Thermoplastic axi-symmetric dish

Chalmers University
Airborne
ASTRON

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Agenda

- Introduction, consortium
- Requirements
- Reflector
  - Reflector Design
  - Reflector Performance
  - Reflector Cost
- Overall mechanical Design
  - Feed support
  - Pedestal
  - Drive
  - Manufacturing
- Electro Magnetic Design
  - Eleven Feed
  - Symmetric, a-symmetric performance
- Future
  - Plans
  - Technology to be developed
  - Risk assessment
  - Summary, Conclusions

Introduction

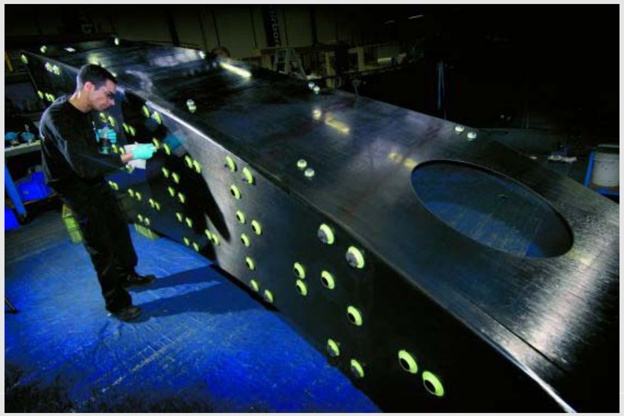
- Dutch Industrial project group
  - TC-SKAR (Thermoplastic Composite Square Kilometer Array Reflector)
    - » Airborne Composites
    - » Dutch Thermoplastic Components (DTC)
      an internationally recognized specialist in thermoplastic press forming
    - » Kok en van Engelen (KvE)
      developed a special induction welding process, which is used in aerospace
    - » Delft University (TU-Delft)
      well known for its material expertise on thermoplastic composites
    - » ASTRON
- Chalmers University
- ASTRON

TC SKAR expertise

Airborne Composites

is selected to manufacture and deliver the composite structures for 25 telescopes to Vertex Antennentechnik from Duisburg, Germany, who supply to the North American part of the **ALMA** project.

- Large backup structure of the reflector dish
- Center hub
- Quadrapod legs
- Head part that contains M2



Functional Requirements

Functional requirements used for design reflector dish:

Top level

- Focal ratio 0.42
- Frequency range 1.2 - 10 GHz
- RMS 1mm
- Lifetime >30 years
- Dish Diameter 15 m

*Lower frequencies not studied, not excluded

Operational requirements

- Elevation from 15 to 91 degrees
- Windspeed 12m/s
- $T_{Ambient}$ 1 to 40°C
- Solar 980 W/m^2
- $Humidity_{max}$ 100%

Product design aspects

- Stow wind speed max 18m/s
- Survival wind speed max 45m/s
- Maintenance interval 5 years
- Lightning protection on construction

Aspect requirements

- Feed weight max 170kg
- Feed mount type four legs attached to dish edge

Requirements defined in cooperation with SPDO

Reflector

Reflector Design
Reflector Performance
Reflector Cost

Dish topics

- Reflector
  - Thermoplastic carbon reinforced composite material
  - Structural Design
  - Mechanical Performance
  - Dish Performance
- Manufacturing Reflector parts
- Assembly Reflector
- Reflector Cost
- To DO

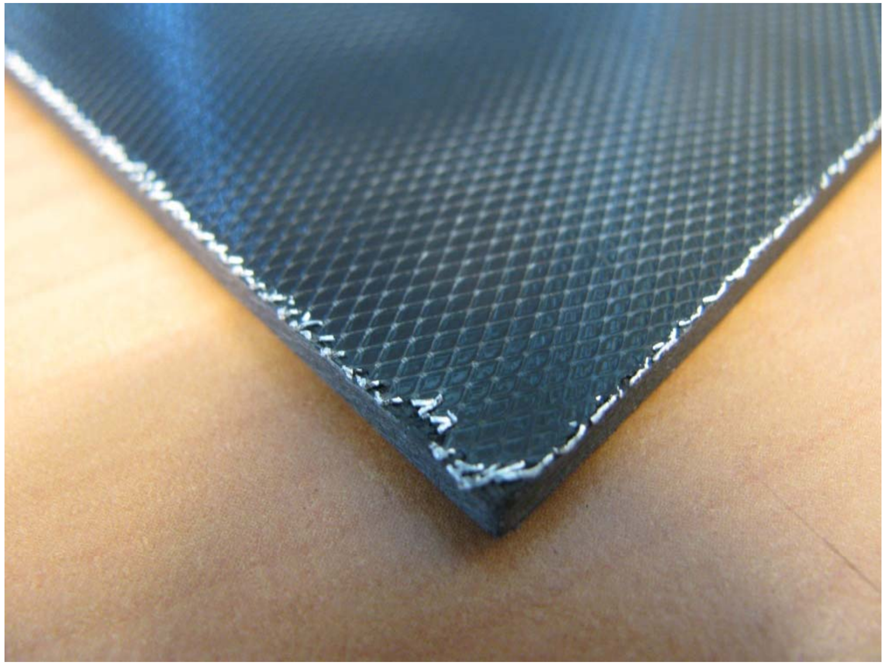
Reflector

Thermoplastic carbon reinforced composite material

Benefits

- Embed a thin metal mesh to add reflectivity performance
- Low thermal coefficient
- Low weight (-30%: metal option)
- Coating to protect from atmospheric influences easily applied
- Suitable for recycling and repairs

- Thermoplastic composite
  - tougher, more ductile and robust compared to metal options,
  - Combined with carbon fibres outperforms aluminium and steel constructions
- ***Reflectivity:*** Embedded thin metal mesh for good reflectivity; initial studies show >99% reflectivity



Reflector

Typical material properties

- CFRP = carbon fibre reinforced plastic

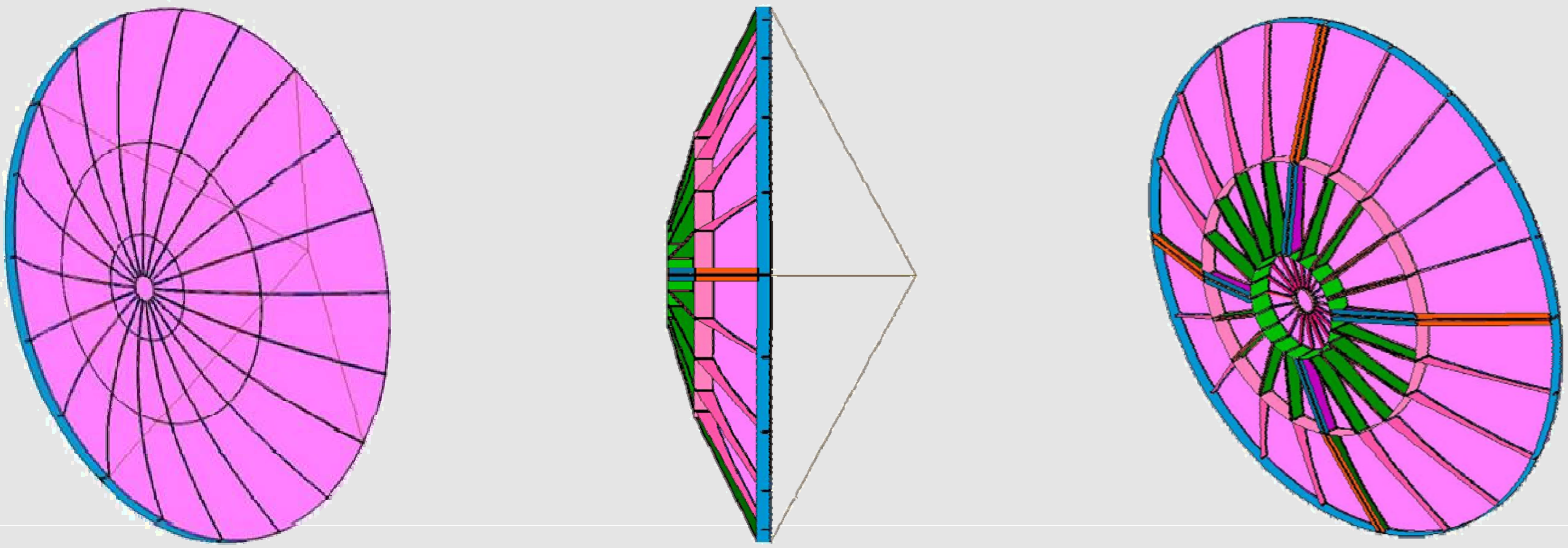
• Modulus of elasticity uni directional	90 GPa
• Modulus of elasticity 0/90 ply	45 GPa
• Modulus of elasticity quasi isotropic	32 GPa
• Tensile / compressive strenght 0/90 ply	700 MPa
• CTE carbon fibres	$-3.6*10^{-7}$ 1/°C
• CTE matrix material	$3.0 – 7.0 *10^{-5}$ 1/°C
• CTE CFRP	$3.0 – 7.0 *10^{-6}$ 1/°C
• Density	1550 kg/m^3

- Creep properties are currently being tested at the University of Delft

Reflector

Structural Design

- Baseline design reflector:
  - a stiffened skin with several different stiffeners.
  - entire structure same thermoplastic carbon based material.
  - manufactured using a single automated production process.



Reflector

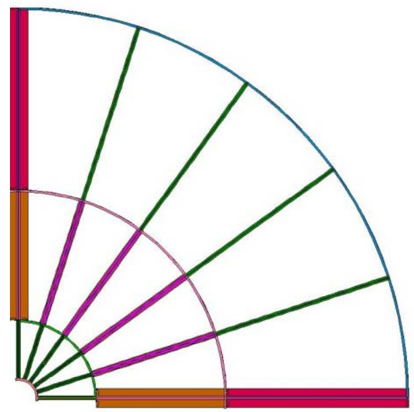
Structural Design

- All the stiffeners are relative **simples parts** which are **welded** together

T-stiffeners
- More efficient (stiffness versus mass) compared to blade stiffeners
- More difficult to produce

Blade stiffeners
- Used in regions with lower requirements

Total weight of the integrated reflector structure = 1580kg.
(Reflector + back structure!!)



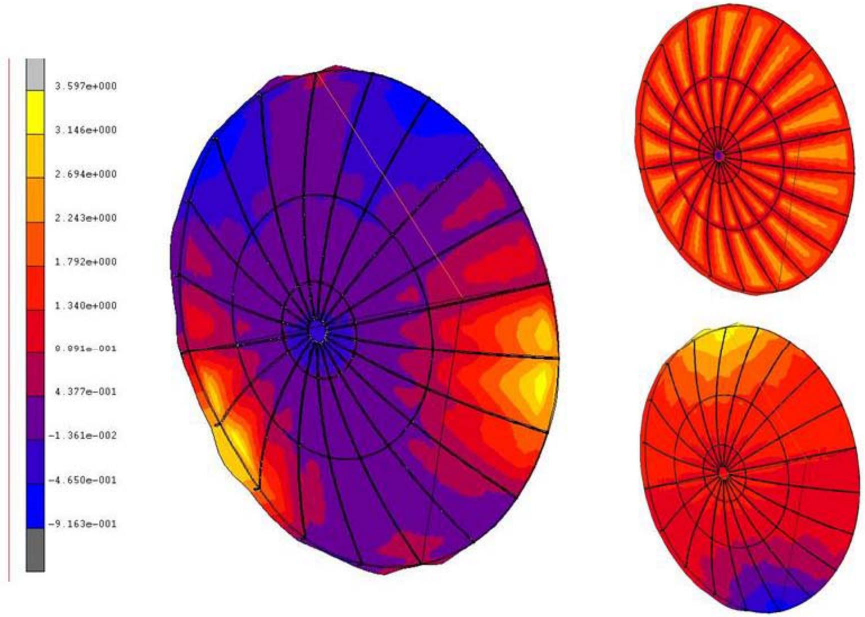
Reflector

FEA results

FEA study evaluated performance of different (and combined) loadcases.

