Antenna design for Space Applications

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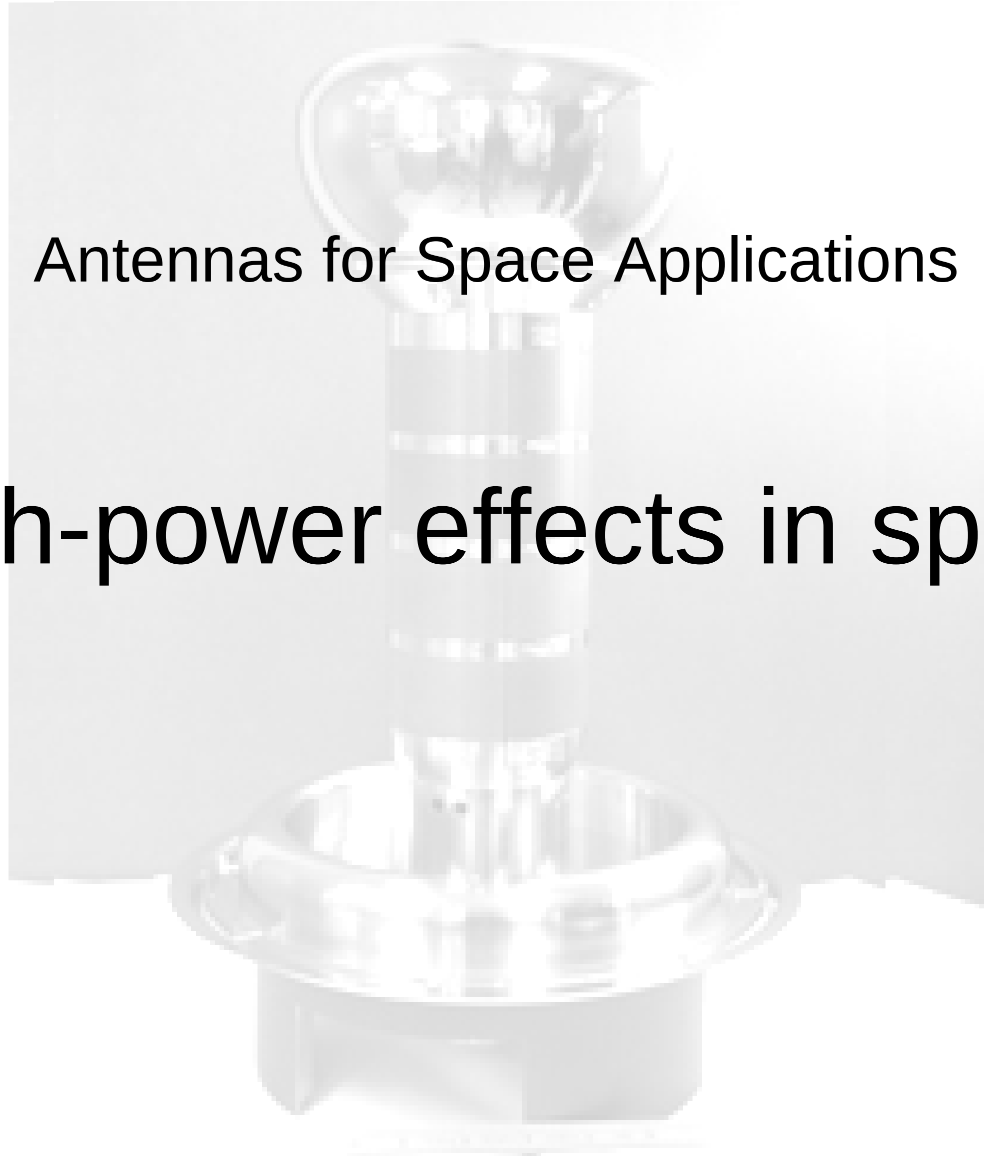
Day 4 overview

- High-power effects in space
- Telemetry and tele-command antennas
- Data downlink antennas
- Navigation antennas
- Ground segment antennas
- Satellite project cycle

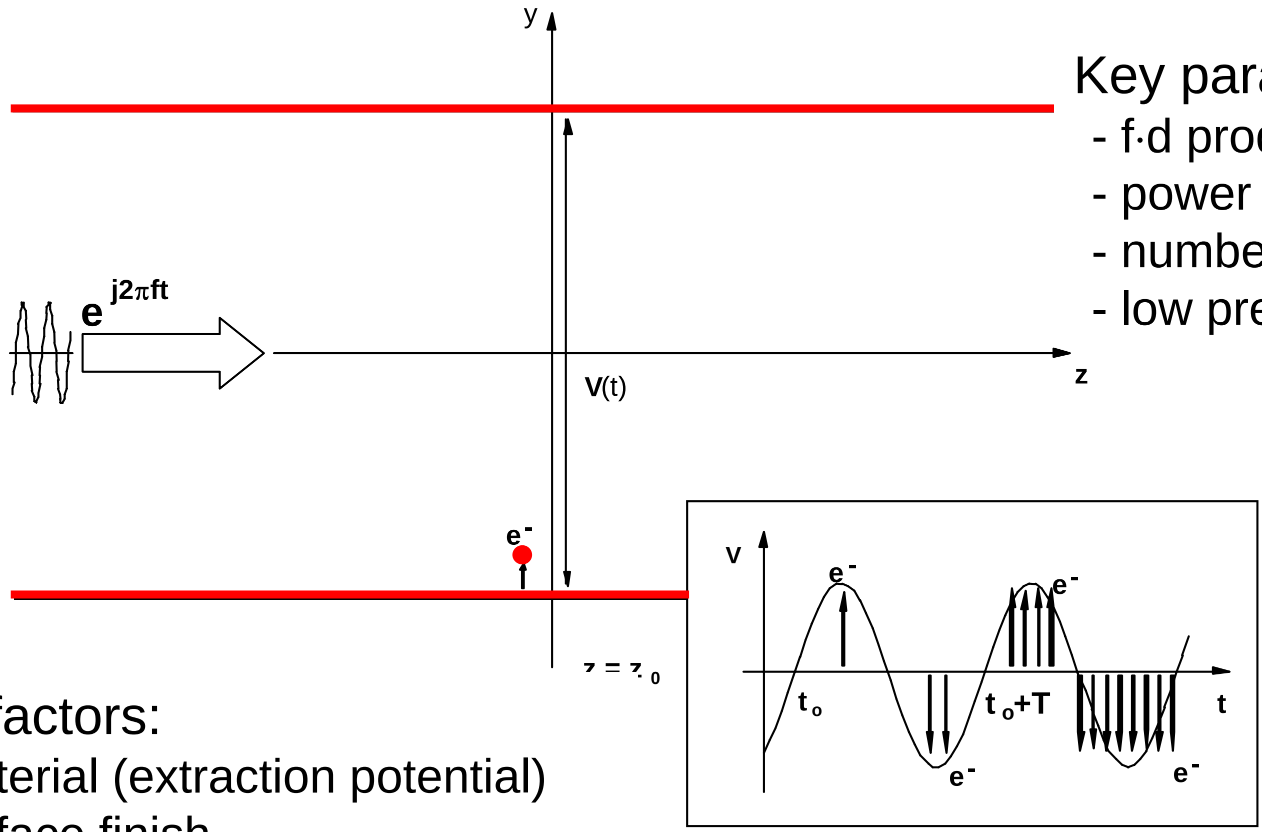


Antennas for Space Applications

High-power effects in space

Resonant discharge in vacuum

Discharge due to the extraction of free electron from waveguide walls



Key parameters:
- f·d product
- power level
- number of carriers
- low pressure

Key factors:
- material (extraction potential)
- surface finish
- sharp features

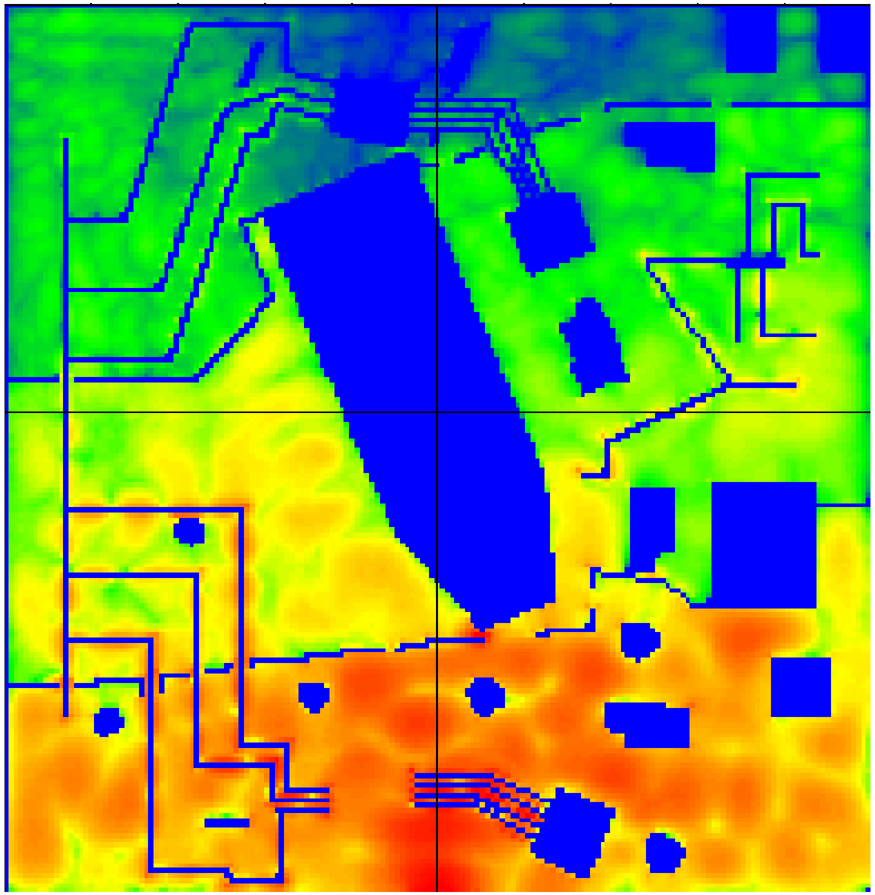
Also known as multipactor or multipaction

Passive Intermodulation products

Generation of intermodulation products in passive elements due to high fields or current densities.

Active mechanisms:
-Metal-metal junctions
-Metal-oxide junctions
-Dielectrics (electrostriction)
-Ferromagnetic material
-Impurities

Sensitive to temperature and to workmanship



Corona

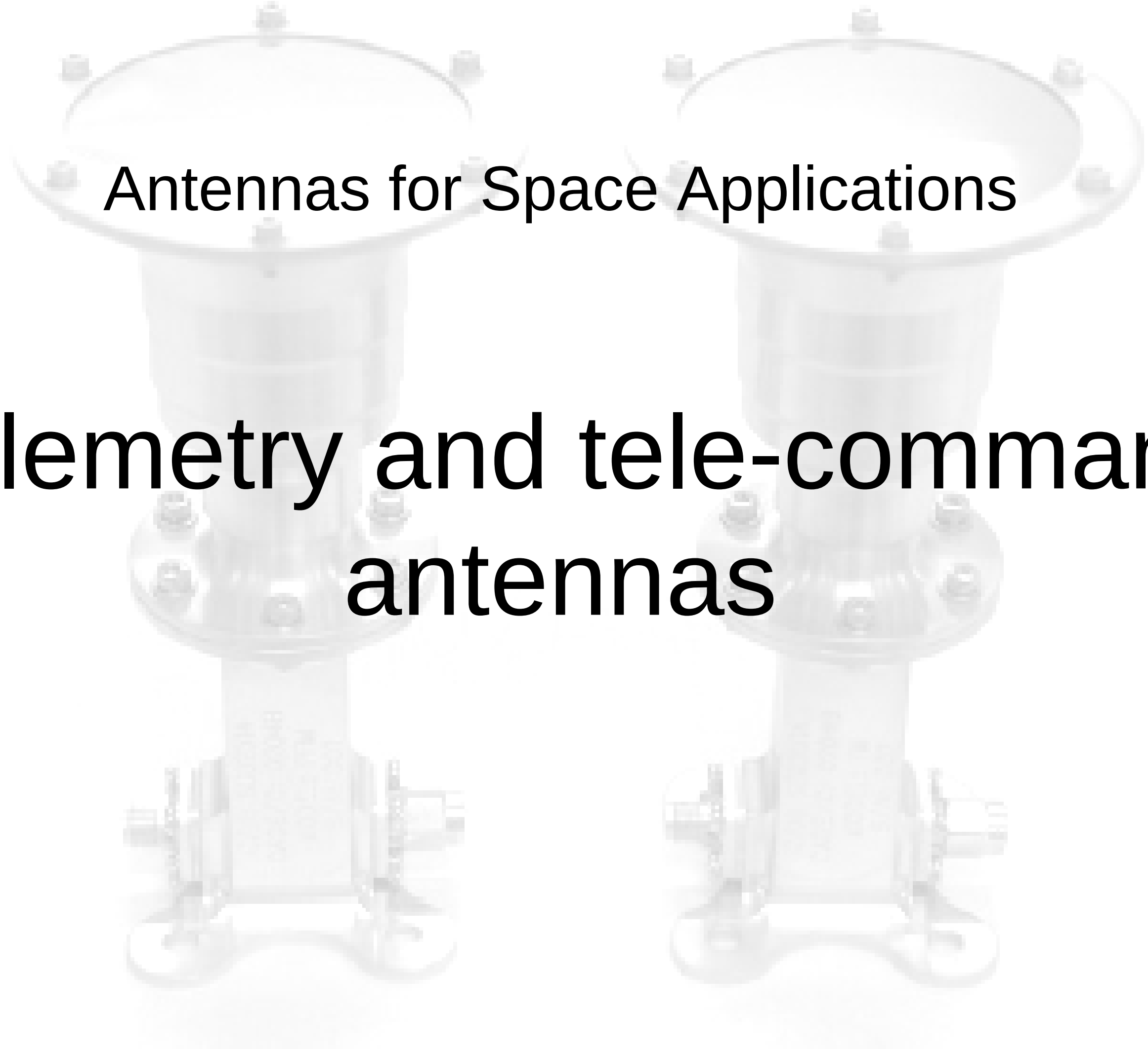
The corona effect is a gas discharge due to ionisation of gases occurring at low pressure levels in RF components.

It occurs during the ascent phase of the launch if RF transmitters are active, which may be the case for some mission critical sub-systems, like the telemetry and tele-command ones.

Permanent damage can be caused to both the device (spark erosion) and the power amplifier (overheating due to RF power reflected by short-circuit induced by spark).

Antennas for Space Applications

Telemetry and tele-command antennas



Basic needs

The antennas for the Telemetry and Tele-command subsystem of a satellite must satisfy the following requirements:

- Provide coverage all around the satellite (full sphere)
- Be extremely reliable
- Have minimum losses

A single antenna is unable to provide full sphere coverage on a satellite unless it operates at relatively low frequencies (VHF for the average satellite). Typically two or more antennas are used, however this creates interference regions in the combined antenna pattern.

Frequency bands

S-band:	2.025 – 2.110 GHz (Uplink)
	2.110 – 2.120 GHz (Deep-Space Uplink)
	2.200 – 2.290 GHz (Downlink)
	2.290 – 2.300 GHz (Deep-Space Downlink)
X-band:	7.145 – 7.190 GHz (Deep-Space Uplink)
	7.190 – 7.235 GHz (Uplink)
	8.400 – 8.450 GHz (Downlink)
	8.450 – 8.500 GHz (Deep-Space Downlink)
Ku-band:	14.400 – 14.470 GHz (Downlink)
	16.600 – 17.100 GHz (Uplink)
Ka-band:	31.800 – 32.300 GHz (Deep-Space Downlink)
	34.200 – 34.700 GHz (Deep-Space Uplink)
	37.000 – 38.000 GHz (Downlink)
	40.000 – 40.500 GHz (Uplink)

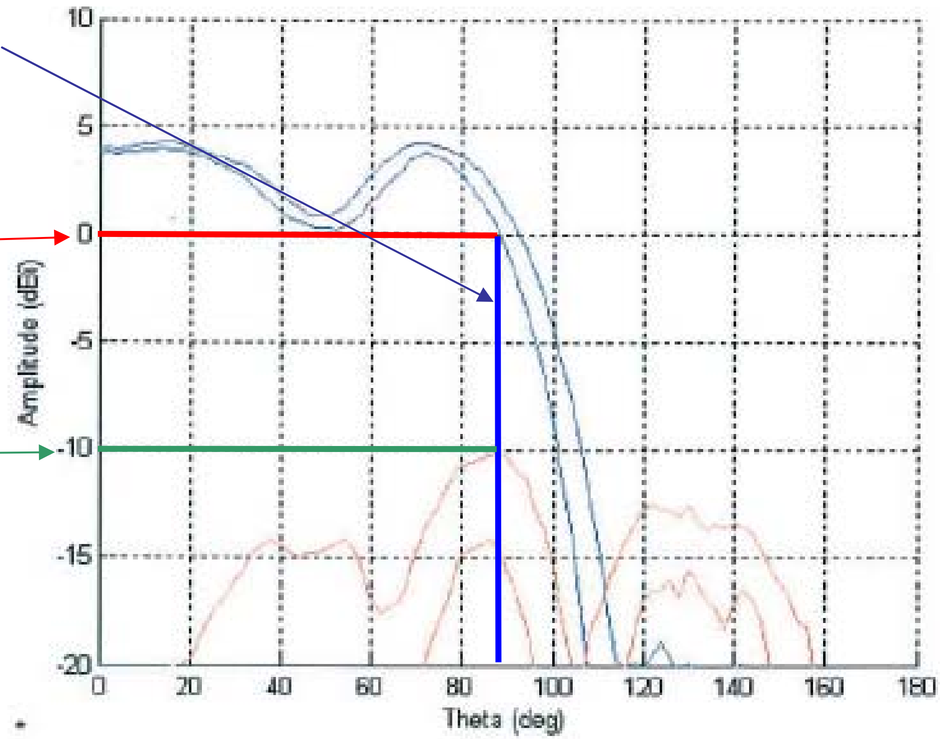
Typical requirements

Polarization

Earth-Space (Uplink) and Space-Earth (Downlink) links shall be circularly polarized.

