Towards SKA
Multi-beam concepts and technology

SKA meeting
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Square Kilometre Array:

Next giant radiotelescope (~2020) at decimetre and centimetre wavelengths

- **Collecting area: 10^6 m²**

  line observation: sensitivity up to 100 x current designs

  continuum observation: sensitivity up to 1000 x current designs (large bandwidth)

- frequency range: 70 MHz – 25 GHz (λ 3 m - 1 cm)
- Field of view: 200 deg² @ f<0.3 GHz 50 deg² @ 1 GHz
- Nb of FoV: 1 to 4
- Baseline length: up to 3000 km
- ***Wideband, wide field of view, multi beam***
- **total construction cost ~ $1.5 \cdot 10^9$ EUR**

SKA will be a very high sensitivity instrument

=> need of a *very large collecting area*

- Very large number of small dishes (~10m ∅)

and

SKA will be a general purpose instrument optimized for large surveys

=> need of *large FoV*

- Very large number of small dishes
- Multi beam operating mode

  and / or
- Large area of aperture array

Multi-beam concepts for synthesis of independent beams:

- Tied array mode with single pixel feed on dishes
  ATA (0.5 – 11 GHz) …

- Phased Array Feed on dishes
  APERTIF(0.7 – 1.8 GHz), ASKAP…

- Aperture arrays using quasi omnidirectional antenna elements
  LOFAR (30 – 240 MHz), EMBRACE (0.5 – 1.5 GHz)…

Multi-beam concept for synthesis of grid of beams:

- Spatial fourier transform from each antenna signal

Multi beam with cluster of feeds on a dish:

- Cluster of corrugated horns (Parkes , 13, Arecibo, 7)

SKA will have a large frequency range and a wide instantaneous bandwidth:

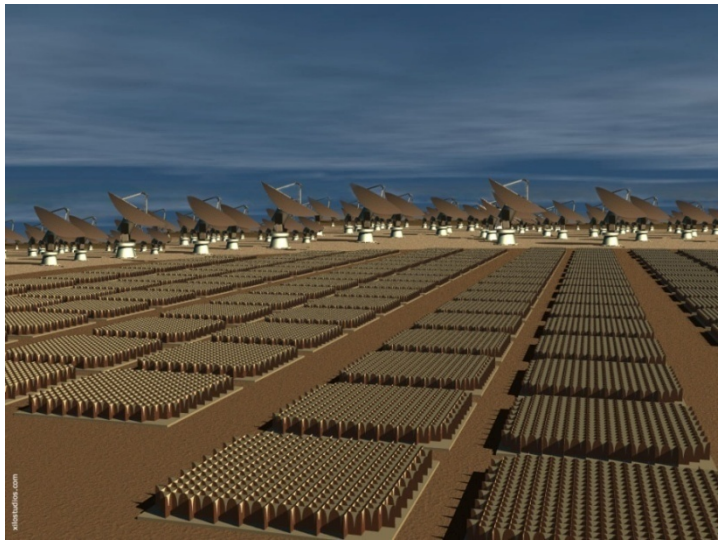
- Single pixel feeds can cope with large frequency range, but are not multi-beam friendly

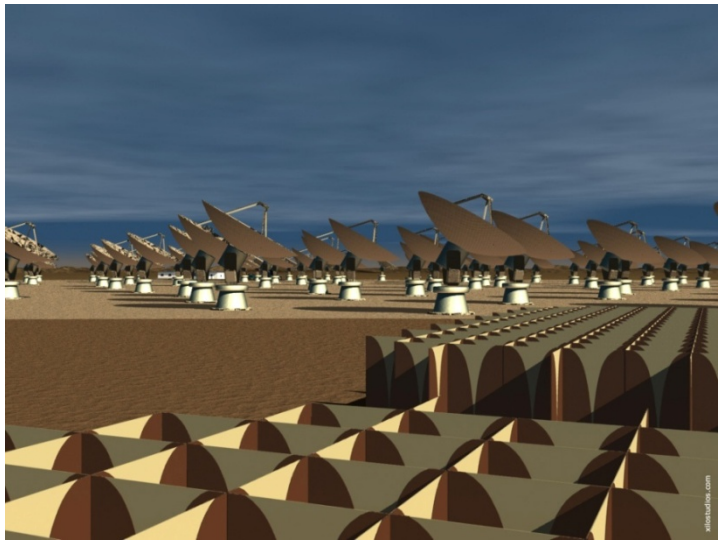
- Phased Array Feeds and aperture arrays can deliver multiple independent beams, but can't cover large frequency range

