SKA Dish Array

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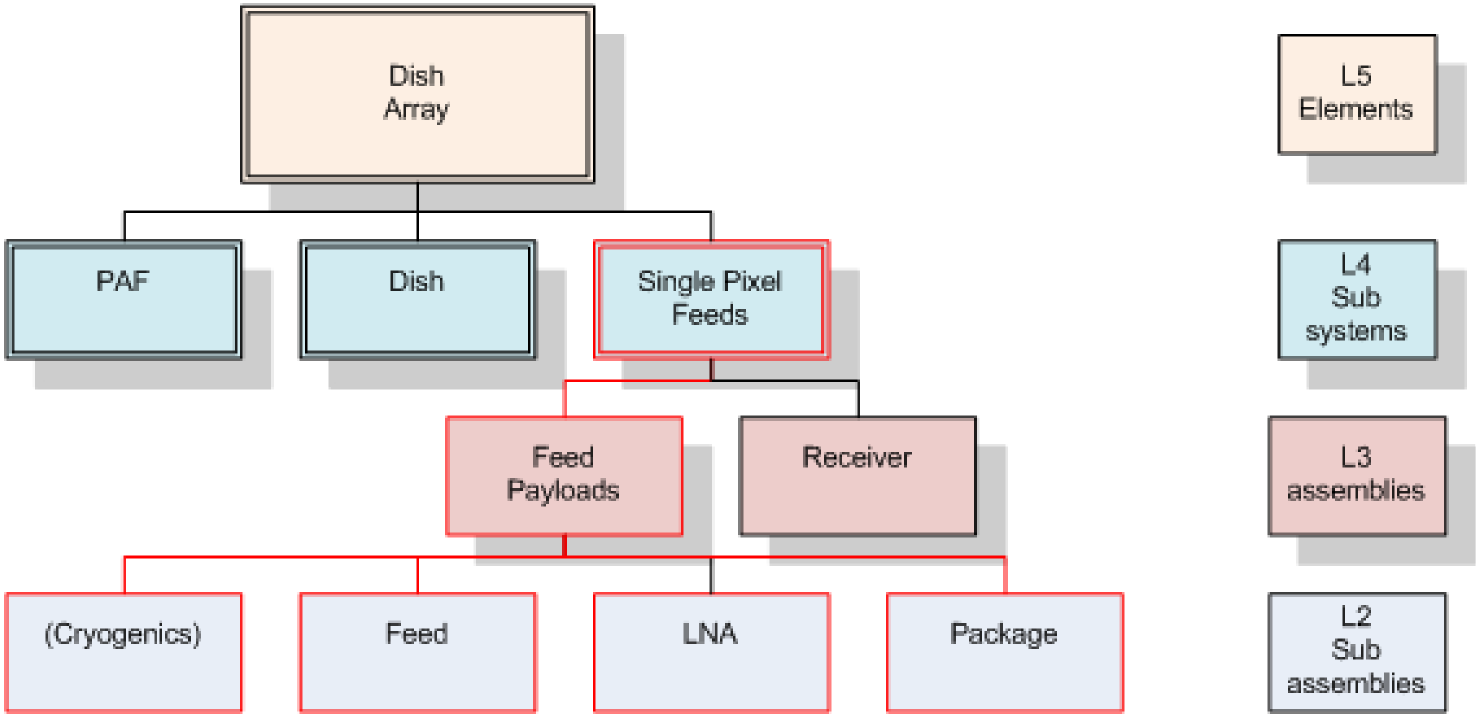
WP2 meeting
Oct 18, 2011

Dish Array Hierarchy

- SPF payloads comprise feed (including OMT if needed), LNAs, cryogenics (if needed) and packaging (dewar or other housing)



- Dish Array
  - PAF
  - Dish
  - Single Pixel Feeds
    - Feed Payloads
      - (Cryogenics)
      - Feed
      - LNA
      - Package
    - Receiver

L5 Elements

L4 Sub systems

L3 assemblies

L2 Sub assemblies

dio telescope

Key Requirements: Frequency range

- SKA1 requires 0.45 to 3 GHz
- SKA2 extends this to 10 GHz: this has implications for the dish design
  - Dish performance must meet specifications up to 10 GHz (SKA1 dishes will not be replaced in SKA2).
  - Dishes must be capable of accommodating feed payloads to cover 0.45 (possibly ~0.30 MHz) to 10 GHz.

Key Requirements: Sensitivity (Aeff/Tsys)

- The Phase 1 Dish Array shall have a sensitivity of 10^3 m^2 K^{-1} in the frequency range 450 MHz - 3 GHz.
- SKA2 requirement is 10^4 m^2 K^{-1} up to 10 GHz:
  - The aim will be to maximize sensitivity per €/$ *total system cost of ownership* whilst meeting other requirements.

Key Requirements:
Imaging dynamic range

- The SKA2 system requirement is for an imaging dynamic range for continuum of at least 74 dB at 1.4 GHz.
  - This requires the dish to have extremely stable, predictable beam shape and pointing in typical environmental conditions.
  - Stability and calibratability of the complete signal chain are also vital.
- Instrumental Pol'n:
  - -40 dB on axis after calibration
  - -30 dB to ½ power point after cal (TBC).
- *These are a whole system requirements, but the dish array performance must not be limiting.*

Key Requirements:
Dish Array operating cost

- There is no one specific requirement, but there are multiple contributors:
  - power consumption, repair period, continuous operation period
  - Thousands of dish systems will be very expensive to operate unless they are designed for high reliability with minimum maintenance.
  - Feeds must be individually maintainable/replaceable.
  - The maintenance regimes at existing radio astronomy observatories will not be affordable on this scale.
  - Routine maintenance intervals of at least one year are required, including dish mechanics and cryogenics.
  - Power consumption is a huge challenge for the SKA and the Dish Array is potentially a big contributor.

Key Requirements: Upgradeability and feed flexibility

- The Phase 1 Dish Array shall be upgradable.
  - Upgrades may include addition and replacement of single pixel payloads and receivers as well as the addition of phased array feeds.
- Multiple single pixel feeds and a phased array feed are to be accommodated.
  - A significant means of improving overall SKA system performance will be obtained through enhancement of feeds and receivers, especially in the transition of SKA1 to SKA2.

Key Requirements:
Minimum life time

- The Phase 1 Dish Array shall be designed for a minimum life time of 30 years, including initial installation, testing and commissioning period.
- Life-time extension
  - Large scale maintenance and/or an upgrade shall give the possibility to reach a life time of 50 years (TBC).

Some other important aspects of the Dish Arrays

- Some other aspects not yet explicitly covered in the requirements documents are as follows:
  - Mass manufacture:
    - Innovative manufacturing techniques will be needed to allow cost effective production of 15 m dishes in quantities of thousands.
  - Rapid installation:
    - Dish systems will need to be installed rapidly using minimal on-site manpower and equipment.
    - This is to minimize the impact on observations, as well as keep down the manpower cost.

Options under consideration: Dishes and Payloads

1. Dishes
   a) US TDP/DRAO
   b) NAOC/JLRAT/CETC54
   c) ASTRON/Airborne
   d) NRF – MeerKAT design
2. Feeds/Receivers and other "payloads"
   a) Single-pixel Feeds (corrugated horns)
   b) Wide-band SPFs (to be discussed under AIP session)
   c) Phased Array Feeds (PAFs) (to be discussed under AIP session)
   d) Receivers (various types of receiver systems)
   e) Other equipment: digitizers, optical modulators

Features of Dish Designs/Options

1. US TDP/DRAO Dish
   a) Offset Gregorian optics
   b) Offset high
   c) Single piece main reflector, CFRP composite
   d) Mold-based reflector fabrication, in-place
   e) Evaluated with various SPF feeds and PAF.
2. ASTRON/Airborne/Chalmers Dish
   a) Thermoplastic composite welded panels
   b) Symmetric optics
   c) Quasi-single piece main reflector, CFRP composite
   d) Welded reflector fabrication on mold, in-place
   e) Evaluated with Eleven feed (>1.2 GHz only).