- Gravity
  - RMS caused by gravity, adjusted for gravity re-pointing
- Thermal loading
  - Typical temperatures calculated from ambient, solar irradiation en wind speed
  - Worse case calculated with lack of convection or conduction
  - Additional worse case is based on built up of dust on the surface
- Wind loading
  - Wind cases based on aerodynamic data as measured by "Kron"

With deformations RMS determined



Reflector

RMS performance during typical conditions

- Gravitational load of feed and its support is most important contributor to the deformation
- Manufacturing and assembly accuracy are not known at this stage.
  - Based on experience 0.4 expected
  - Will be validated my manufacturing and measuring several reflector panels for WSRT

$$rms_{tot} = \sqrt{rms_{typical}^2 + rms_{manufacturing}^2}$$

$RMS_{max;expected}$ = 0.67mm

During typical conditions requirements are met easily

Description	rms original surface	rms incl. gravity re-pointing	rms fitted surface
Gravity 15 degrees elevation	0.71	0.25	0.25
Gravity 60 degrees elevation	0.47	0.37	0.34
Gravity 90 degrees elevation	0.49	0.49	0.44
Typical thermal (thermal load case 1)	0.05	-	0.04
Typical wind (4 [m/s]), 60 degrees elevation. (wind load case 1)	0.09	-	0.06
Typical wind (4 [m/s]), 120 degrees elevation. (wind load case 2)	0.07	-	0.02
Total typical (thermal + wind + gravity, 60 degrees elevation)	0.53	0.44	0.41
Manufacturing and assembly accuracy	0.5	0.5	0.5
Total typical incl. manufacturing and assembly	0.73	0.67	0.65

Reflector

RMS values for more extreme conditions

- Current design will meet requirement of a RMS lower than 1 mm even in unrealistic extreme combination of worse case load cases.
- This leaves potential for a design optimisation
  - To further reduce weight and the amount of composite components.
  - That will allow for an increase in the diameter of the dish

Description	rms original surface	rms fitted surface
Thermal load case 2	0.38	0.07
Thermal load case 3	0.52	0.1
Thermal load case 4	0.22	0.20
Thermal load case 5	0.22	0.21
Wind 12 [m/s], 60 degrees elevation. (wind load case 3)	0.78	0.55
Wind 12 [m/s], 120 degrees elevation. (wind load case 4)	0.65	0.17
Total extreme conditions (thermal loadcase 4 + gravity + wind 12 [m/s] (wind loadcase 3), elevation of 60 [degrees])	0.79	0.73
Total extreme conditions typical incl. manufacturing and assembly	0.93	0.88

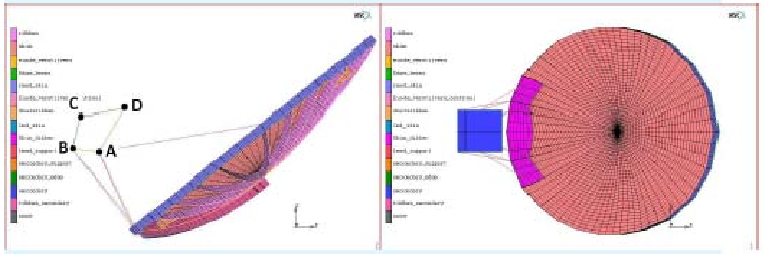
Symmetric versus offset

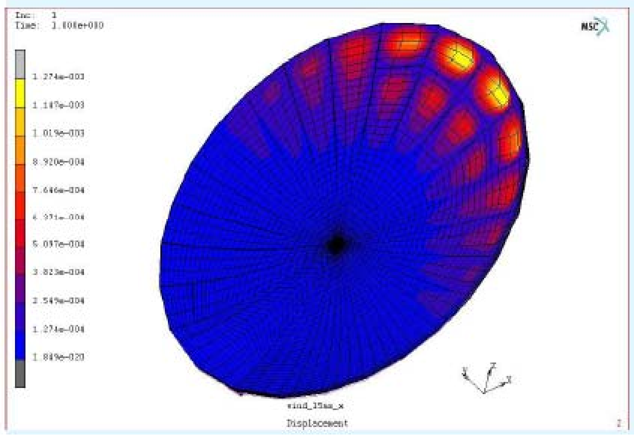
Mechanical difference

TC-SKAR started with offset

- **weight offset = 2500 kg,**
    - **1,6 times symmetric**
- **Cost offset 1,5 times symmetric**
- **Multiple risks in assembly**

• Vertical and forward bracing	200	kg
• Secondary support beams	100	kg
• PAF and positioned	500	kg
• SPF feed indexer and center frame	700	kg
• Secondary reflector	85	kg

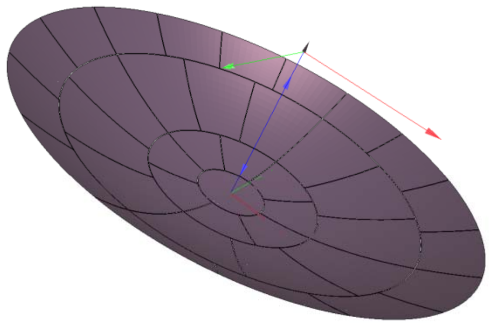




Reflector

Dish performance

- Base material
  - ε_r~4.2
  - tanλ~0.01
- With integrated mesh
  - T_{noise} contibution 1-1.5 K
  - Analysed with cavity method also used by DRAO
- Currently a study is running to investigate the noise contribution of a reflector build out of panels



Manufacturing

Parts

- Skin section
  - Skin build up with 5 types of panels
  - Average area about $2m^2$ (90p)
  - Enables high volume production
  - Press forming technique
  - Integrated reflective mesh
- Centre ring
  - Composite ring supports the dish structure and is the connection point to the pedestal
- Ribs
  - Rib structure is integrated
  - Tappered I-shaped beams for optimal weight & performance
  - Press forming
  - Attached by automated welding process
- Mid and Outer ring
  - Adds extra stiffness to the structure

Assembly Reflector

Problem definition reflector assembly

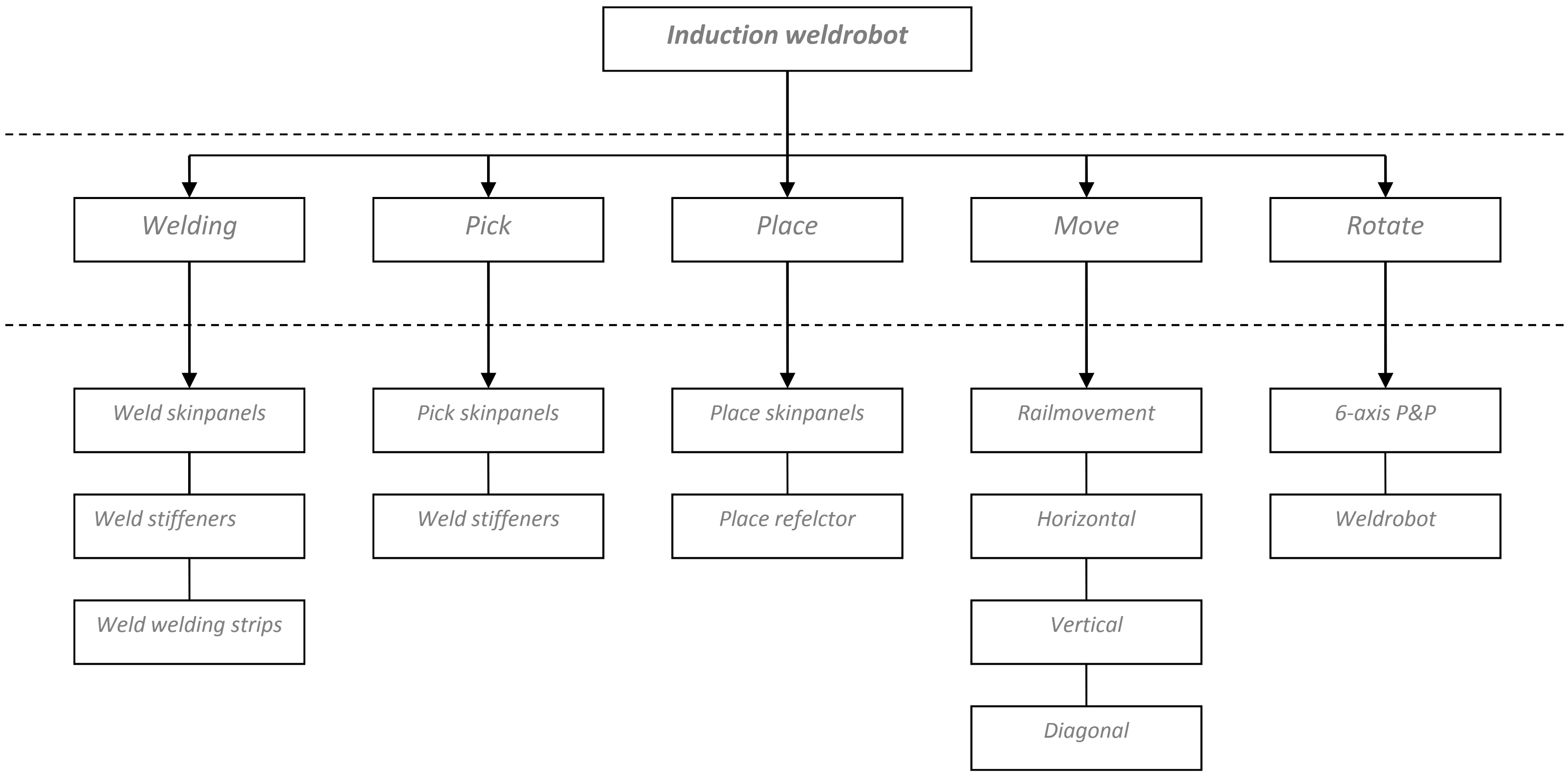
- Placing en welding reflector part
- Welding by induction
- Cost effective and efficient assembly concept
- Maintain high reflection performance of reflector

  - Diameter reflector:
    - Ø15 [m]
  - Accuracy / tolerances:
    - 1 [mm] RMS
    - 3 [mm] peak-to-peak
  - Reflection performance:
    - 80%-90%

Assembly Reflector

13/15 july '11

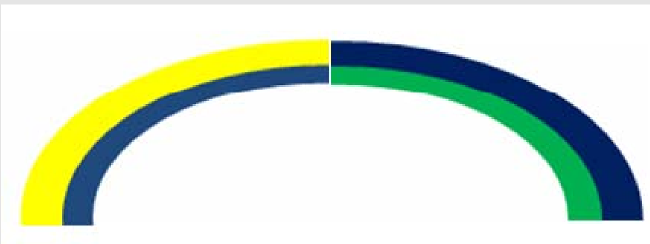
KvE welding functions



Assembly Reflector

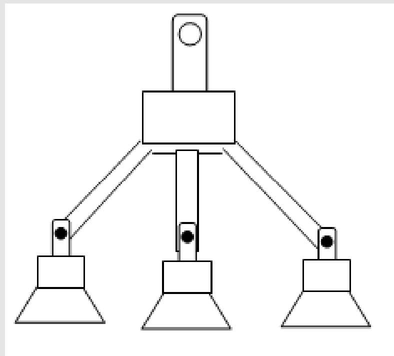
Welding per compartment

- Reflector in two or four parts
- Multiple assembly processes at the same time
- Short weld first, last welds are longer