=> SKA will use a *hybrid design* with

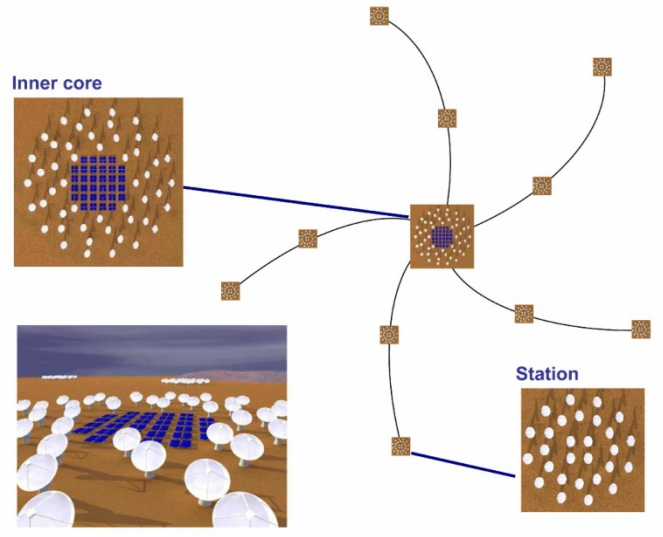
- Small to medium dishes with single pixel feeds, or (preferably) with phased array feeds
- Aperture arrays

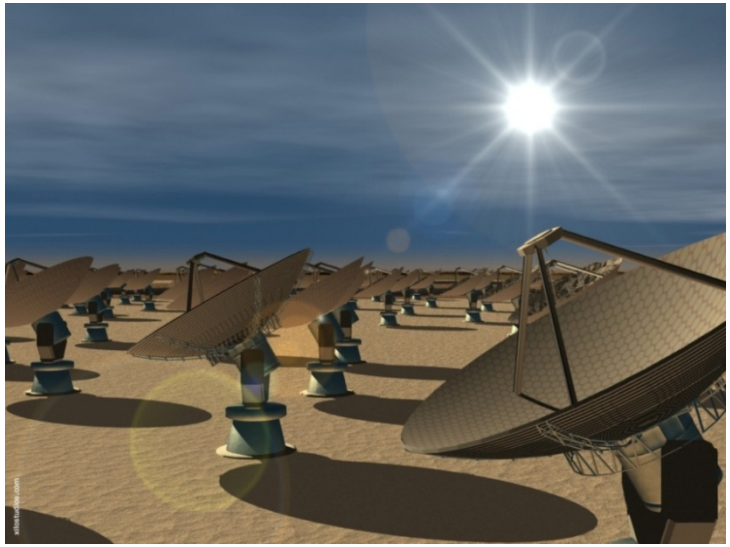
SKA reference design (1)





