Large Deployable Antennas for Space Telecommunications

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and

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1. Introduction

Technical disciplines

-Spacecraft and mission design

-Electromagnetism and RF wave propagation

-Thermal control in space

-Structures and Mechanisms

-Materials science and technology

-Manufacturing processes

esa

1. Introduction

Fundamental performances

-Frequency allocation: ITU Radio Regulations

-Link budget

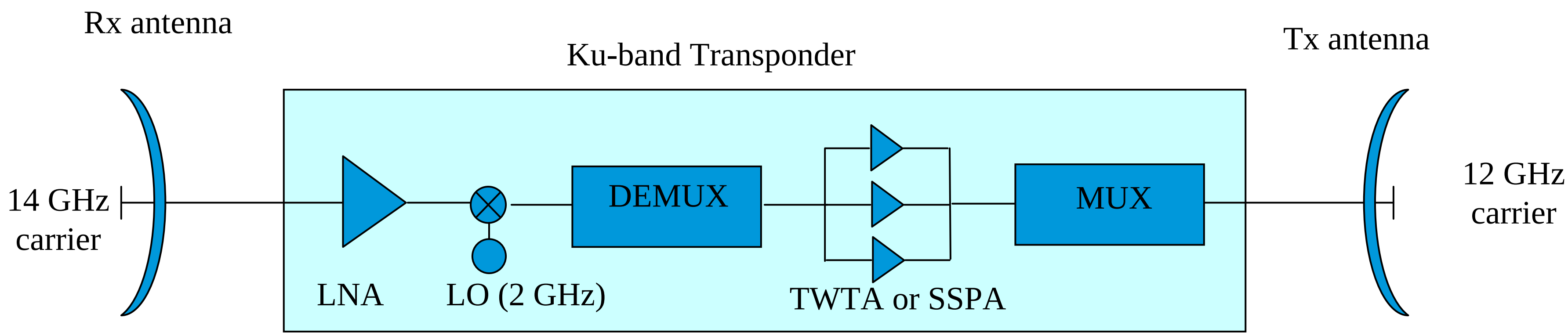
-Polar radiation pattern: gain, directivity and sidelobe isolation

-Power handling

Frequency bands in the microwave spectrum	
L	400 MHz ÷ 1.5 GHz
S	1.5 GHz ÷ 3.9 GHz
C	3.9 GHz ÷ 6.2 GHz
X	6.2 GHz ÷ 10.9 GHz
K	10.9 GHz ÷ 36.0 GHz
Q	36.0 GHz ÷ 46.0 GHz
V	46.0 GHz ÷ 56.0 GHz

1. Introduction

Telecom payloads and antennas



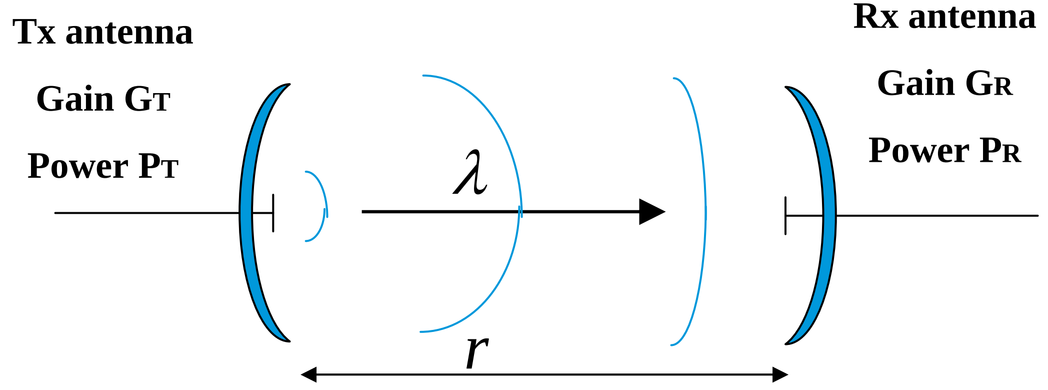
Telecommunications satellite payload example.

- Reflectors and radiating elements (feed horns) are directly exposed to the space environment and highly sensitive to the launch mechanical loads. Therefore, they are a major topic in mechanical and thermal design.

- Above 1 GHz the reflector (dish) antenna is the preferred solution in most applications.

