WBSPF Consortium Partners
- Organization and WBS
- General Scope of Work
  - WBSPF advantages
  - Frequency band definition
- Schedule and milestones
- Technical overview

WBSPF CONSORTIUM PARTNERS

SKA WBSPF Countries and Institutions

- **Sweden**
  - Onsala Onbservatory – Consortia lead, integration, system tests
  - Chalmers/MEL – LNA design
  - Chalmers/S2/Antenna group - feed design
- **China**
  - JLRAT – overall management
  - NAOC – Feed and LNA design
  - CETC54 – Feed design, integration and tests
  - IPC – small Turbo-Brayton Cryo Cooler
  - SHAO – LNA design
  - Caltech – LNA design and Feed/Cryogenic consultancy
- **Germany**
  - IAF – MMIC processing
  - MPI – LNA design and testing
- **Netherlands**
  - ASTRON – cryogenics and system tests
- **Turkey**
  - Ozyegin University – feed design

Experience and linkages

Experience

- Experience in building receiver systems at national radio astronomy institutes
- Experience at national institutes and universities in developing very wideband LNA
- Work done in the feed community in support of the VLBI2010
- WBSPF built at single dish radio telescopes (i.e. at Effelsberg 100m) or planned (i.e for FAST)
- Design work for PrepSKA on the Eleven feed done under contract between Chalmers University and the former SKADO

Consortia linkages

- Large overlap in membership between SKA-WBSPF and SKADC
- Chalmers is involved in SKADC Band 1
- Linkage with SKADC in the area of antenna optics
- IAF Fraunhoffer and Chalmers MEL are identified within SKADC as possible sources of LNAs for bands 3, 4 and 5

Lead organisation and Key people

Lead organisation
Chalmers/Onsala Observatory

Formal Head of Project/Project Scientist
John Conway

Project Manager
Miroslav Pantaleev

System engineer
Bhushan Billade

Dish optics
Marianna Ivashina

Band A System Engineer
Jin Chengjin

Band B System Engineer
Bhushan Billade

WBS

WIDE BAND SINGLE PIXEL FEEDS

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.R&D.BandA
R&D Band Low

SKA.TEL.WBSPF.R&D.BandB
R&D Band High

SKA.TEL.WBSPF.SE.IM
Interface Management

....R&D.BandA.LNA
LNA design 0.3-2GHz

....R&D.BandB.LNA
MMIC for 2-10+GHz

SKA.TEL.WBSPF.SE.MOD
Performance modelling

....R&D.BandA.FEED
Band LO feed design

....R&D.BandB.FEED
Band HI feed design

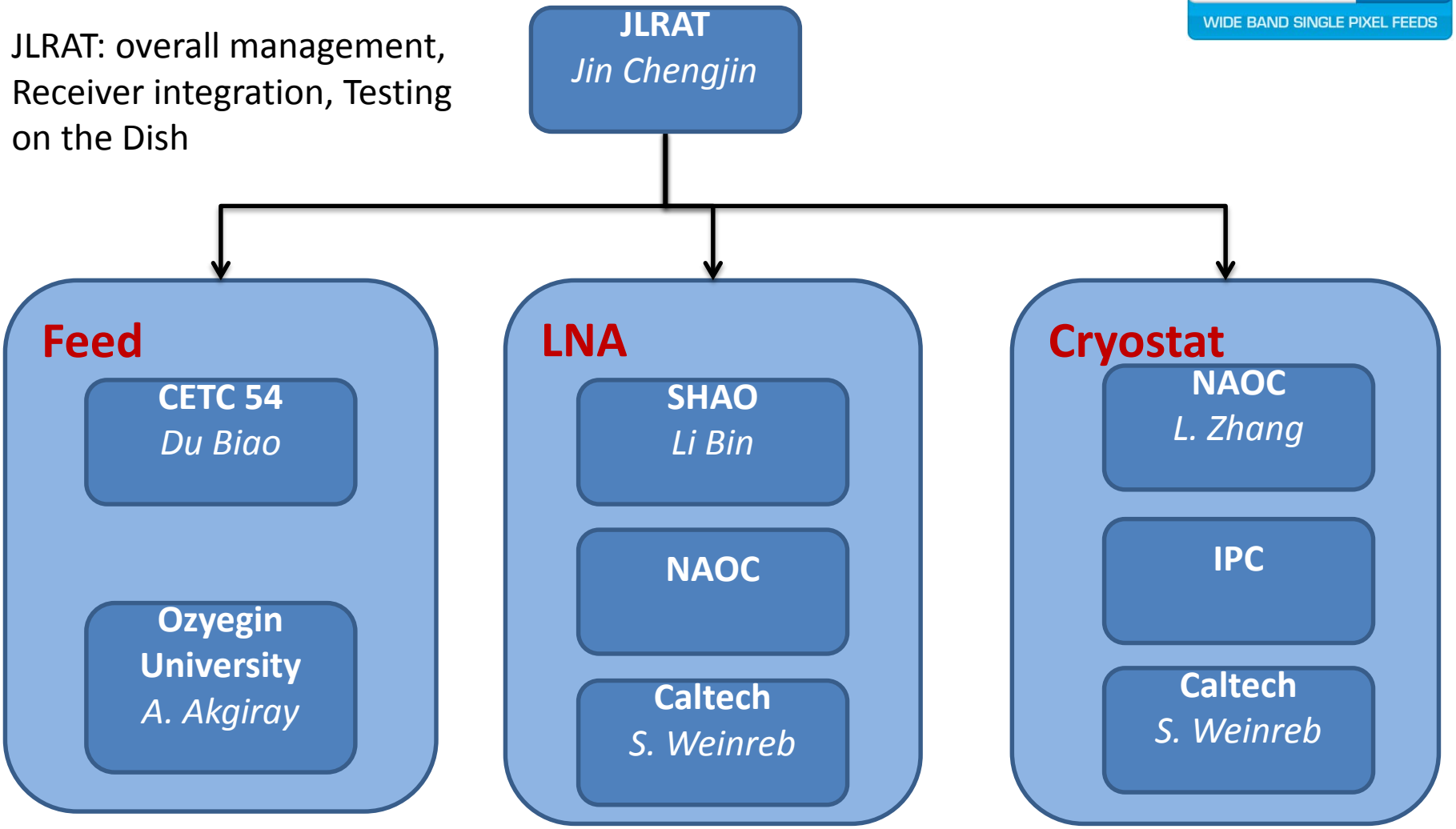
SKA.TEL.WBSPF.SE.STUDY
Study of availible WBSPF