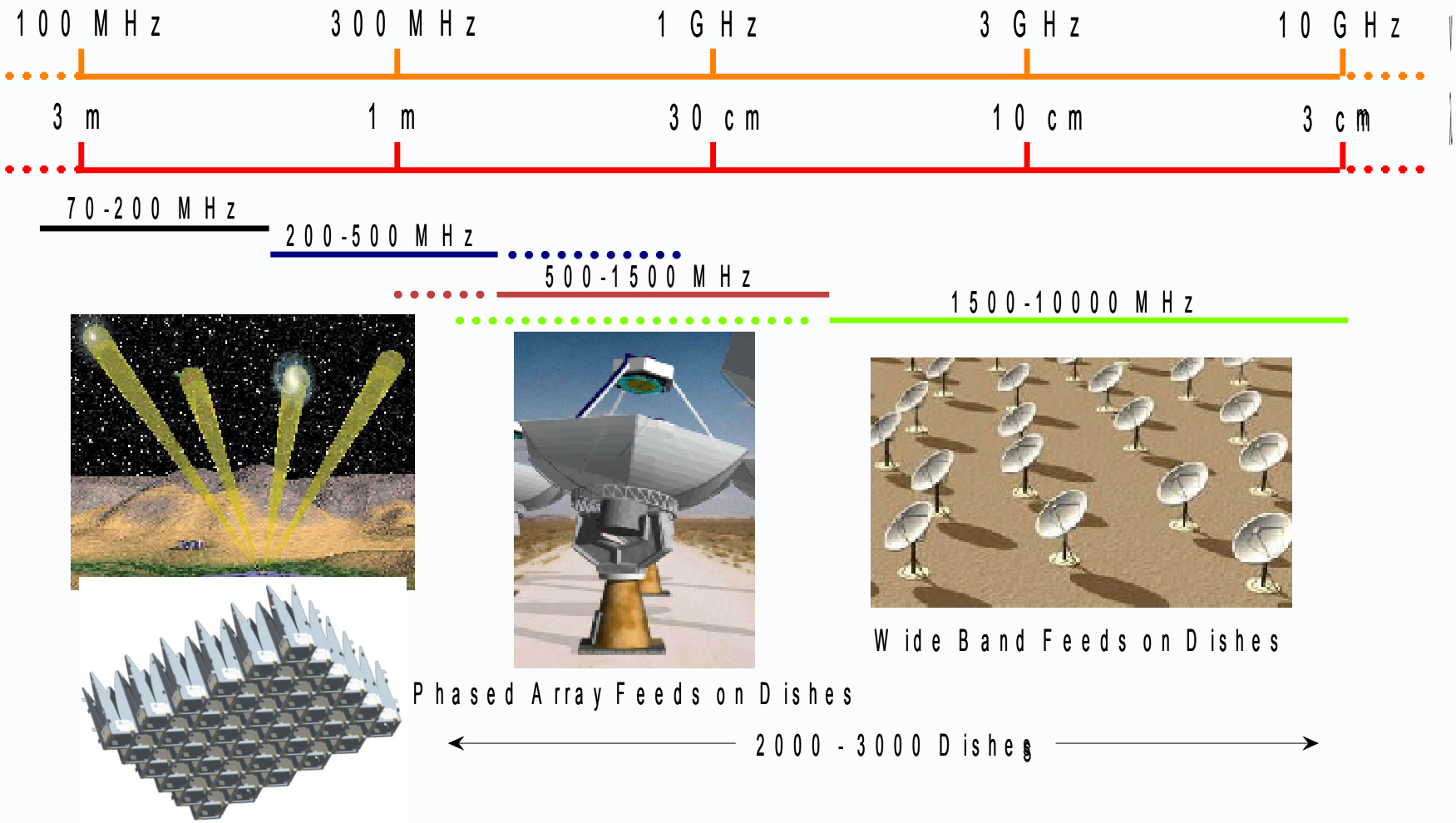
Core:
200,000 m^2 of
phased array
- tiles





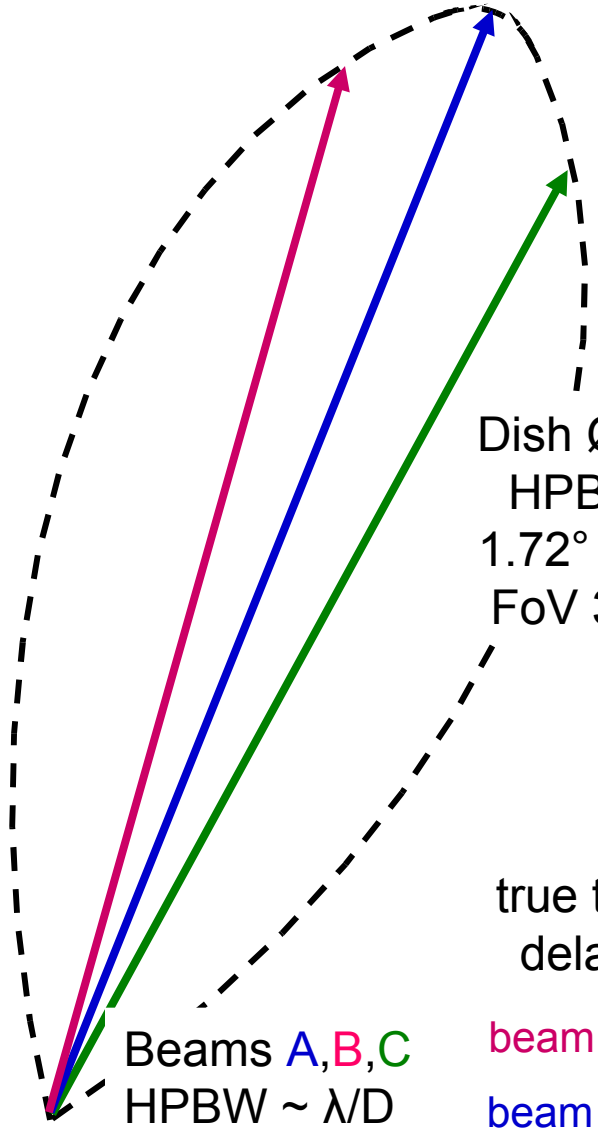
Station:
parabolas
with Phased
Array Feed