Coverage

Hemispherical. $0° \leq \phi \leq 360°; 0° \leq \theta \leq 90°$



Gain value

~ 0 dBi

Cross-polarization

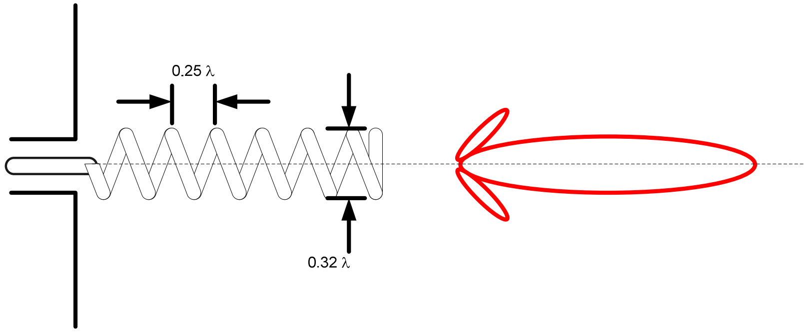
~ -10 dBi

Power handling

Up to 10 Watts for tele-command

Helix antennas

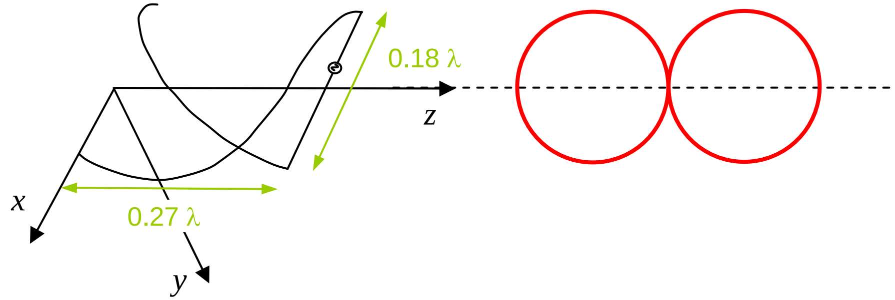
Axial Mode:



Normal Mode:

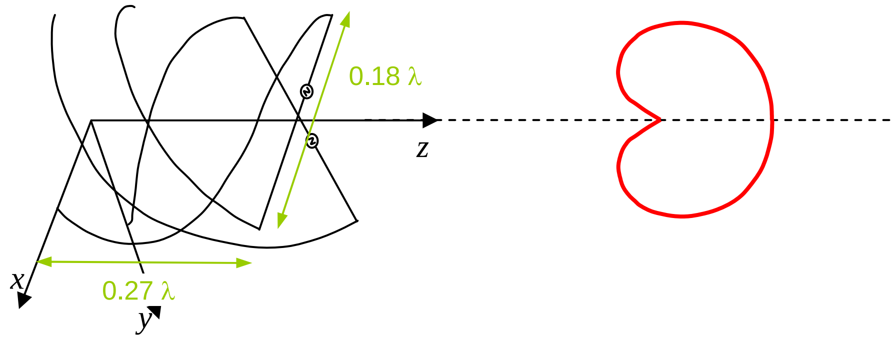
Bifilar helix antennas

Two short resonant helices are combined to obtain bidirectional radiation



Quadrifilar helix antennas

Two bifilar helices, concentric and orthogonal, radiate a cardioid-shaped, circularly polarized pattern when fed in phase quadrature



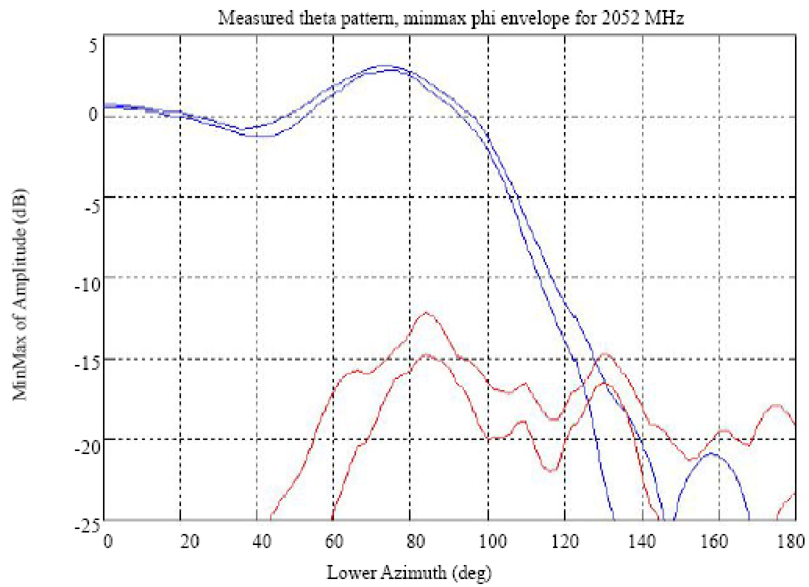
Conical Helix antennas

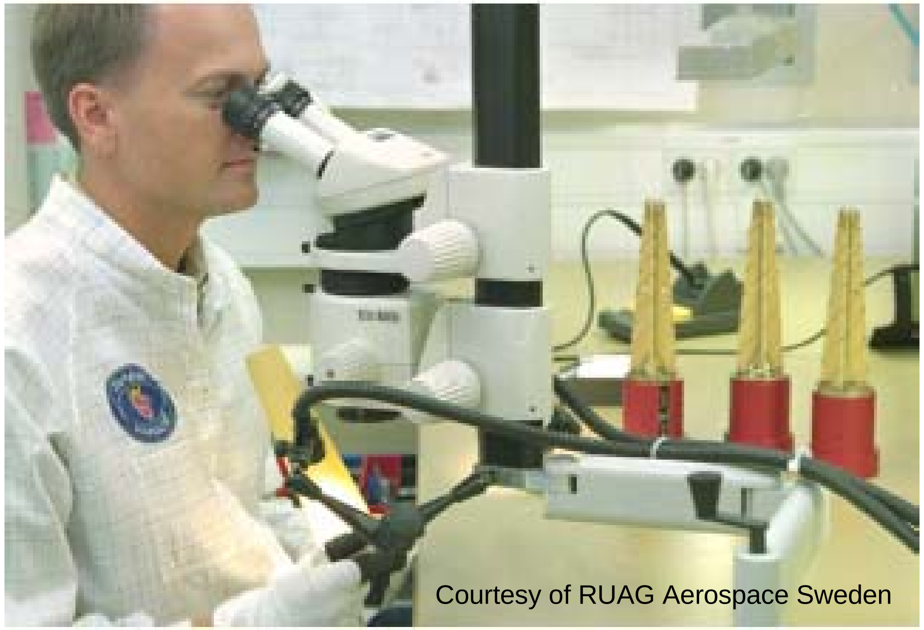
Resonant helices are suitable for narrow band operation.

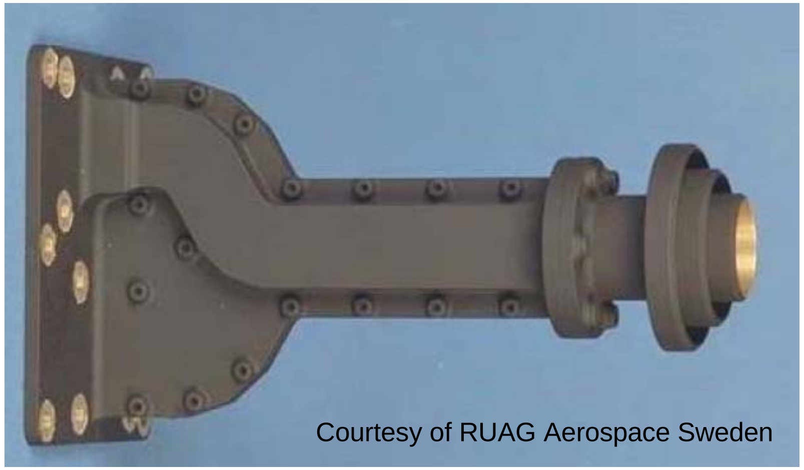
To enlarge the bandwidth it is necessary to increase the length so as to have an integer number of turns.

Quadrifilar conical helix antennas also have a wide CP radiation pattern.

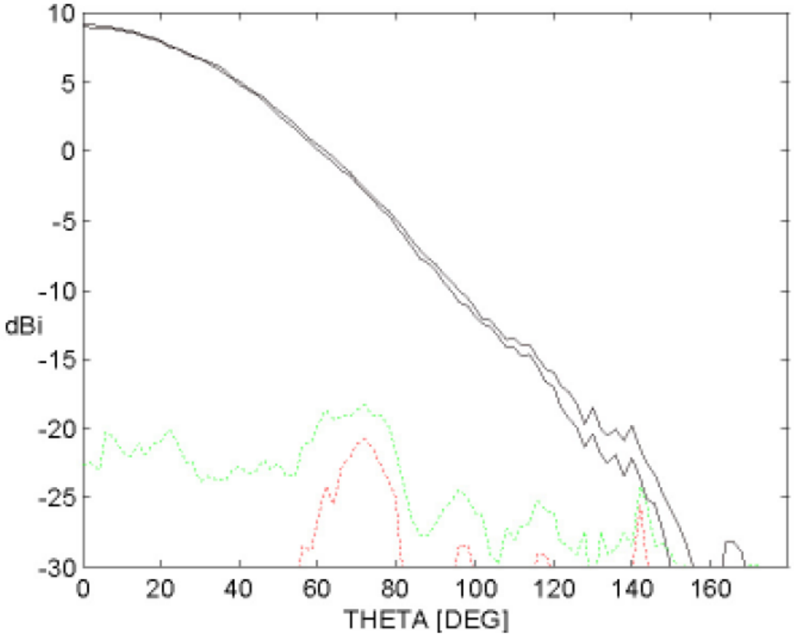

Courtesy of RUAG Aerospace Sweden

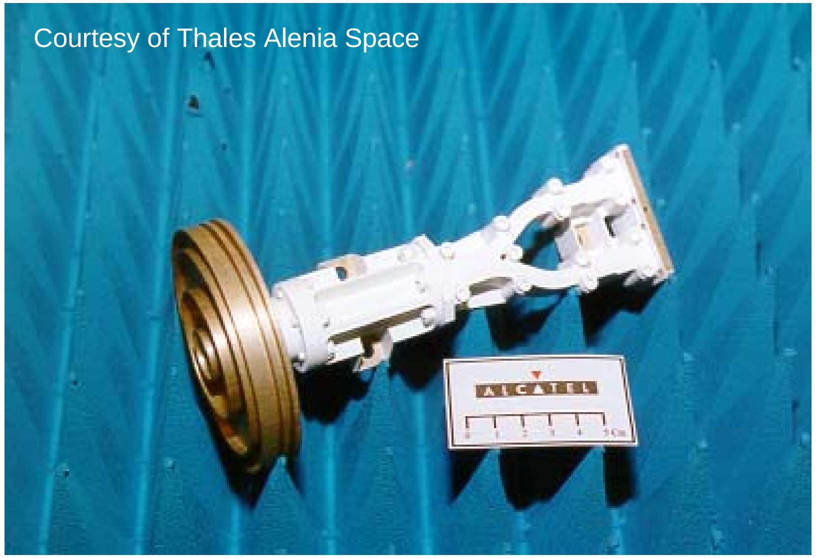



Courtesy of RUAG Aerospace Sweden

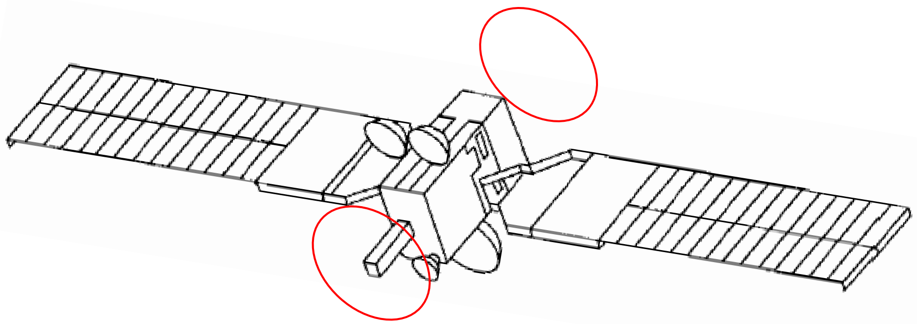

Courtesy of RUAG Aerospace Sweden


Courtesy of Rymsa


10
5
0
-5
-10
dBi
-15
-20
-25
-30
0
20
40
60
80
100
120
140
160
THETA [DEG]