Pick & Place by vacuum

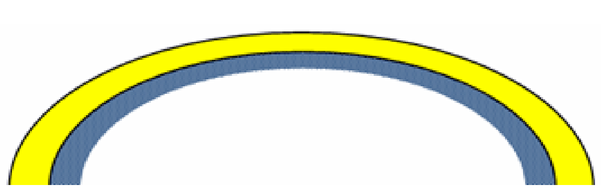
- No damage on reflection surface
- Stable movement by compensators



Assembly Reflector

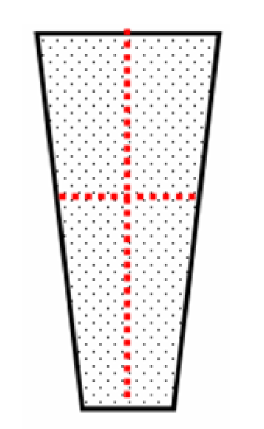
Placement on mould

- Mould in four parts, simultaneous processing
- Stable movement
- No damage on reflective surface since it is on the mould side



Stiffeners welded up front

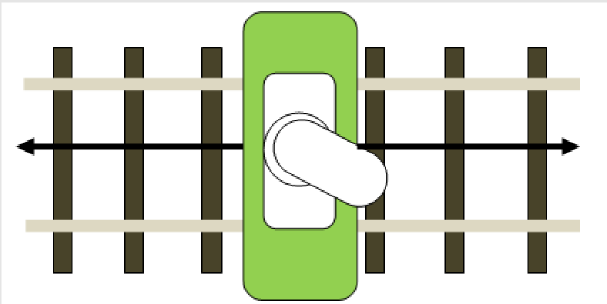
- Reduces welding time during assembly
- Potential for mass production
- Better attuned with storage



Assembly Reflector

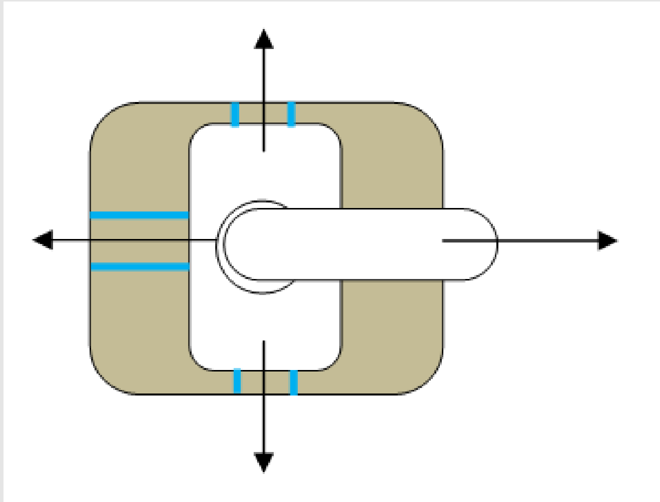
Line movement over rails

- No deviation of production line
- Standard wheels and motor
- Low wear



Linear movement on platform

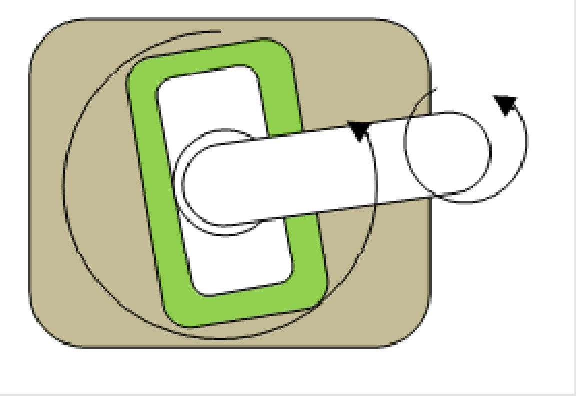
- Larger coverage of robot arms
- Off the shelf robots possible



Assembly Reflector

Rotational movement

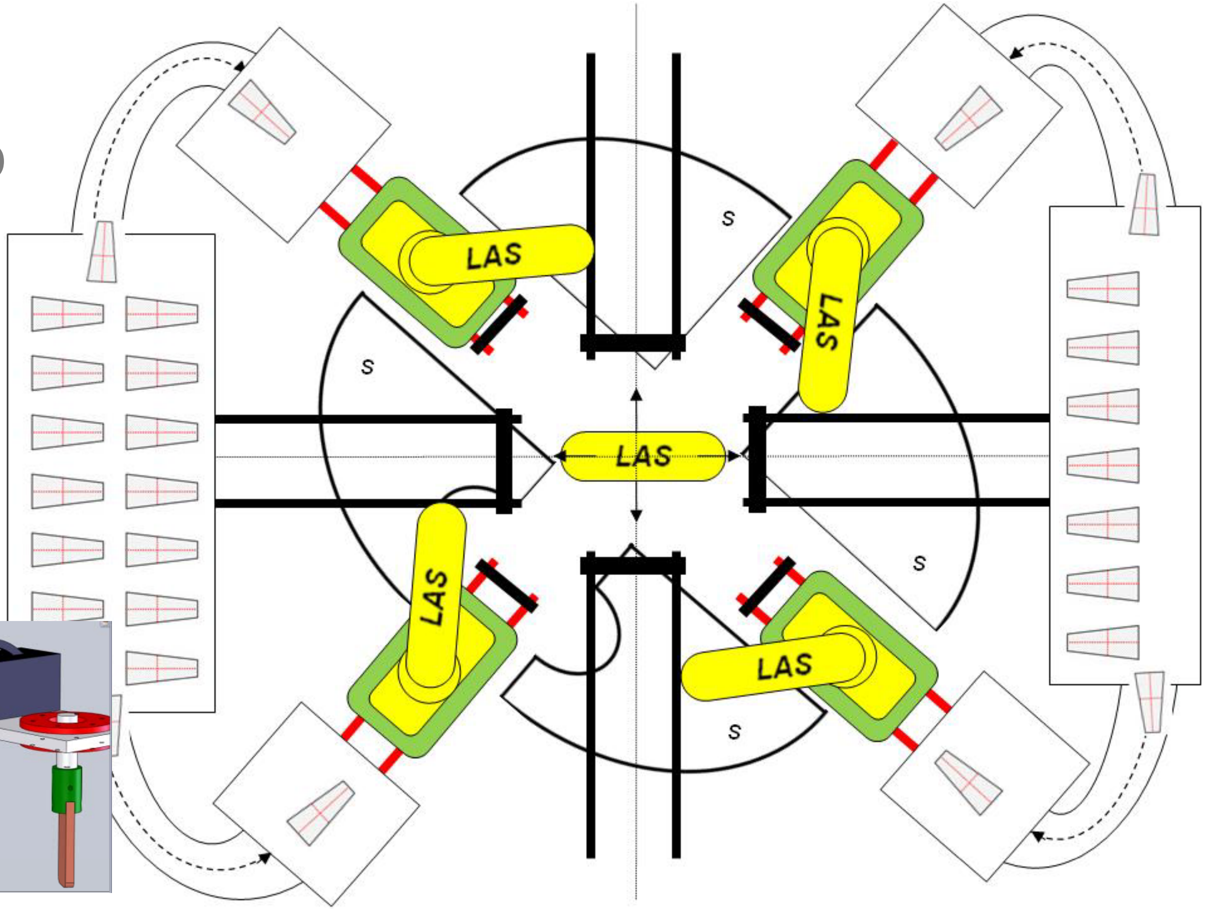
- Industrial welding robot are limited concerning rotation

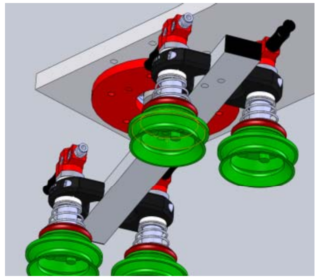


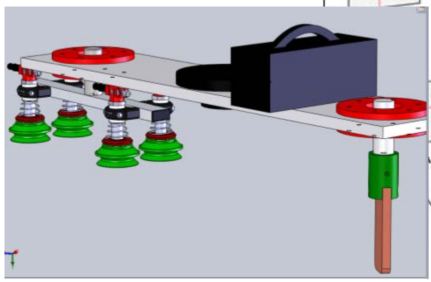
Assembly Reflector

First concept production

LAS = WELD







Assembly Reflector

Textual summary

- Automated lay-up skin panels on assembly mould
- Middle section skin panels are welded together and create 3m dish
- Inner hub and 3m stiffener structure are attached

- Skins and ribs for rotational identical sections are placed and welded automatically by a robot
  - Weldline of rib structure doubles as connection for skin panels
- 9m ring is attached to further stiffen the structure (9 meter dish is complete)
- Assembly mould can rotate for easy access to all “pie” sections.
- Outer ring (panels, ribs and outer ring) are attached
  - Outer ring can be pre-manufactured in 4 sections and assembled ‘on-site’ for easy transportation of the dish

- All surfaces are coated

Reflector Cost

Reflector cost including structure

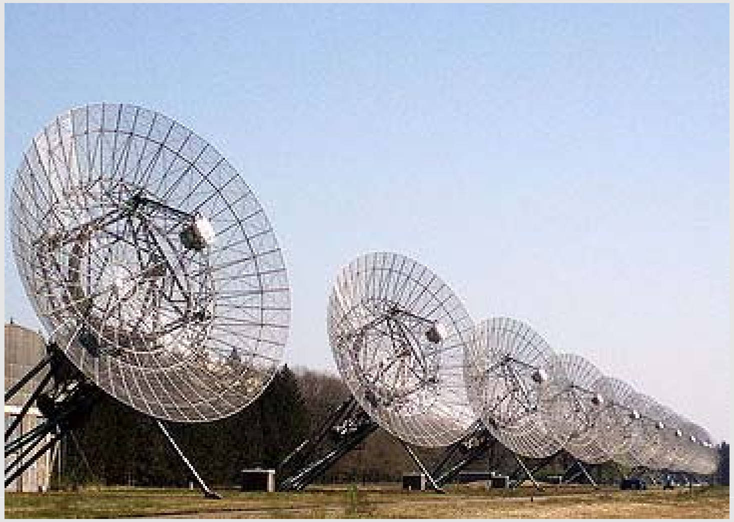
- Fully finished & integrated reflector (including back) structure
  - Total price € 106.000 (based on Dutch hour rates)
  - € 594 /m²
  - Potential reduction 20%

Optimising design by more details on structural requirements	= 3-5%
Optimising integrated production process, optimise settings	= 3-8%
New production processes available in next 2-3 years	= 5-10%

To DO

Reflector to DO

- Replace and measure panels at WSRT
- Continue dish performance study, on solid versus panels reflector
- Evaluate production and assembly process



Overall mechanical Design

Feed support
Pedestal
Drive
Manufacturing

Mounting reflector

Pedestal and drive

Main study and design was done on the reflector
Pedestal is not defined in detail

- Cone shaped pedestal
  - Minimizes material
  - Maximizes stability
  - Axis close to dish centre of mass
- Balancing to minimize load on bearings and drive system
- Drive system and control for both axis based on commercial available components
- Feed box struts will be made out of off-the-shelf carbon fibre composite tubes
- Extreme lightweight dish eases requirements on :
  - Motor drive
  - Pedestal
  - Power consumption
  - Transport
  - Assembly

Manufacturing

Logistics flexible by design

- Production of the dish surface parts, the ribs and the struts can be done any place convenient.
  - The dish surface parts are produced with moulding machines and can be semi automatic.
  - Up to now we foresee the dish surface parts have size <2.5 meter, so suitable for transportation and storage within containers.
  - The ribs and struts will be transportable and stored pretty easy in standard containers.
- Assembly of the dish will be close to the site.
  - The assembly is rather quick with a mould as reference.
  - We are studying the possibility to assemble on site, right near the pedestal, with only the need of special transportation of the assembly mould.