SKA reference design (2)



Numbers of dishes (2000-3000) depends on whether Phased Array Feeds and/or Aperture Arrays are used in the SKA.

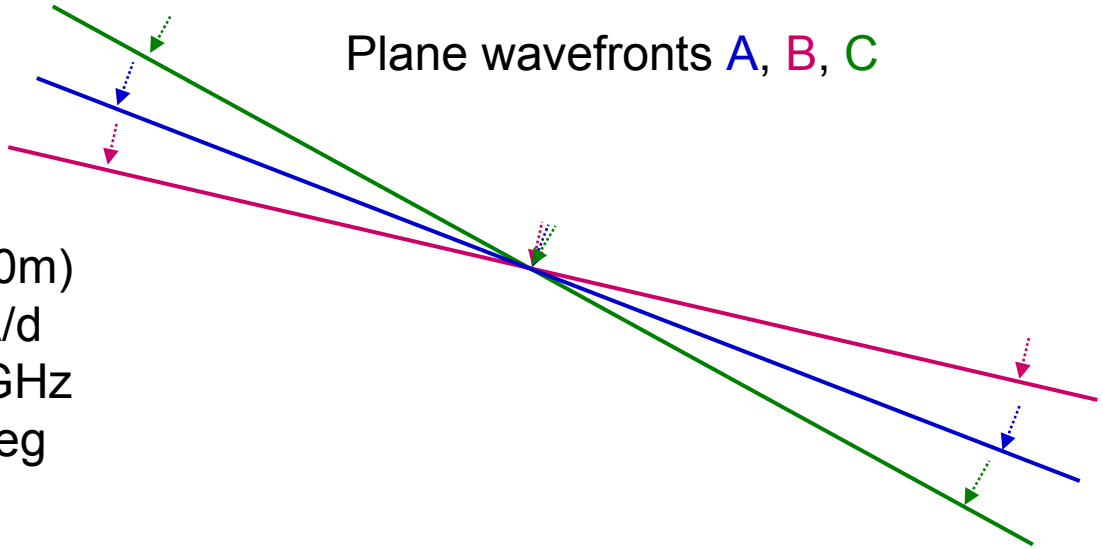
Tied array mode and multi-beam for single pixel feeds