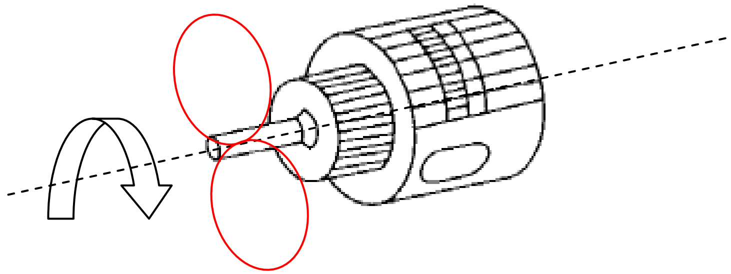

Courtesy of Thales Alenia Space
ALCATEL

Toroidal pattern antennas



Three-axis stabilized spacecraft

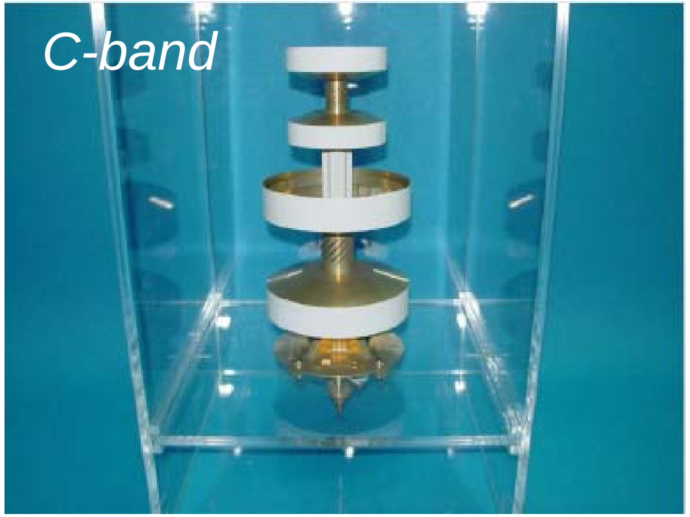
Hemispherical coverage



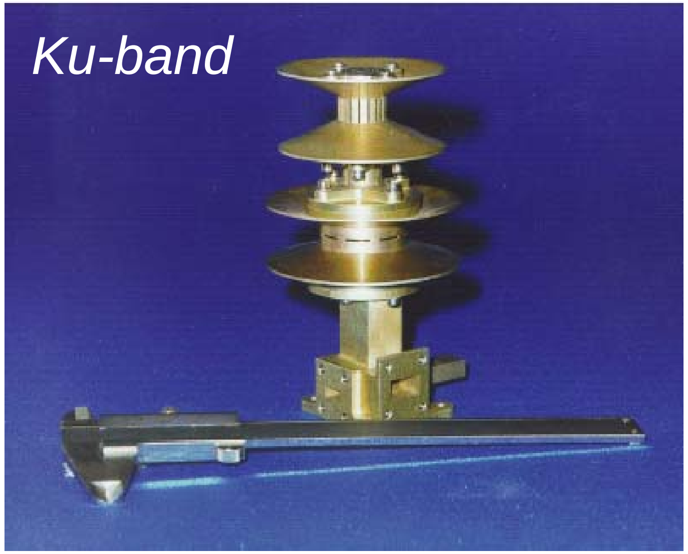
Spinning spacecraft

Toroidal coverage

Courtesy of RUAG Aerospace Sweden

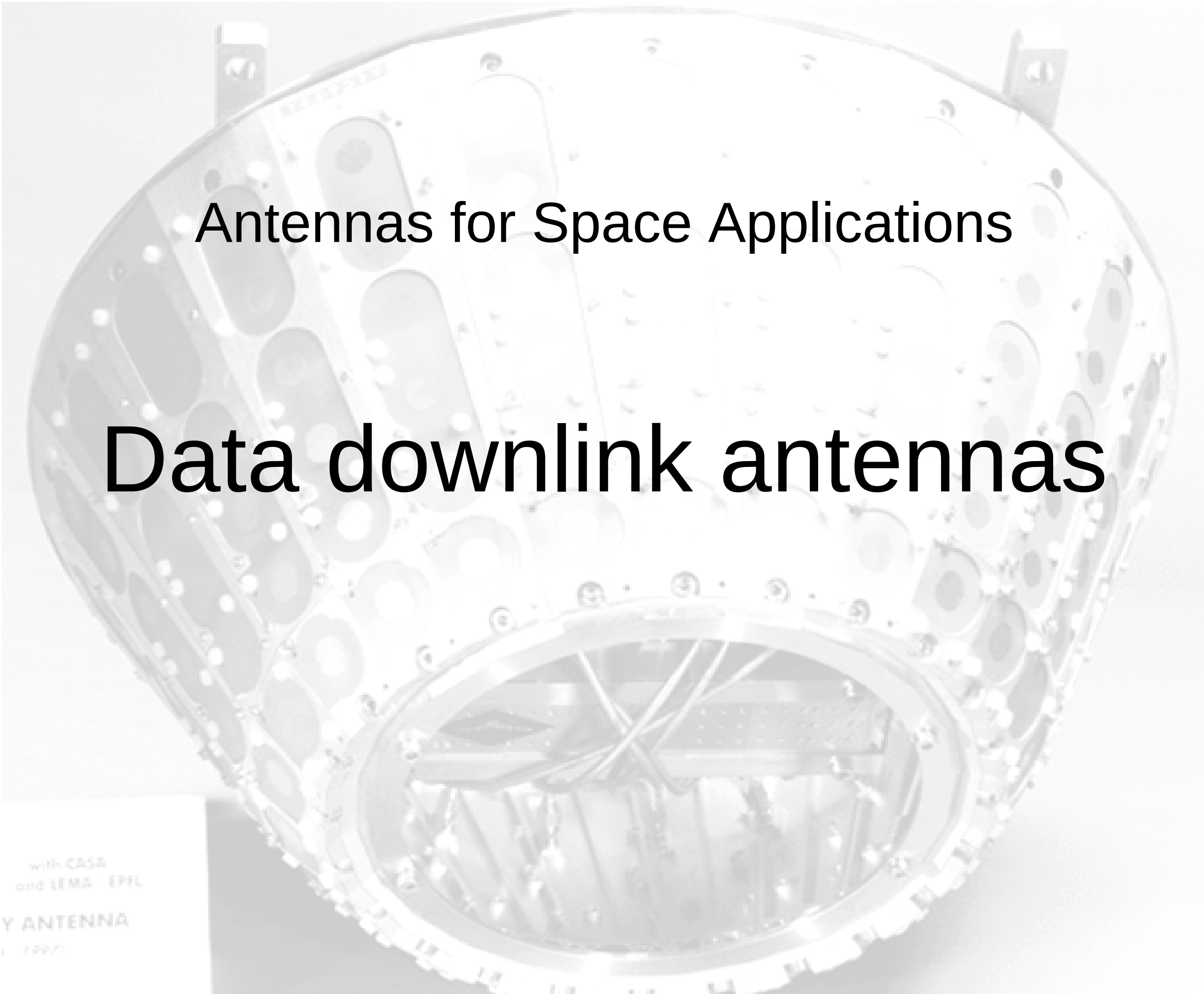


Courtesy of Rymsa



Antennas for Space Applications

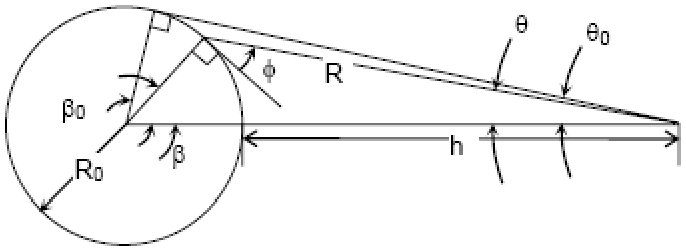
Data downlink antennas



Isoflux coverage for data downlink

Isoflux condition

The desired earth-coverage antenna patter *P(θ)* must equalize the change in R and attenuation in the field of view



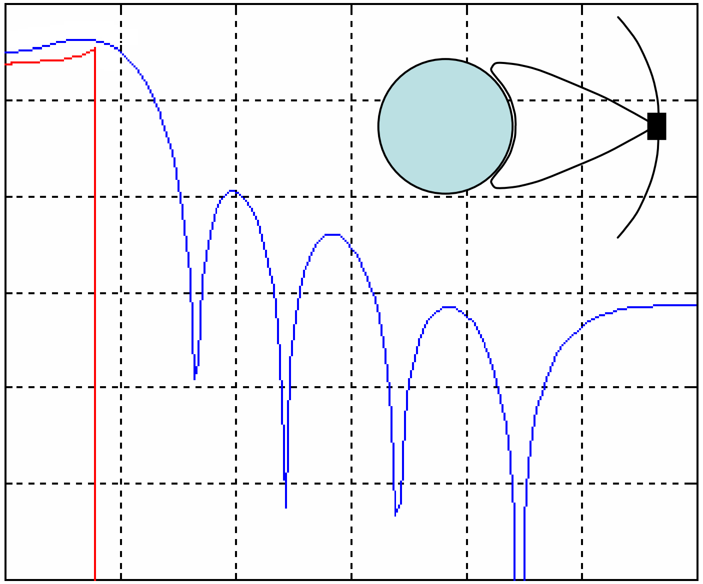
$$P(\theta) \propto (R(\theta)/h)^2 A(\theta)^{-1}$$

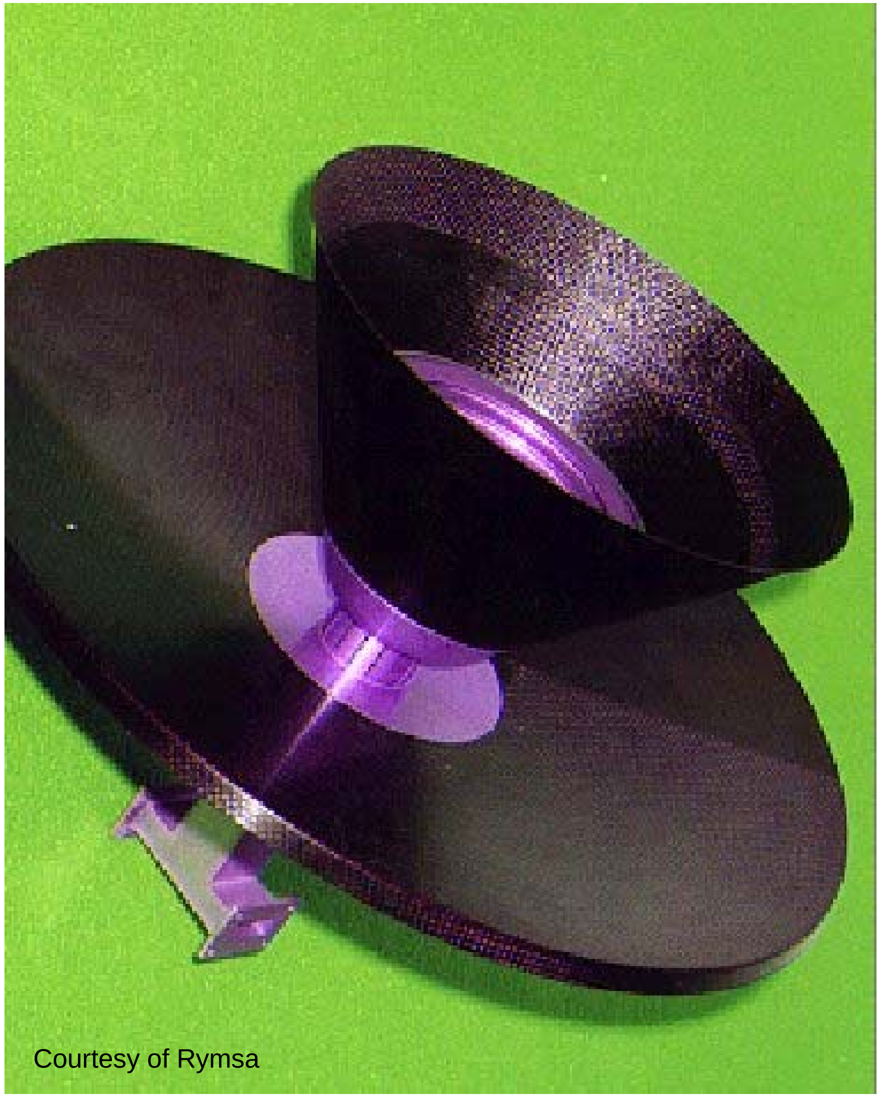
$$A(\theta) = A_0 e^{(1-L_a/h_a)}$$

$$R = h\left\{1+4\left[(R_0/h)^2 + R_0/h\right]\sin^2(\beta/2)\right\}^{1/2}$$

$$\beta = \frac{\pi}{2} - \theta - \phi$$

$$\phi = \cos^{-1}\left[\left(1+h/R_0\right)\sin\theta\right]$$





Courtesy of Rymsa

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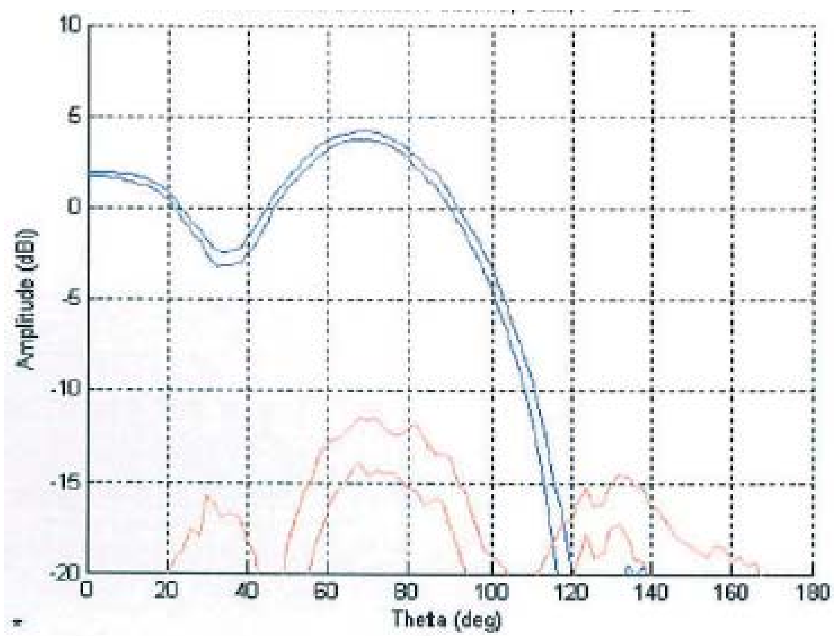
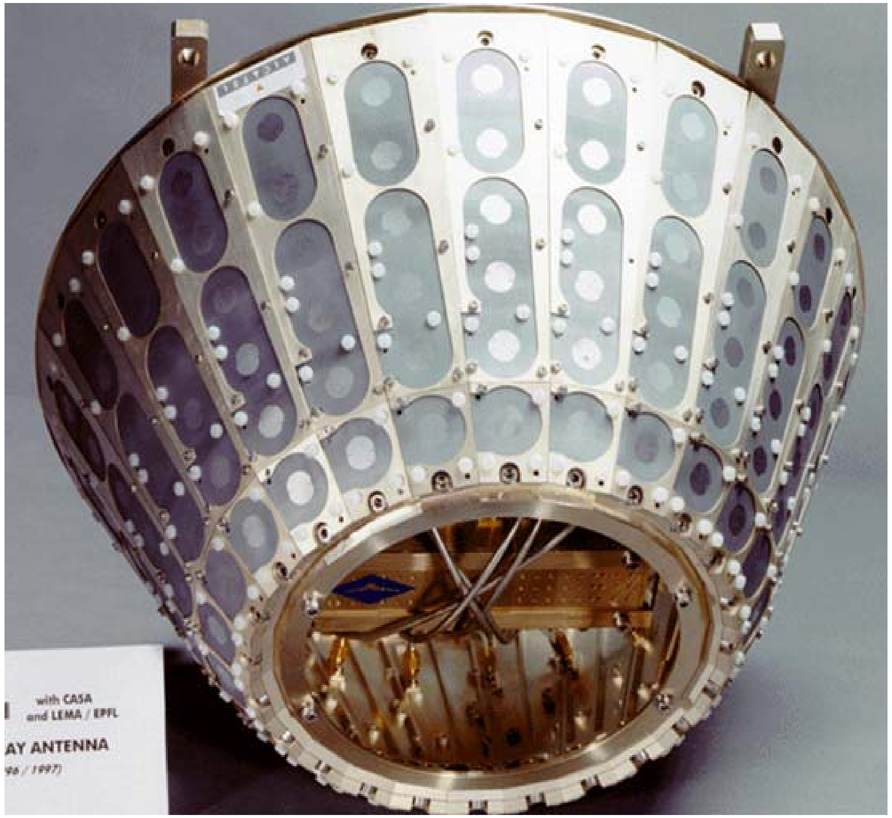


High data-rate antennas

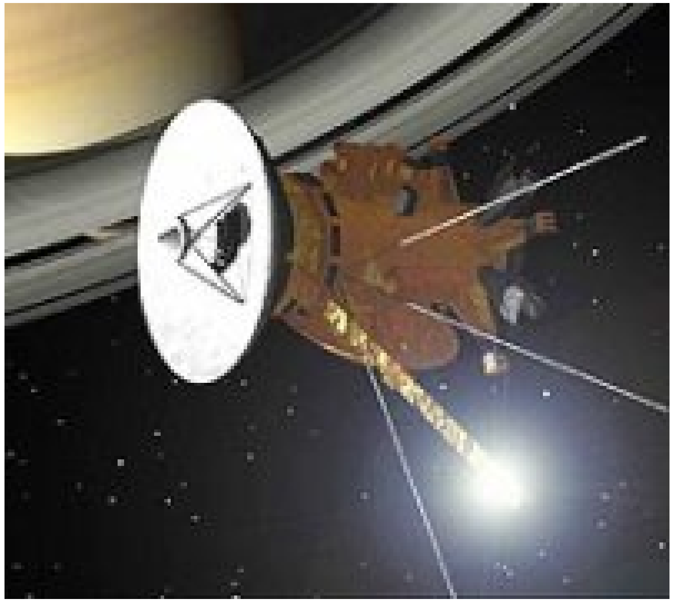


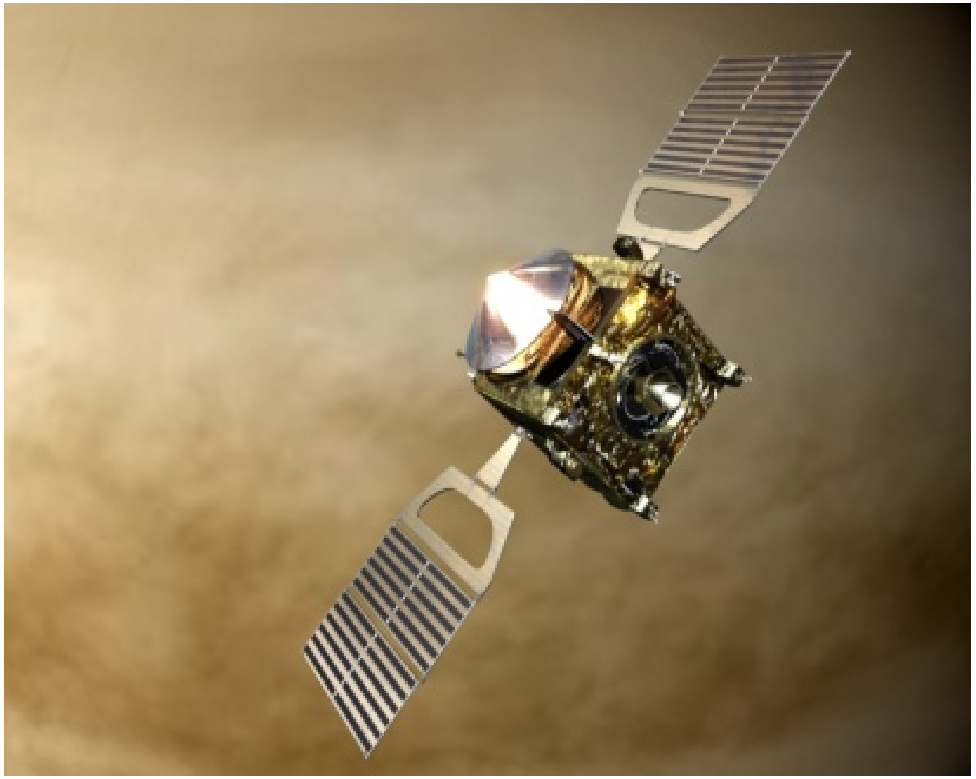
Courtesy of Thales Alenia Space

To achieve higher data-rates it is necessary to increase the antenna gain and reduce the beam width.

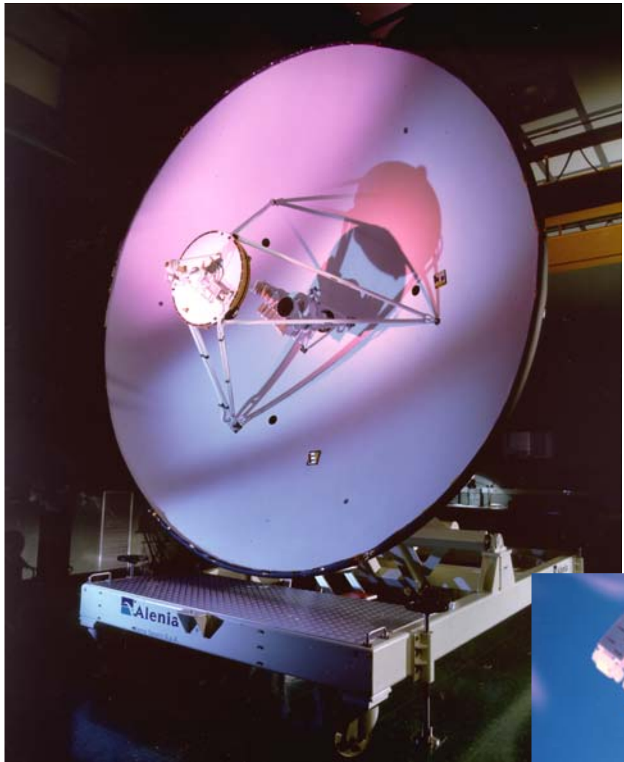
To ensure coverage for ground stations in any position with the satellite field of view the antenna beam must be pointed in the proper direction, tracking the ground station as the satellite passes over it.