....R&D.BandA.CRYO
Cryostat Band Low

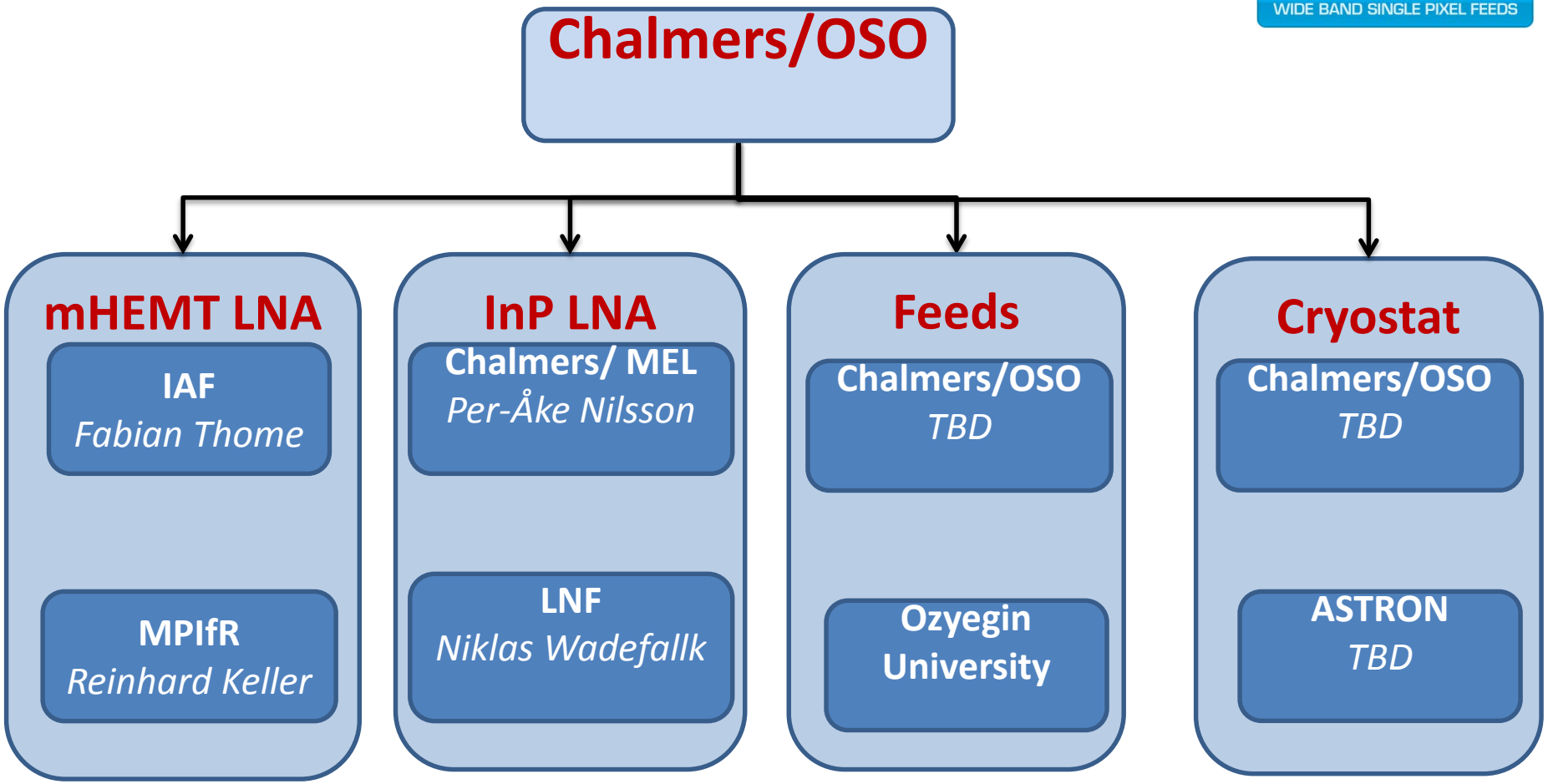
....R&D.BandB.CRYO
Cryostat Band High

Band A

JLRAT: overall management, Receiver integration, Testing on the Dish



Band B


Chalmers/OSO
mHEMT LNA
IAF
Fabian Thome
MPIfR
Reinhard Keller
InP LNA
Chalmers/ MEL
Per-Åke Nilsson
LNF
Niklas Wadefallk
Feeds
Chalmers/OSO
TBD
Ozyegin University
Cryostat
Chalmers/OSO
TBD
ASTRON
TBD

WBSPF Consortium partners, Signatories and FTE commited (as at RfP submission)

Partner	Type	Contact	LoI Signatory		FTE –yr Committed		FTE-yr Tentative	Material Cost and Travel
					Stage 1	Stage 2	Stage 1+2	kEuro
Chalmers University - Sweden	Full	Miroslav Pantaleev	Hans Olofsson		4.5	2.25		247
JLRAT – China	Full	Jan	Hao Jinxin		4	2		700
Fraunhofer - Germany	Full	Fabian Thome	Oliver Ambacher		1	0.5	1.5	30
MPIfR - Germany	Full	Reinhard Keller	Michael Kramer		0.7	0.3	2	18
ASTRON	Associate	Jan Geralt bij de Vatte	Michael Garrett		0.35	0.35		16
Ozyegin University - Turkey	Associate	Ahmed Akgiray	Reha Civanlar		0.4	0.2		0
				Totals	10.95	5.6	3.5	1011

WBSPF AIP
GENERAL SCOPE OF WORK

Advantages of WBSPF

Science advantages

- Wide z space for blind HI and OH
- Simultaneous observations of multiple spectral lines, including multiple molecular rotational lines
- Higher bandwidth giving higher sensitivity for continuum observations surveys increasing survey speed
- Advantages for observing fast continuum transients
- WBSPF can search (or time) simultaneously pulsars at a very wide range of galactic dispersion measures along some lines of sight
- Higher probability of serendipitous discoveries including SETI signals

Advantages of WBSPF

System and Operational advantages

- Capital costs- for any reasonable budget dish costs for SKA2 must be pressed down
- 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

FREQUENCY BAND DEFINITION

Considerations

SKA1 baseline requiremens

- Continuous frequency coverage
- For the 350MHz – 20GHz a range of 57:1, two ultra-wideband feeds 7.5:1 are needed
- Frequency range would be:

  Band A 0.30 – 2.6GHz

  Band B 2.60 – 20.0GHz
- Lower band (Band A) would encompass all red-shifted ***HI***, ***OH*** and non-galactic centre pulsar work
- Upper band (Band B) would cover most molecules of the Cradle of Life science goal and detection and timing of pulsars toward the galactic centre