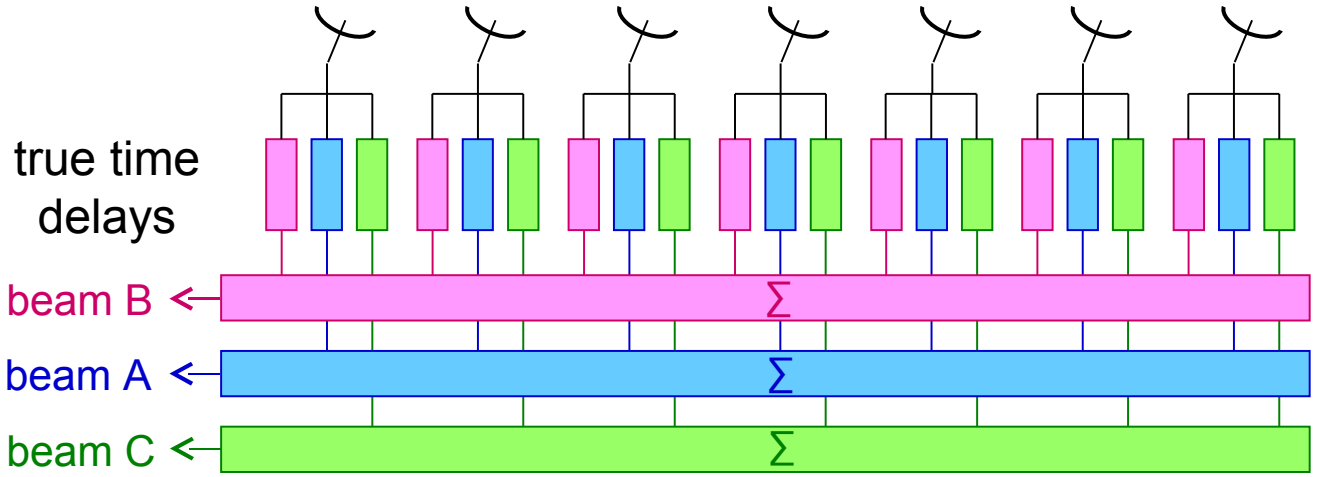


Dish Ø d (10m)
HPBW ~ λ/d
1.72° @ 1 GHz
FoV 3 sq deg

Beams A,B,C
HPBW ~ λ/D

Max FoV limited by dish diameter





Multi-beam mode with Phased Array Feeds:

HPBW of each beam: ~ λ/d

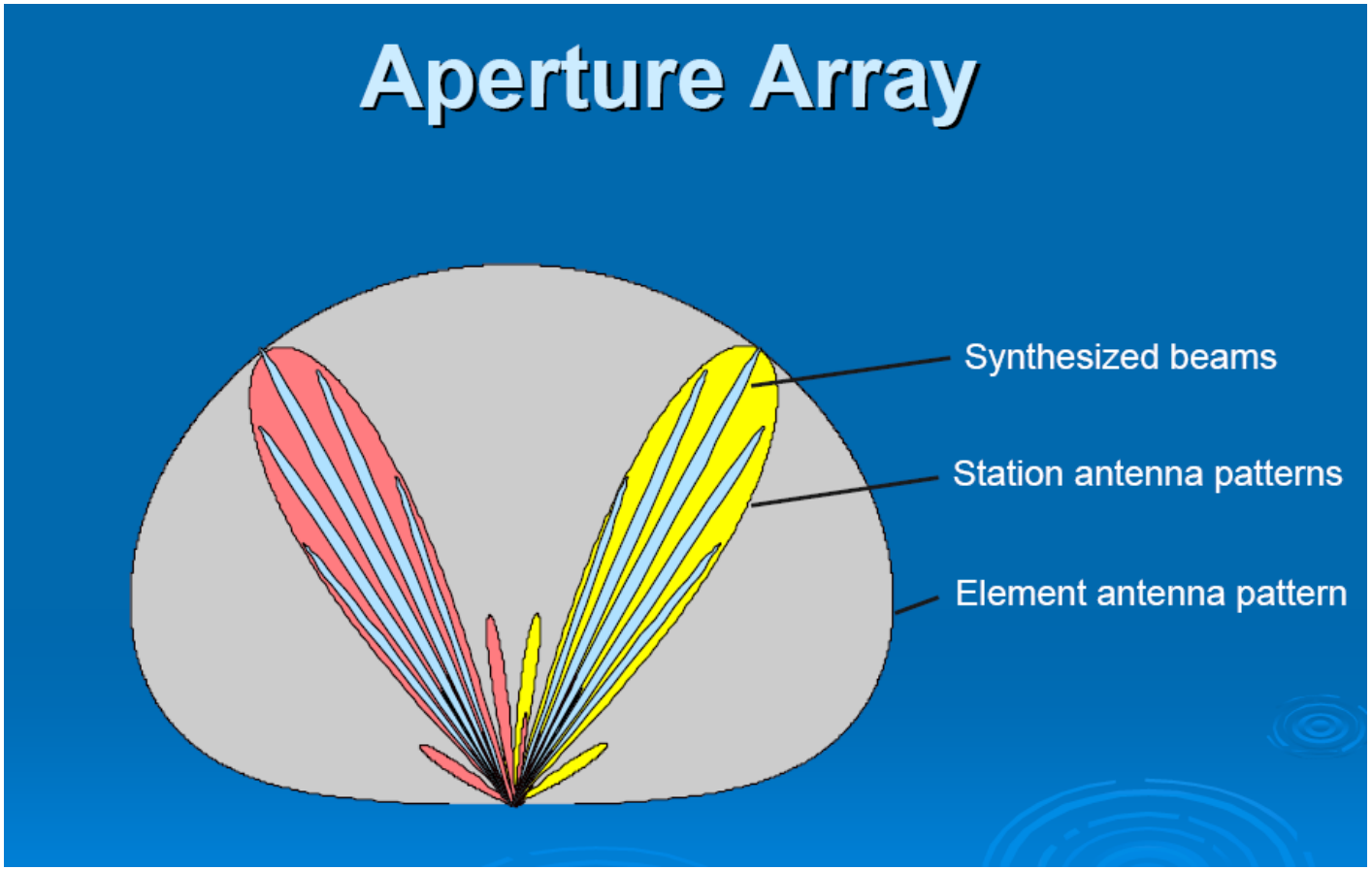
For d=12m
FoV one beam ~ 1 sq deg @ 1.4 GHz