Deep-space antennas

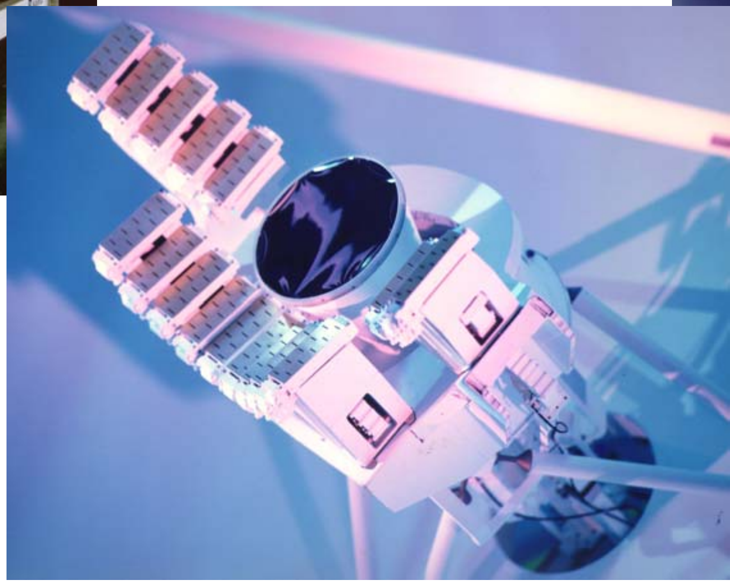




Cassini antenna



Frequency selective subreflector and X/S-band feeds



Detail of the X, Ka and Ku band feeds for the Cassini antenna

Antennas for Space Applications

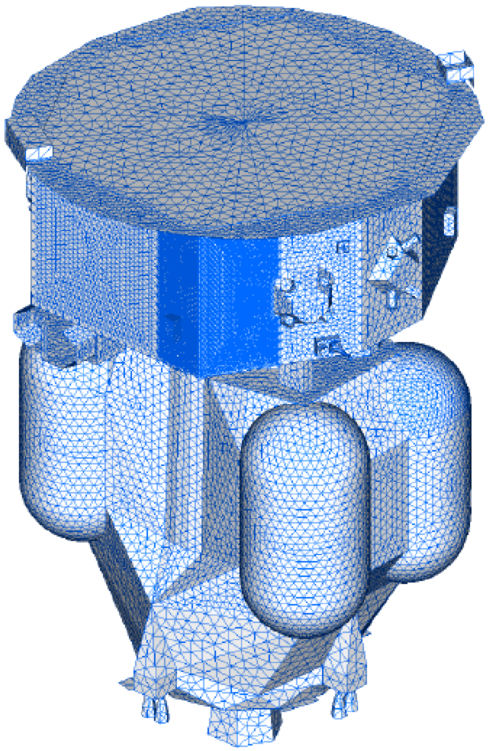
Antenna installation

Antenna on-board

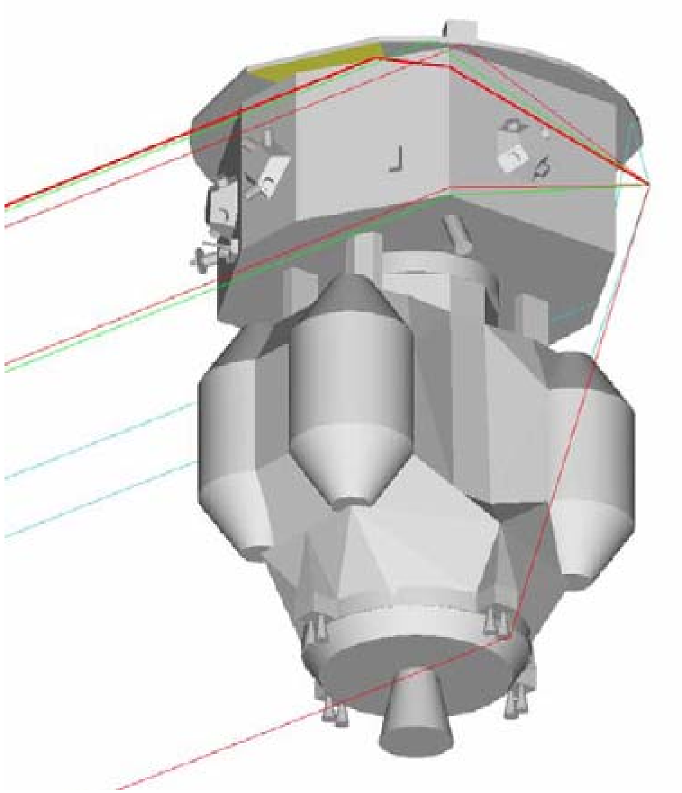
All low-gain wide-pattern antennas are affected by the presence of the satellite body and appendages, which produce spurious scattering and alter their radiation patterns.

Furthermore in service antenna systems, to avoid switches for reliability reasons, several antennas are operated at the same time in the same or opposite polarisation.

Installed antennas: LISA Pathfinder

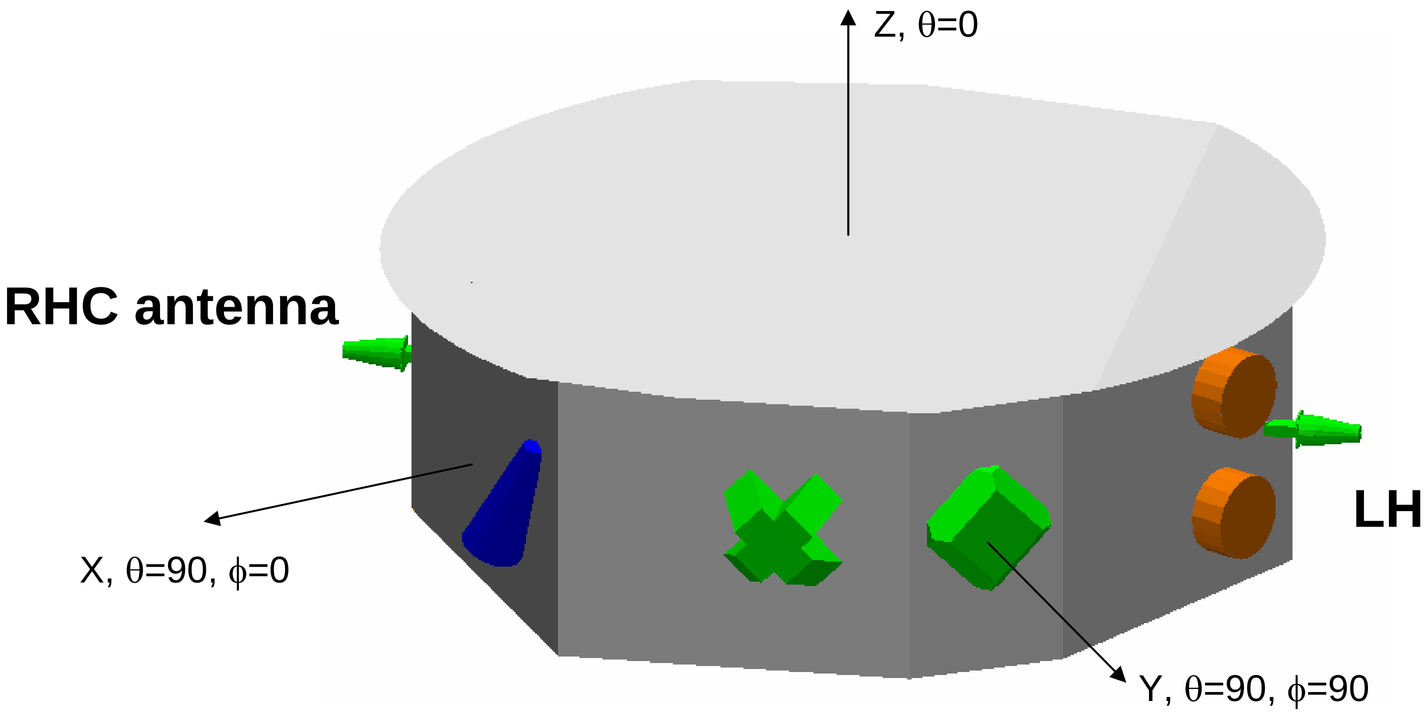


Meshed model for
numerical analysis



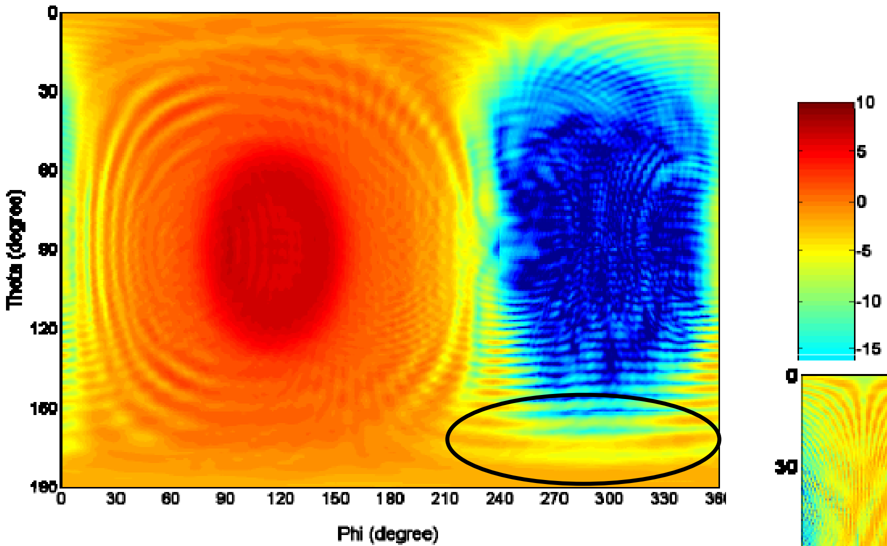
Ray traces for
quasi-optical analysis

Antenna positions



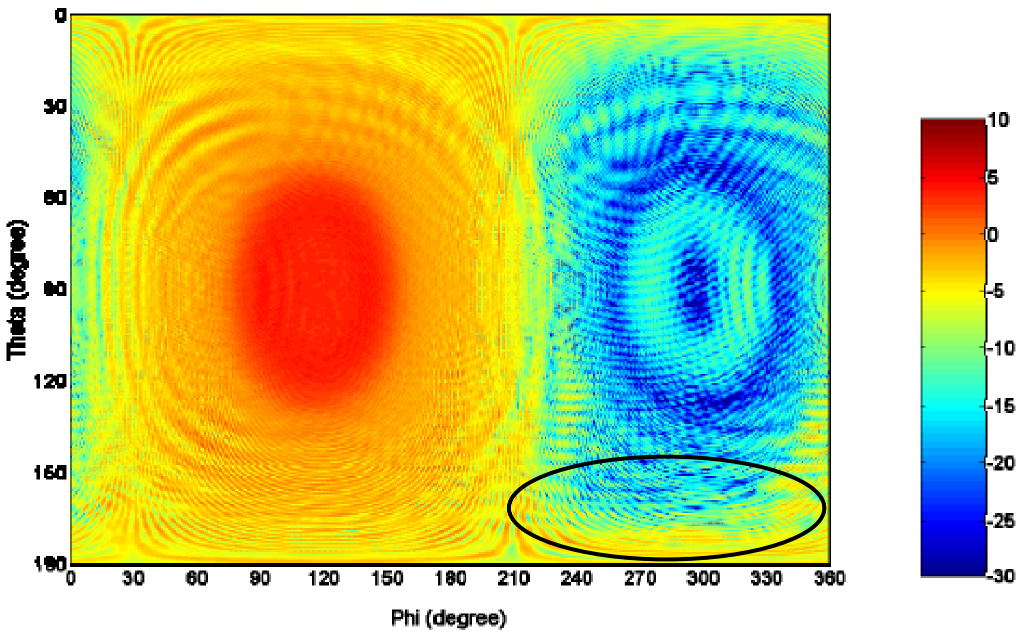
Antennas operate simultaneously, but in opposite polarisation to minimise interferences between them.

Full-sphere coverage at 7235MHz, LHC



One antenna

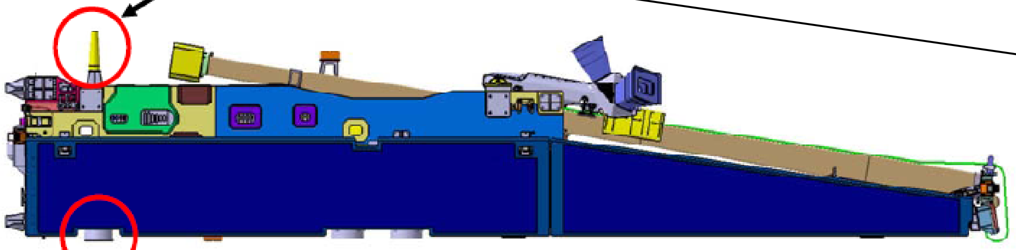
The combination of the two radiation patterns creates interference fringes affecting the performances of both antennas.