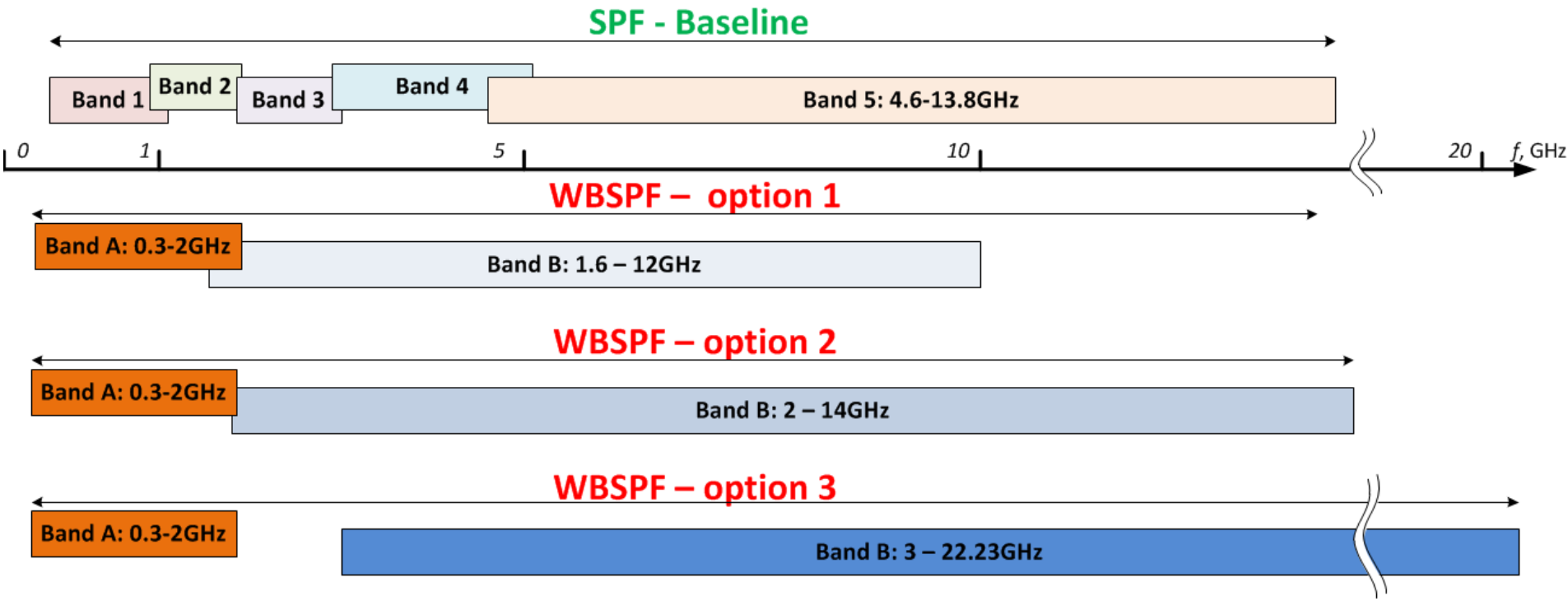
Practical considerations as presented in tender

- Using the dish in 0.30-0.35GHz frequency range, not covered by SPF Band 1
- Sky noise contribution
- Cooling of feed Band A
- Feed B cryogenic integration about 1.6GHz
- Overlaps SPF Band 3 frequency:

  Band A 0.30 – 2.0GHz

  Band B 1.60 – 12.0GHz

WBSPF Band B alternatives



- Option 1: Original proposal in tender.
- Option 2: Similar to VLBI2010.
- Option 3: pulsar timing towards galactic centre, redshifted CO(1-0), Galactic and redshifted H20, large molecules in interstellar medium.

General Scope of Work

WIDE BAND SINGLE PIXEL FEEDS

- 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.

SCHEDULE AND MILESTONES

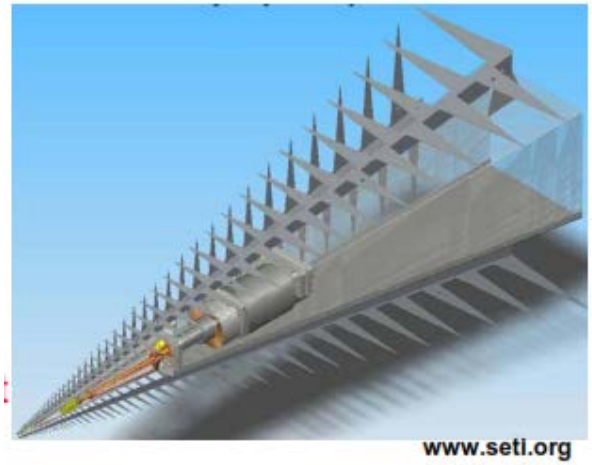
WBSPF AIP High-Level Schedule

- WBSPF AIP requirements definition - 2013-12-20
- Bands A and B Feed Design Report - 2014-08-31
- LNA modules for integration with the Band B feed - 2014-12-31
- Bands A and B Feed Test report - 2015-03-31
- SRR and PDR data package - 2015-06-15
- Bands A and B cryogenic package test report - 2016-03-01
- Testing on Dish Report - 2016-03-31
- PDR data package - 2016-07-01

TECHNICAL OVERVIEW

WBSPF alternatives

WIDE BAND SINGLE PIXEL FEEDS

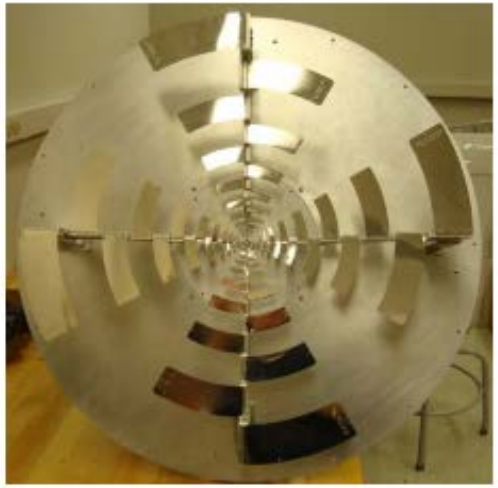


Tn ~40 to 45K over 7:1 BW

The ATA Feed

- Allen Telescope Array or ATA
- Frequency: 0.5 to 11.5 GHz
- The -10dB HBW=43°
- Phase Center is frequency dependent
- Size: 0.3 m x 0.3 m x 1.2 m
- Good Match, better than –14 dB

Non-planar log-periodic antenna feed for integration with a cryogenic microwave amplifier, *G. Engargiola Antennas and Propagation Society International Symposium 2002, IEEE San Antonio, TX, Volume 4, 16-21 June 2002 Page(s):140 - 143 vol.4*



QSC-Feed

- Frequency: >10:1 Bandwidth
- The -10dB HBW is ~ 65°
- Phase Center is frequency independent
- Now Compact Size ~$(0.75\lambda_{max})^2$ x $0.2\ \lambda_{max}$
- Input Matching better than –10 dB

Novel Non Planar Ultra Wide Band Quasi Self-Complementary Antenna, *Germán Cortés M. IEEE AP-S International Simposium, Honolulu, Hawaii, June, 2007*