1. Introduction

Fundamentals: link budget



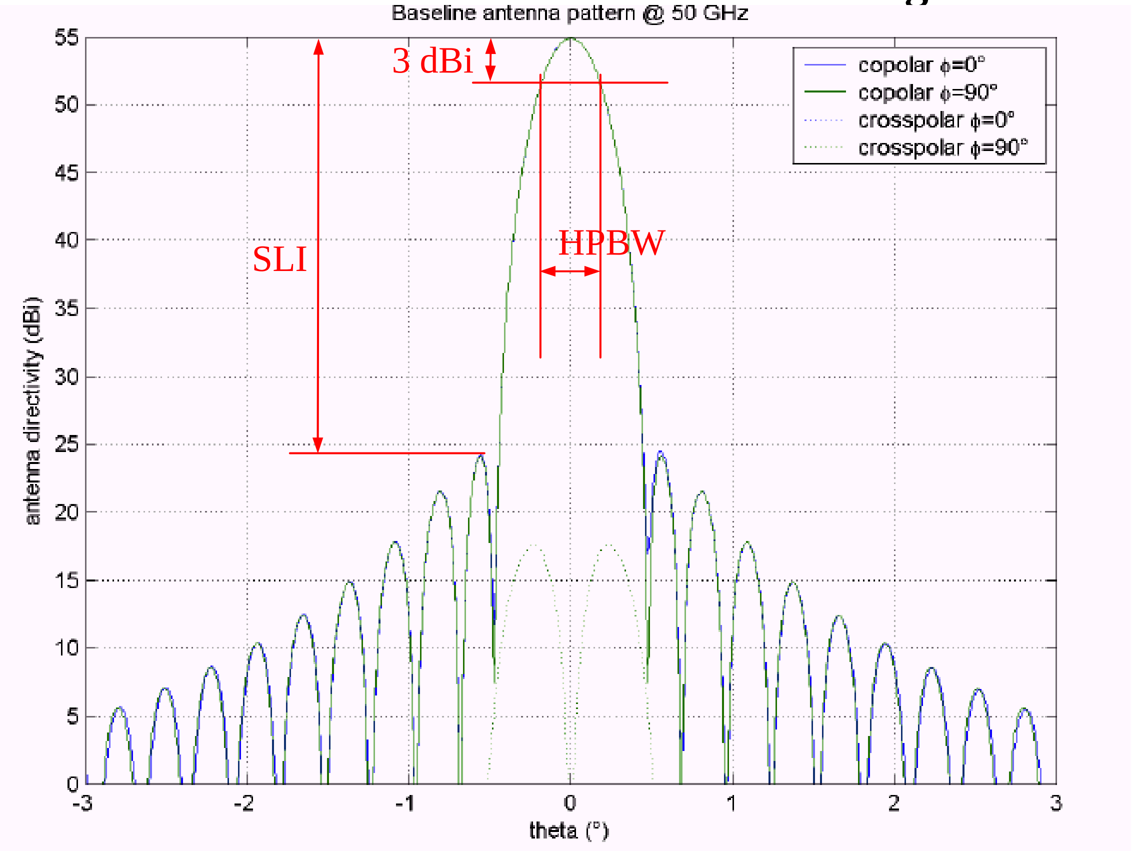
$$\frac{P_R}{P_T} = G_T + G_R - P_L \qquad \text{(dB)}$$

Path loss $\quad P_L = \left(\frac{4\pi\, r}{\lambda}\right)^2$

Boresight gain $\quad G_{T,R} = \frac{4\pi\, A_{eff}}{\lambda^2}$

1. Introduction

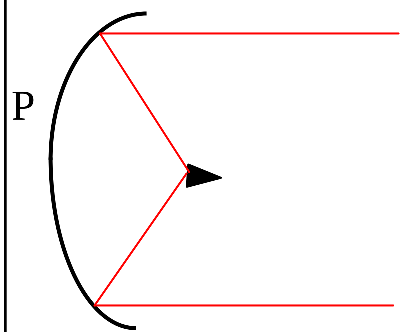
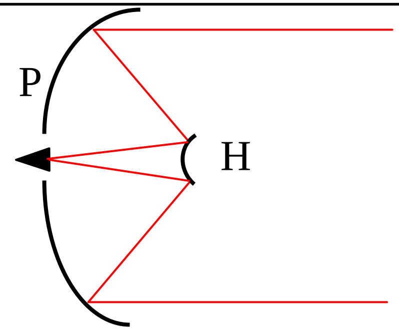
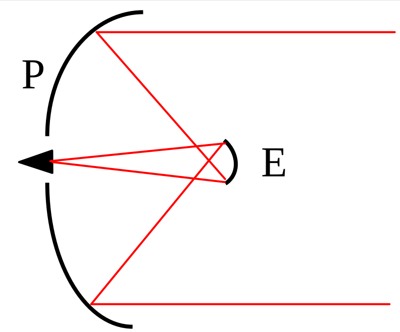
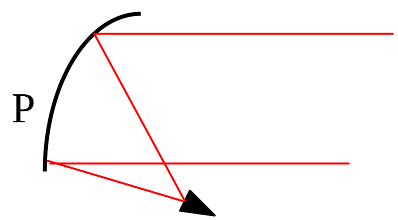
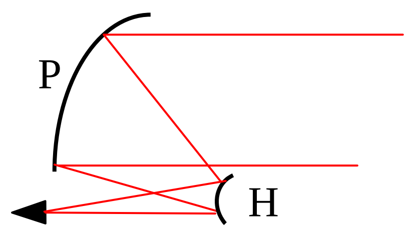
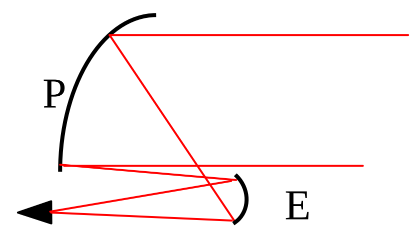
Fundamentals: radiation diagram