Two antennas

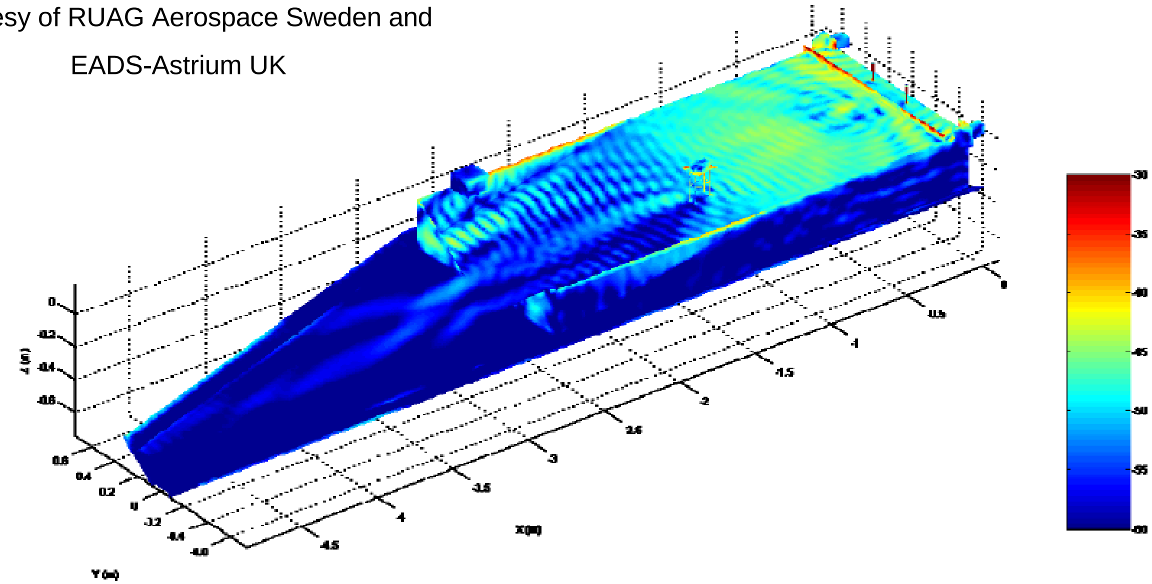
Installed antennas: SWARM

Nadir Helix Antenna

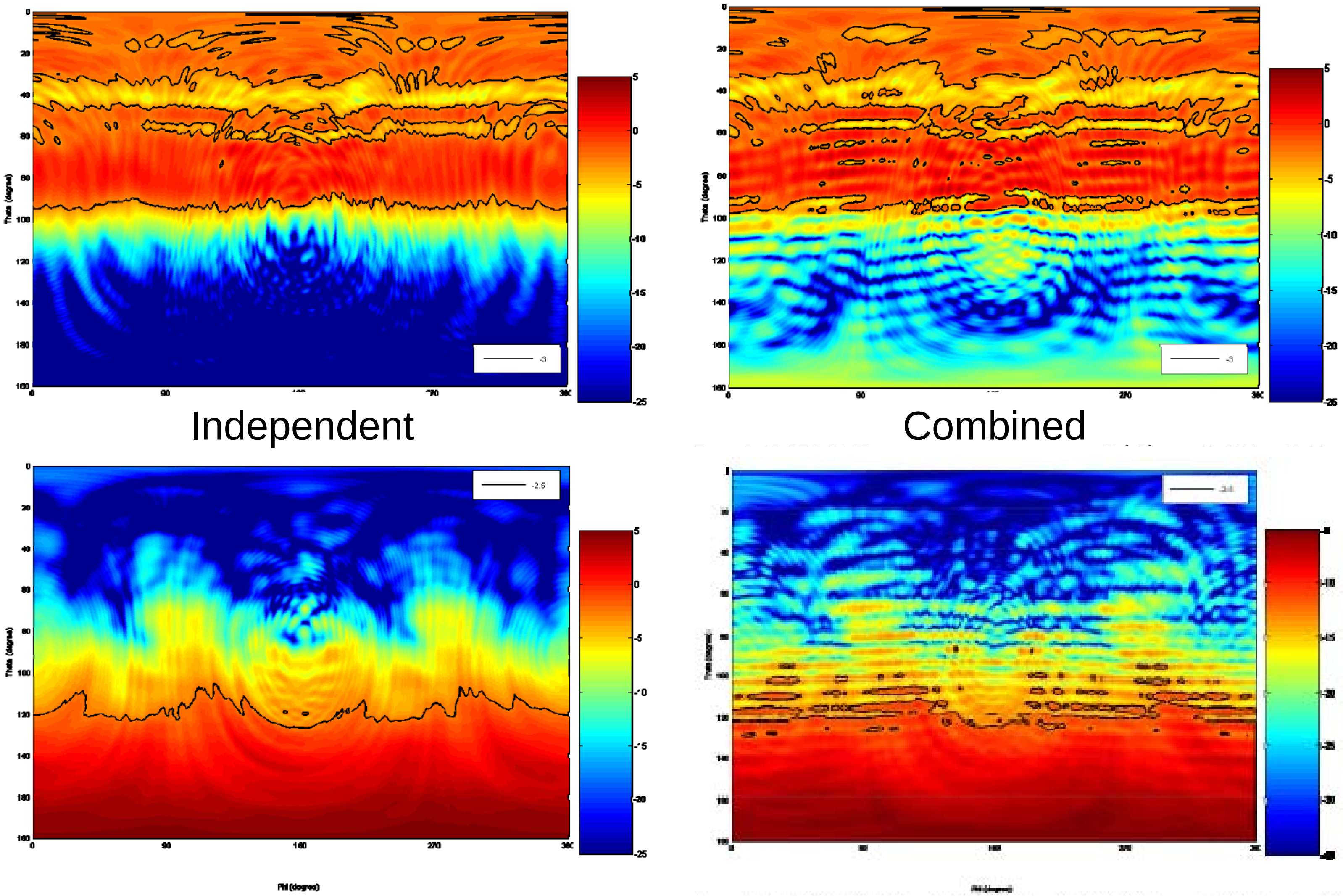


Zenith PEC Antenna

Courtesy of RUAG Aerospace Sweden and EADS-Astrium UK

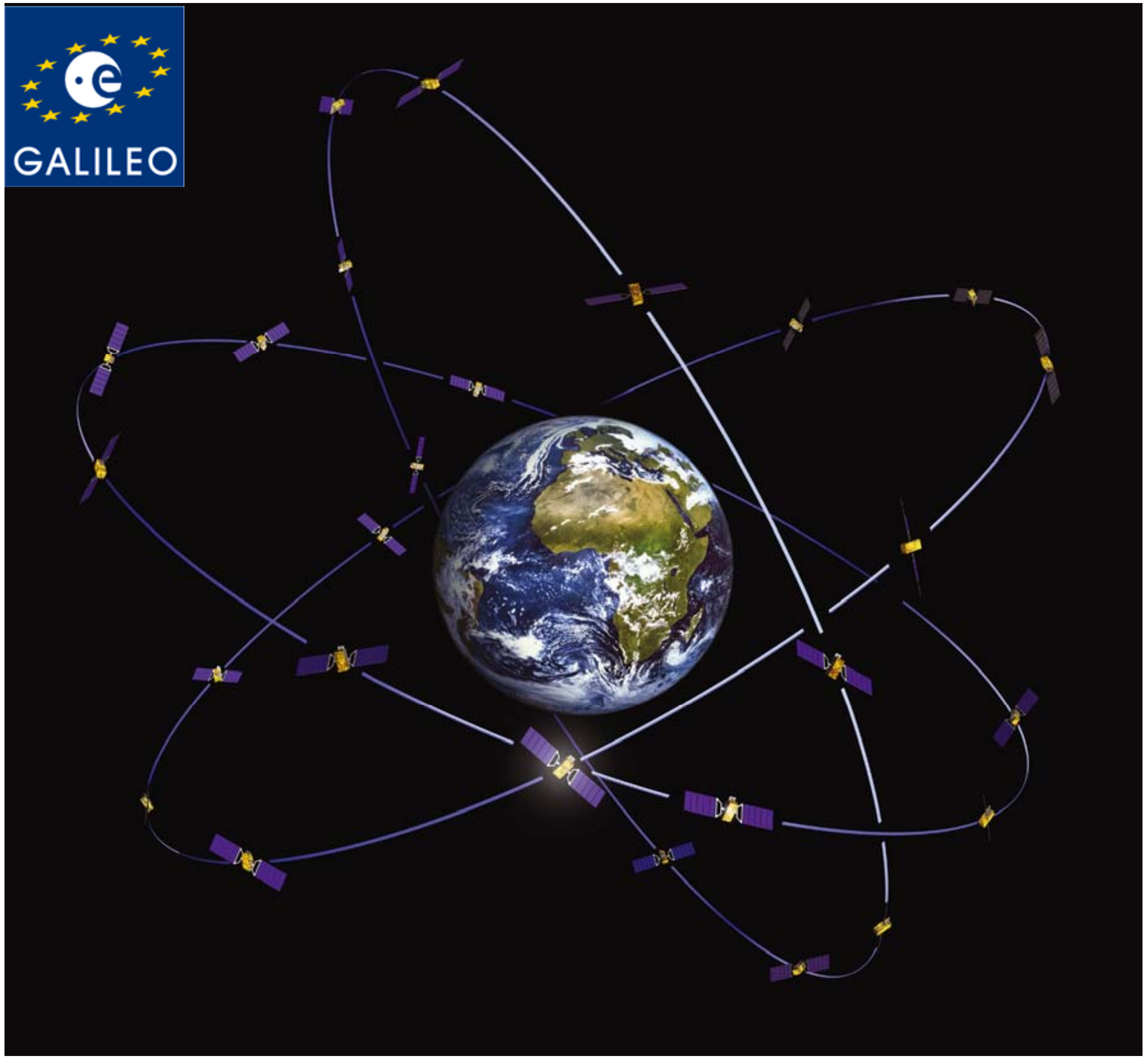


SWARM antenna patterns



Antennas for Space Applications

Navigation antennas



The European navigation satellite constellation

GALILEO

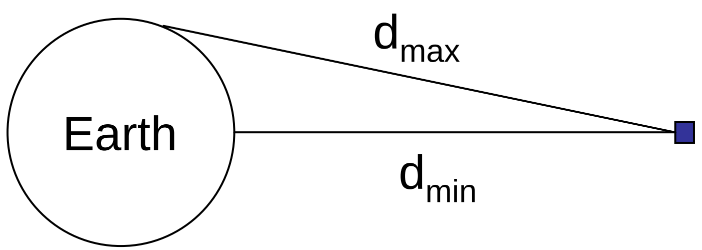
- 30 MEO satellites
- 3 orbital planes
- 56° inclination
- 23222 Km altitude

Developed by ESA for the European Union

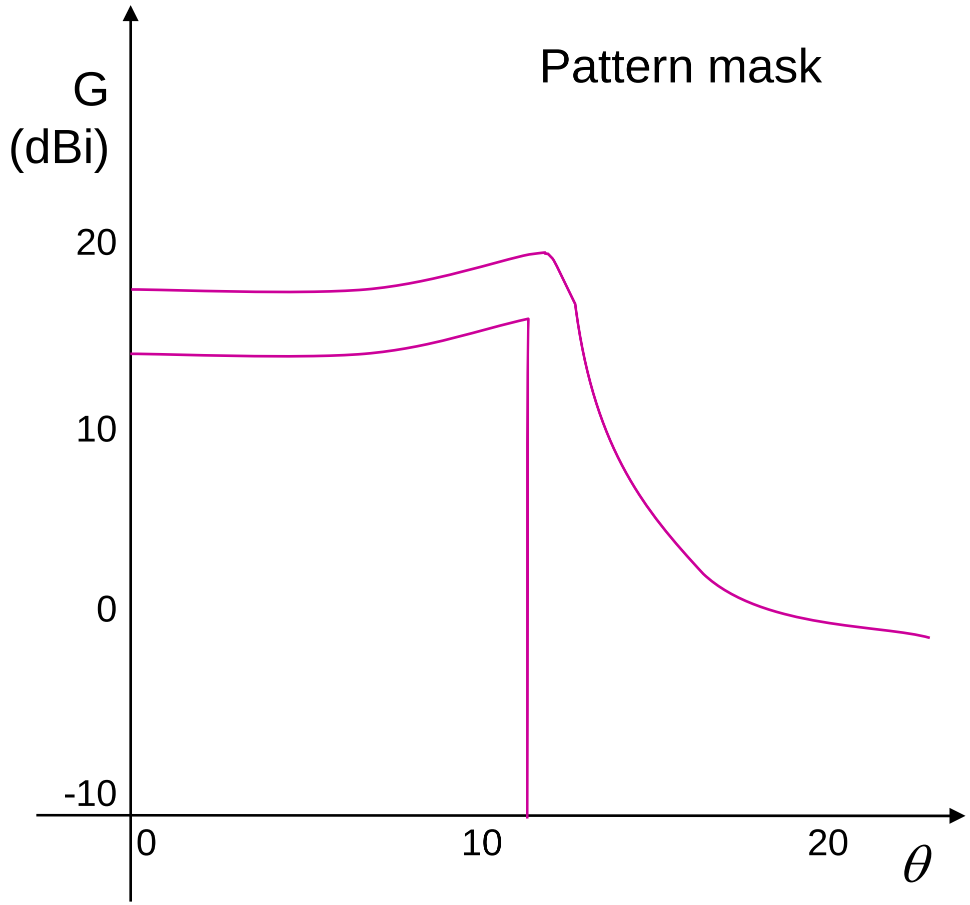
Antenna design

Requirements

- Cover full visible Earth (~25° beam width)
- Compensate range attenuation



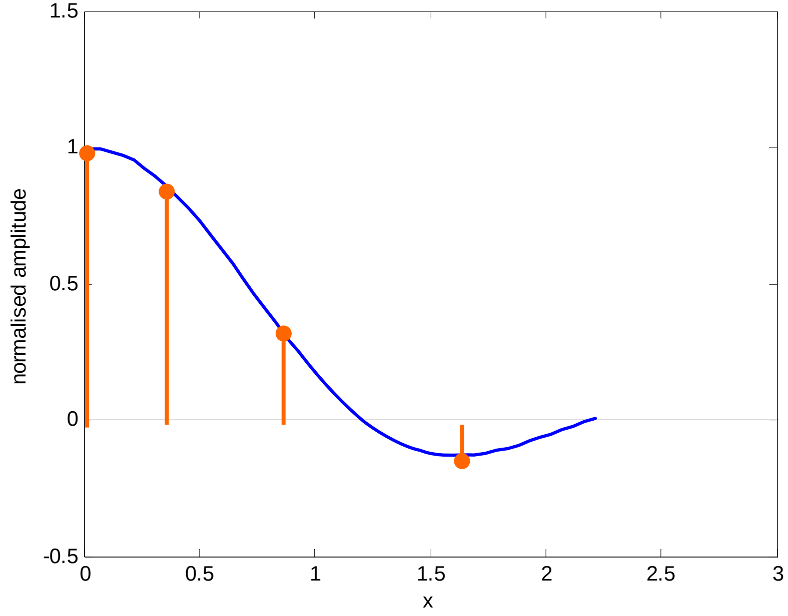
- Have very stable phase centre

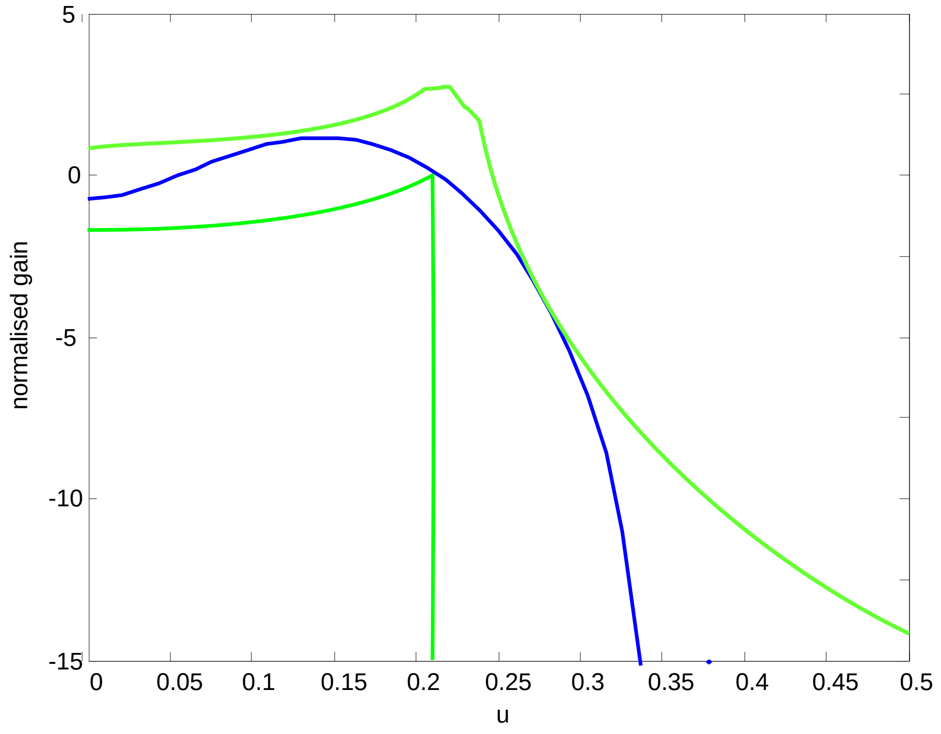


Phase centre stability

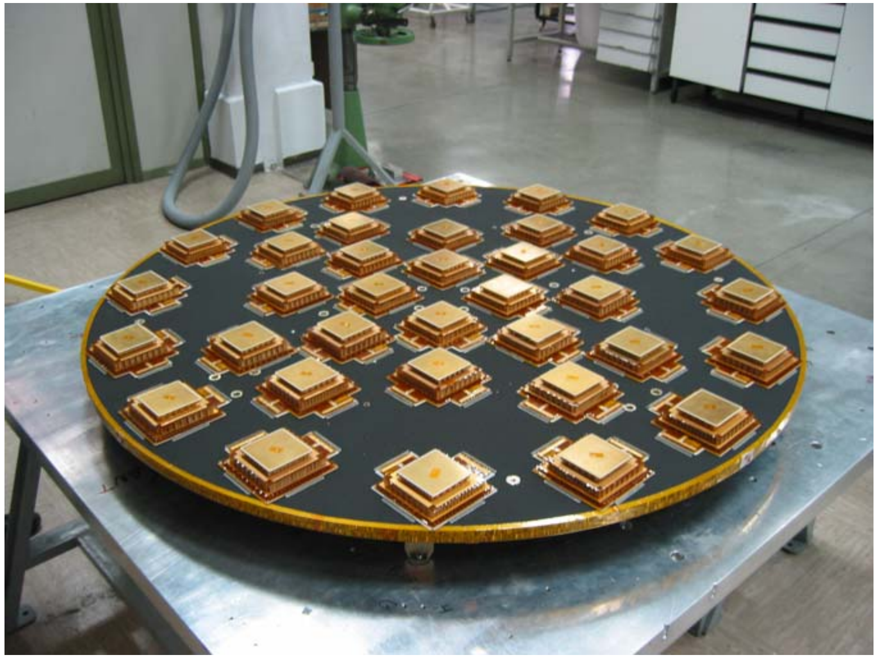
- The phase centre of an antenna is a virtual point, which is the centre of the spherical wave front that best fits the radiation antenna pattern, i.e. the point in space for which the electrical distance to all points on a sphere centred at it has the least variation (in quadratic sense).
- A constant phase pattern has an exact phase centre.
- It is well known that a real and even function as a real and even Fourier transform.
- Ideally an antenna should have a purely real and even aperture illumination to have a well defined phase centre.
- If the above is true across the whole operating frequency band then the phase centre does not vary with frequency.