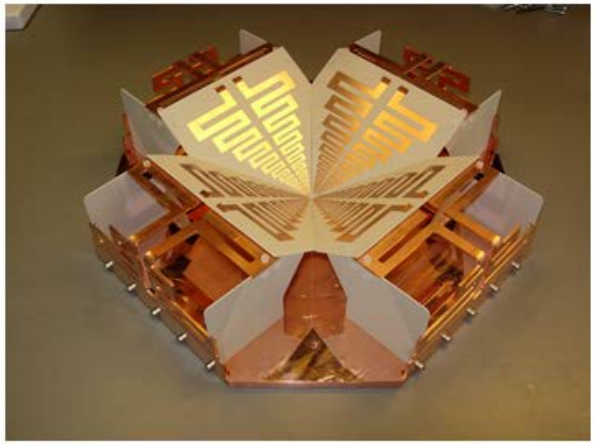
Frequency: 0.5 to 3 GHz

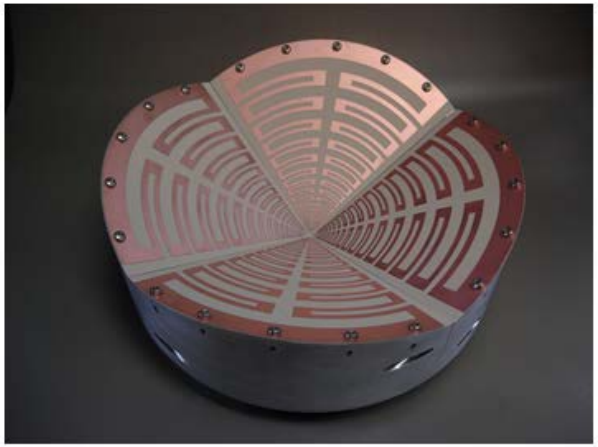
Inverted, Conical, Sinuous Antenna over a Ground Plane

- Frequency: 10:1 Bandwidth
- The -10dB HBW is ~ 65°
- Phase Center is frequency independent
- Size ~$(?\lambda_{max})^2$ x ? λ_{max}
- Input Matching better than –8? dB

The Inverted, Conical, Sinuous Antenna over a Ground Plane, *Rohit S. Gawande and Richard F. Bradley.URSI 2007 Ottawa, Canada, July, 2007*

WBSPF overview - Eleven Feed





diam. 785mm, height 311mm	*diam. 280mm, height 68mm*	*diam. 210mm, height 68mm*
0.4-1.5GHz	*1.2-10GHz*	*1.2-14GHz*

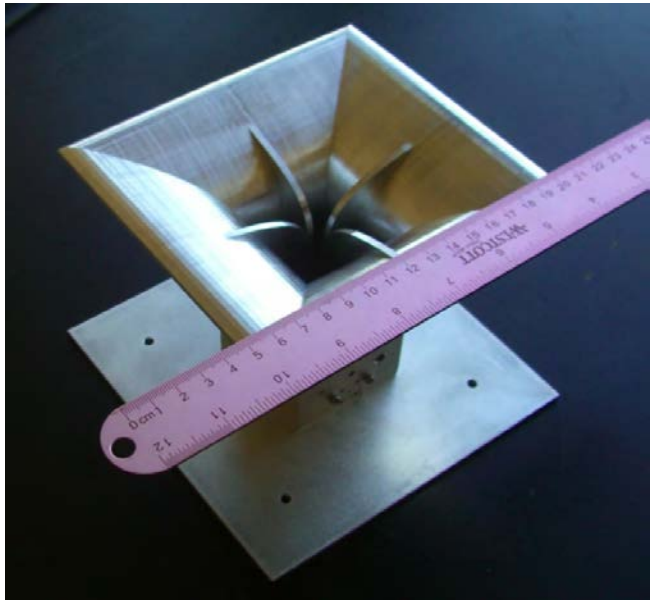
- Frequency band up to 11:1
- The -10dB HBW ~ 62°
- Phase Centre is frequency independent
- Compact size - Ø0.65 λ_{max} x 0.2 λ_{max}
- Input matchning better than -12dB
- Good beam and polarisation symetry

Challenges:

- Complicated feeding
- Work well over small F/D range

Jian Yang, Miroslav Pantaleev, Per-Simon Kildal and Leif Helldner, "**Design of compact dual-polarized 1.2-10 GHz Eleven feed for decade bandwidth radio telescopes**", *IEEE Trans. on Antennas Propagat.*, vol. 60, no. 5, pp. 2210–2218, May 2012.

WBSPF overview - QRFH



- Frequency band near-constant beam width over 5:1 to 7:1 frequency ranges
- The -10dB HBW can be designed for the range of 25-75°
- Compact size - Ø1.1 λ_{max} x 1.2 λ_{max}
- Input matchning better than -12dB
- Can be optimised for wide F/D range

Challenges:

- Polarization and beam symmetry

A. Akgiray, S. Weinreb and W. A. Imbriale, "**Circular Quadruple-Ridged Flared Horn Achieving Near-Constant Beamwidth Over Multi-Octave Bandwidth: Design and Measurements**," IEEE Trans. Antennas Propag., vol. 61, no. 3, 2013.

Challenges of WBSPF

Performance issues

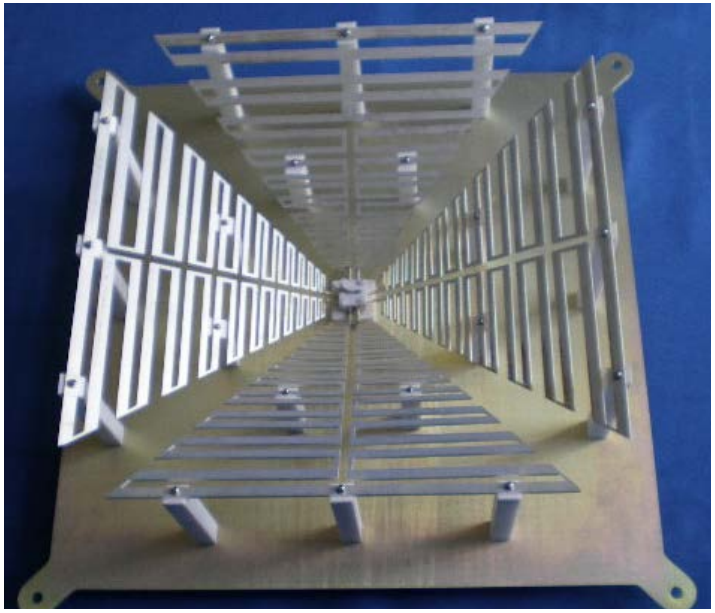
- Lower sensitivity than octave feed horn
- Some degradation in performance if they are made very wide band
- We believe the gap in performance can be narrowed given further R&D