Copolar and crosspolar radiation diagram for a 1.2 m parabolic reflector in V-band (courtesy of HPS GmbH and ASD)

1. Introduction

Reflector antenna configurations

	Single paraboloid	Cassegrain	Gregorian
Symmetric (on-set)			
Asymmetric (off-set)			

2. Mechanical / thermal design, analysis and testing

- Validate materials and processes selection

- Provide support to RF design

- Provide deployment and pointing capabilities

- Maintain performance parameters within tolerance during lifetime

- Survive on-ground and launch loads

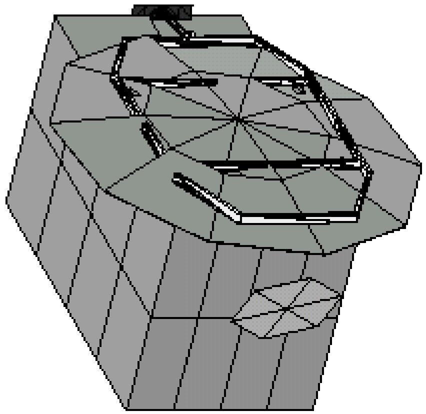
- Survive space environment

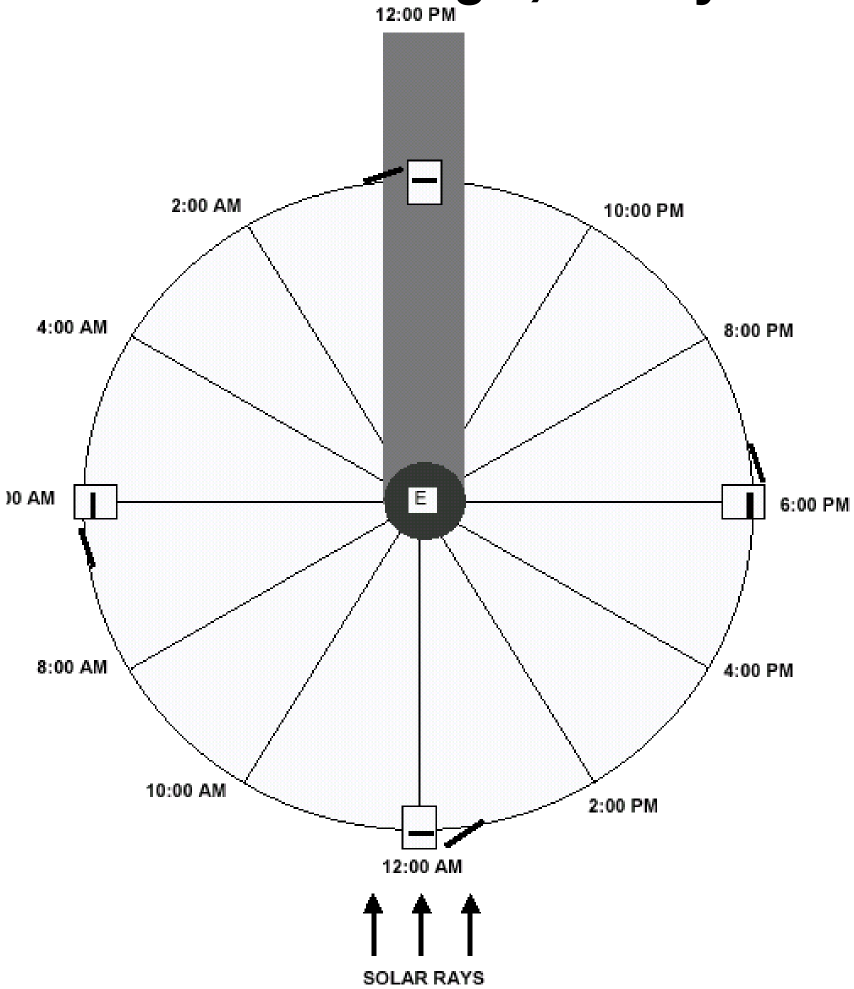
2. Mechanical and thermal design, analysis and testing