Array of ~ 10x10 small elements with
20 beams: FoV 20 sq deg

All beams can be set independently

Phased array feeds allow access to a FoV larger than the dish FoV

Aperture array:



Tiles of ~1 to a few m², 8 x 8 up to 16 x 16 dual polarized antenna elements

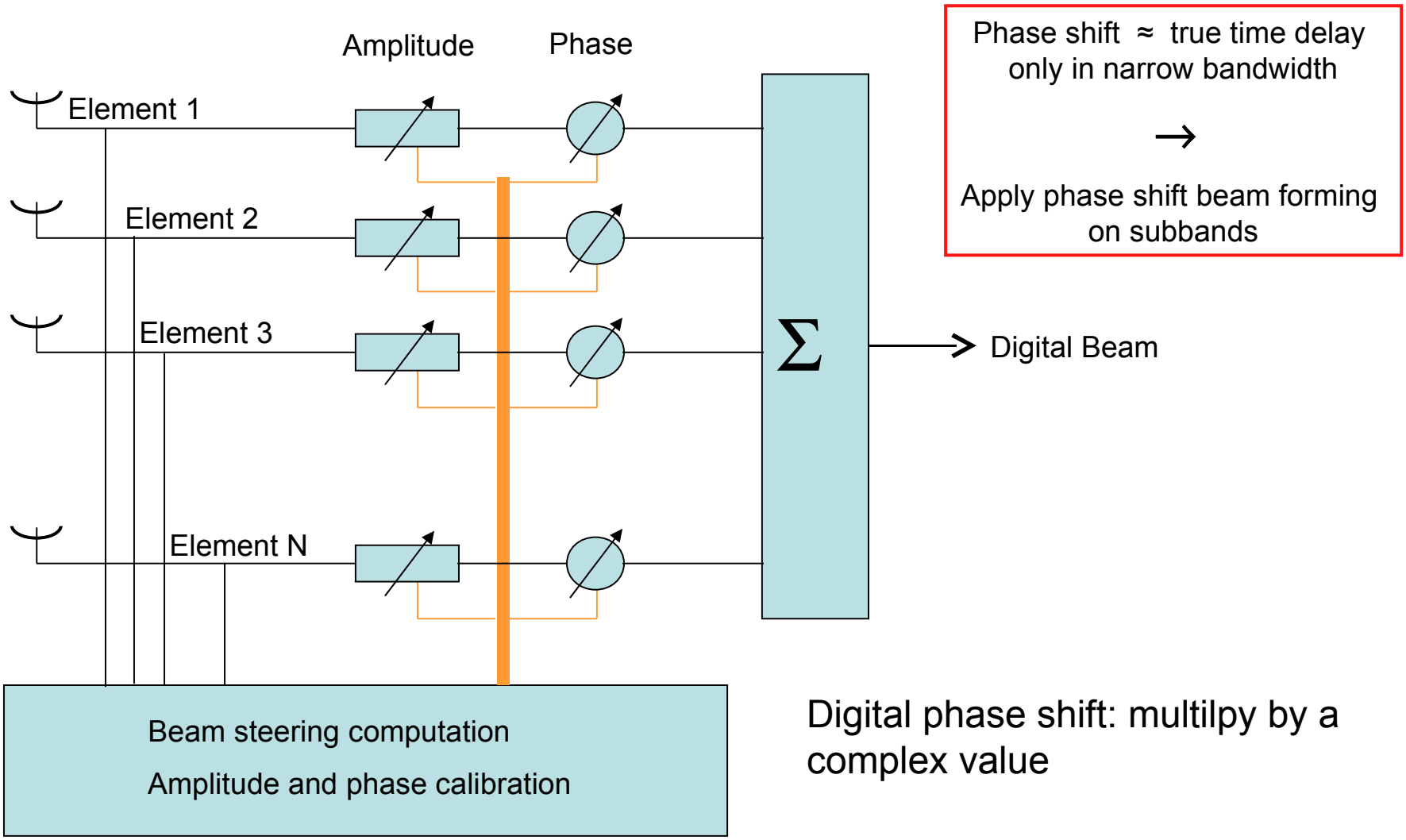
RF analog beamforming + digital beamforming (EMBRACE demonstrator)