Relative merits of octave horns versus WBSPF

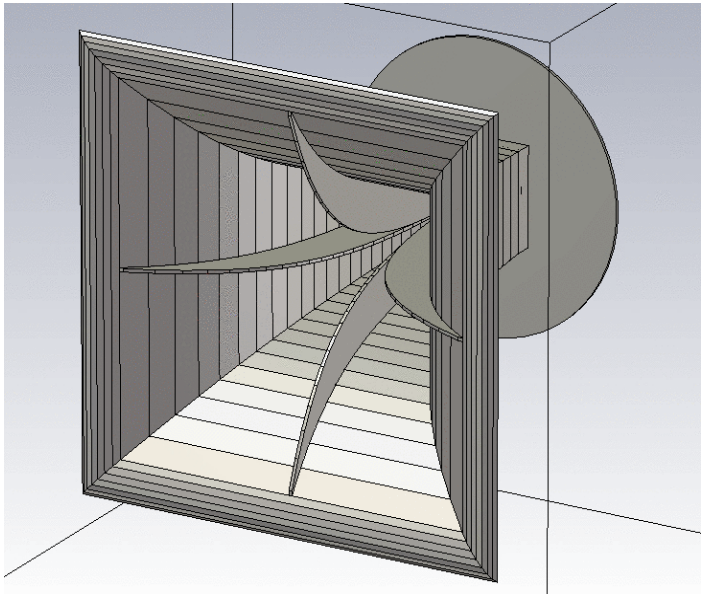
- Full ‘cost of ownership’ analysis including
- Initial investment
- Operations costs

TECHNICAL OVERVIEW – BAND A

Feed candidates for Band A – 0.3 -2GHz



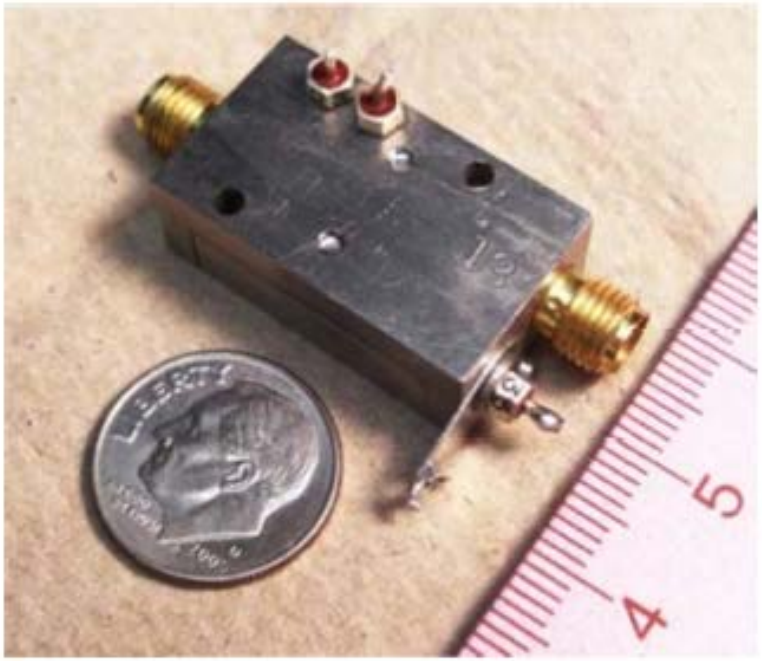
0.4-2GHz UWB feed for CSRH. Dimensions 465mm x ×465mm × 185mm (h).

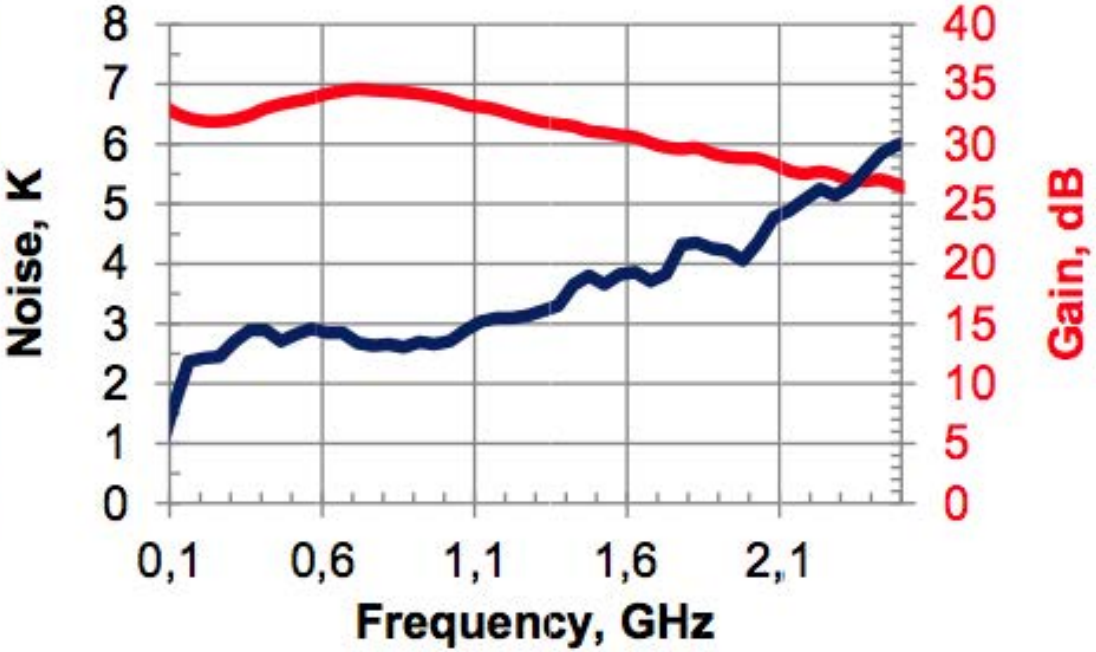


QRFH for, preliminary design by Caltech for FAST (F/D = 0.461) for 0.27 to 1.62 GHz.

Size 1m x 1m x 0.83m.

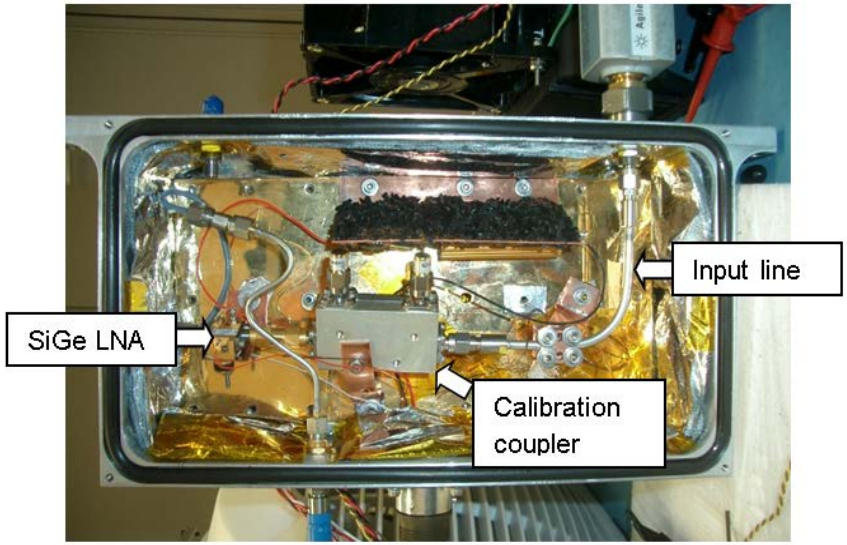
LNA—0.01-2GHz





- Caltech CITLF2 SiGe low noise amplifier.
- The noise and gain data is measured at 22K with DC bias of 2.5V and 22mA.
- Input and output return loss are better than 10 dB.
- The design will be further optimized for FAST and SKA frequency bands.