Range compensation



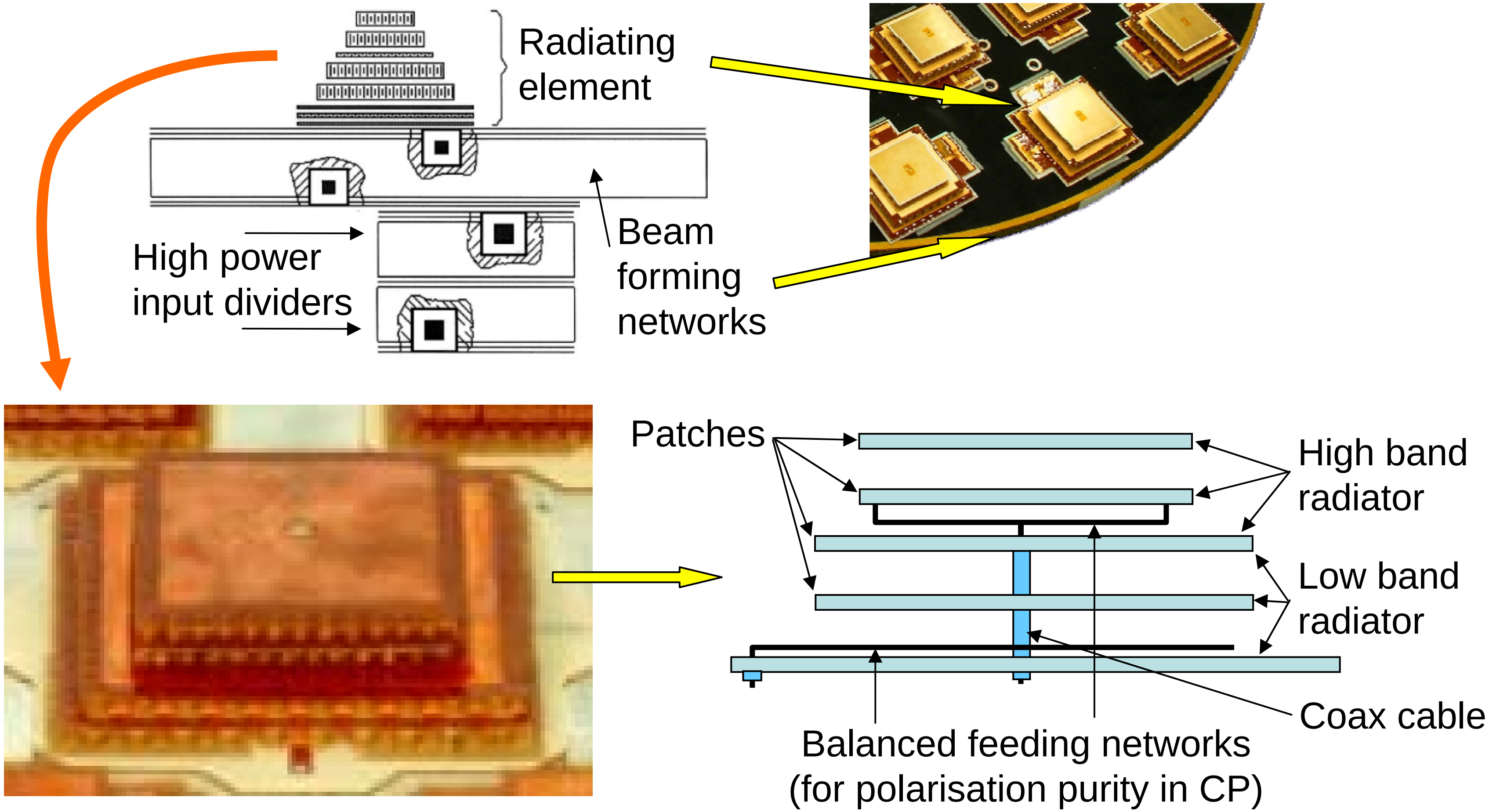


Giove-A antenna

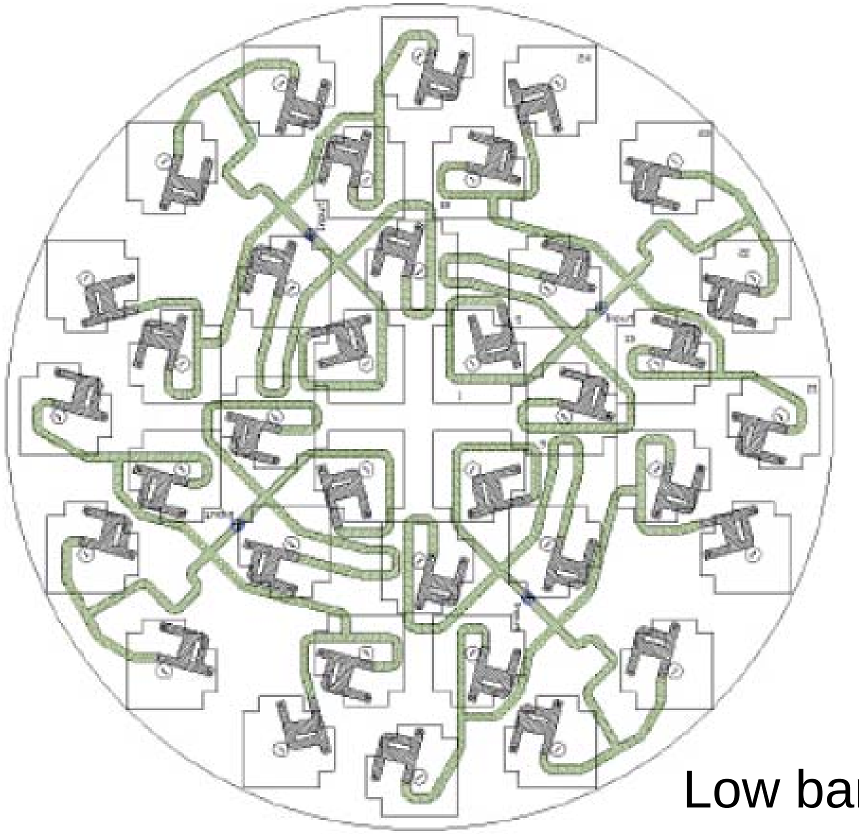


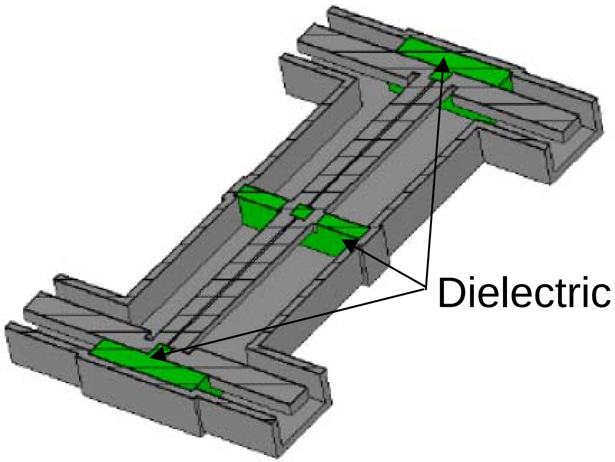
Courtesy of Thales Alenia Space

The antenna is a double array, with separate beam forming networks for the two frequency bands and combined radiators.



The beam forming networks (4 layers in total) are quite complex and the phase stability requirements (a few degrees over the whole lifetime) make it necessary to accurately model all details to have a good design.

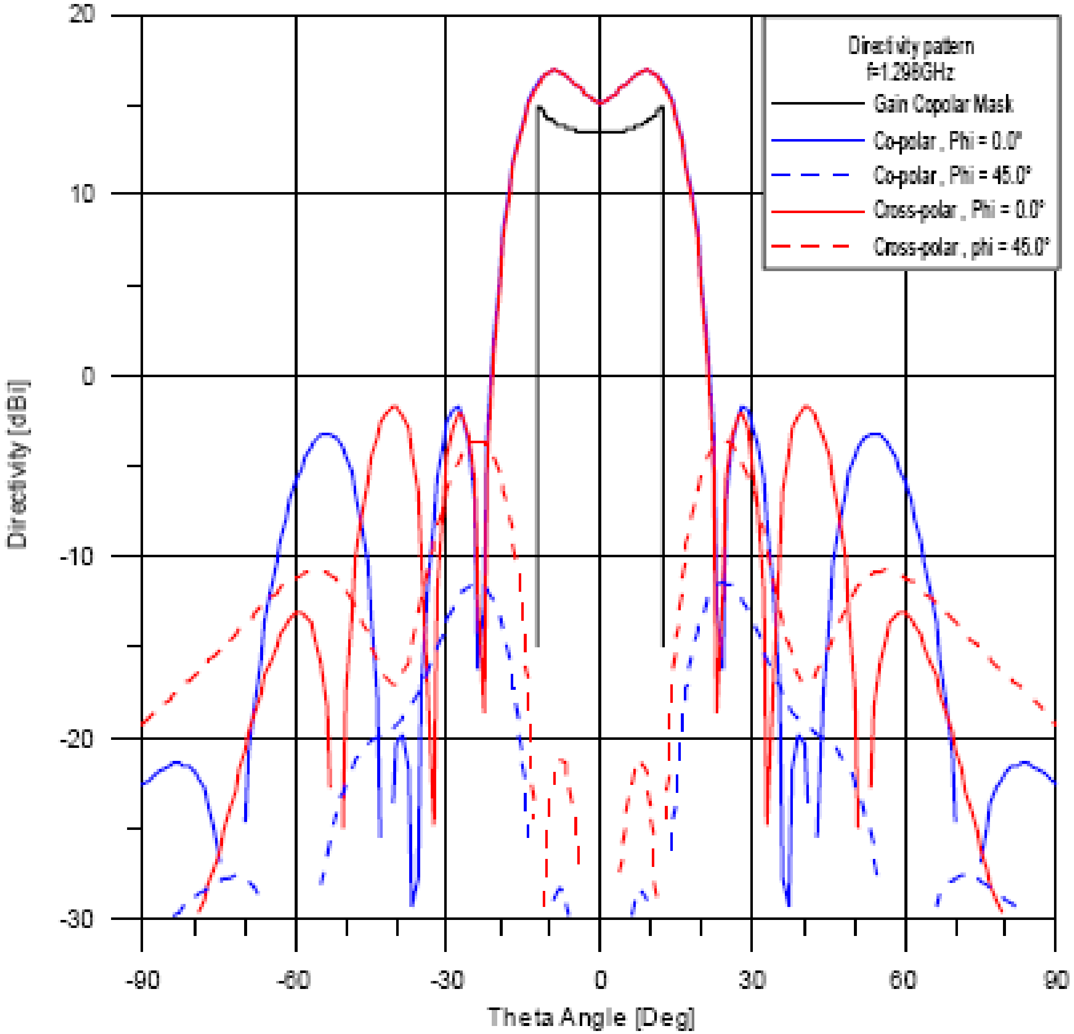


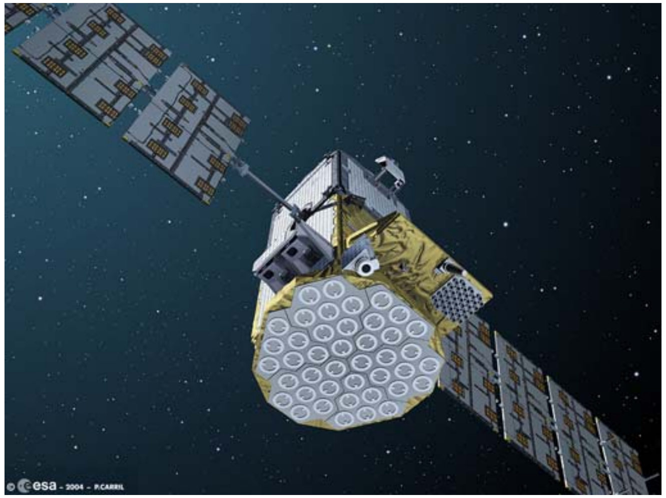


Proximity coupler

Low band beam forming network

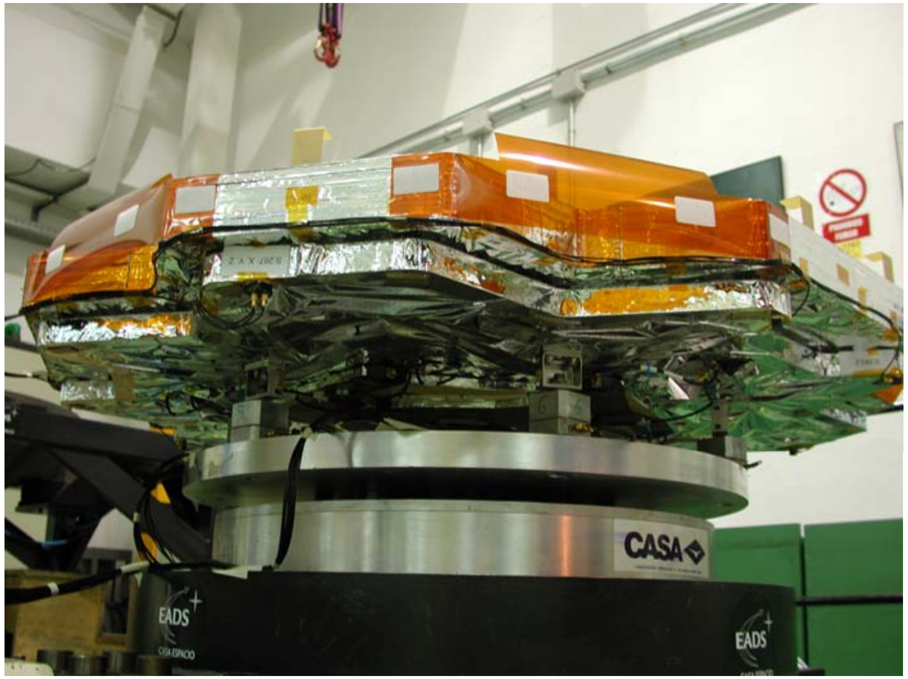
Antenna pattern

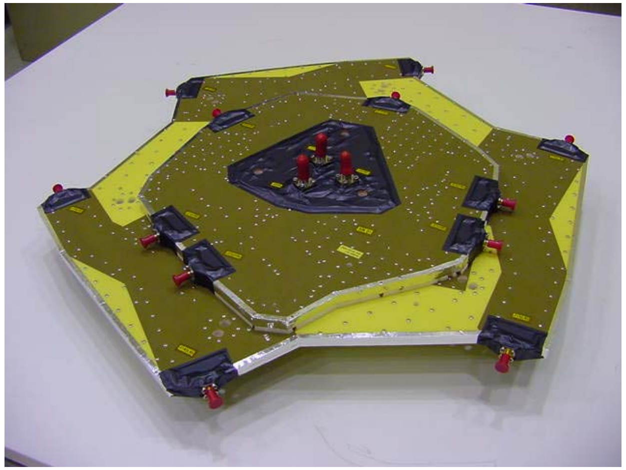




Giove-B antenna

Courtesy of EADS CASA Espacio



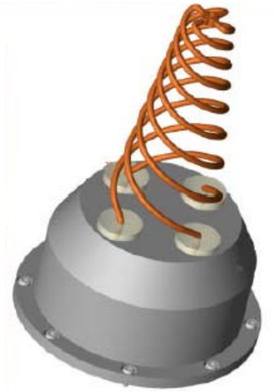


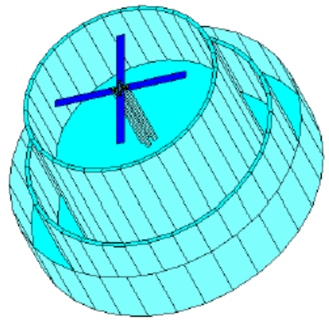
User antennas

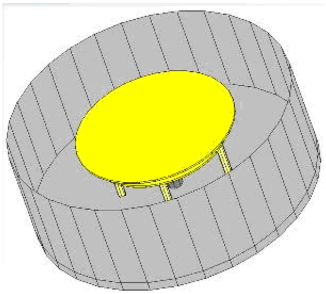
Key design issue: to have a well defined a angle-independent phase centre and to have low gain around the horizon to minimise spurious signal paths (reflections from environment).

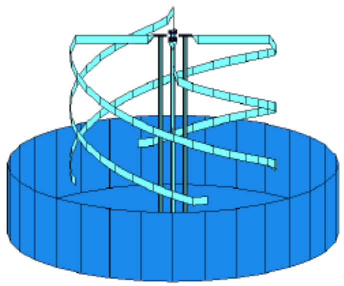
Typical radiating elements

- Helix antenna;
- Cross dipoles;
- Stacked circular patches;
- Shaped wire antenna.