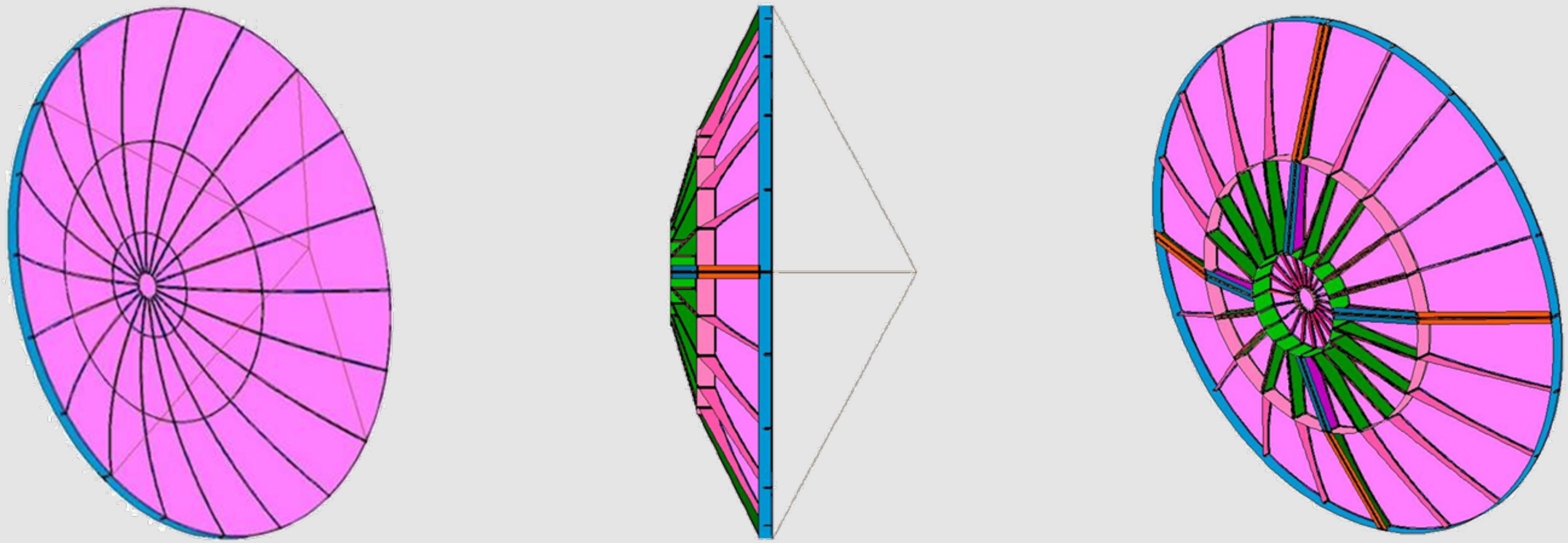
Features of Dish Designs (cont'd)

3. NRF – MeerKAT Dish
    1. a) Offset Gregorian optics
    2. b) Offset low
    3. c) Single piece main reflector, Fibreglass composite
    4. d) Mold-based reflector fabrication, in-place
    5. e) Corrugated horn feed(s)
    6. f) Smaller than required for SKA (13.5 m).
4. NAOC/JLRAT/CETC54 (many combinations)
    1. a) Offset or Symmetric.
    2. b) Alt-Az or 3-axis.
    3. c) Composite or metal
    4. d) Evaluated with similar to Eleven feed.

Thermoplastic Reinforced Composite 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.



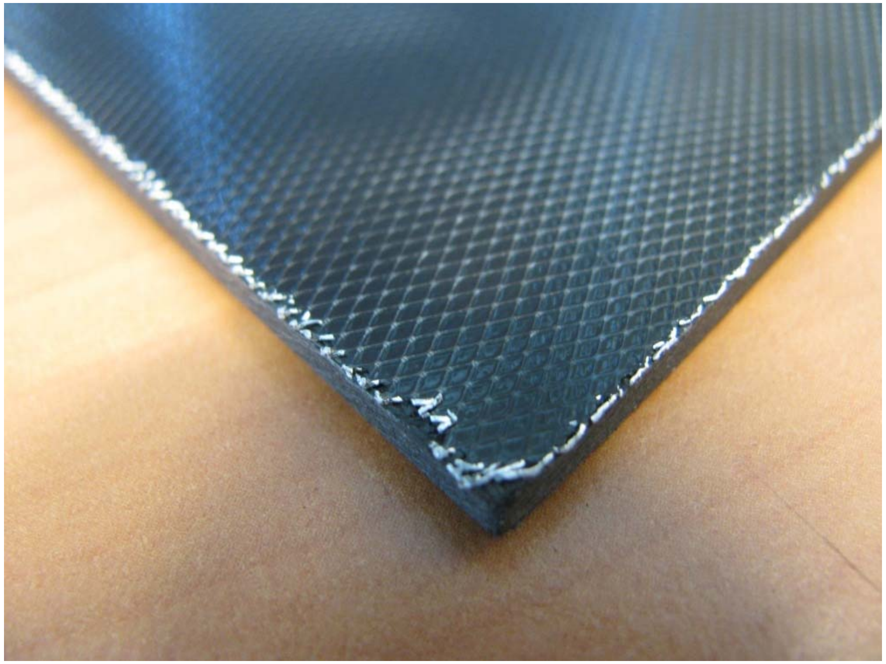
Symmetric Dish
Thermoplastic Reinforced Composite