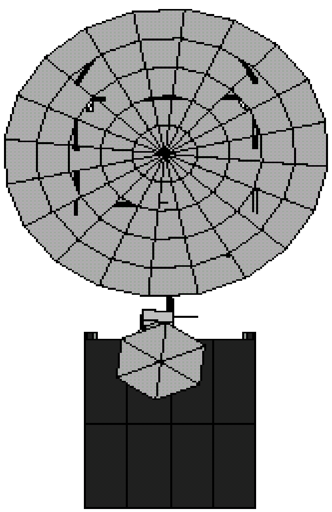
Space Environment (orbit dependent)

- Vacuum: volatility and contamination
- Partial compensation of gravity in orbit: orbital and attitude manoeuvres, gravity gradient
- Thermal environment: sun, earth, albedo, eclipse, deep space
- UV, radiation and particles
- Micrometeoroids and debris impacts
- Magnetic field
- Electrostatic discharge

2. Mechanical and thermal design, analysis and testing





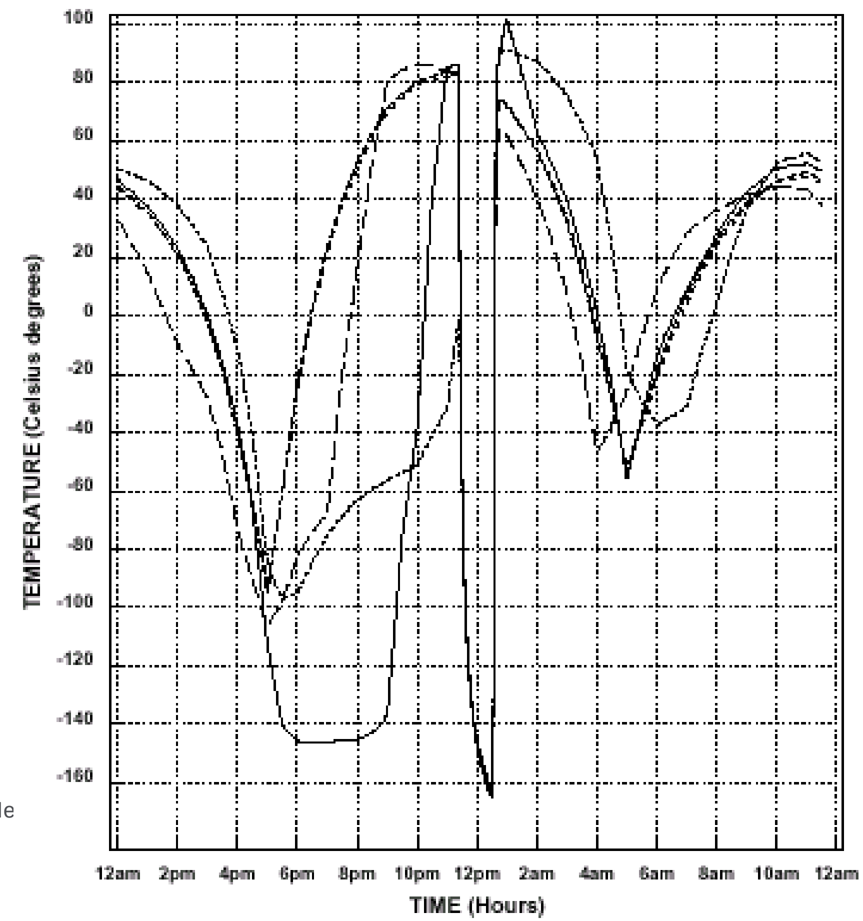


Courtesy of Astrium ST

2. Mechanical and thermal design, analysis and testing

FRONT SHELL TEMPERATURE vs. TIME

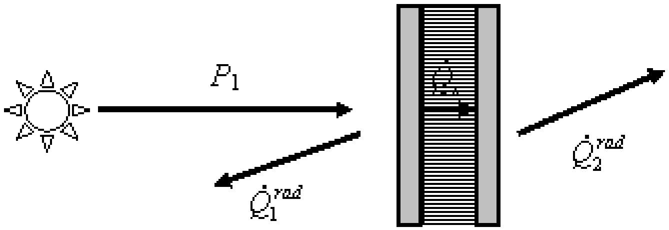
EQUINOX SEASON - BOL thermooptical properties



Courtesy of Astrium ST

2. Mechanical and thermal design, analysis and testing

$$\left.\begin{aligned} P_1 &= \dot{Q}_1^{rad} + \dot{Q}_c \\ \dot{Q}_c &= \dot{Q}_2^{rad} \end{aligned}\right\}$$



$P_1 = G_s \alpha_s A$ Input solar flux to the front skin

$\dot{Q}_1^{rad} = \varepsilon_1 \sigma \left(T_1^4 - T_0^4\right) A$ Radiation emitted by the front skin