Manufacturing

Logistics flexible by design

- pedestal and its internal structure
  - we aim for construction and production any place
  - The unit might be split in 2 or 3 pieces for shipment and easy assembly. Eventual a shipment as full assembly might be possible.
  - Eventual storage might be in open air, with some protection for the drive head.
  - The founding for the pedestal we see as infrastructure.
- The feed unit needs are typical high end units to be produced any place convenient
  - Multiple feed units in standard containers for transportation and storage.

Manufacturing

Manufacturing, assembly, installation

	production	Shipment / storage	Assembly	Installation
Reflector	Any place	Container	On site / on spot	On spot
Struts of feedbox	Any place	Container	-	On spot
Feed and box	Any place	Container	-	On spot
Pedestal	Any place	Crate (container size) or container	-/ on spot	On spot

Cost

Total Cost 15 meter dish

	Cost per unit	cost per sq.meter	
• Reflector + backing structure	105 kEuro	594 Euro/m^2	(based on Dutch hour rate)
• Feed support	10 kEuro	57 Euro/m^2	
• Pedestal , Feed	xx kEuro		

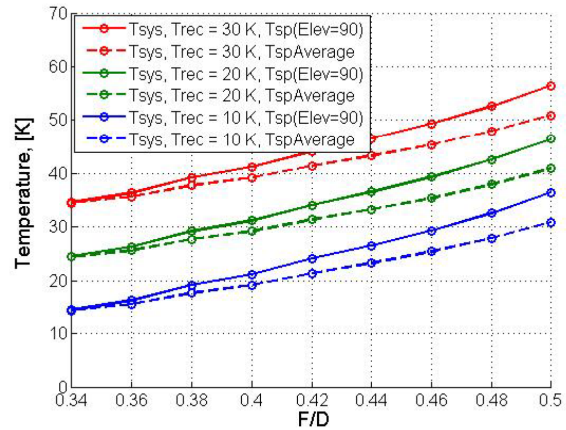
- Shipment, Storage, Assembly strongly influenced by design and weight

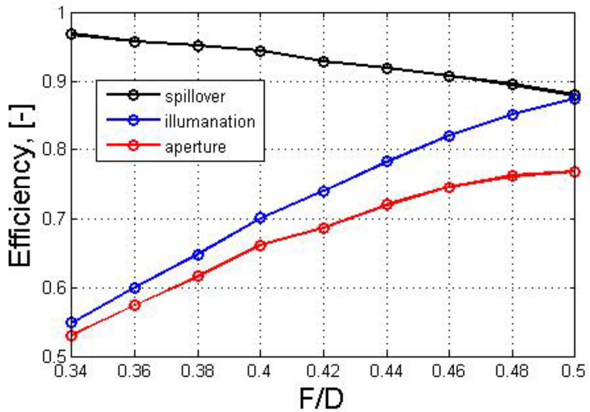
Electro Magnetic design

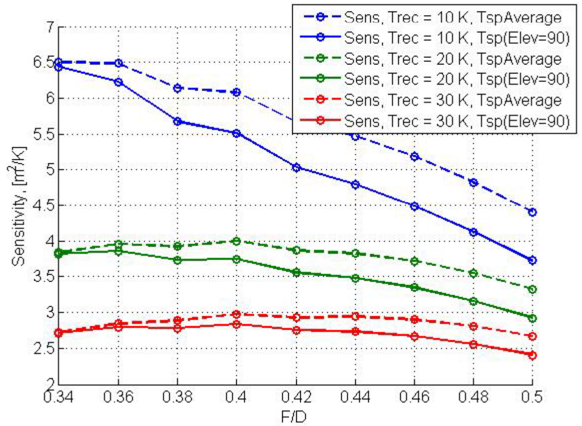
Eleven feed

Prime-focus antennas with Eleven feed (F/D dependence)

- Opt. F/D is around 0.4
- (equivalent to 60deg angle)
- that leads to the maximum sensitivity for Trec=20-30K

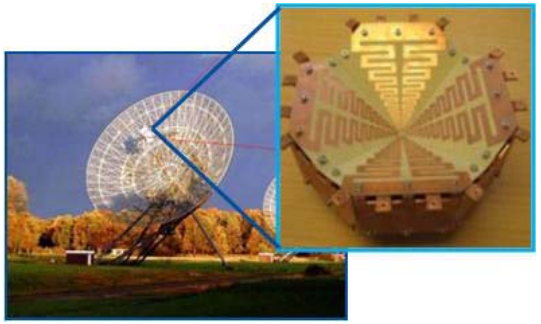




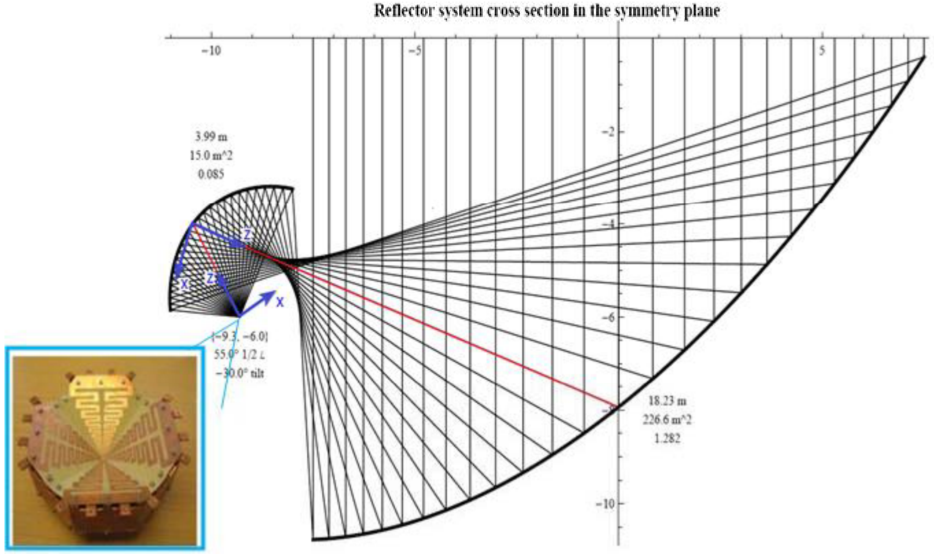


Eleven feed

Prime-focus antennas vs. displaced-axis dual reflector antennas for the SKA-mid (1-10GHz)



In this study, Tsp=*var* and Trec is assumed to be constant and equal to 10, 20 and 30K.



Simulations by Oleg Iupikov

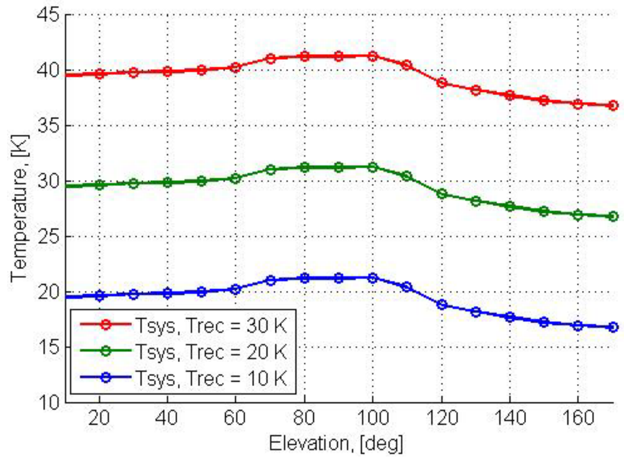
- The key questions: (i) which optics configuration would provide the best performance in combination with a practical feed (like Eleven feed) over a wide frequency band and elevation scan range; and (ii) what is the difference in the costs of design and operation.

Eleven antenna feed (J. Yang, M. Pantaleev, P.-S. Kildal, Y. Karadikar, L. Helldner, B. Klein, N. Wadefalk, C. Beaudoin, "Cryogenic 2-13 GHz Eleven feed for reflector antennas in future wideband radio telescopes", Special issue on Antennas for Next Generation Radio Tele-scopes in IEEE Trans. on AP, Vol.59, Issue 6, June, 2011.)

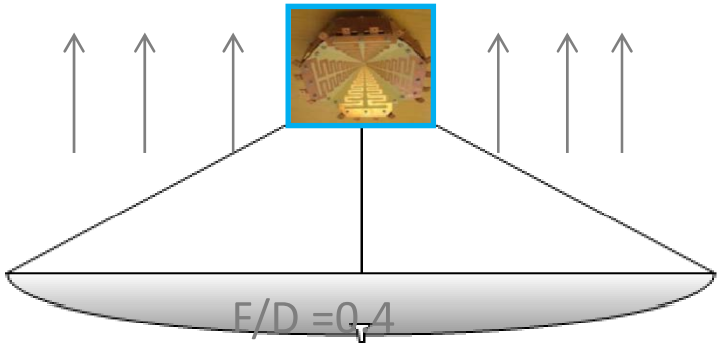
Eleven feed

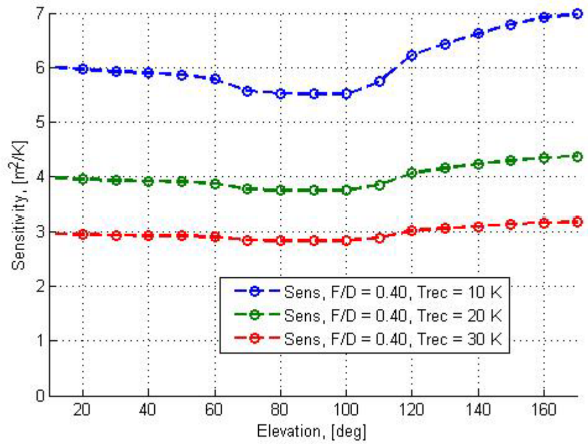
Prime-focus antenna with F/D=0.4 (Elevation dependence)

- *~ 5K variation of the system noise temperature with the elevation angle*
- Example for 5.6 GHz