Thermoplastic carbon reinforced composite material

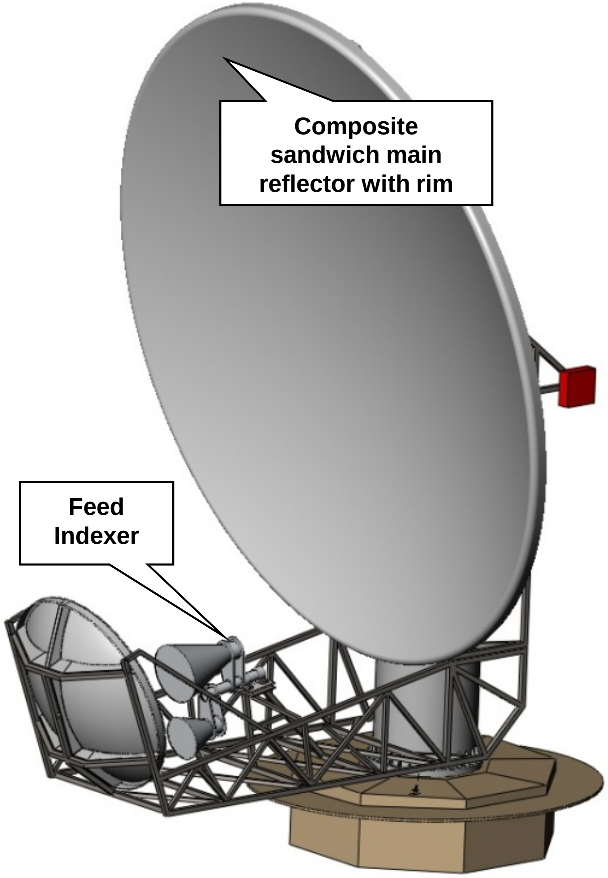
Benefits

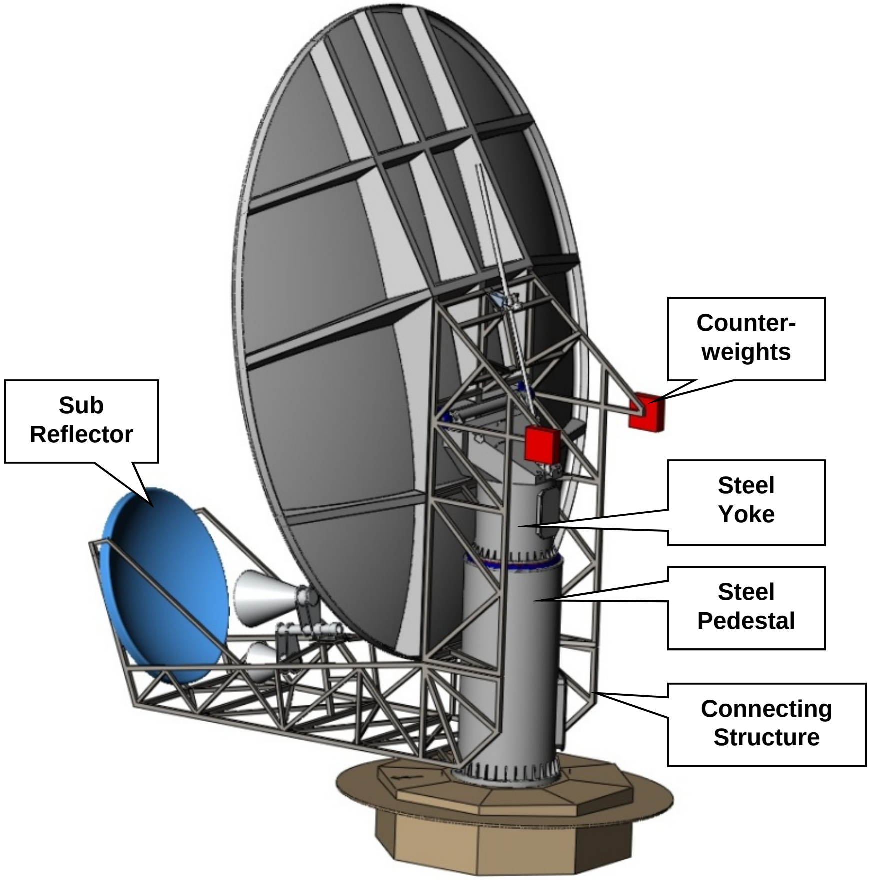
- Embed a thin metal mesh to add reflectivity performance
- Low thermal coefficient
- Low weight (-30%: metal option)
- Coating to protect from atmospheric influences easily applied
- Suitable for recycling and repairs

- 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



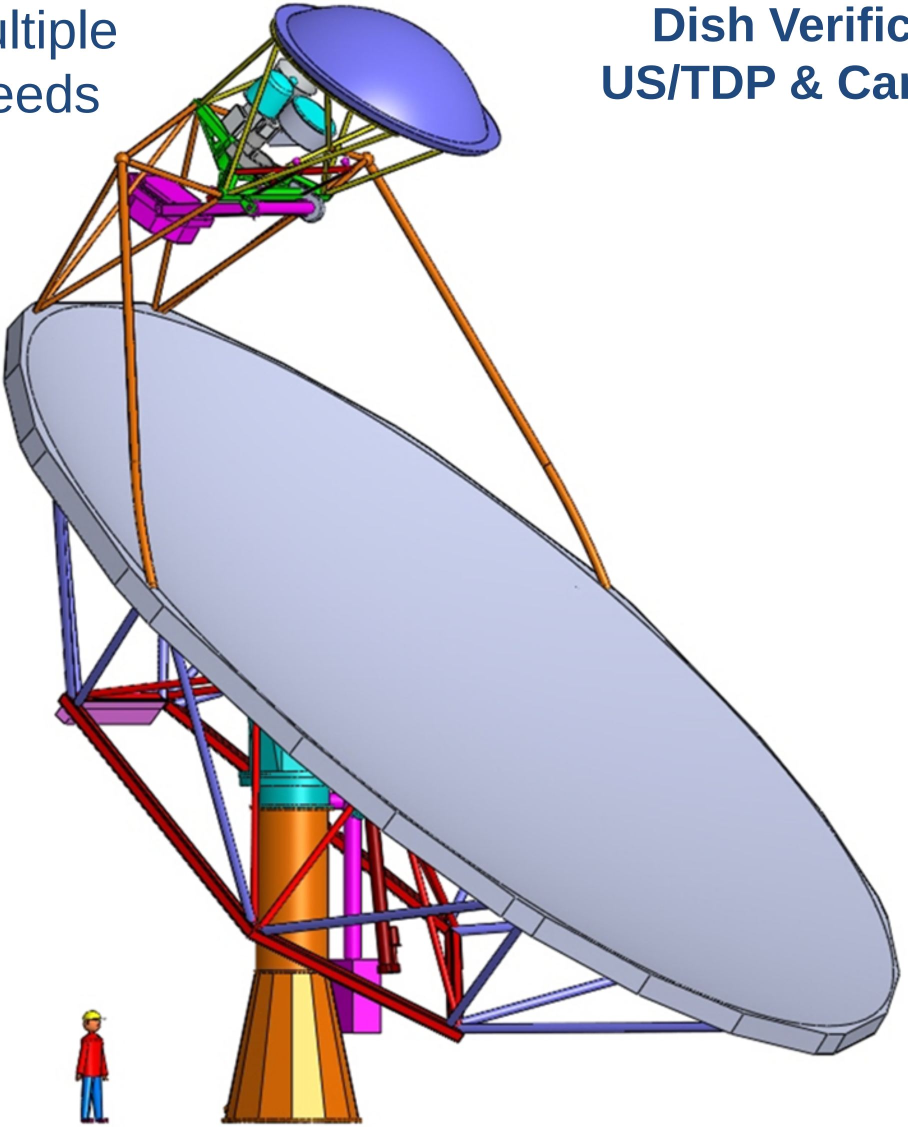
MeerKAT Dish Concept



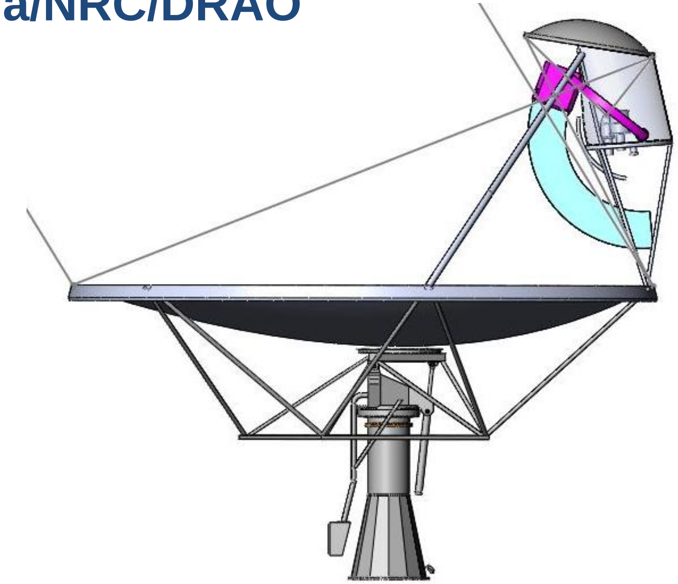


Offset-Optics Antenna Design

Multiple
Feeds



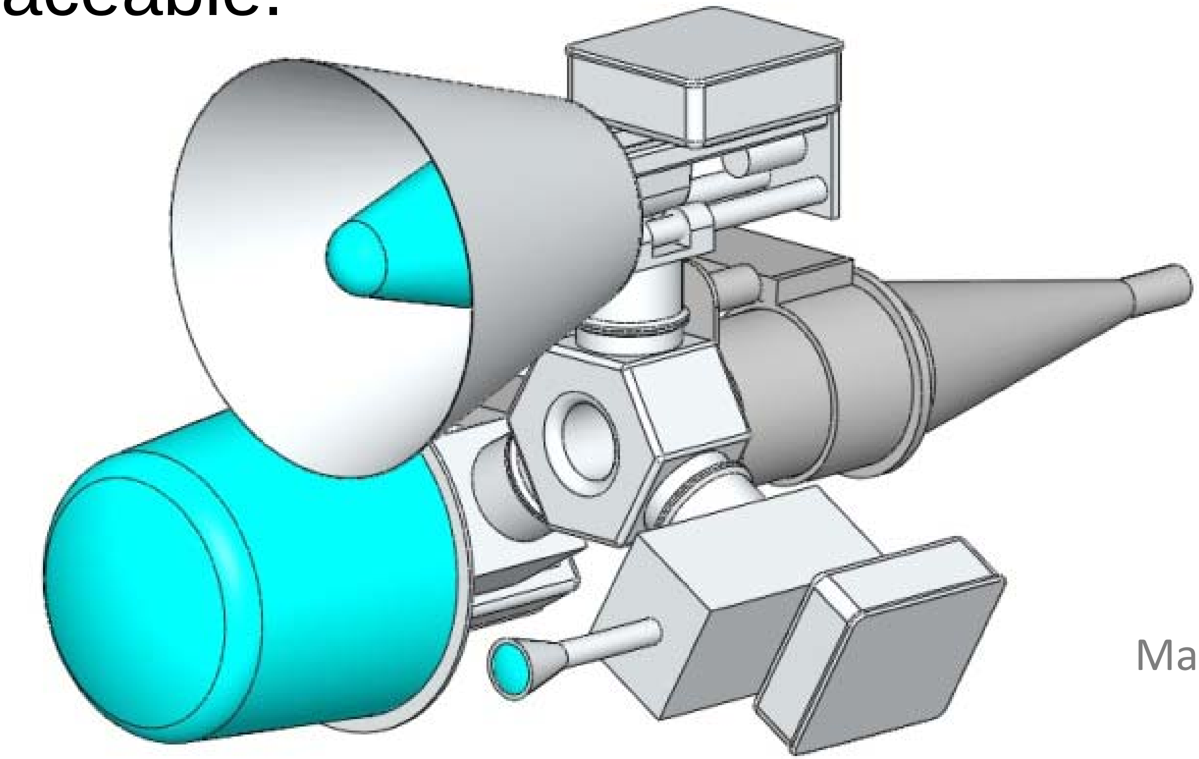
Dish Verification Antenna
US/TDP & Canada/NRC/DRAO



Deployment of PAFs.
Mid-freq. Wide-Field.