$\dot{Q}_2^{rad} = \varepsilon_2 \sigma \left(T_2^4 - T_0^4\right) A$ Radiation emitted by the back skin

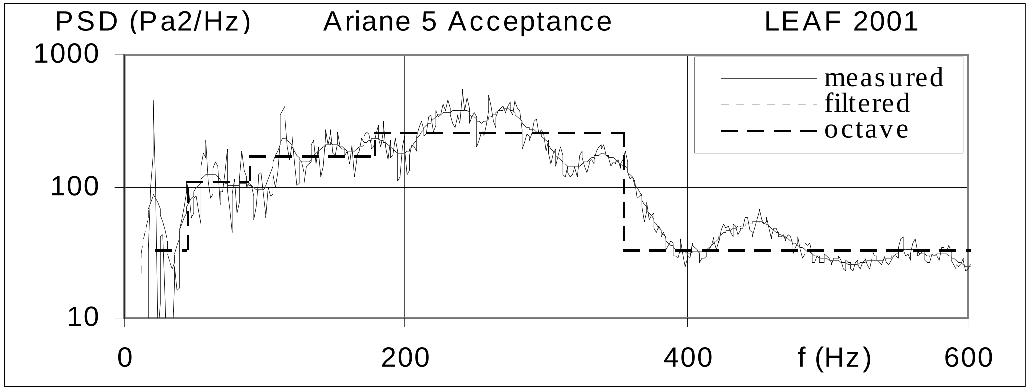
$\dot{Q}_c = C_s \left(T_1 - T_2\right)$ Conductive heat flux from the front to the back skin.

$$G_s \alpha_s = \varepsilon_1 \sigma \left(T_1^4 - T_0^4\right) + \frac{C_s}{A}(T_1 - T_2)$$

$$\varepsilon_2 \sigma \left(T_2^4 - T_0^4\right) = \frac{C_s}{A}(T_1 - T_2)$$

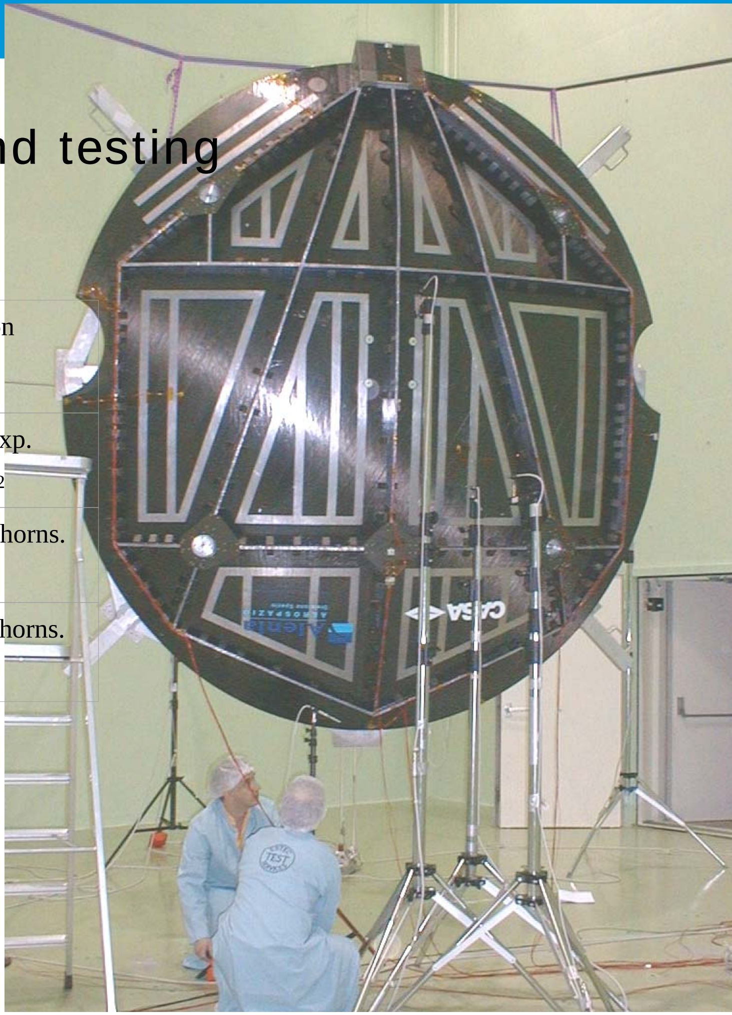
2. Mechanical and thermal design, analysis and testing

Octave Band Centre Freq. (Hz)	Ariane 5 Qualification SPL (dB re P_0)	Ariane 5 Acceptance SPL (dB re P_0)	Test Tolerance (dB re P_0)
31.5	132	128	-2, +4
63	134	130	-1, +3
125	139	135	-1, +3
250	143	139	-1, +3
500	138	134	-1, +3
1000	132	128	-1, +3
2000	128	124	-1, +3
Overall SPL	146	142	-1, +3
Test duration	120 s	60 s	0