Elevation angle 90deg

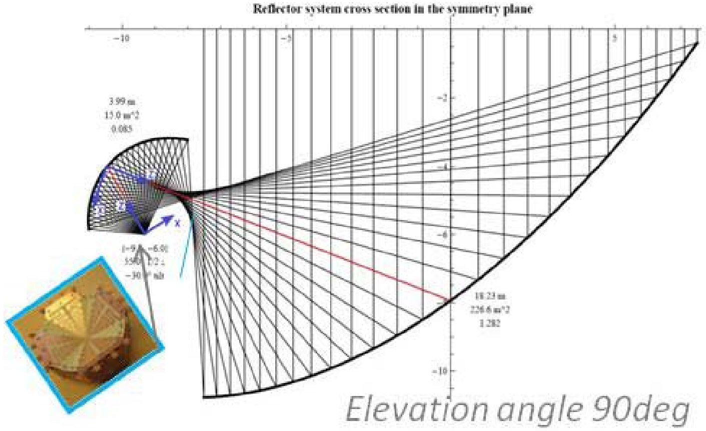


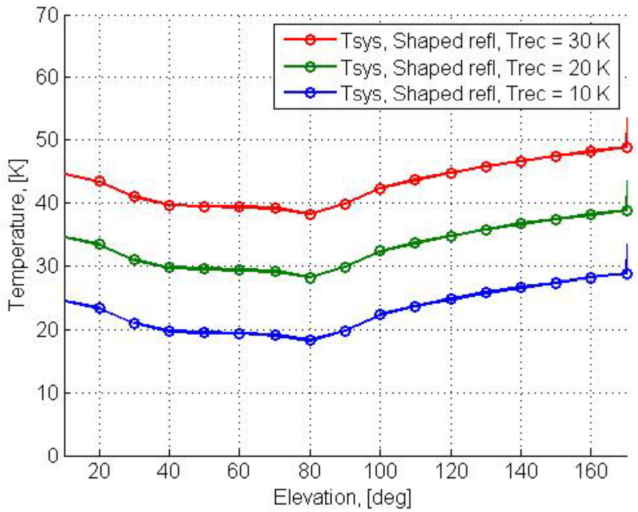


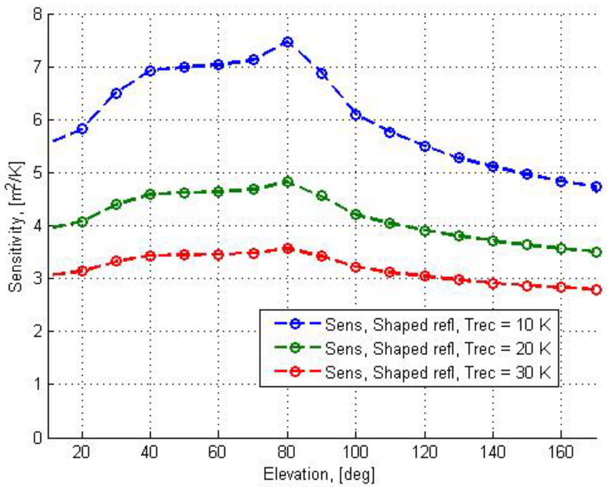
Eleven feed

Gregorian reflector antenna (Elevation dependence) at 5.6GHz

- ***~10K** variation of the system noise temperature with the elevation angle*

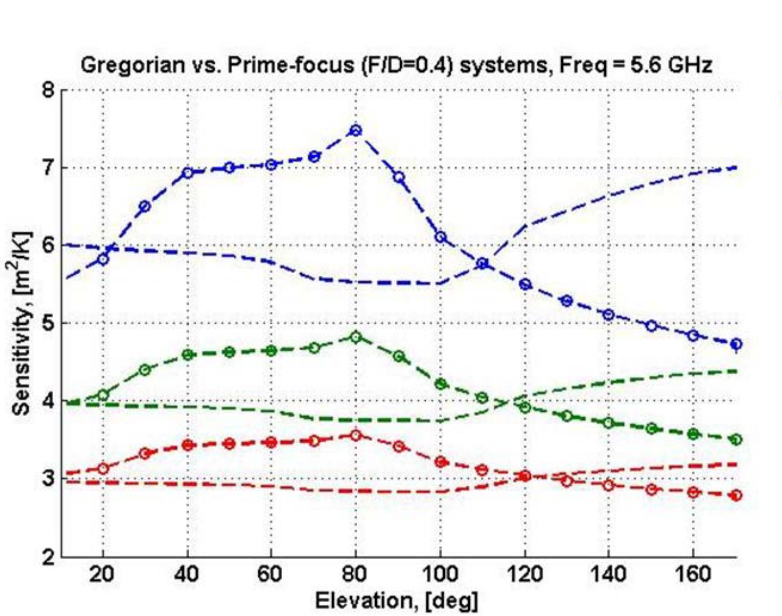


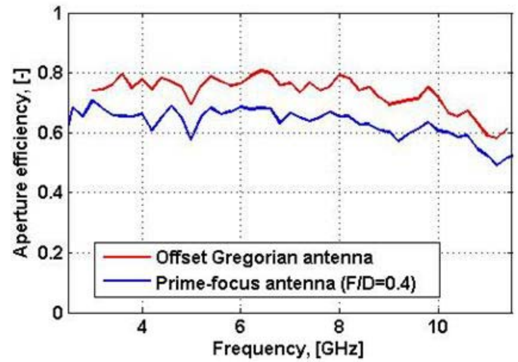




Prime-focus vs. Gregorian

Comparison: prime-focus antenna (F/D=0.4) vs. Gregorian antenna





Sensitivity elevation dependence at 5.6GHz

The aperture efficiency of the offset Gregorian system is about 10% higher than that of the prime-focus antenna, but the sensitivity values of these systems will be likely comparable when considering wide-field surveys (due to stronger elevation dependence of the spillover noise temperature for this offset design).

Conclusion from Radio design

Conclusion

- Initial study based on real feed indicates comparable results between two concept configurations
- Further studies with other and optimized feed in both configurations may be needed to further discriminate
- Work is ongoing to further optimize dish with symmetric dish which includes optimized feed support structure
- Discussions with calibration teams are taking place to get overall agreement on potential dynamic range impact of all configurations

Future plans

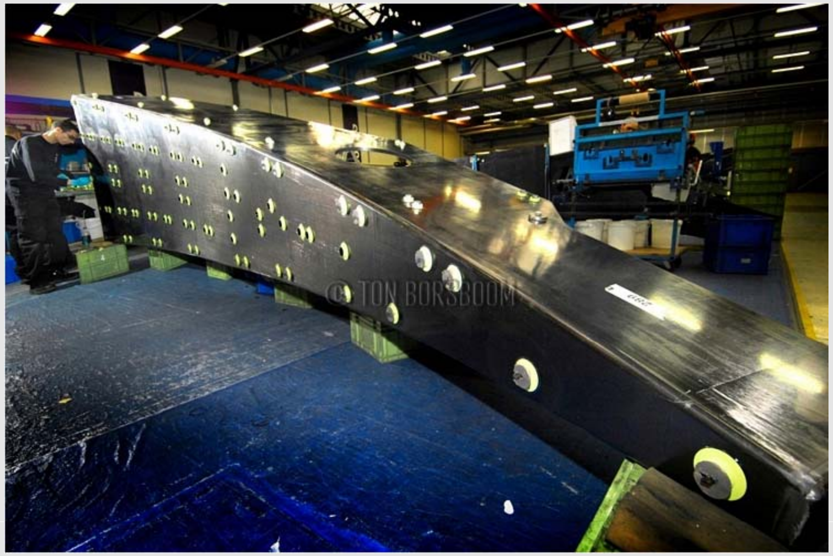
Plans
Technology to be developed
Risk assessment
Summary, Conclusions

Technology to be developed

- **Further detailing the dish material performance and coating**
  - A lot of knowledge is already available and can be used.
  - Thermo plastic materials are more and more used in industry for airplanes. We will take a next step in this, by selection of different type of thermoplastics, what will be in potential cheaper and suitable for use in e.g. telescopes and automotive.
  - The required development is towards the use of the other type of thermoplastic materials. Typical UV, coating, mechanical stability and thermal stability need to be studied further.
    Also production can be optimized.
  - Tests on performance of some single dish panels within the Westerbork radio telescope are foreseen within 2011.
  - Further development is required to push the cost further down and check on quality. Several demonstrator steps are expected. This development is expected to benefit from developments within the aerospace and automotive industry.

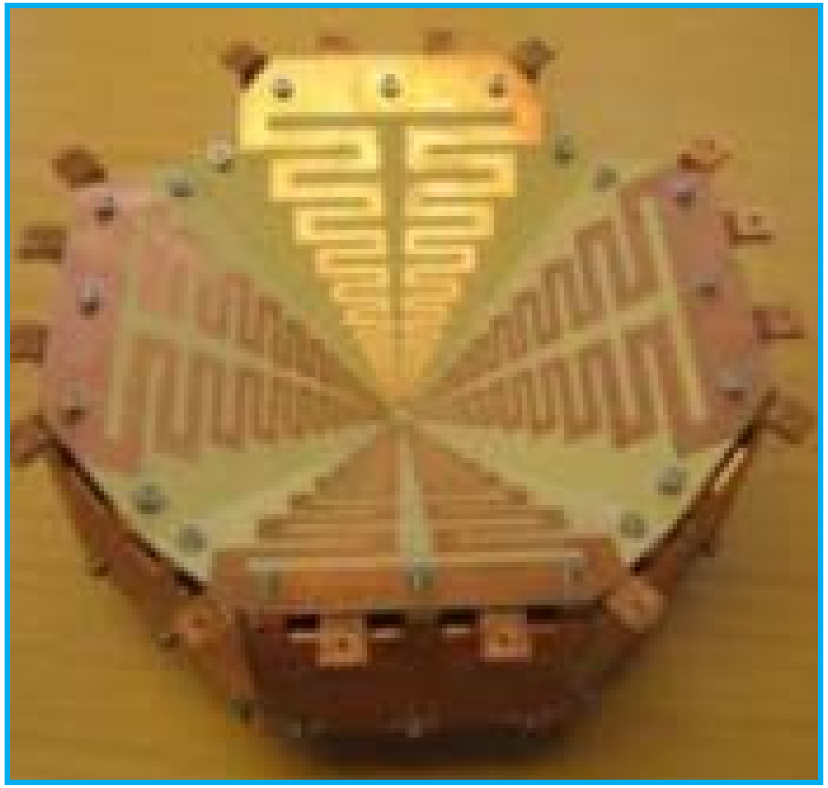
Technology to be developed

- **Detailing the assembly of the dishes**
  - The assembly needs further development to find the optimal assembly and correct stability
  - Find the optimal mould for on site transportation (if required)