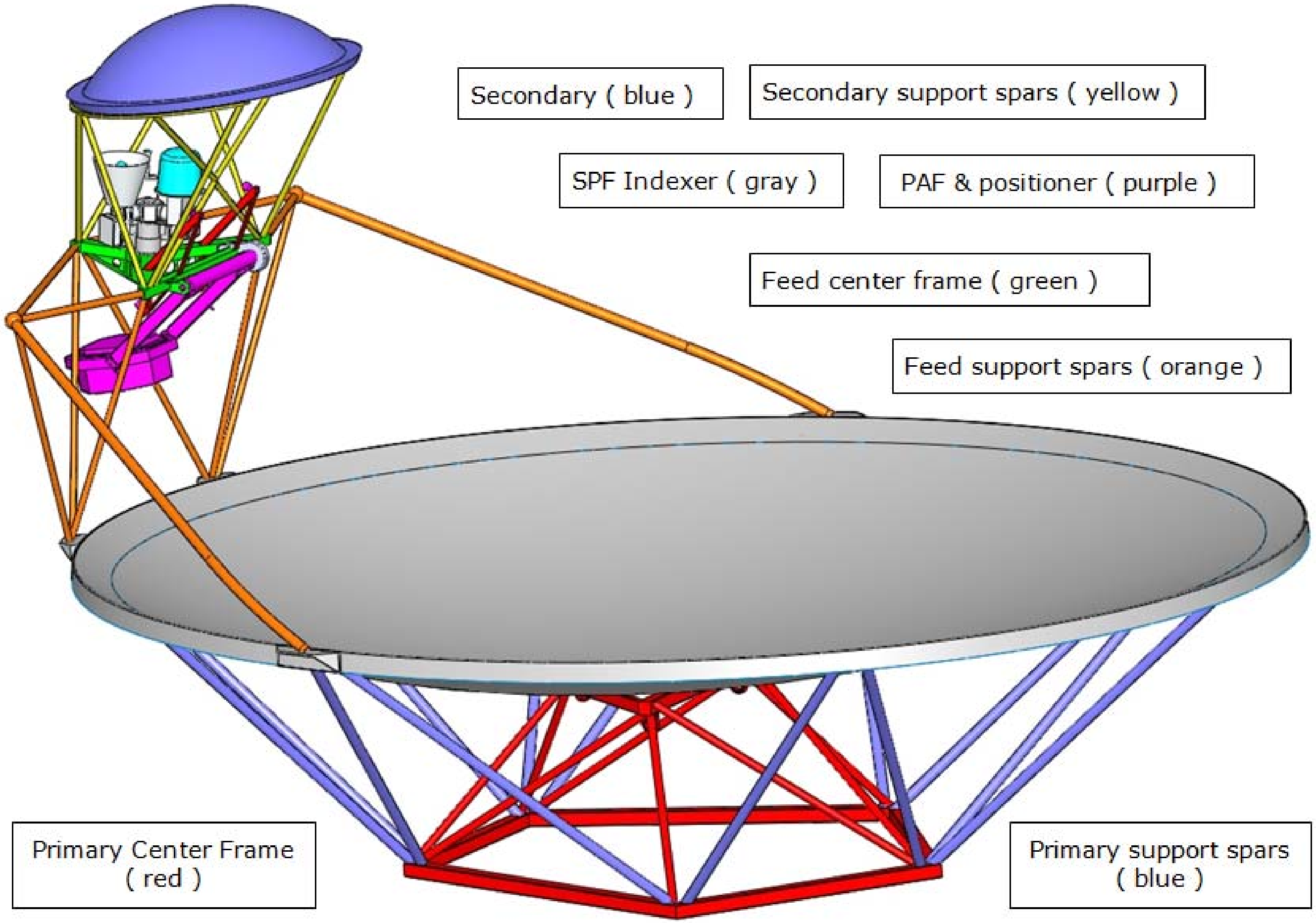
SPF feed payloads

- This shows one concept to accommodate multiple feed payloads on a ‘feed indexer’, individually replaceable.



Matt Fleming

Feed and Support Structure



Secondary (blue)

Secondary support spars (yellow)

SPF Indexer (gray)

PAF & positioner (purple)

Feed center frame (green)

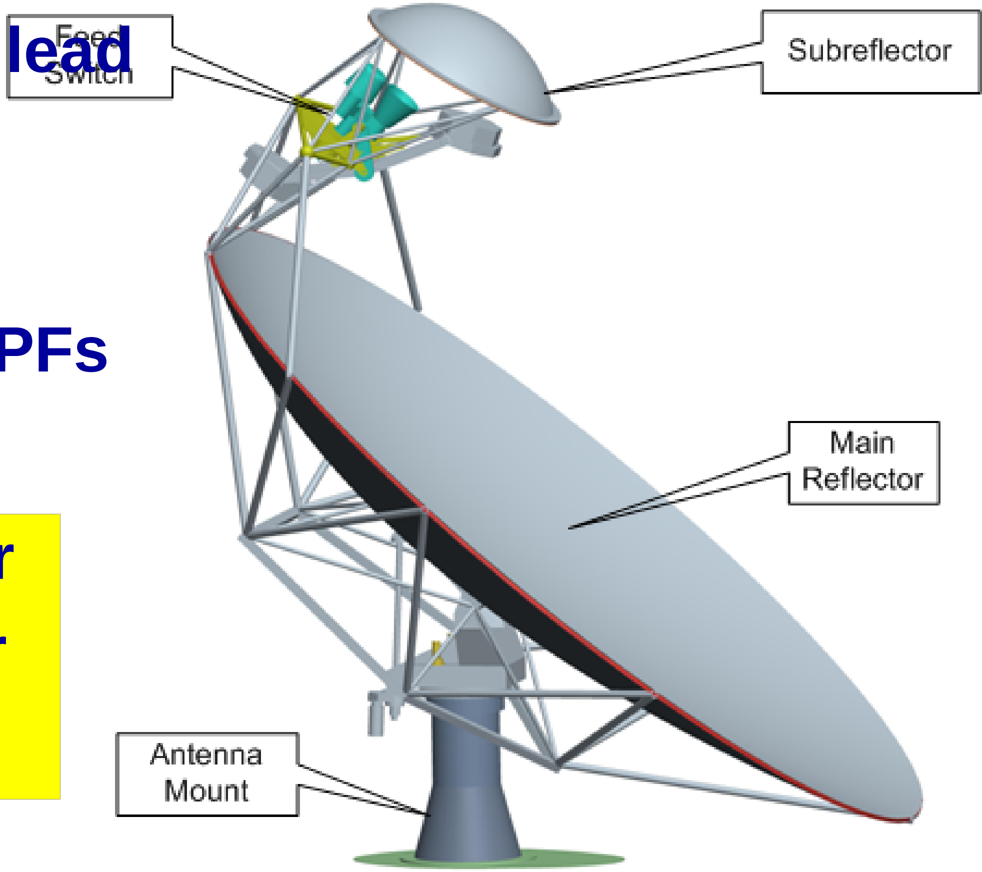
Feed support spars (orange)

Primary Center Frame (red)