2. Mechanical and thermal design, analysis and testing

Chamber	Dimensions (m) & Volume (m^3)	OASPL (dB re Po)	Reverberation time	Sound production
LEAF	9×11×16.4 1630	155	35 s at 100 Hz	4 modulators & exp. horns. Fluid: N_2
IABG	8.4×10.4×15.2 1380	156	25 s at 100 Hz	3 modulators & exp. horns. Fluid: air
Intespace	8.2×10.3×13 1100	156	30 s	3 modulators & exp. horns. Fluid: N_2



Courtesy of EADS-CASA

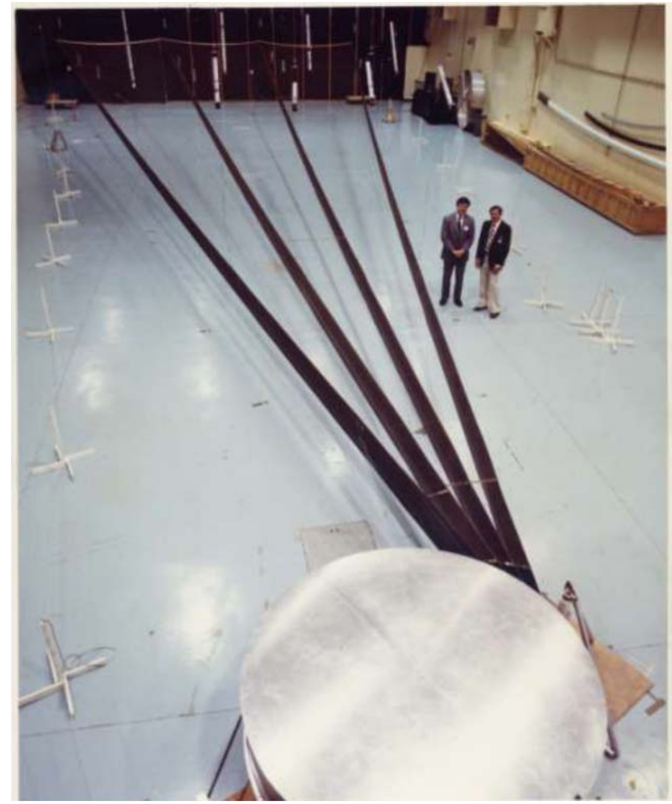
3. Large Deployable Antennas

Courtesy of Thales Alenia and NPO-EGS

3. Large Deployable Antennas

Wrap-Rib Antenna, JPL & Lockheed Missiles

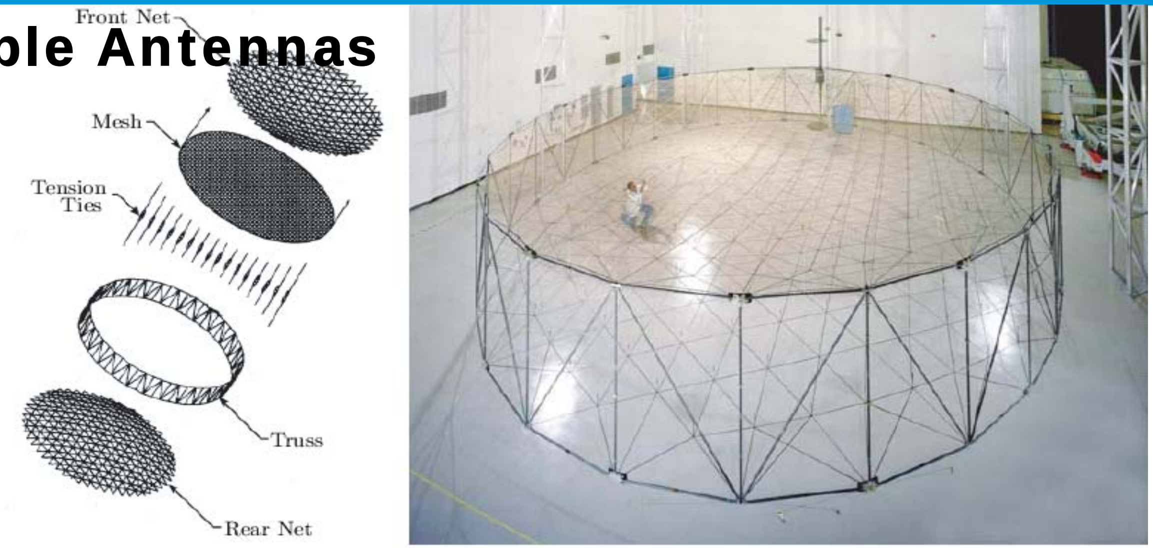
9.1 m WRA launched in 1974 with the *Applications Technology Satellite* 6