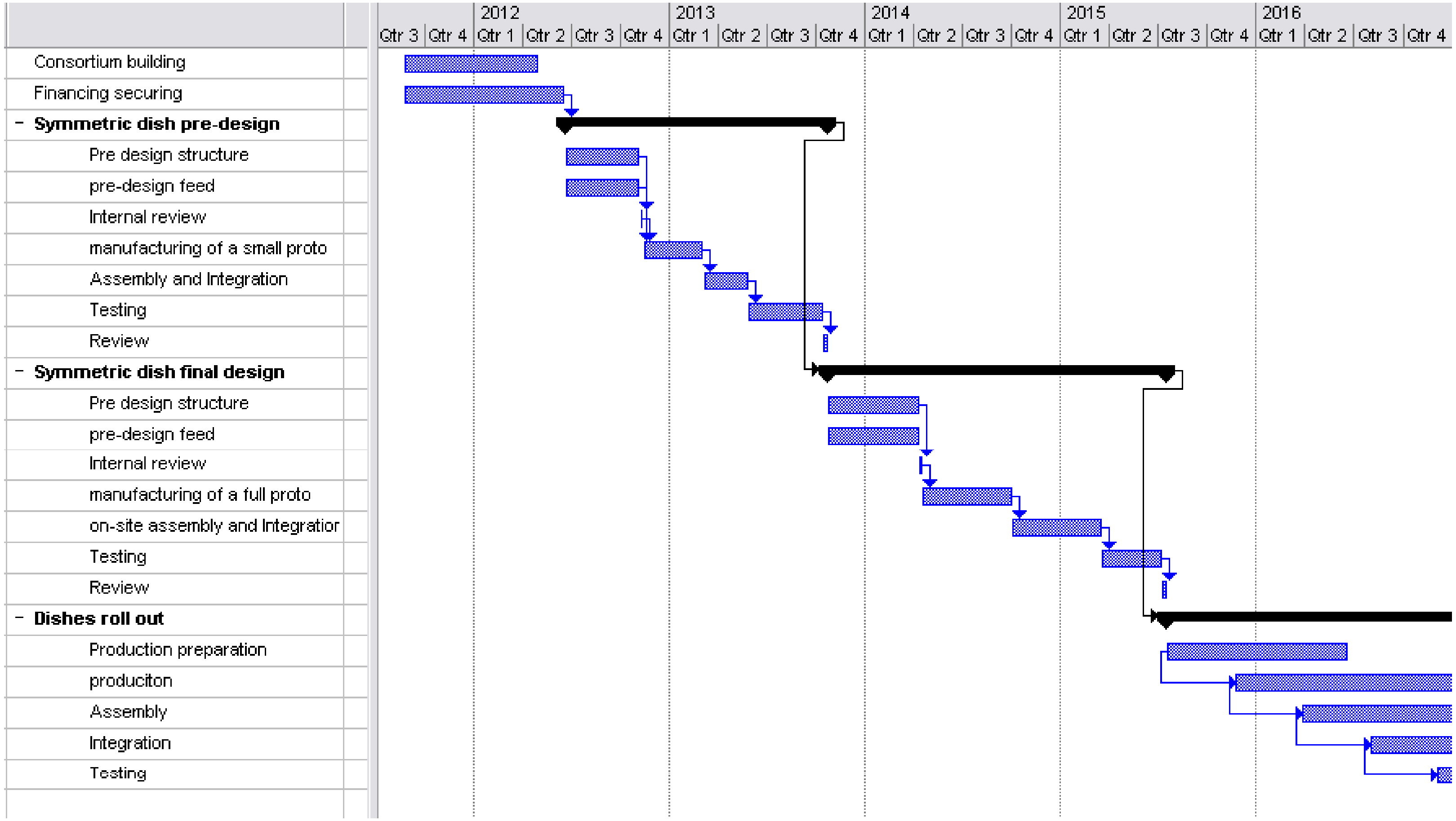


Technology to be developed

- **Feed**
  - Test and development of the eleven feed and optimizing its performance; the feed is seen as development trajectory with relative low risk, but still significant items to address.
  - Typical its sensitivity over the bandwidth should be pushed to the limits, this in relation to relative small and lightweight construction and possibly cooling.
  - We expect to develop this further over the coming years and not on the critical path.
  - Symmetric dish design can be combined with any other feed type:
    - Any other wide single pixel feeds
    - PAFS



Schedule


2012
2013
2014
2015
2016
Qtr 3 Qtr 4 Qtr 1 Qtr 2 Qtr 3 Qtr 4 Qtr 1 Qtr 2 Qtr 3 Qtr 4 Qtr 1 Qtr 2 Qtr 3 Qtr 4 Qtr 1 Qtr 2 Qtr 3 Qtr 4 Qtr 1 Qtr 2 Qtr 3 Qtr 4
Consortium building
Financing securing
Symmetric dish pre-design
Pre design structure
pre-design feed
Internal review
manufacturing of a small proto
Assembly and Integration
Testing
Review
Symmetric dish final design
Pre design structure
pre-design feed
Internal review
manufacturing of a full proto
on-site assembly and Integratior
Testing
Review
Dishes roll out
Production preparation
produciton
Assembly
Integration
Testing

Risk Assesment

- The risk assessment is focussing on the technical issues within this study.
- The systems and science related risks are seen as low or known
  The presented concept is rather classical and wide spread knowledge is available for this system concept

Risk Assesment

- **Reflector**

	Risk	Short description	Impact	Proposed mitigation
1.1	Wavelength range	The specified wavelength range is 1-10 GHz. This wavelength range is not matching the baseline specification for SKA-phase 1	The lower frequencies (0.45 – 3 GHz), as specified for SKA phase 1, will change the feed design and feed mount design. It can also impact the dish material choice.	Early input for this concept and the defined wavelength range is required. With that new (more relaxed) tolerances can be provided to industry.
1.2	Cost	The cost of the dish is driving the total cost. This cost is defined by industry by aid of costing tools and by industry expressed as realistic. The feed design is not costed in detail and need further study. Certainly the type of cooling is one of this issues in costing and performance	The impact is rather low. The main risk is in the feed, what is not the most driving element in the total cost.	Early definition of the wavelength range is important. Detailed study and test needed in near future on feed-cost.

Risk Assesment

- **Reflector**

	Risk	Short description	Impact	Proposed mitigation
1.3	Lifetime	The material of the dish is a thermoplastic material, which is not yet used in telescopes as mirror as far as we know. This dish (and its material) is dominating the cost of the telescope. Other parts are seen as more classical and low in risk	Failure of the 30 year lifespan of the dish would be dramatic for SKA. This really needs to be excluded (see mitigation).	Measuring/testing These tests are nowadays standard and reliable to perform, but testing in the real environment would be the ultimate test. Industry already measured several parameters of this material e.g. e.m. absorption, index of refraction, reflection coeff.. , strength, stiffness, …

Risk Assesment

- **Reflector**

	Risk	Short description	Impact	Proposed mitigation
1.4	Environmental unknowns	more information is required especially with regard to extreme events and unknowns (such as animal life and flooding).	Failing to understand and include these requirements in the design will most probably result in rework and retrofit. Given the scale of the SKA, this will be very costly.	Experience gained with the MEERKAT/ASKAP system will be valuable, and lessons learned must be transferred to the SKA system.
1.5	Lightning	Lightning is a serious issue. Up to now a connection between antenna elements of the dish is foreseen. A study is required to see if this will be beneficial for the design in cost and performance. Biggest change on lightning impact is the feedbox. It is advised to protect at least the feedbox for lightning.	Lightning damage of the feedbox is probably more costly then damage of the mirror (exchange some elements). Damage of the feedbox will stop the full telescope. Local damage of the disc will reduced performance, but not stops the observing.	Lightning protection of the feedbox as minimum requirement. Eventual simple electrical connection of the dish elements can be provided if necessary.

Risk Assesment

- **Reflector**

	Risk	Short description	Impact	Proposed mitigation
1.6	Remote operations	The fact that the SKA will be deployed, operated and supported on a very remote site poses many challenges in almost every aspect of the system, especially quality aspects. Other examples are reliability, availability, maintainability, monitoring and control, support from a distance, safety etc.	If the requirements for remote operations and support are not part of the design from the outset, the cost of rework and upgrades may be excessive.	Investigate all aspects that will influence remote operations and support. Evaluate different options. Keep full lifecycle aspects in mind. Ensure that requirements are flowed down into the design and budgeted for. Experience in operating ASKAP/MEERKAT will be valuable

Risk Assesment

- **Reflector**

	Risk	Short description	Impact	Proposed mitigation
1.7	Scope of logistics and support	To be able to operate and support the SKA over its lifetime will require well designed and supplied logistics and support. So far, this aspect has not received much attention. Specific moving parts are subject of maintenance and failure.	Due to the scale of the SKA, the logistics and support requirements will be significant and will call for large numbers of people, spares, tools, test equipment, support equipment, facilities, training etc.	Specific design towards low maintenance and high reliability is crucial. Focus on moving parts and UV-protection of sun-loaded parts (e.g. dish).
1.8	Damage	During manufacturing, transport, installation or operation, damage can occur.	Depending on the damage, the functionality or performance of the antenna can be reduced.	Reliable and adequate repair method needs to be developed. Airborne has experience with repair techniques of thermoplastic structures, for example for offshore operations. A method to replace element could be used.

Risk Assesment

- **Reflector**

Risk	Short description	Impact	Proposed mitigation
Creep	Continuous load on the material structure may incur creep of the material.	The performance of the dish will decrease over time.	Extensive test are being performed at different conditions to map the material properties. Design will be adapted to embed the allowable loads.

Risk Assesment

- **Feed**

	Risk	Short description	Impact	Proposed mitigation
2.1	Performance	The performances of the feed design is depending on the design and probably also temperature of the feed and LNA. Cooling concepts might be important for a good balance of performance and cost.	The feed is a driving element in the total Aeff/ Tsys specification, the main parameter of the telescope. Improving the Aeff/Tsys can lower the overall cost and improve the operations overhead.	Study the type of feed (Eleven feed) in more detail. In principle the systems are well known, but a correct balance between technology, cost performance and risk is important.

Summary, Conclusion

Summary

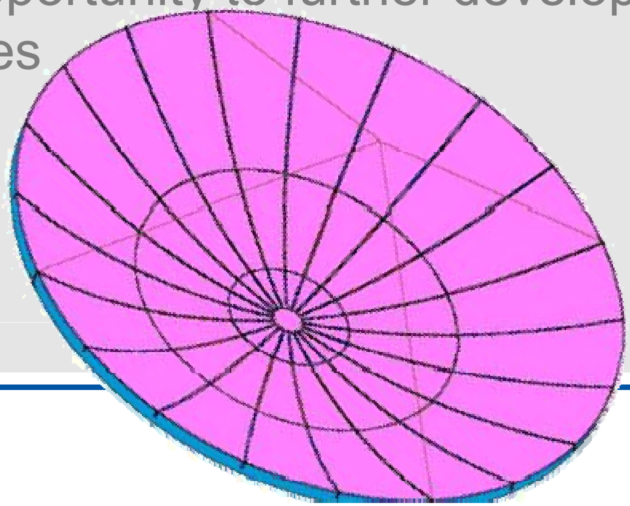
- Focus on a simple system with lightweight structure:
  - Reflector and backing structure 1580 kg
  - Simple motor drives and pedestal (alt-az. / equatorial ?)
  - Progress could further reduce productioncost,
  - Consider: transportation, handling, safety, storage, maintenance and dismantling, environmental aspects.
  - Industry closely involved in development

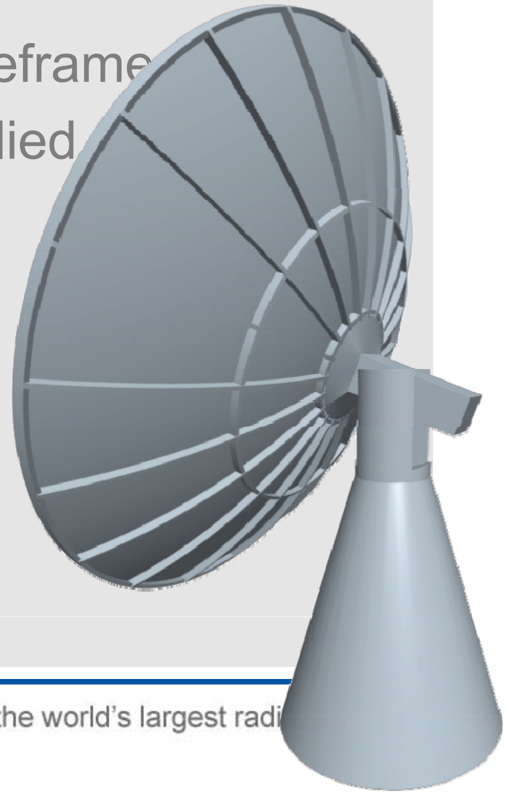
- Some technologies to be developed towards the final TRL
  - Development is 'piggy backing' with other markets like Automotive and Aerospace
  - Feed developments are at high TRL, but need further optimizing
  - Other feeds can be included (PAFS, WBSPF).