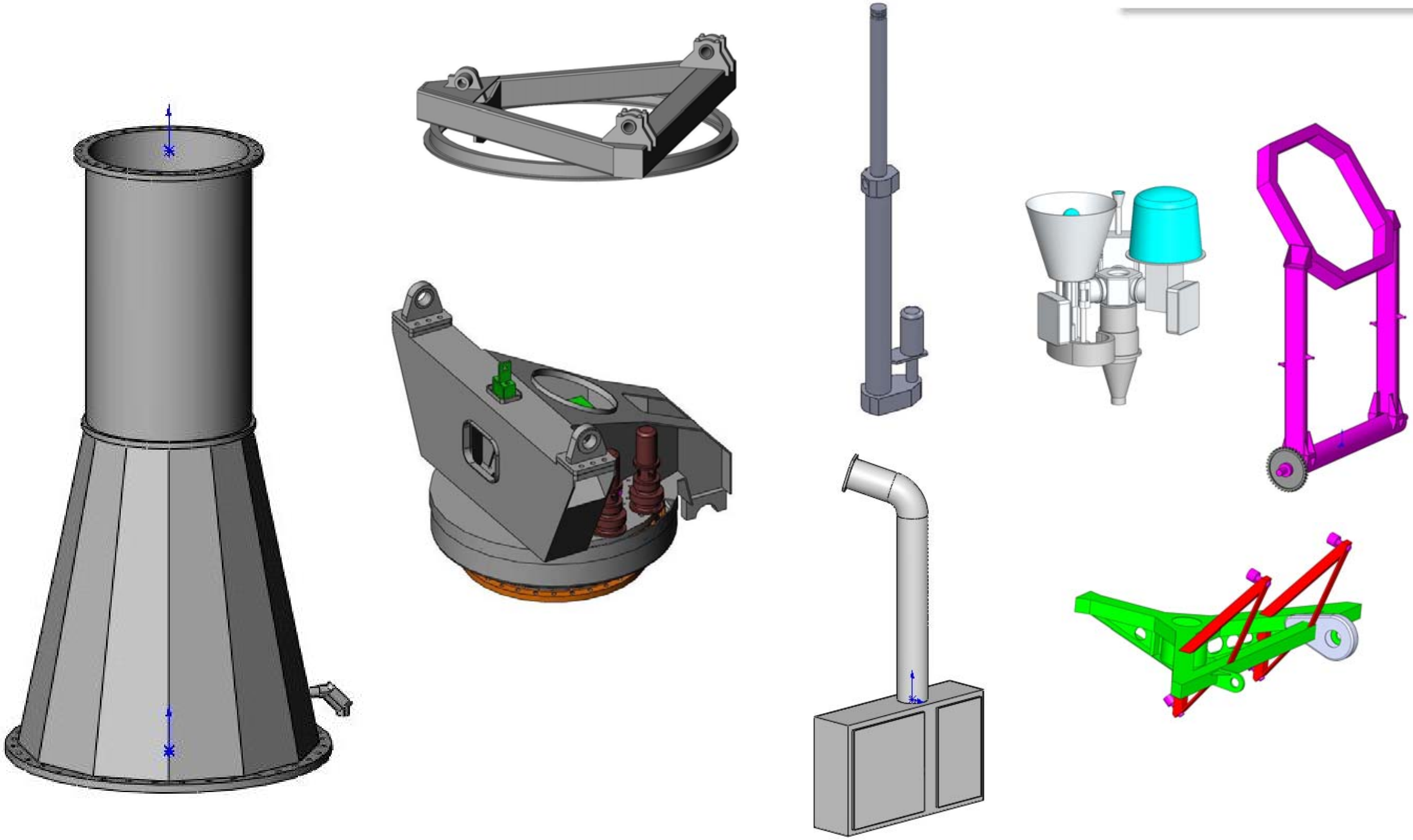
Primary support spars (blue)

DVAC-1 : Offset design from JLRAT (China)

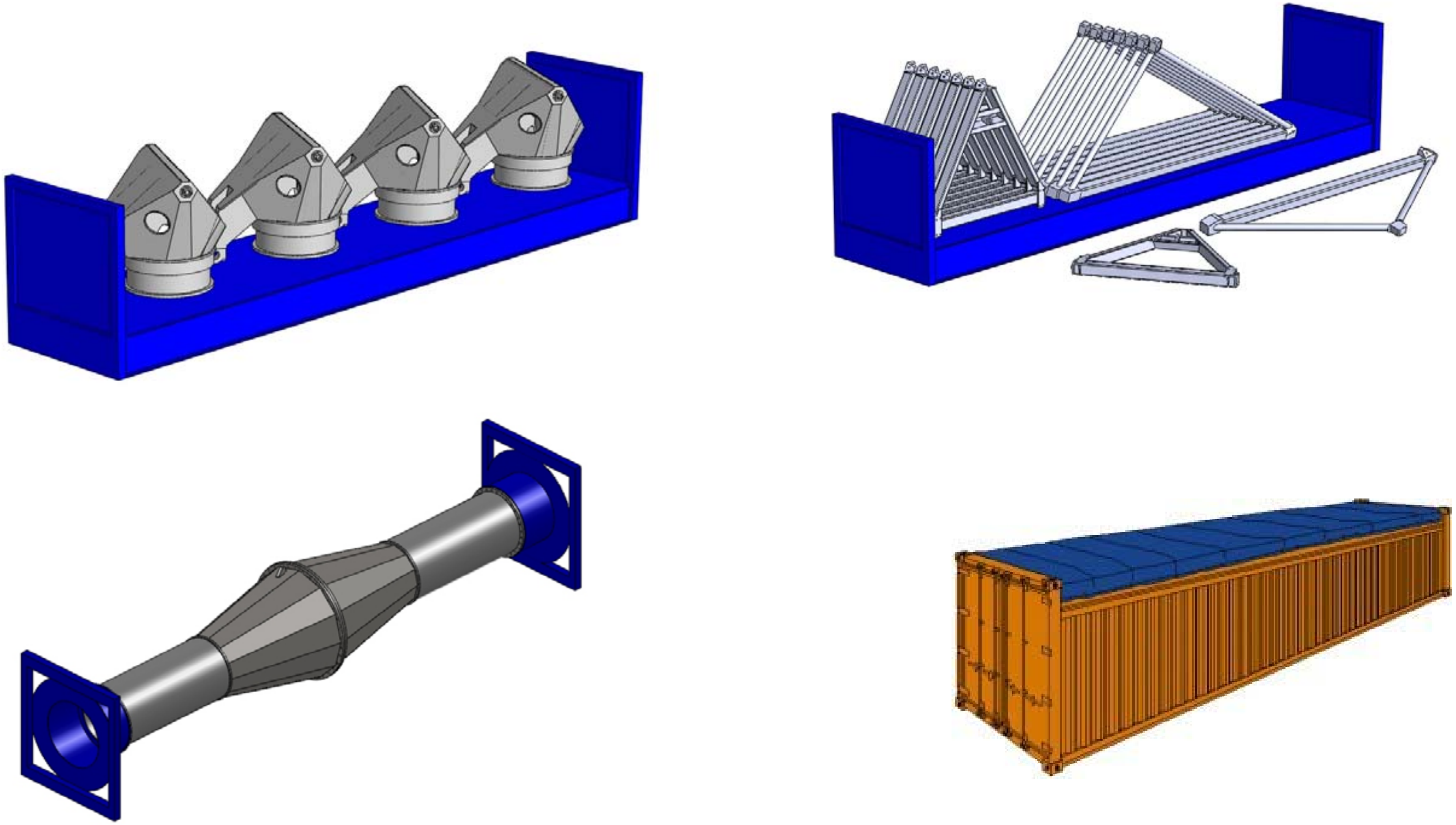
- **Single integrated main reflector**
- **Minimal spar structure**
- **Turning head design with a lead screw elevation actuator**
- **Support and interchange mechanism for a PAF and 3 SPFs or 2 WBFs.**
- **Can be designed with either metal or carbon fibre reflector skins**