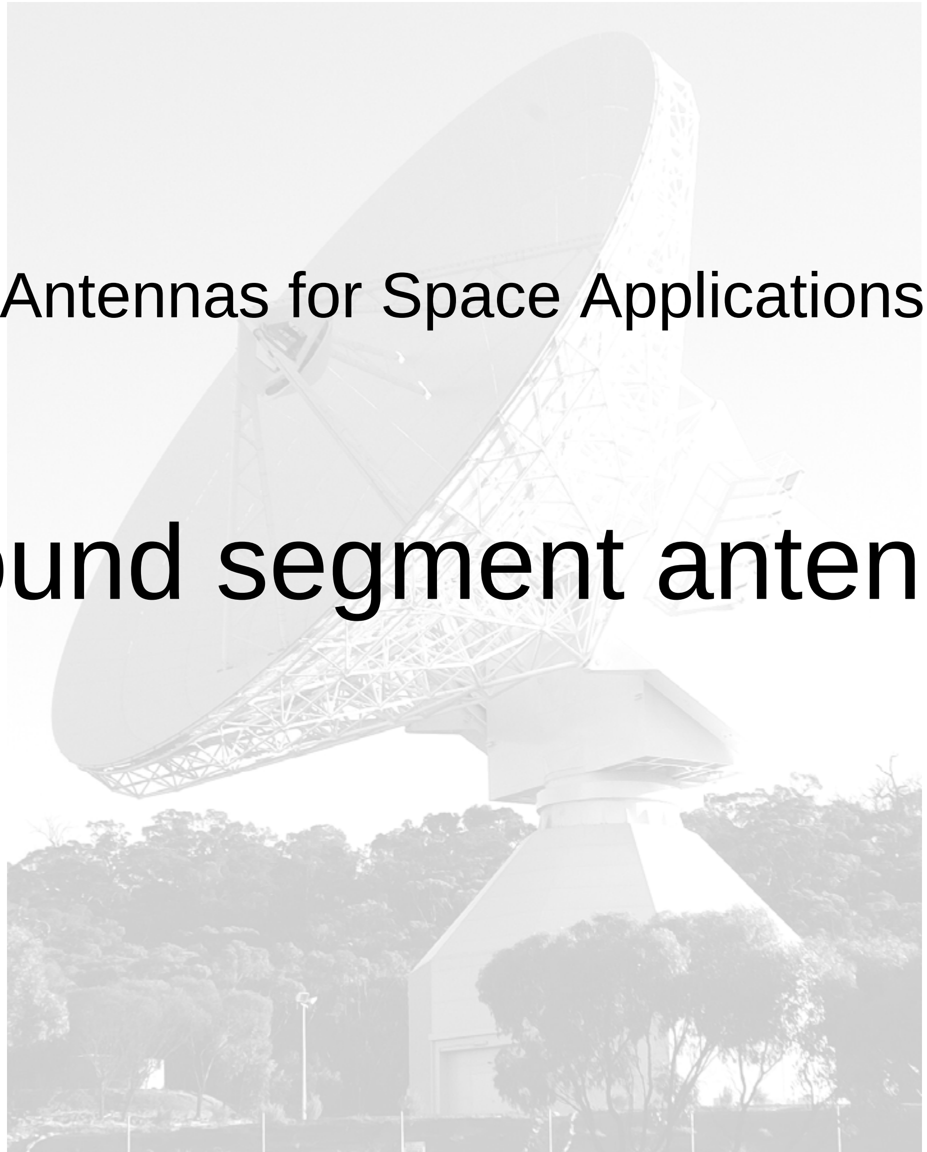




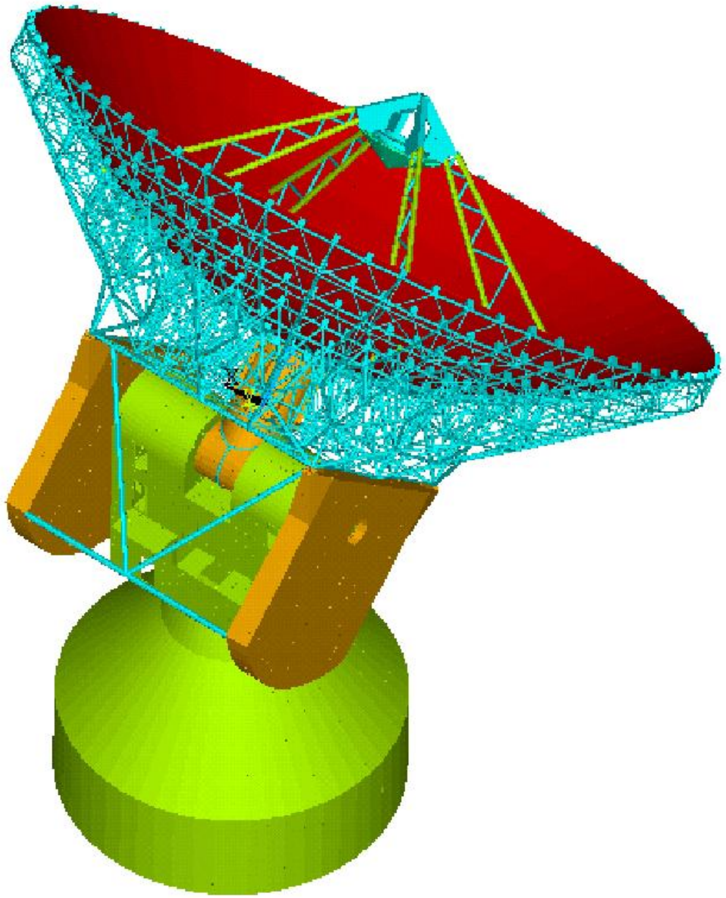


Antennas for Space Applications

Ground segment antennas



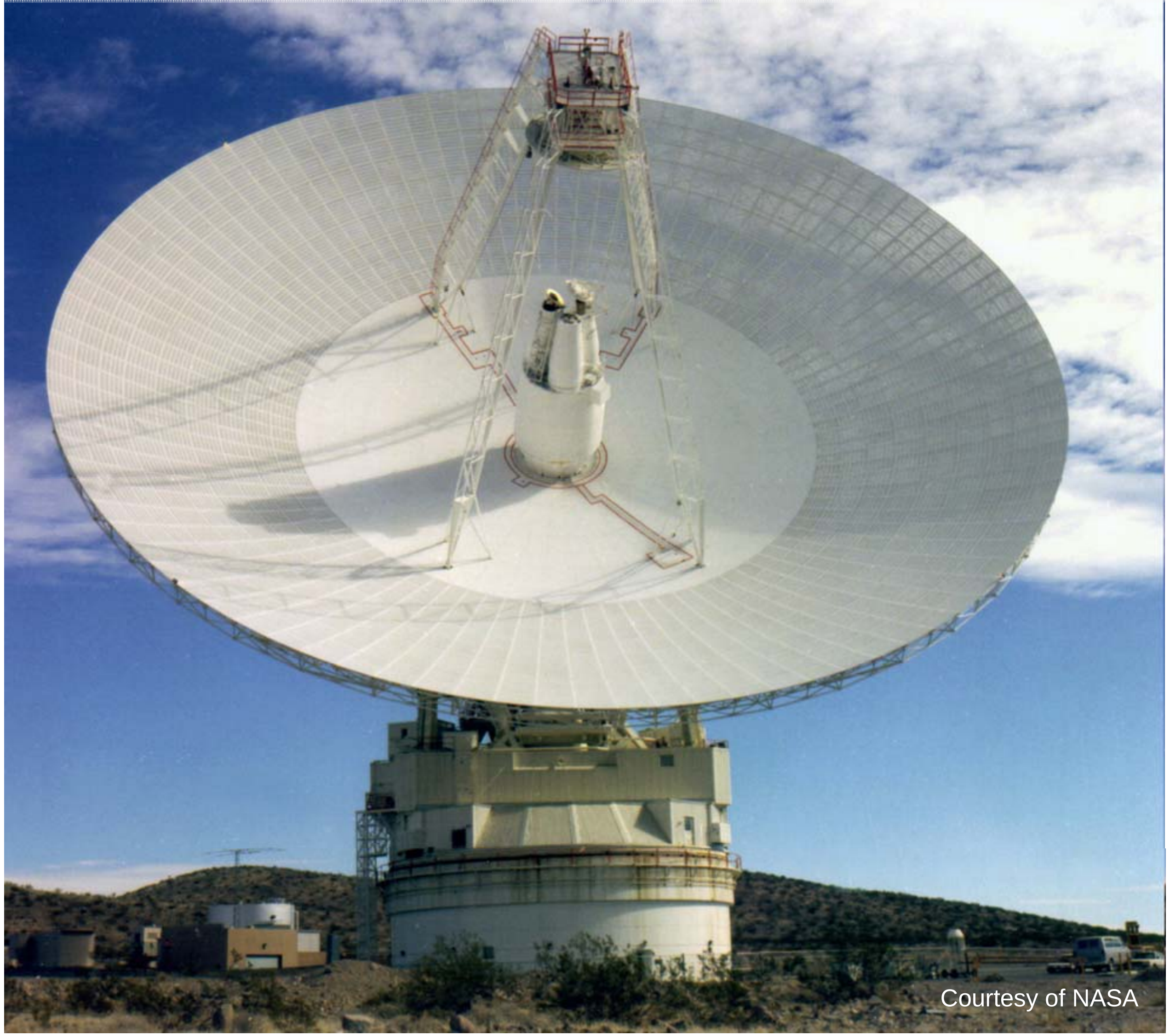
Ground Segment Antennas



Antennas on ground are used to control the satellite and to track its position in space.

They are usually quite large, to compensate for the very low gain of Telemetry and Tele-command antennas on board.

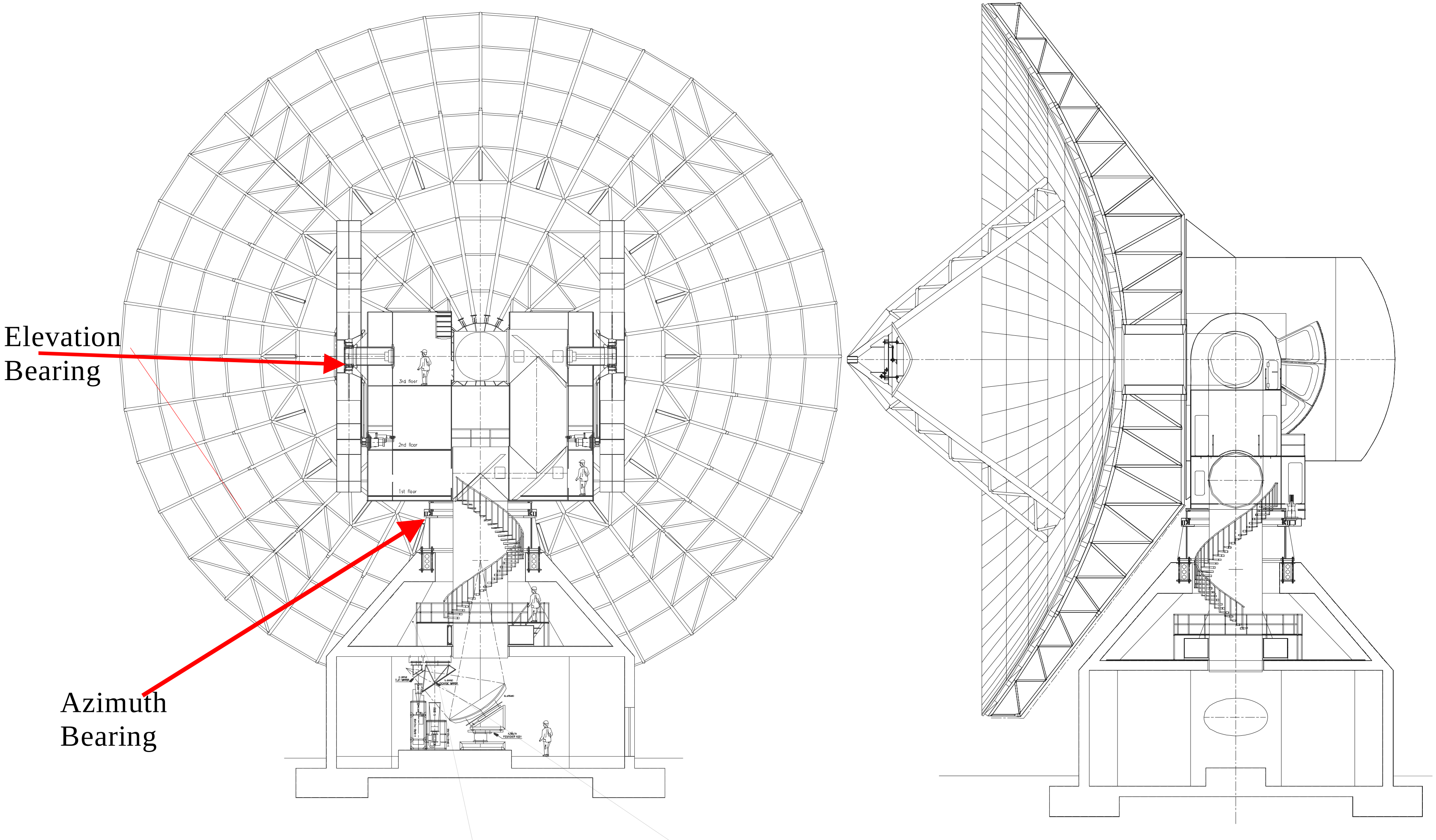
The NASA Goldstone 70m Deep Space Network Antenna



Courtesy of NASA

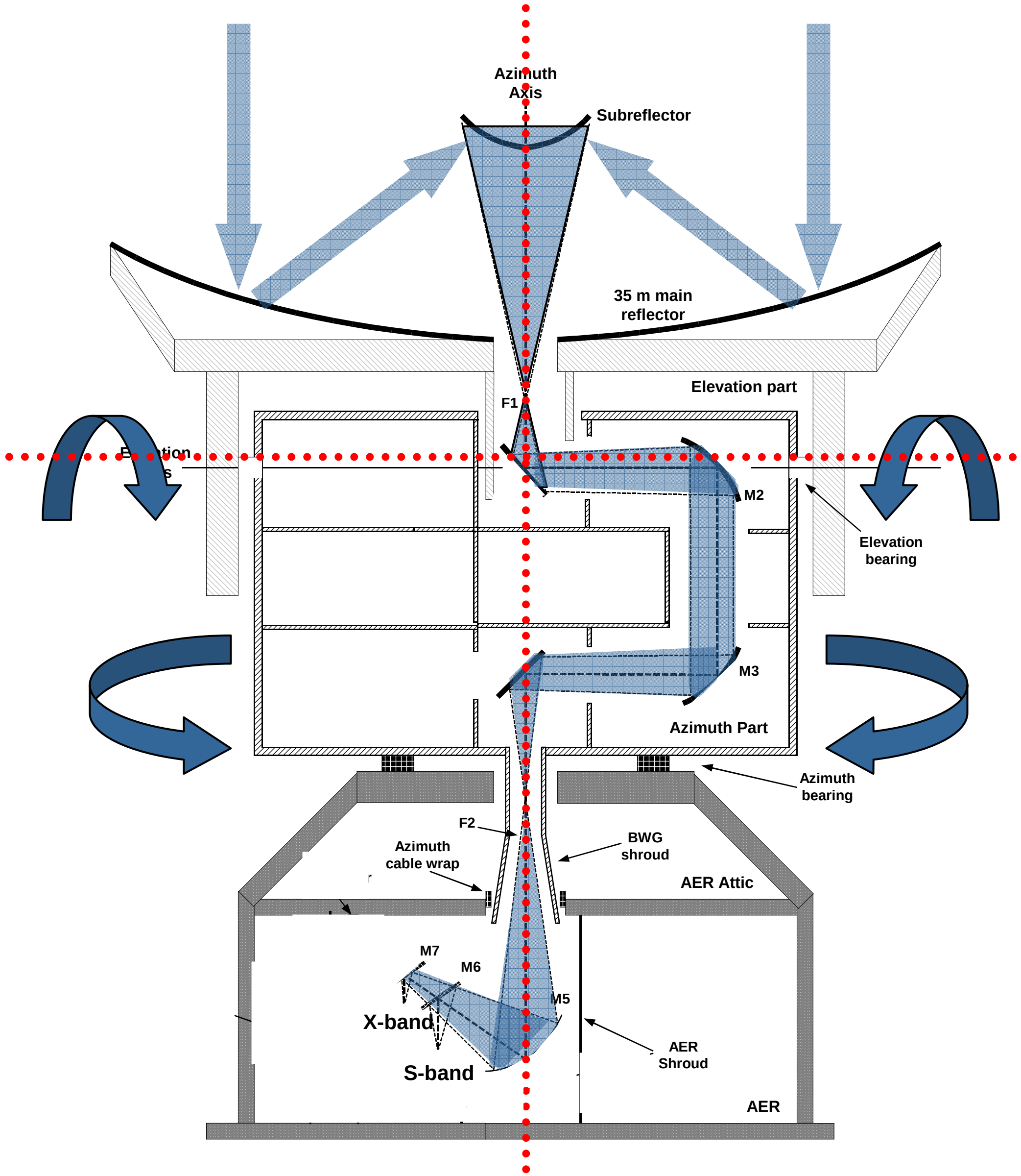
The ESA Cebreros (E) and New Norcia (Au) 35m Deep Space Antennas

Antenna pointing



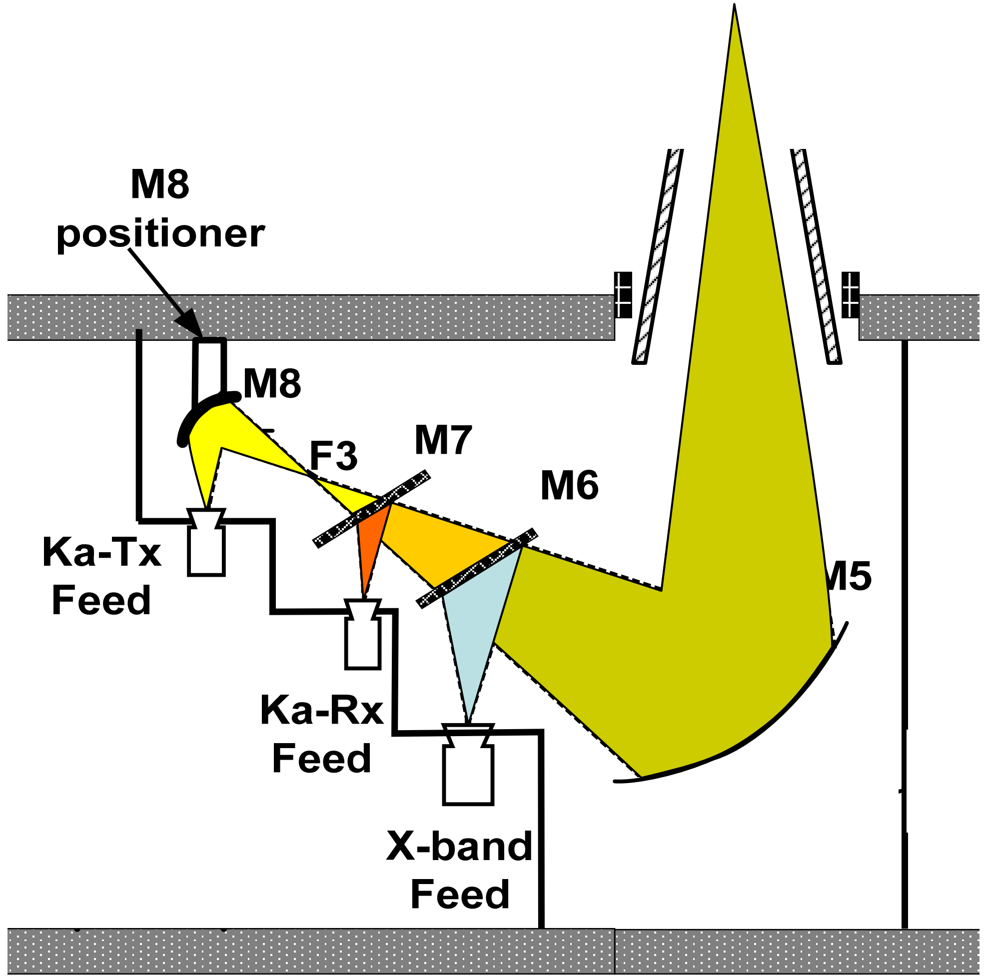
RF Path

One of the key issues in large ground segment antennas is the arrangement of the RF path (beam wave guide) to allow antenna rotation with minimum performance impact.