Conclusion

- **Conclusion from this study**

- Axi-symmetric dishes are
  - low risk,
  - low (operational) cost
  - high performance
- SKA-phase 2 requirements can be met in phase 1 timeframe
- Thermo plastic materials are very promising to be applied for SKA and for Automotive and Aerospace market
- Industry opportunity to further develop the required technologies

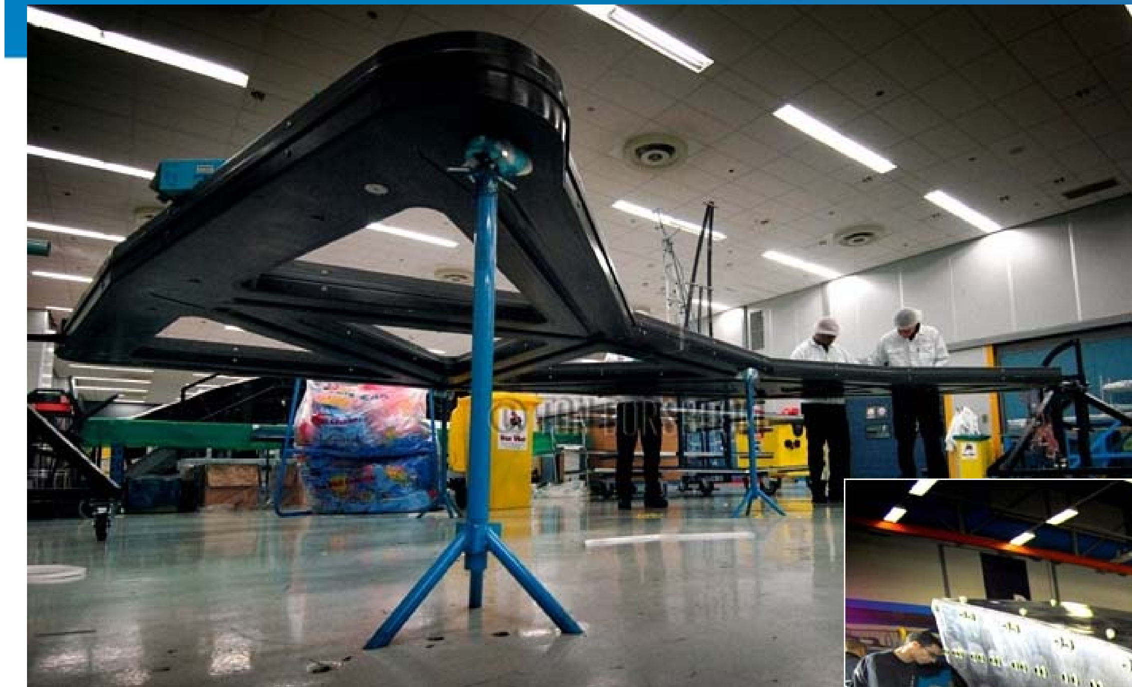




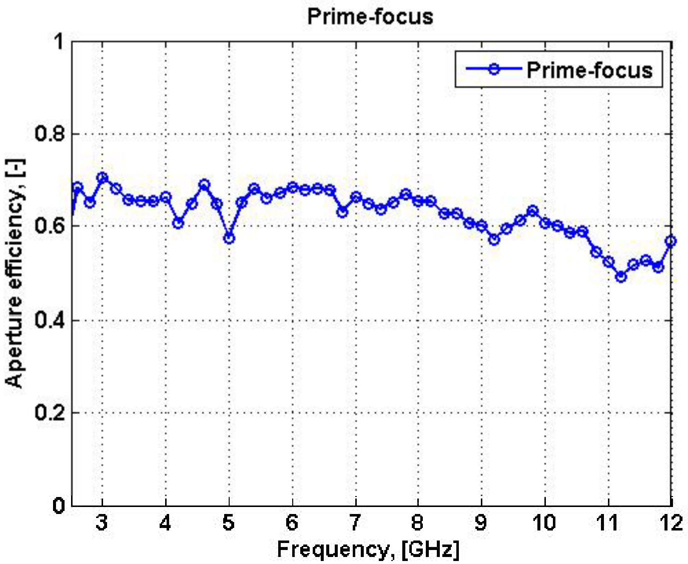
Summary

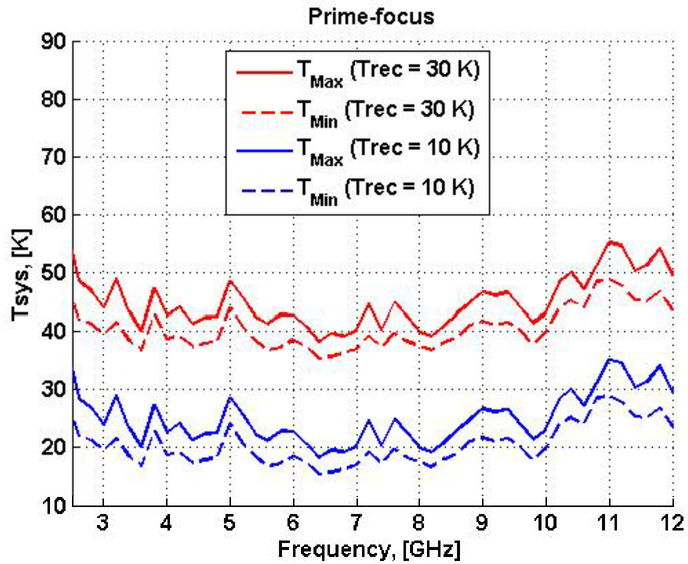
- RESERVED SLIDEs

Summary



Frequency dependence: **Aperture efficiency and Tsys for the prime-focus system with F/D=0.4:**





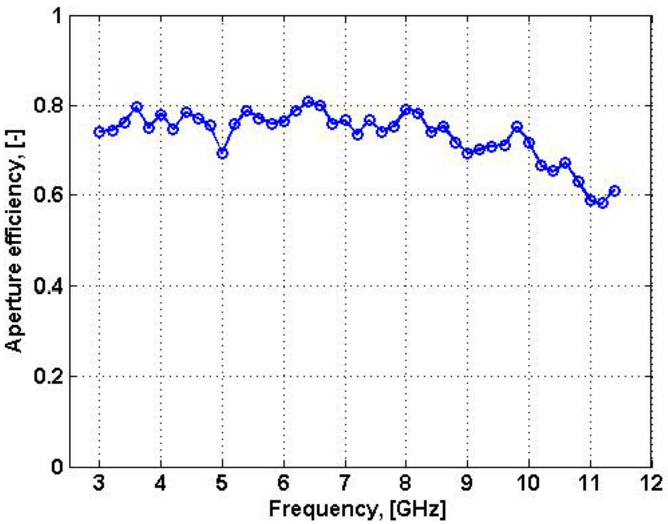
a) Aperture efficiency
is ranged between 50 and 73%

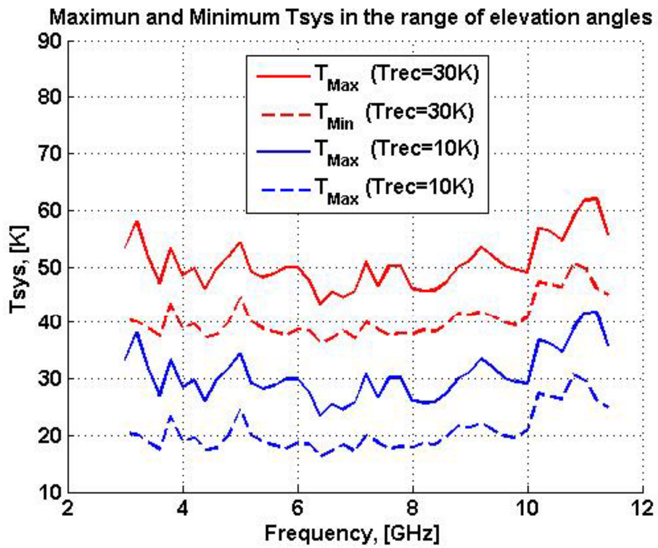
b) The maximum and minimum values of Tsys
in the range of elevation angles vs. frequency

The range of elevation angles is 10-170°

Variation of the system noise temperature with elevation angle (Tmax-Tmin) is ***3-7K*** *over the frequency band from 3 to 15 GHz.*

Frequency dependence: Aperture efficiency and Tsys for the Gregorian system:





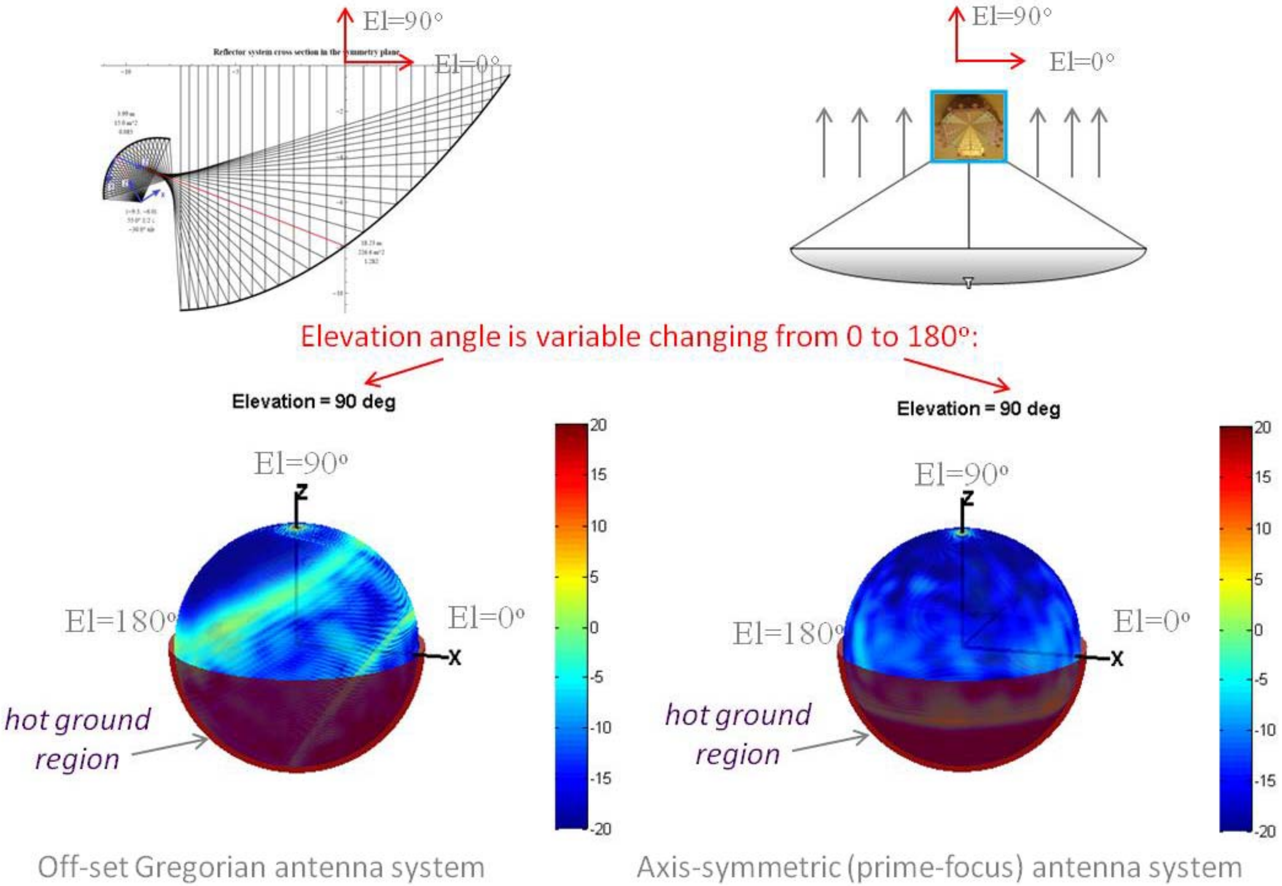
a) Aperture efficiency
is ranged between about 60 and 80%

b) The maximum and minimum values of Tsys
in the range of elevation angles vs. frequency

The range of elevation angles is 10-170°

*Variation of the system noise temperature with elevation angle (Tmax-Tmin) is **7-16K** over the frequency band from 3 to 11 GHz.*

Animation: **The antenna far-field pattern (mapped on the sphere) when antenna points at different elevation angles at 5.6 GHz**



Acknowledgement

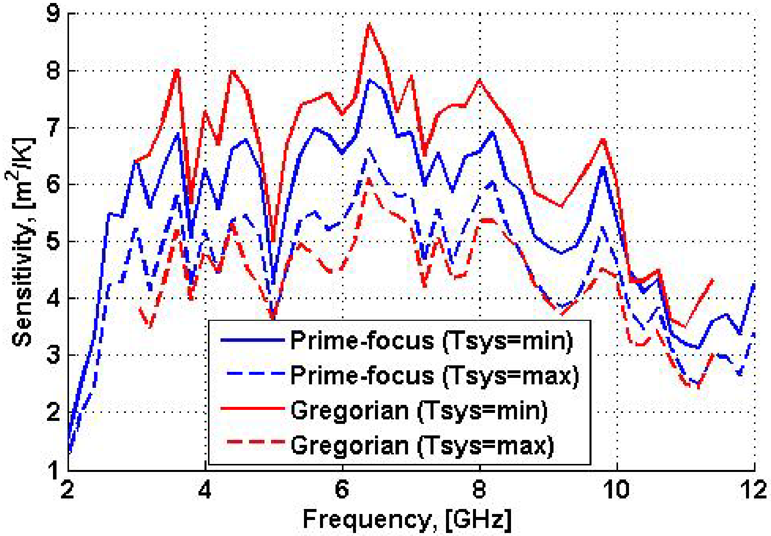
- CHALMERS: The measured patterns of the Eleven feed were provided by Dr. J. Yang. Simulations in GRASP and analysis were carried out by Oleg Iupikov (international PhD student) and Wan-Chun. Liao (MSc student).