All digital beamforming (2-PAD demonstrator)

Aperture Array

Engineering test of an EMBRACE tile (Nançay lab)

Digital beamforming

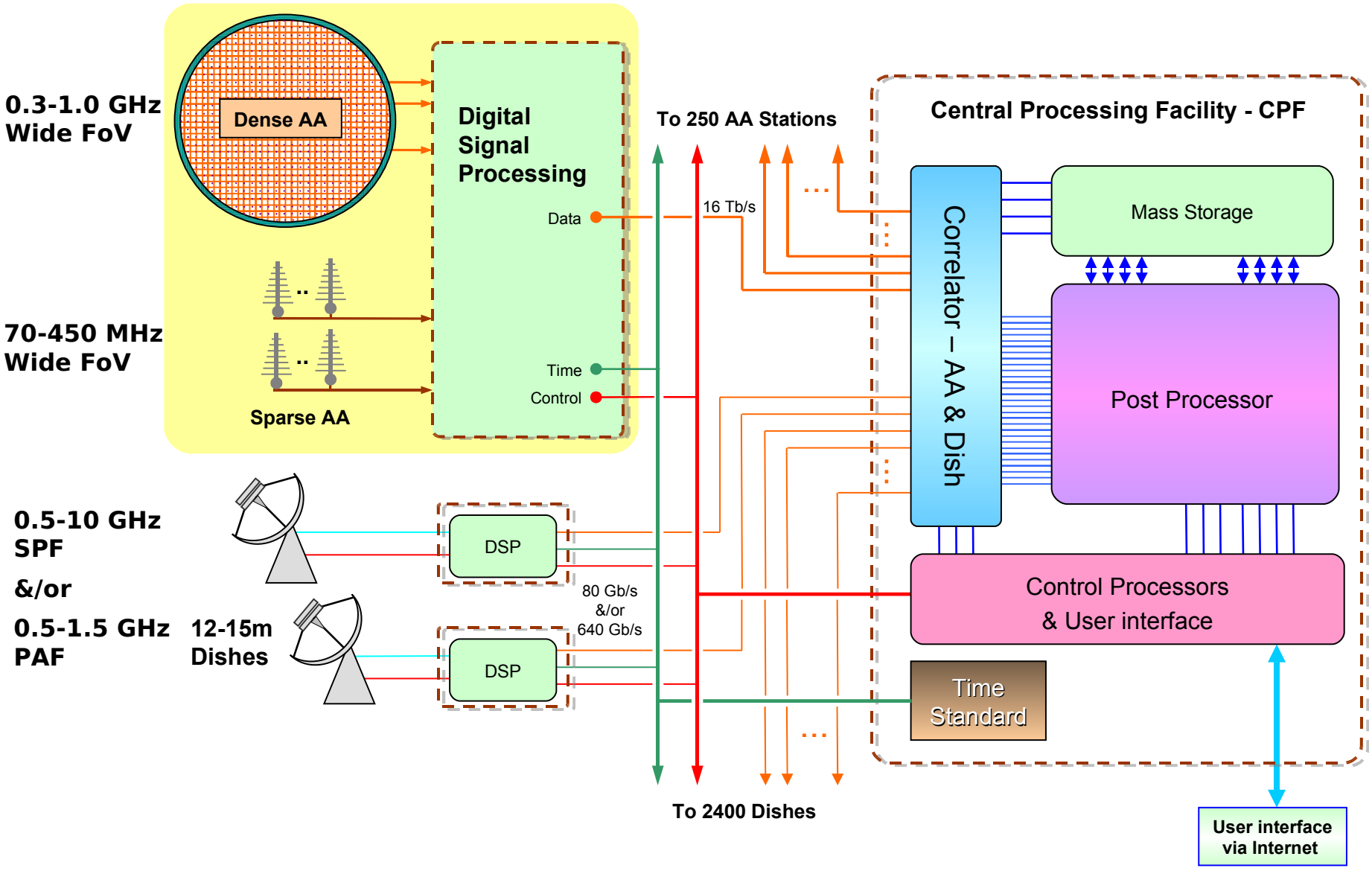


Phase shift ≈ true time delay only in narrow bandwidth

→

Apply phase shift beam forming on subbands

Digital phase shift: multilpy by a complex value


0.3-1.0 GHz
Wide FoV
Dense AA
Digital
Signal
Processing
Data
Time
Control
70-450 MHz
Wide FoV
Sparse AA
0.5-10 GHz
SPF
&/or
0.5-1.5 GHz
PAF
12-15m
Dishes
DSP
DSP
80 Gb/s
&/or
640 Gb/s
To 250 AA Stations
16 Tb/s
To 2400 Dishes
Central Processing Facility - CPF
Correlator – AA & Dish
Mass Storage
Post Processor
Control Processors
& User interface
Time
Standard
User interface
via Internet

Technology and operation challenges:

Small dishes with single pixel feed:

- mature technology to be optimized for low cost
- Front end cooling system

Phased array feed and aperture arrays:

- System noise ? (no use of cooled front ends)
- Very high digital bandwidth for digital signal processing (Tb/s)
- Very high power requirement

Output data flow from such a system:

- Tera bytes of data / hour...
- Availability of raw data? (10 min., 1 hour, 3 days?)
- Data archive

Ongoing developments under SKADS (E.C. FP6) and PrepSKA (E.C. FP7):

- Antenna elements for aperture arrays and phased array feeds
- LNA (Cmos, SiGe, AsGa)
- Low cost front ends (aperture array tiles)
- Cooling system for phased array feeds
- RF beamforming: Beamformer chip
- Digital beamforming
- Array layout
- Signal transport
- Calibration

SKA Pathfinders and Precursors:

ATA (USA) - Pathfinder

Up to 350 dishes, Ø 6m
Feed: Wideband single pixel
Frequency range: 0.5 to 11 Ghz

Max. baseline: a few km
Operation: ATA 42 since end of 2007 – future enlargement?