Band A – 0.3 -2GHz - cryogenic integration



- Cryostat housing the LNA
- Either SiG or InP LNA
- Either 20K or 60K cryostat
- The table below shows the noise budget for either physical temperatures

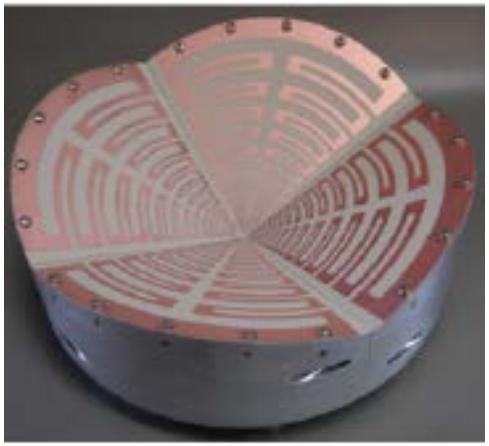
Cryostat Temp, Tphy	LNA Noise	Loss at Tphy, dB	Noise Added by Lphy	Transition Loss, dB	Noise Added by Transition	Cable Loss, dB	Noise Added by Cables	Total Noise at Feed Connector	Ant Temp	Tsys, K
60	10	0.4	6.2	0.1	4.5	0.1	7.3	28.0	15	43.0
20	4	0.4	2.1	0.1	3.8	0.1	7.1	17.0	15	32.0

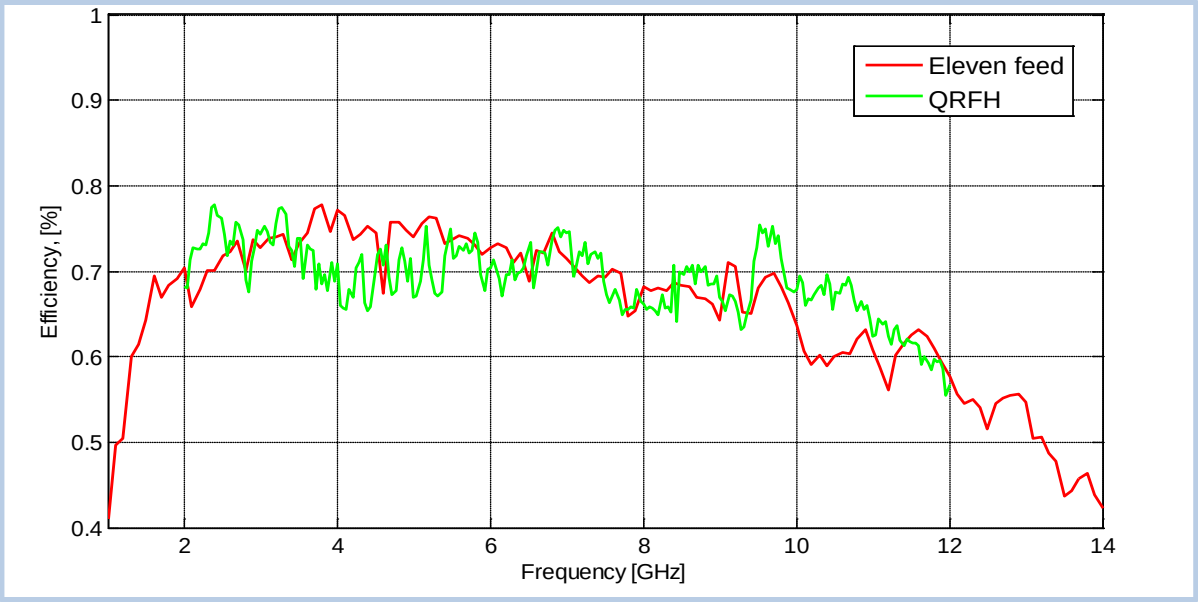
Turbo-Brayton Cooler – 2-5K – 200K

- Great reliability: operating lifetimes without maintenance of over 100,000 hours(~11 years)
- Reduced vibrations: low level of vibration (a few µg at 1500 Hz)
- Simplify the cryostat design

TECHNICAL OVERVIEW – BAND B

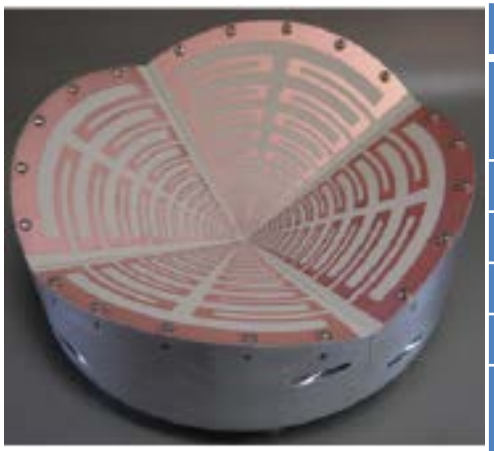
Feed candidates for Band B – 1.63 - 12GHz





- Both feeds are well developed for the VLBI2010
- The efficiency in the above plot is for 12m Cassegrain antenna with ring focus sub-reflector.

Feed candidates for Band B – comparison

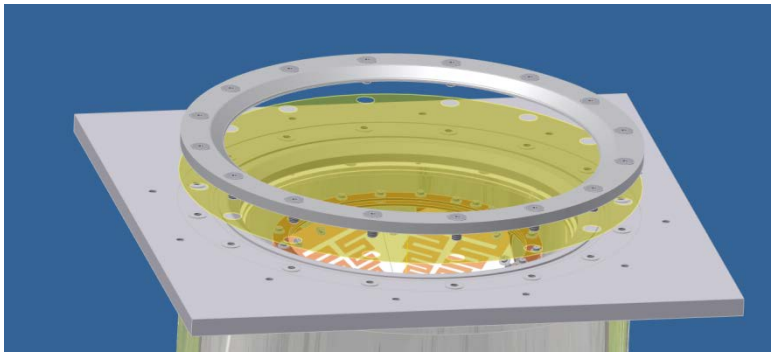


	Eleven	QRFH
Frequency range (GHz)	1.2-14	2.2-14
Polarization	Dual-Linear	Dual-Linear
Port Configuration	Differential	Single-Ended
LNAs per Polarization	4	1
LNAs per Feed	8	2
LNA Balance Requirements	1.6 dB amp 14° phase	None
Aperture Efficiency (F/D ~ 0.4)	60-70% (1-10GHz) 50-60% (10-14GHz)	55-65% (2-10GHz) 45-55% (10-14GHz)
Ground Noise Contribution (F/D ~ 0.4)	Preliminary 10-20K, but more research is needed	<20K (2.2-5 GHz) <10K (5-14 GHz)
F/D Range	0.35-0.5	Adaptable for nominal 0.3-0.7
Feed 10-dB half-beamwidth	65°	Adaptable for nominal 55°-140°
Size	Diameter 210mm height 65 mm	diameter 160mm height 150mm