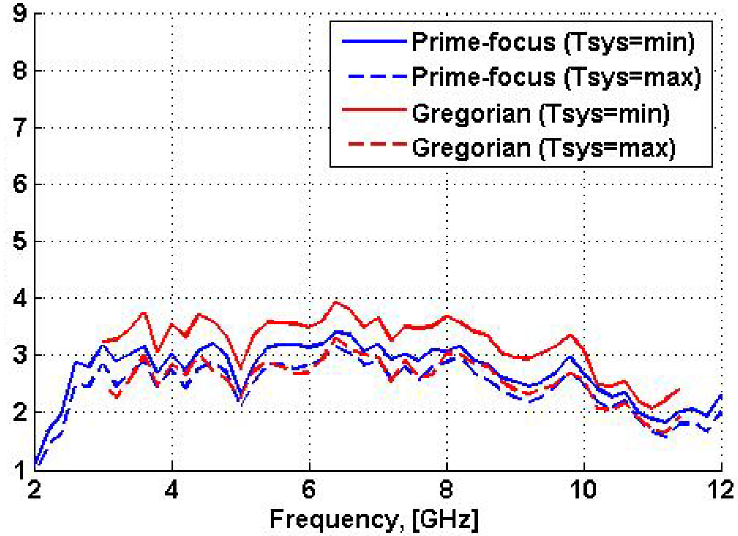
- ASTRON: The study was initiated by Arnold van Ardenne and embedded in the larger Eu SKA activities led by ASTRON in collaboration with TUDelft and Airborne.

- US SKA: The geometry of the Gregorian system was provided by Lynn Bakker

Comparison: prime-focus antenna (F/D=0.4) vs. Gregorian antenna

- **Sensitivity frequency dependence**

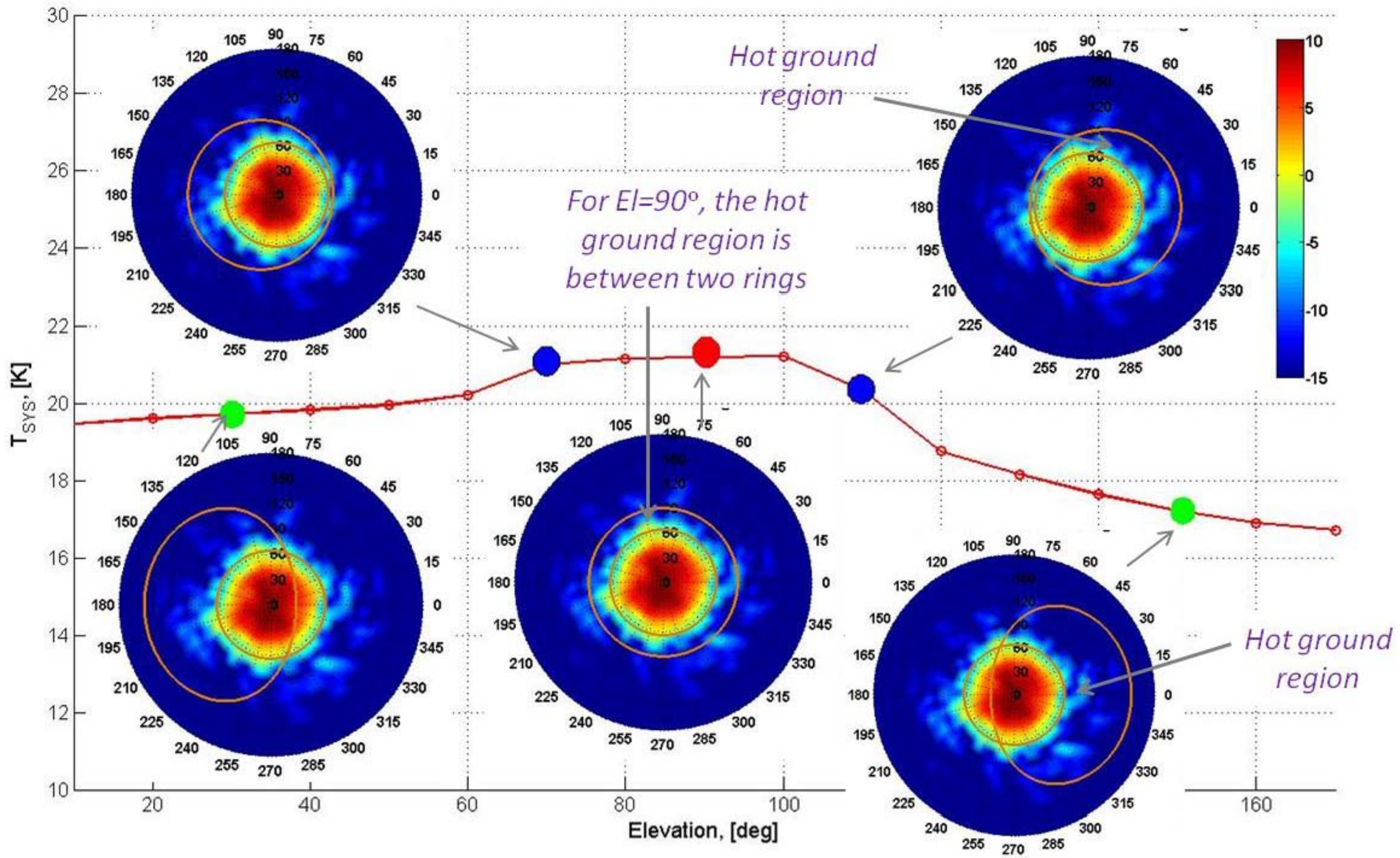




The upper and lower bounds of sensitivity correspond to the minimum and maximum values of the antenna ground noise contribution over the range of elevation angles (10-170º)*.*

The maximum sensitivity is always higher for the Gregorian system, but the minimum sensitivity is lower for cooled receivers with Trec=10-20K or close to that of the prime-focus system for Trec=30. Difference between the corresponding values of two bounds is much smaller for the latter case for all frequency points.

Effect of the feed pattern asymmetry on the elevation dependence of the ground noise contribution



Displaced-axis dual reflector antenna (Gregorian configuration) with Eleven feed

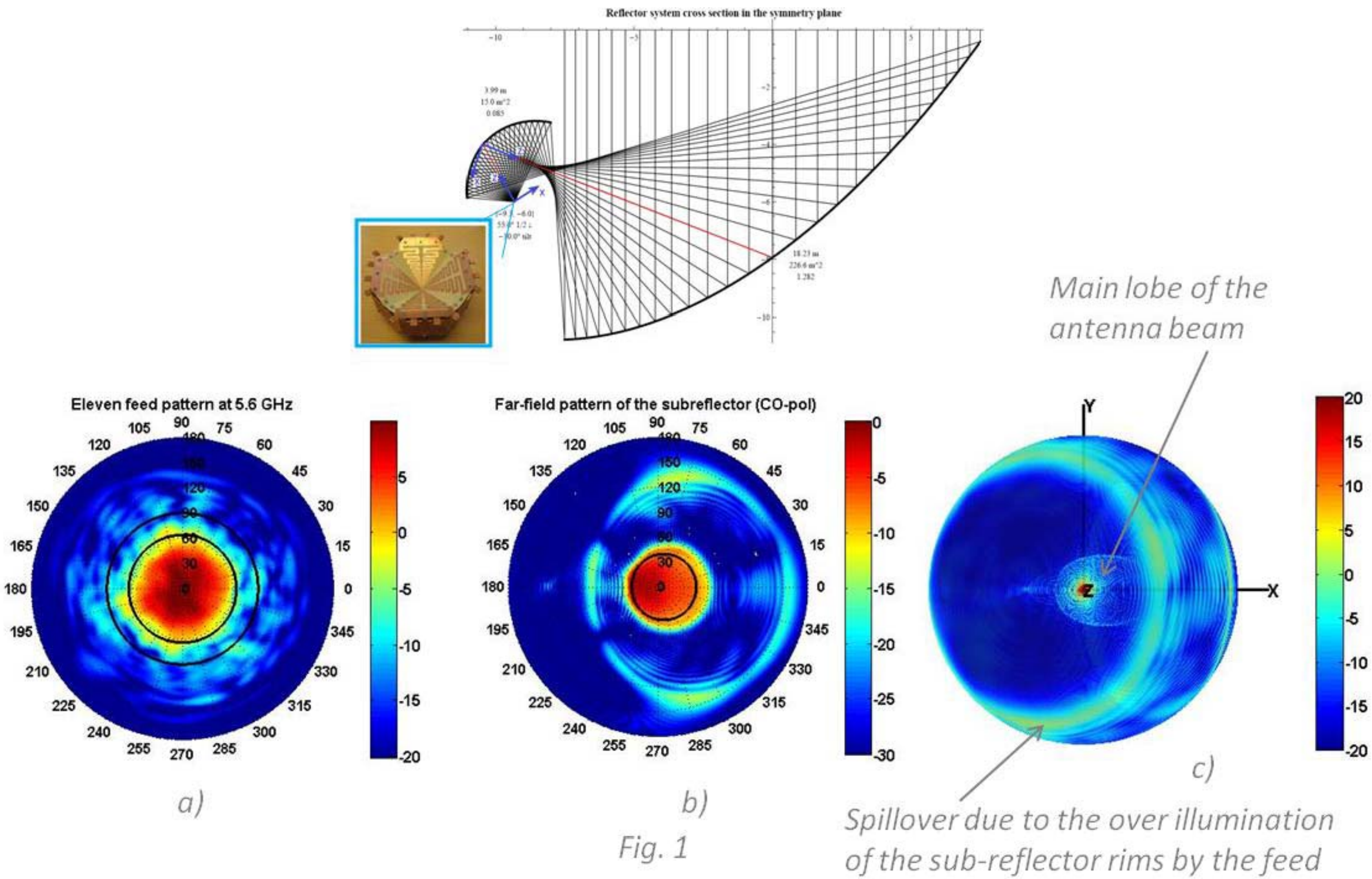


Fig. 1