Deliverables

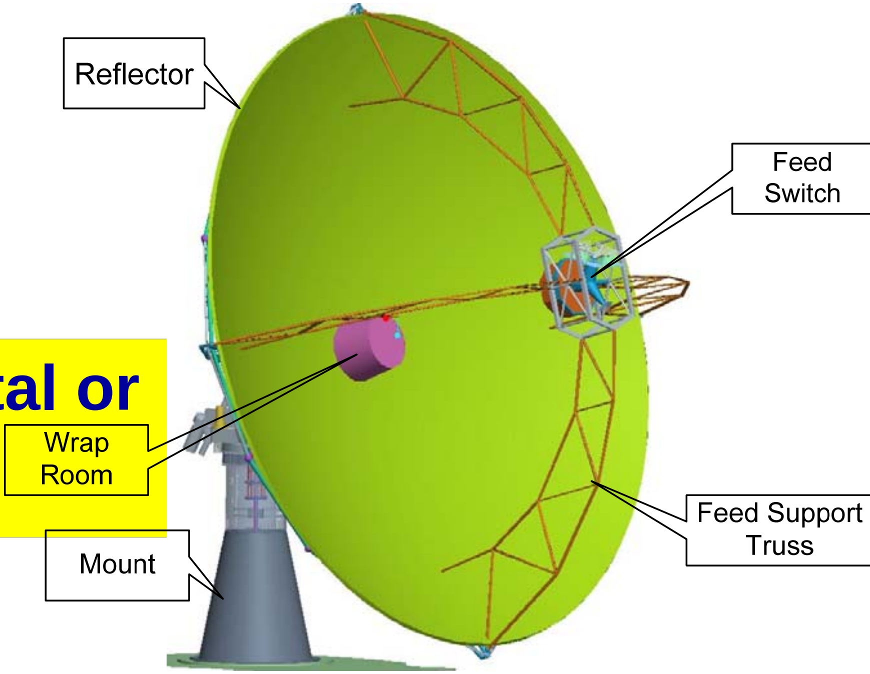


Shipments



DVAC-2 : Symmetric design from JLRAT (China)

- **Single integrated main reflector**
- **Minimal spar structure**
- **Turning head design with a lead screw elevation actuator**
- **Four support legs and interchange mechanism for a PAF and 3 SPFs or 2 WBSPFs.**
- **Can be designed with either metal or carbon fibre reflector skins**



4. Concept Design

(2) Structure Design

➔ Reflector Design — Main reflector

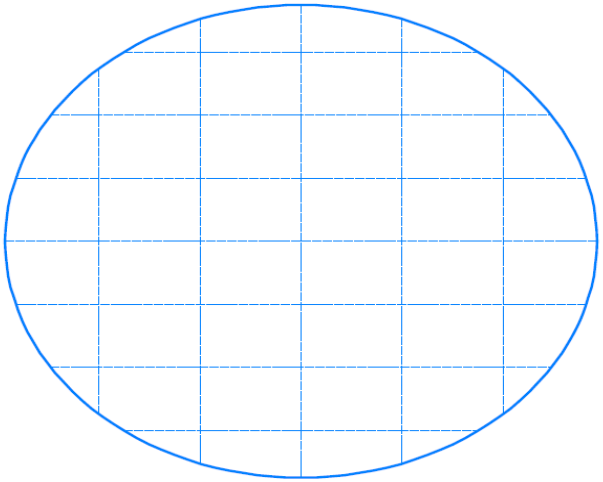
✓ **Design 1: Aluminum sandwich structure**

Single aluminium panel

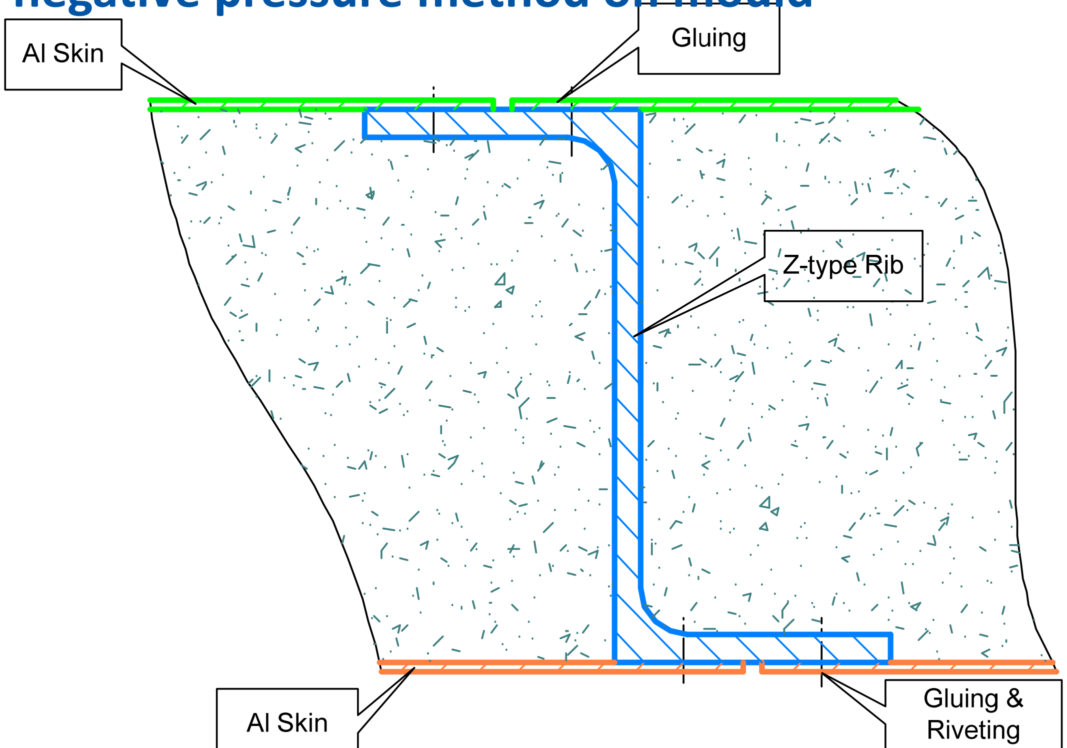
Skins: 2mm (upper)/1mm (lower) in thickness, 2m in width

Skin and ribs are glued through negative pressure method on mould

Surface accuracyσ≤0.8mm



Rib Configuration



4. Concept Design

(2) Structure Design

➔ Reflector Design — Main reflector

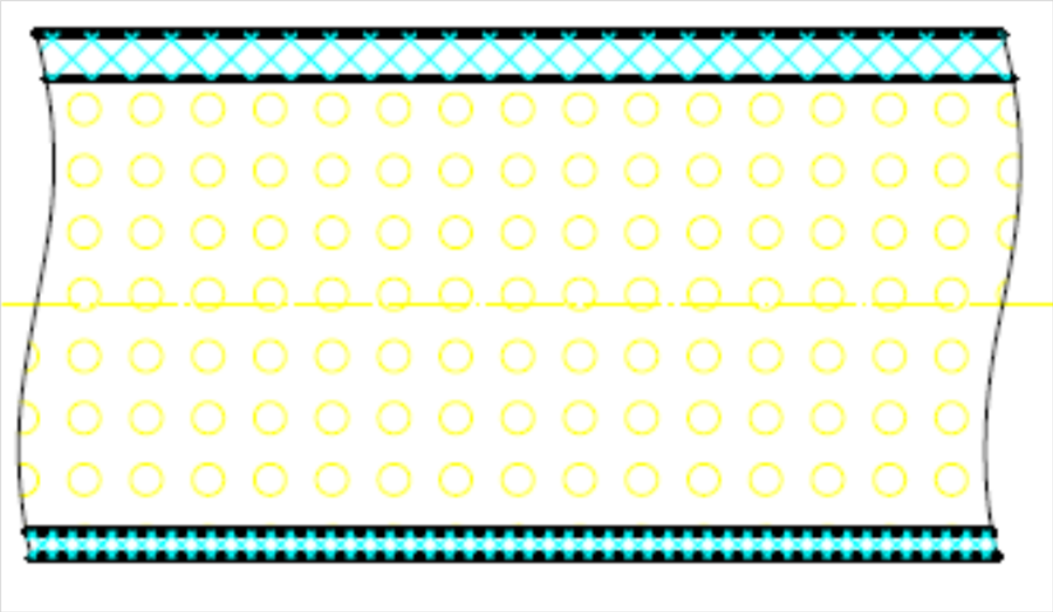
✓ Design 2: Carbon fibre sandwich structure