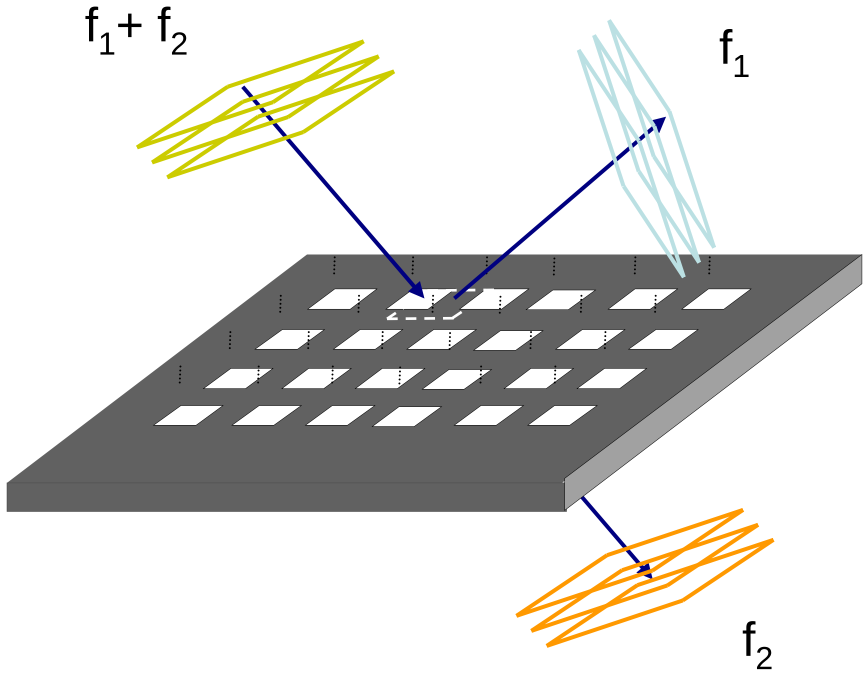
Feeds

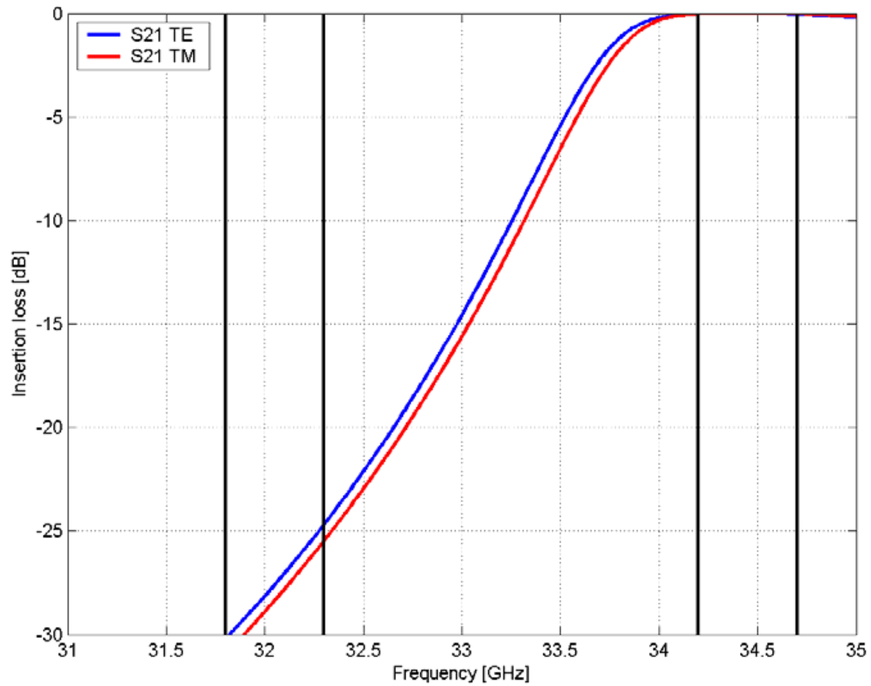
A second key issues in large ground segment antennas is the arrangement of the feeding section, with high power transmitters and low noise receivers, requiring cooling and ease of servicing.



Dicroics

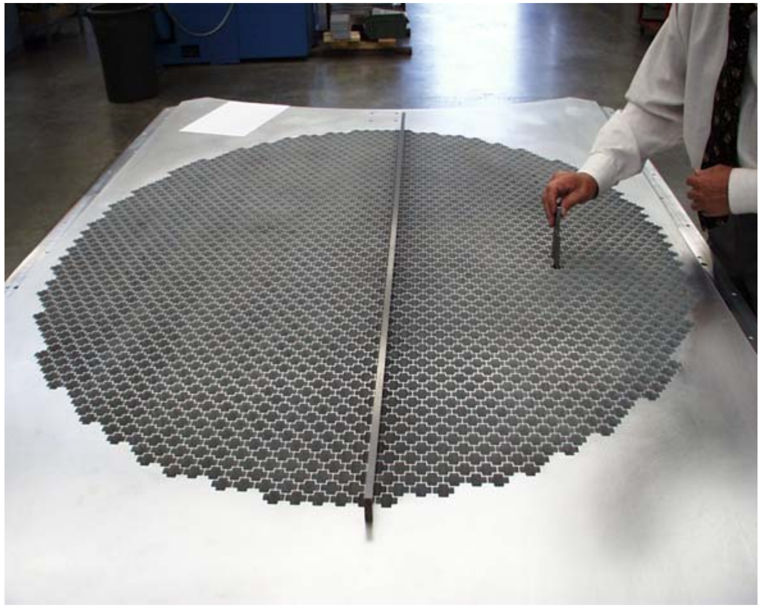
A dicroic is a partially reflective mirror with frequency dependent reflection and transmission coefficients.



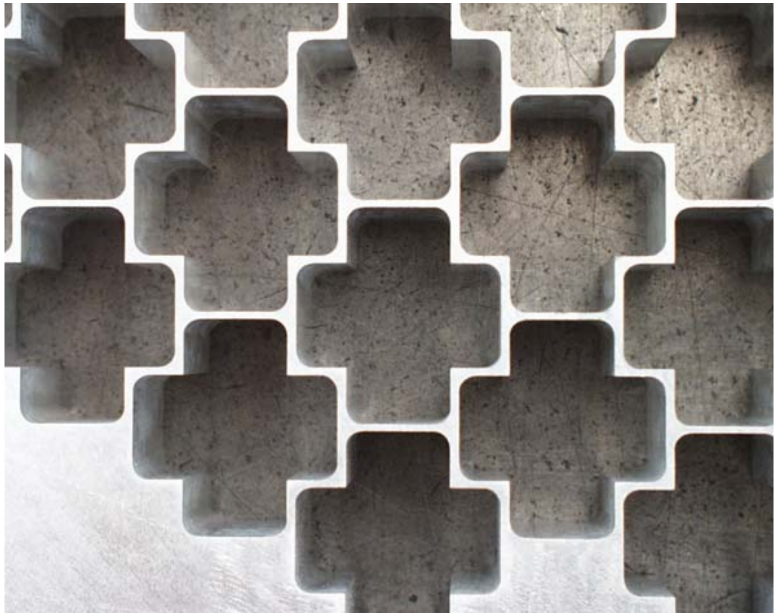


Resonant elements arranged in a periodic grid are used to create the frequency dependent behaviour.

Dicroic mirror for ESA DSA

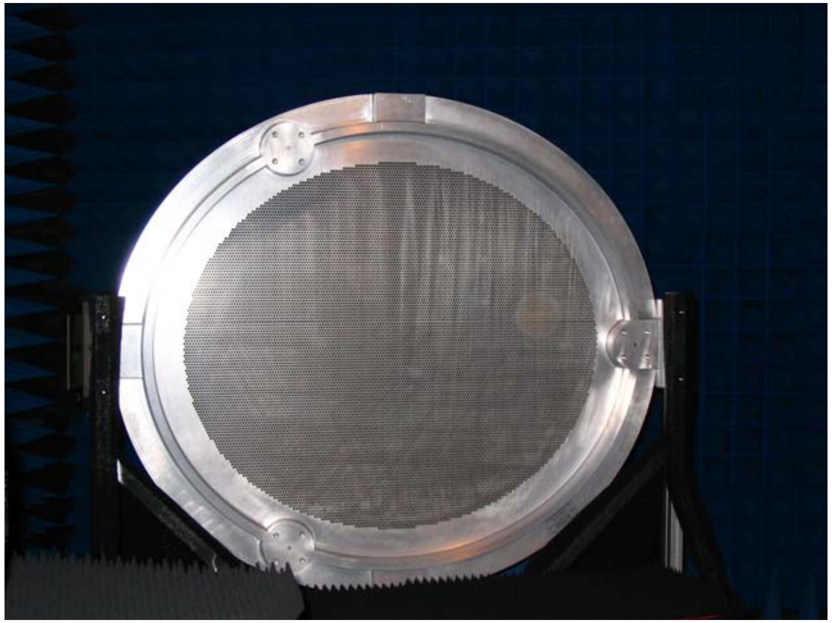


Mirror: 2.5 x 2.4 meter
Dichroic area: 1.3 x 1.4 meter
Thickness: 28 mm ± 0.1 mm

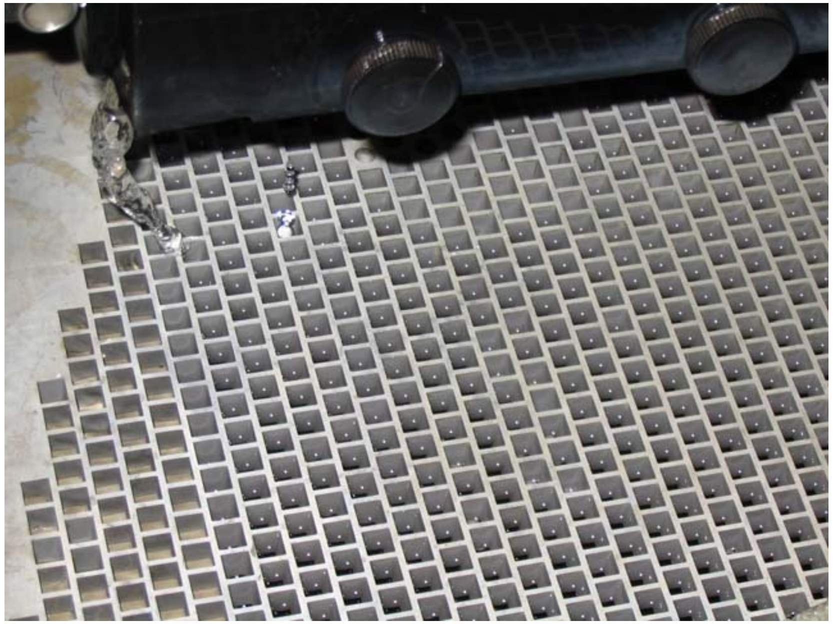


Number of Cross holes: 2430
Accuracy: ± 50 μm

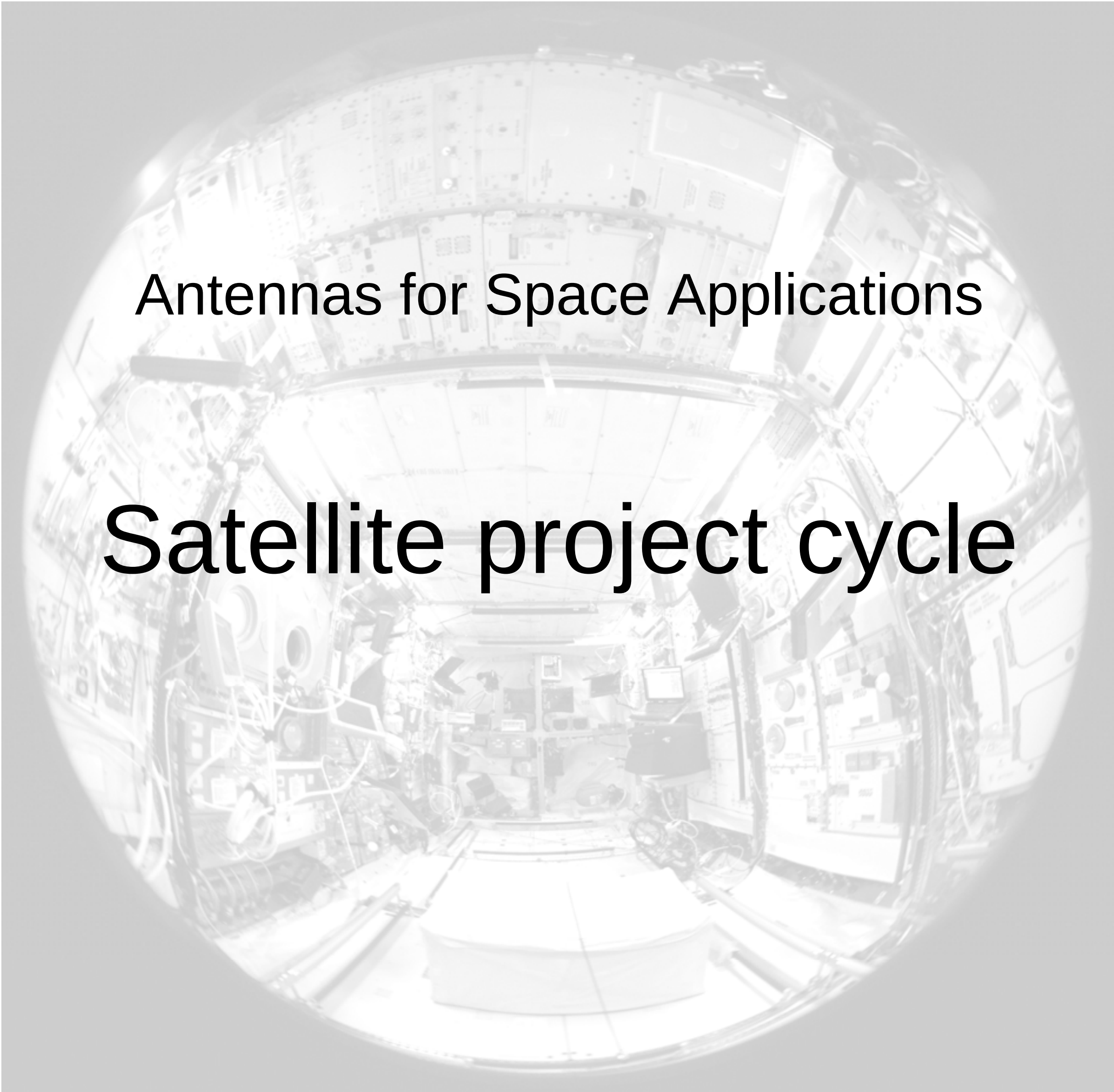
Dicroic mirror for ESA DSA



Mirror: 1.2 x 1.1 meter
Dichroic area: 0.92 x 0.8 meter
Thickness: 7.9 mm ± 0.05 mm



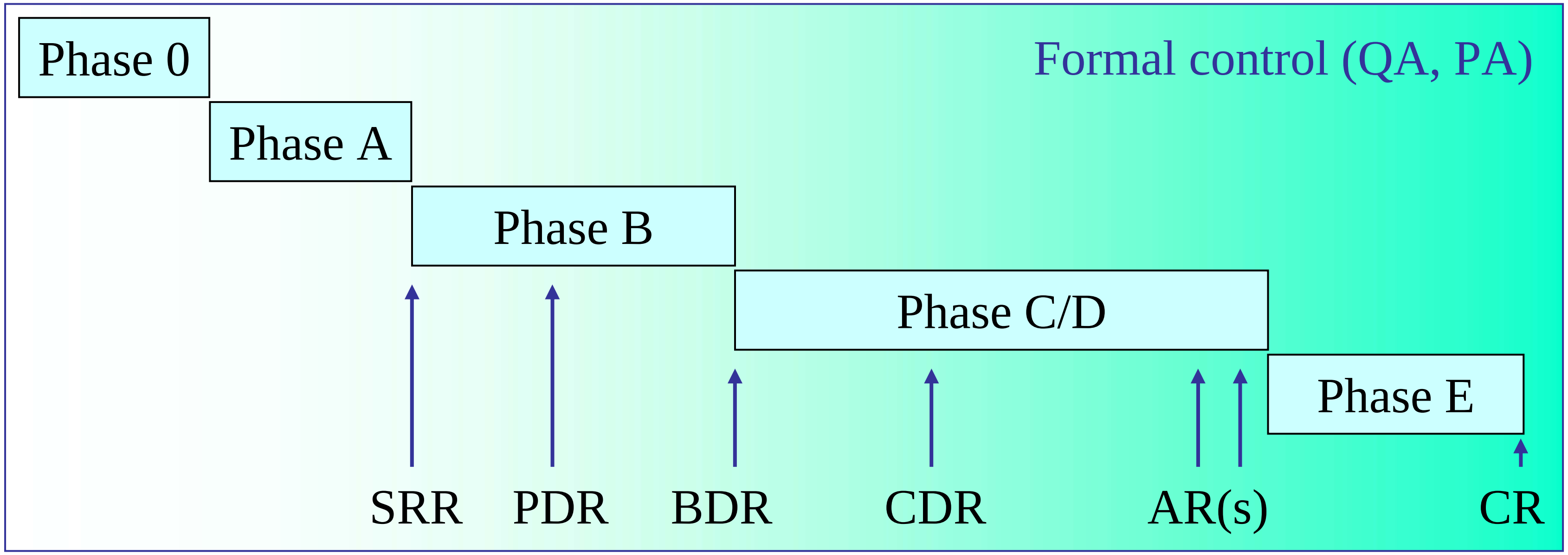
Shape: Rectangular holes
Accuracy: ± 10 μm



Antennas for Space Applications

Satellite project cycle

Phases and Reviews



Phase 0: Feasibility of mission

Phase A: Definition of mission

Phase B: Satellite design

Phase C/D: Design consolidation, manufacturing and testing

Phase E: In-orbit test and commissioning

Antenna models

Type 1 development (new technologies - high risk)

- EM: engineering model, to check design not technology
- STM: structural and thermal model (rarely used)
- QM: qualification model, to verify design and technology
- FM: flight model

Type 2 development (proven technologies - low risk)

- EQM: engineering and qualification model
- PFM: proto-flight model

Typical test flow

- Inspection (geometry, integrity, connectors, etc.)
- Electrical parameters check (S-parameters)
- Initial RF test (pattern, gain, etc.)
- Mechanical tests with intermediate electrical checks
- Thermal-vacuum test with electrical check (possibly with RF power in antennas – use of anechoic cups)
- Final RF test (pattern, gain, etc.)