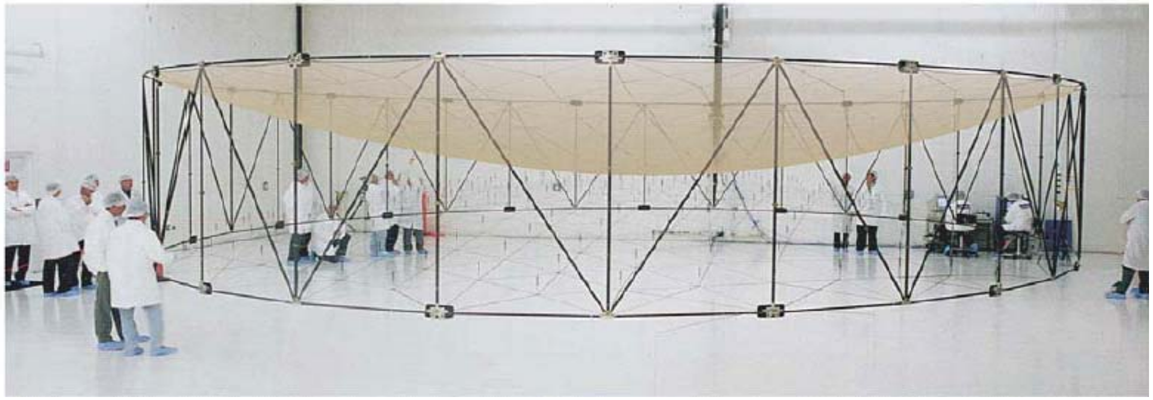
Sector of the 55 m wrap-rib reflector antenna

3. Large Deployable Antennas

The AstroMesh deployable reflector antenna: concept and the 12.25 m diameter reflector for Thuraya



(a) (b)