Single carbon fibre panel

Carbon fibre skins: 1.5mm (top)/1mm (bottom) in thickness

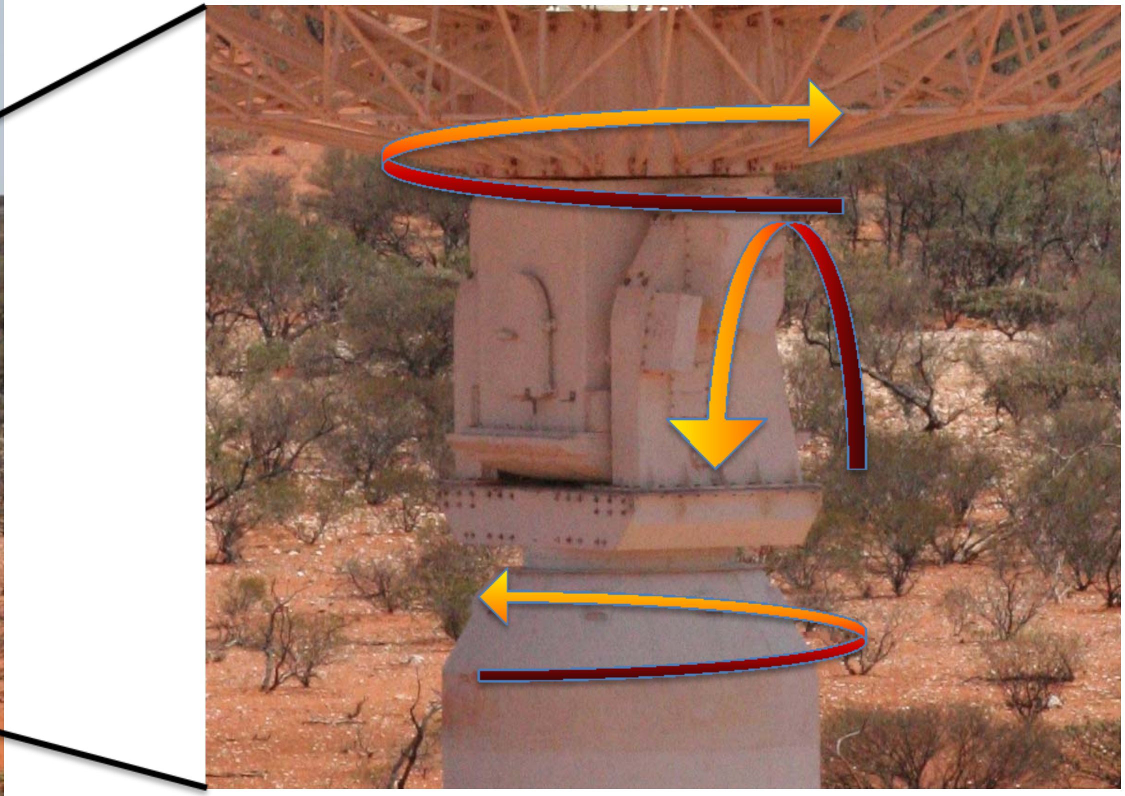
Polyurethane foam: in the middle

Surface accuracyσ≤0.8mm



ASKAP 3-axis Antenna Design

3-axis ASKAP antennas in Australia



Dish CoDR Panel Members

Roger Norrod (Chair)

National Radio Astronomy Observatory, USA (ret).

Trevor Bird

Antengenuity/CSIRO, Australia.

Peter Dewdney

SKA Program Development Office (SPDO), UK.

Bob Plemel

SED Systems (formerly, ret), Canada.

Tony Willis

National Research Council, DRAO, Canada.

CoDR Panel Recommendations

1. Program in which imaging experts work with dish designers
   - modeling and interaction
   - assess the impact of dish design on imaging dynamic range.
2. Formal engineering requirements document for the Dish Array,
   - specification document for the dish antenna element.
3. For composite fabrication techniques,
   - accelerated lifetime testing in an outdoor environment
   - under conditions similar to the SKA candidate sites.
4. Establish a clear and uniform methodology to assess all antenna designs.
5. Develop a test plan for candidate antennas.
   - Build prototypes of the best candidate(s), test, and
   - feed results back into array system models (per Recommendation 1).
6. Establish a specific set of feeds and receivers to include in SKA1.
   - Perform accurate cost analysis (total cost of ownership) and develop receiver prototypes.
7. Address the challenges related to use of cryogenic receiver systems in the SKA.
8. Trade-off study of shaped vs. non-shaped (conic section) optics.

Gaps

1. Uncertain future availability of cryogenic LNA transistors/MMICs.
2. Lack of cryogenic coolers of adequate reliability and performance that are also operationally affordable.
   - Work on cryogenics has been done for KAT7.
   - Experience with 80K Stirling coolers.
3. Insufficient interaction between imaging and antenna design experts.
4. Current lack of a detailed Operational Plan.

Current Dish Cost Estimates

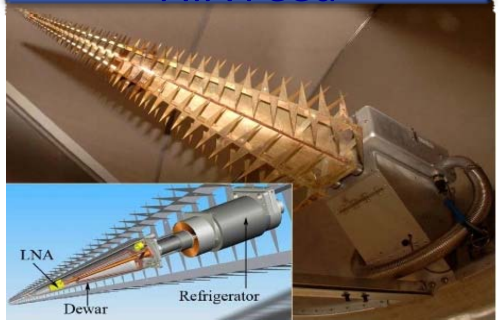
Cost estimates for 15 m offset Gregorian dishes for the SKA						
quantity basis	600	3000	1 - 250	1 - 250	251 - 3000	251 - 3000
concept	DVA1	DVA1	DVAC1 aluminium	DVAC1 carbon fibre	DVAC1 aluminium	DVAC1 carbon fibre
estimator	DRAO/TDP	DRAO/TDP	NAOC/JLRAT	NAOC/JLRAT	NAOC/JLRAT	NAOC/JLRAT
total cost €	€ 201,557	€ 185,432	€ 198,000	€ 207,000	€ 191,000	€ 199,000
reflector cost €	€ 69,775	€ 64,193	€ 75,000	€ 85,000	€ 73,000	€ 82,000

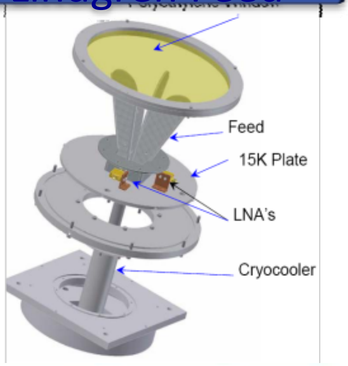
Cost estimates for 15 m axi-symmetric dishes for the SKA						
quantity basis	1 - 250	1 - 250	251 - 3000	251 - 3000	?	?
concept	DVAC2 aluminium	DVAC2 carbon fibre	DVAC2 aluminium	DVAC2 carbon fibre	Thermoplastic axi-symmetric	Thermoplastic axi-symmetric (future)
estimator	NAOC/JLRAT	NAOC/JLRAT	NAOC/JLRAT	NAOC/JLRAT	ASTRON	ASTRON
total cost €	€ 211,000	€ 220,000	€ 202,000	€ 210,000		
reflector cost €	€ 65,000	€ 75,000	€ 63,000	€ 72,000	€ 106,000	€ 84,800

Cost Minimization Principles for Dishes & Payloads

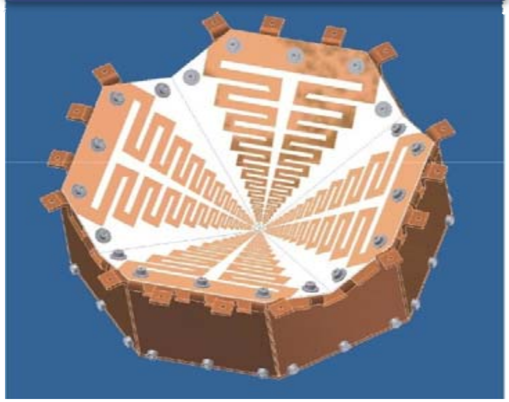
1. Keep the number of dishes as low as possible for a required system sensitivity.
   - Dramatically affects capital and operational system costs.
   - e.g. SKA1 needs only 153 dishes for $A_e/T_{sys} = 6.5\ m^2/K$.
   - Dish numbers ripple through the system costs.
2. R&D and spending on noise reduction is very efficient.