MeerKAT (South Africa)

Up to 80 dishes, Ø12m
Feed: 2:1 corrugated horns + wideband feeds
Frequency range: 0.7 to 10 GHz
Instantaneous bandwidth: 1 GHz

Max. baseline: 8 km ; with flexible beam size (6-60 arcsec)
Fully operational by 2013

KAT-7: 7 antennas on site by the end of 2009

ASKAP (Australia)

Array of 36 dishes Ø12m with Phased Array Feed

- Frequency range 0.7 to 1.8 GHz
- Instantaneous bandwidth 300 MHz
- T_{sys} 50 K after beamforming
- 30 independent beams of 1 sq deg each @ 1.4 GHz
- Cross correlation on a per beam basis
- FoV: 30 sq deg @ 1.4 GHz
- Max. baseline 6 km (optimized for beam size of 30 arcsec)

Western Australia site (Murchison Radio Observatory),
very low RFI environment

Digital beamforming per antenna: ~100 dual pol elements
After sub-banding, beamforming in each subband by a weighted sum of all elements, up to 30 beams in each subband.
Cross correlation of all same beams for all antennas

Beta phase of six antennas by 2011
Fully operational by 2013

ASKAP survey speed and sensitivity:

Parameter	10"	18"	30"	90"	180"	units
Continuum survey speed (300 MHz, 100uJy)	220	361	267	54	17	sq deg/hr
Line survey speed (100kHz, 5mJy)	184	301	223	45	14	sq deg/hr
Surface brightness survey speed (5 kHz, 1K)	-	-	1.1	18	94	sq deg/hr

Survey speeds for different angular resolutions under the assumption of a 50 K system temperature and an aperture efficiency of 0.8.

Parameter	10"	18"	30"	90"	180"	units
Continuum sensitivity (300 MHz)	37	29	34	74	132	μJy/bm
Line sensitivity (100 kHz)	2.1	1.6	1.9	4.1	7.3	mJy/bm
Surface brightness sensitivity (5kHz)	51	12	5.2	1.3	0.56	K

Sensitivity (1-sigma) for a one hour observation

Square Kilometre Array

Within a week,

SKA could deliver information equivalent to...

All the words ever spoken by human beings