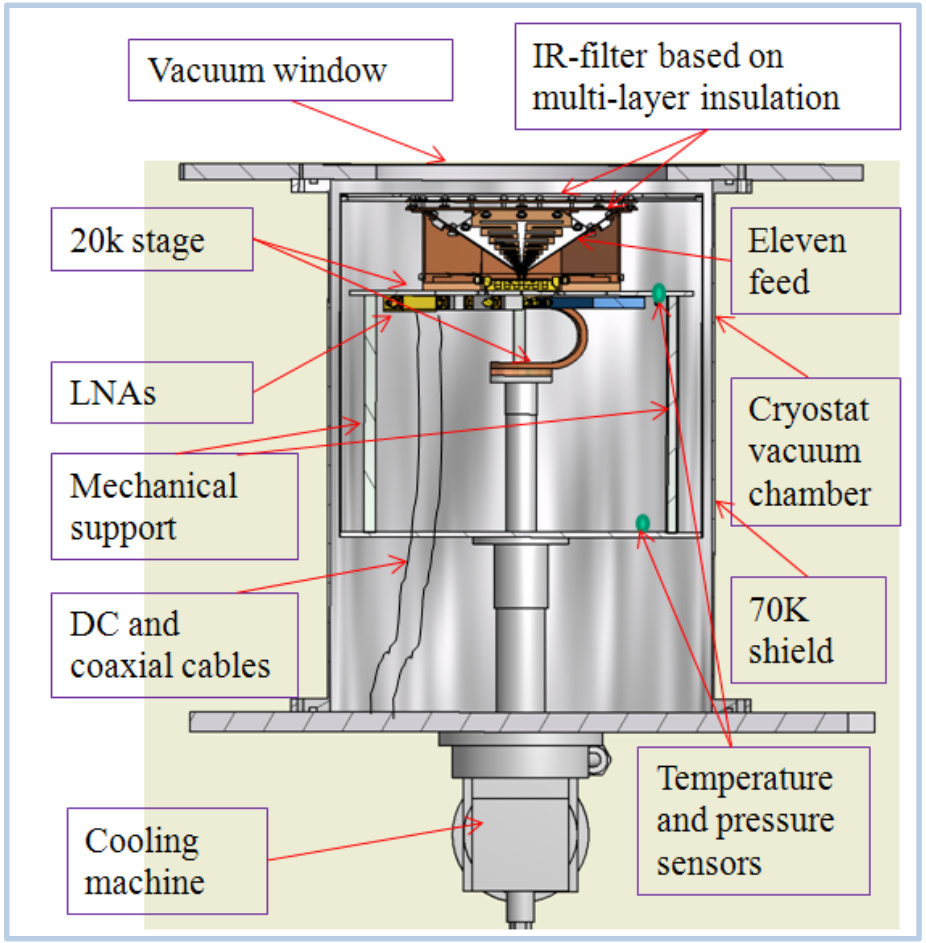
Feed Band B design optimisation

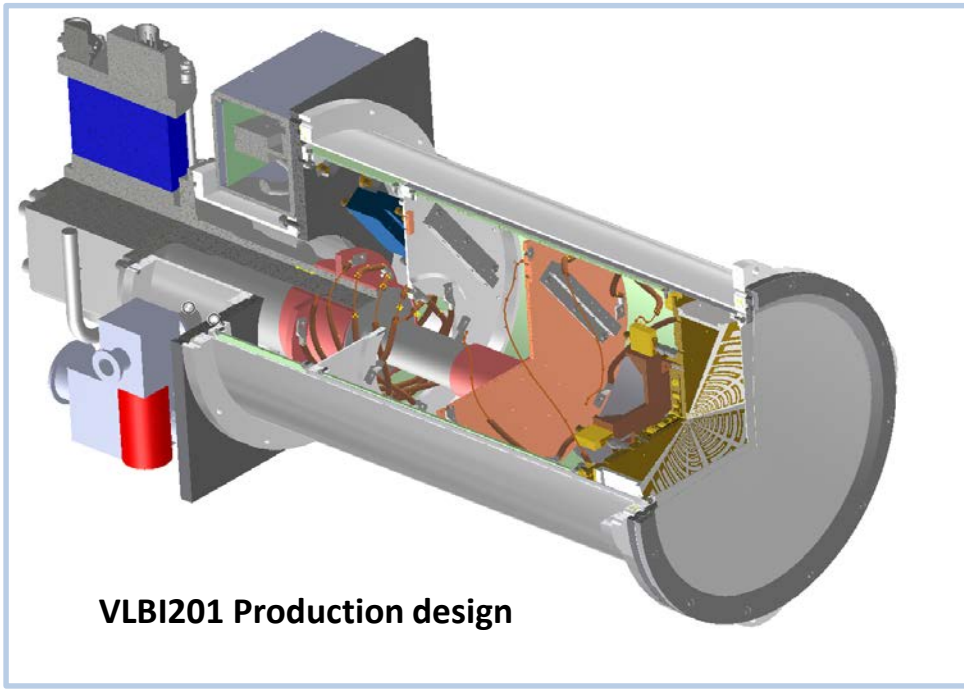
- SKADC will fix the design of the dish after CDR in spring 2014.
- MATLAB code runs CST or FEKO to iterate over space of design parameters
- Evaluate the best design for given design goal
- Verify the performance in given Antenna optics design using FEKO or GRASP
- Verify the Receiver noise using MATLAB code
- Calcualte Eeff/Tsys
- Verify polarimetric performancen

Band B cryogenic Integration



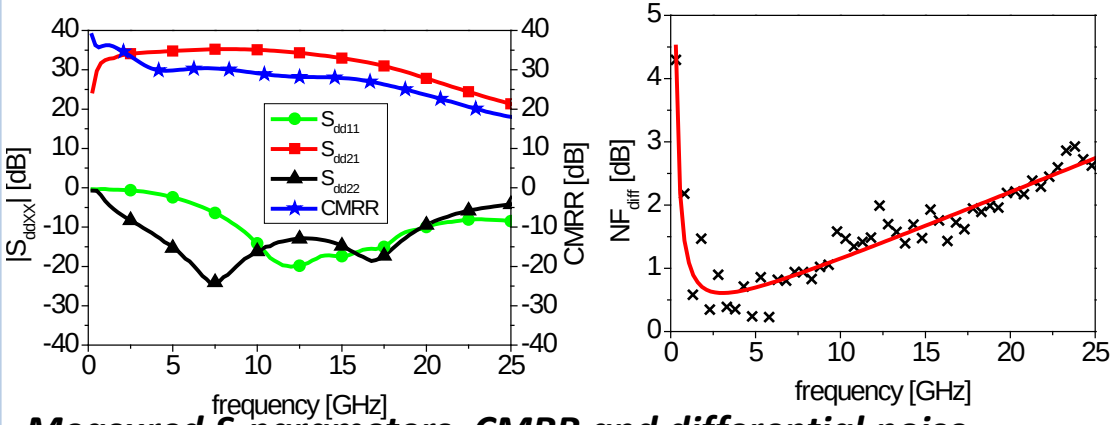
- Vacuum window 0.35mm thick Mylar
- Deflection of about 25mm
- The location of the Feed is determined by the deflection of the window