Wide Band Single Pixel Feeds

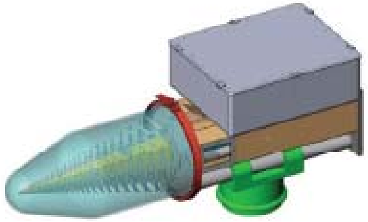

ATA Feed


Lindgren Feed


QSC Feed


Eleven Feed

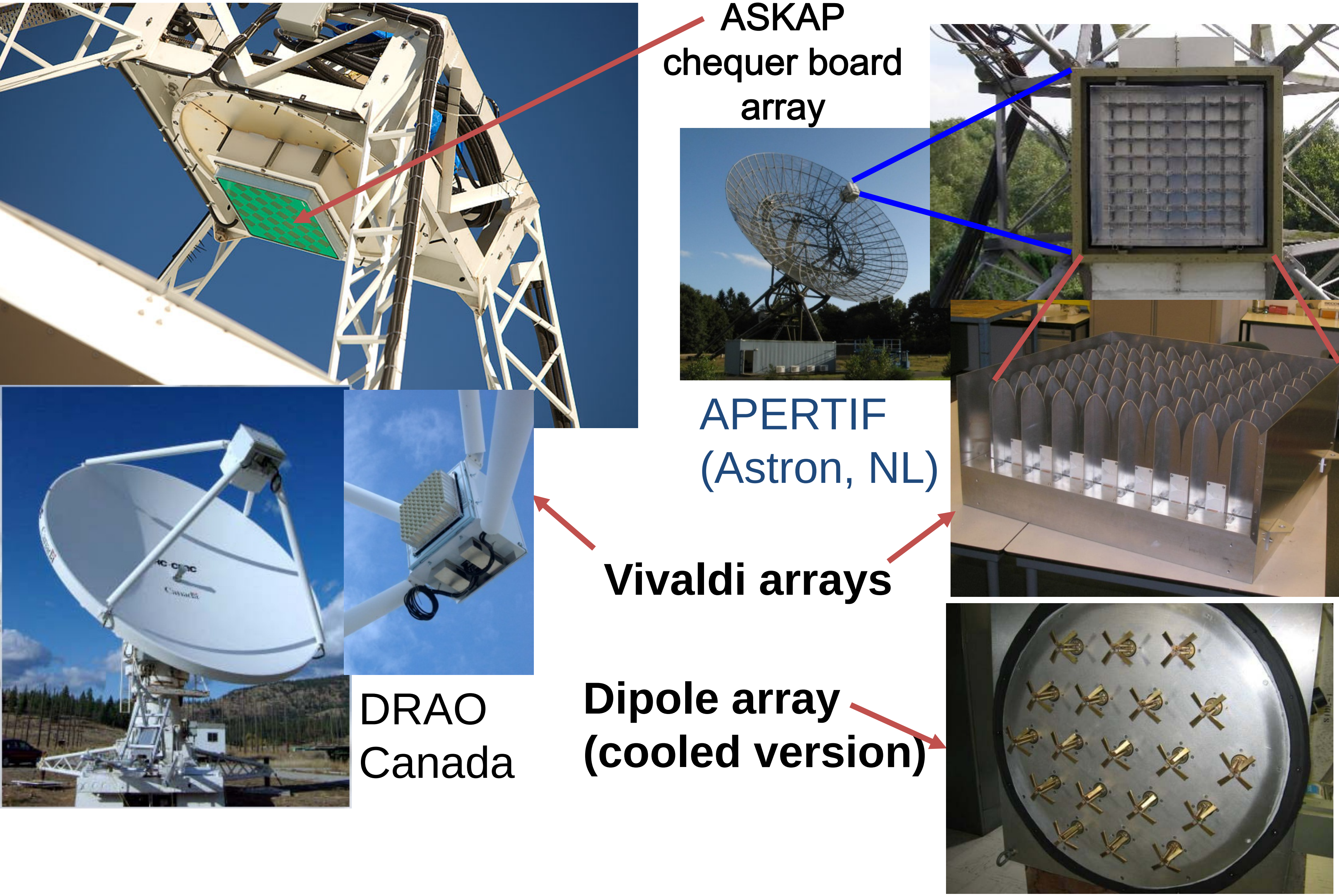

Inverted Sinuous Feed


Cooled ATA Feed


Quad-Ridge Flare Horn


Log-Periodic Log Spiral

Phased Array Feed Concepts



ASKAP
chequer board
array

APERTIF
(Astron, NL)

Vivaldi arrays

DRAO
Canada

**Dipole array
(cooled version)**

Risks:

1. 24 slides containing risks presented at Dish Array CoDR
2. Considerable risk:
    a) Programmatic
    b) Cost
    c) Schedule
    d) Gaps

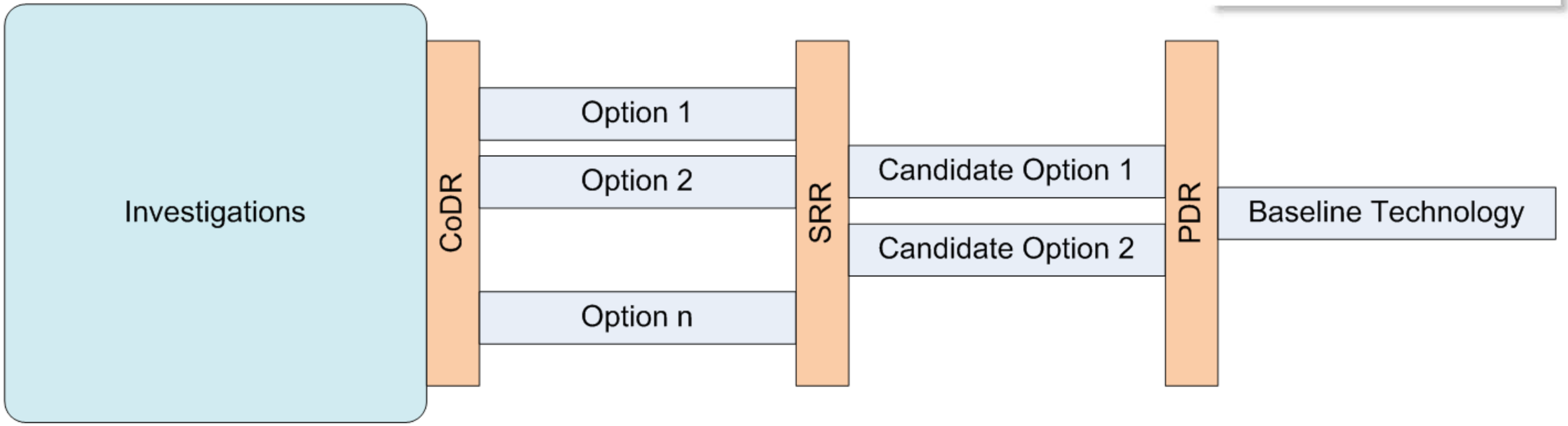
Risk Summary

- Dishes
  - Insufficient development funding.
  - Production cost: developing a full understanding.
  - Performance: limiting spatial or spectral dynamic range at full sensitivity.
  - Remote site: maintenance and access.
  - Environment: longevity.
- SPF feed/LNA payloads:
  - Development gaps:
    - not enough attention to development of the best performance feeds
    - Not enough attention to cryogenics: weight, power, maintenance, longevity
  - Power consumption: especially with cryogenics.
  - Cost of ownership: maintenance costs (esp cryogenics).
  - EMC, RFI

Risk Summary (cont’d)

- PAF Sub-System
  - PAF System Performance
  - Weight and Volume
  - Power Consumption
  - EMC and RFI Compliance
  - Development Timeline
  - Costs (full system costs)
- SPF Receiver
  - Analog Performance
    - Gain/Phase stability
    - Analog bandshape stability
    - ADC
  - Technology Maturity
  - Power Consumption
  - EMC, RFI.

Narrowing of Options



- System Engineering Approach => happens at every level of the system hierarchy.
  - see SKA System Eng. Management Plan and other docs.

CoDR = Concept Design Review
SRR = System Requirements Review
PDR = Preliminary Design Review

End