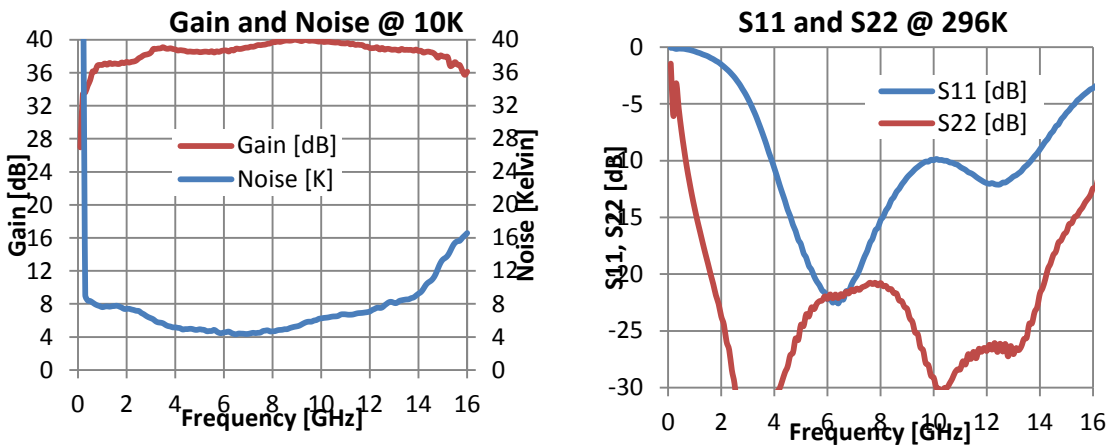


VLBI201 Production design

LNAs for Band B



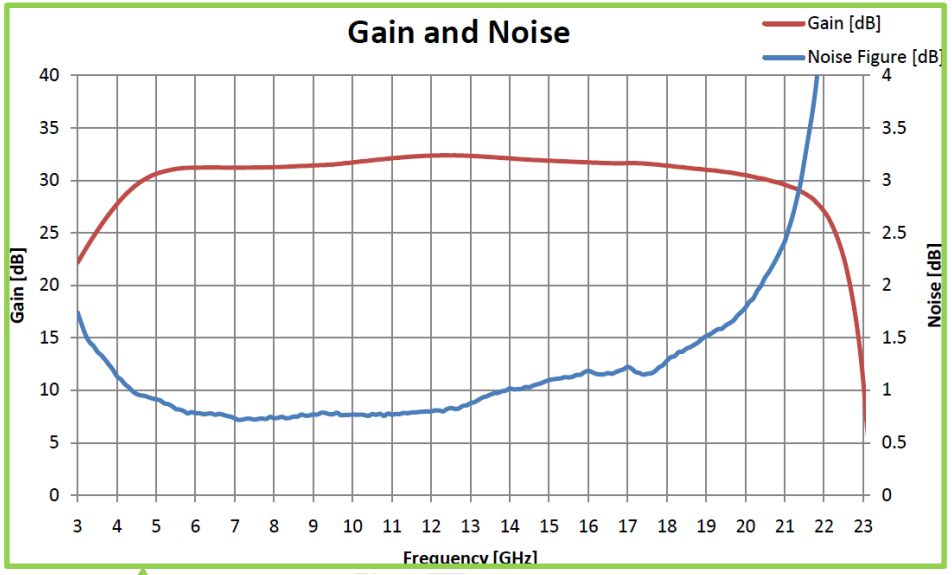
Measured S-parameters, CMRR and differential noise fat room temperature of the differential LNA from IAF.



Measured typical performance of MEL/LNF LNA

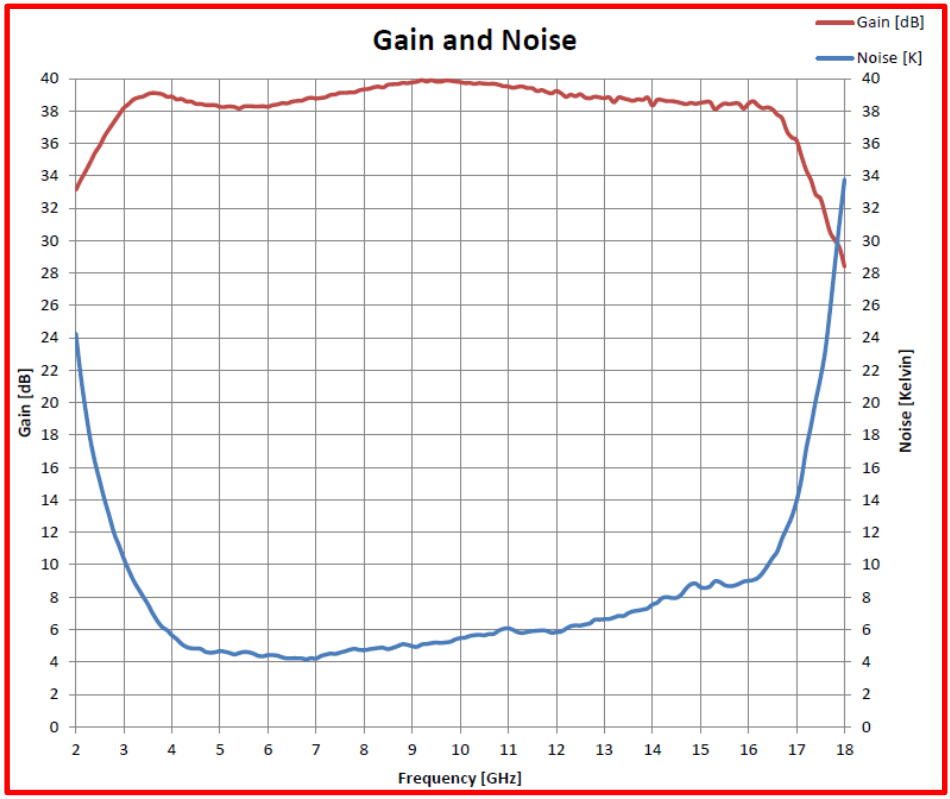
- Two foundries are involved: IAF from Germany and MEL from Sweden
- Designs will be made for InP processes in both foundries
- Designs will be made for 50ohm single ended and 100ohm differential inputs of the LNA

LNAs for Band B alternative 3-22GHz



6-22GHz at room temperature

4—16 at cryogenic temperature



- Commercially available from Low Noise Factory
- 6-22GHz, room temperature
- More than 800pcs. sold to customers
- 4-16GHz - cryogenic
- Design for 3-22GHz is possible with gain degradation towards edges of the band.