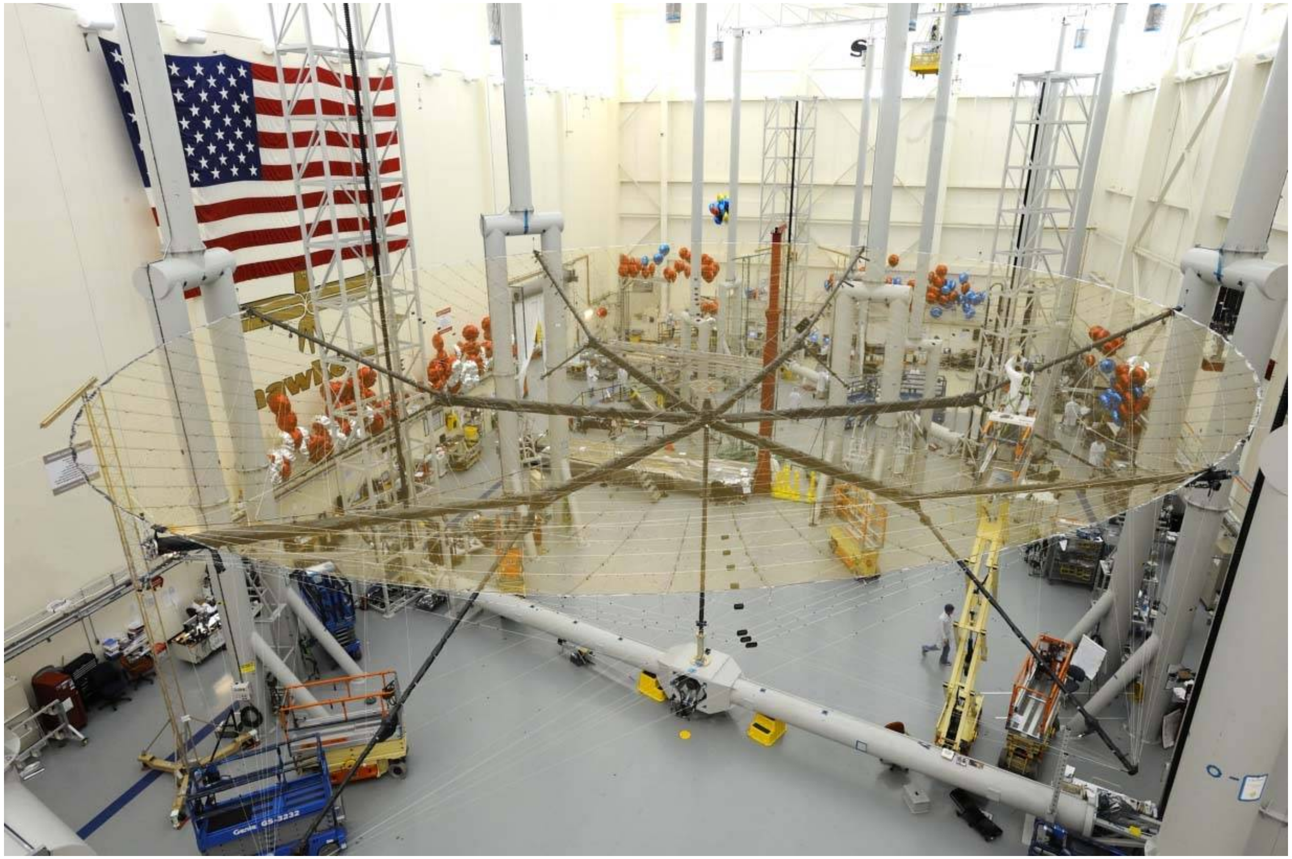


3. Large Deployable Antennas

Hinged-Rib Antenna, Harris Corporation

12 m diameter HRAs for ACeS Garuda-1

3. Large Deployable Antennas



Terrastar 18 m reflector, Harris Corporation

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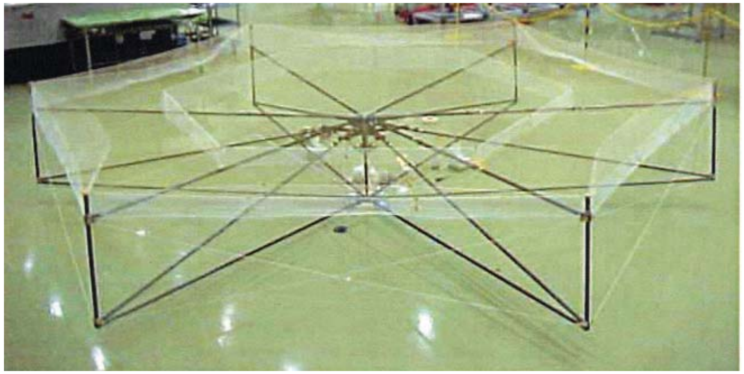
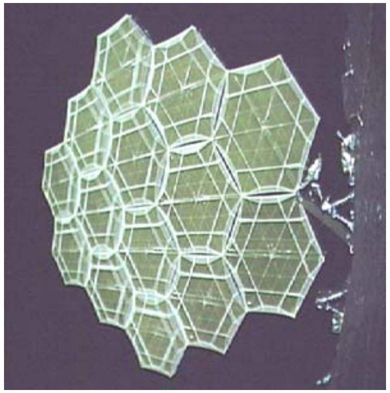
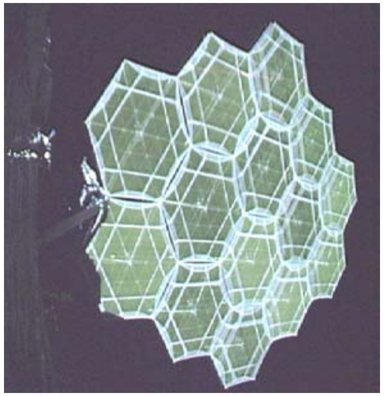
3. Large Deployable Antennas

Modular Mesh deployable reflector for
Engineering Test Satellite VIII, JAXA





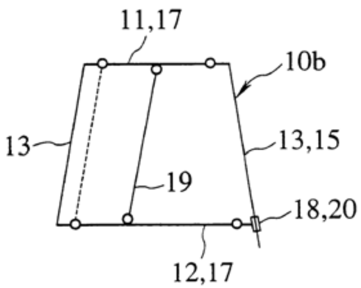


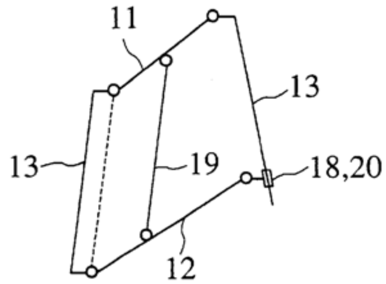
3. Large Deployable Antennas

Hughes SBA (a) one stowed another deployed, (b) vibration test on TDRS-H (two SBAs are stowed on the top of the satellite)

4. Critical Review of the state of the art

The Japanese modular deployable antenna, patented by NTT (US6550209 B2)





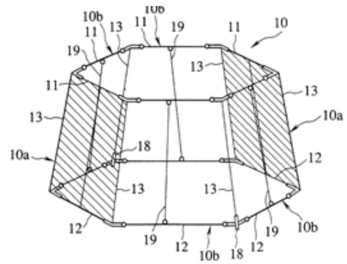
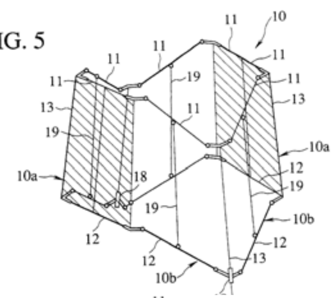
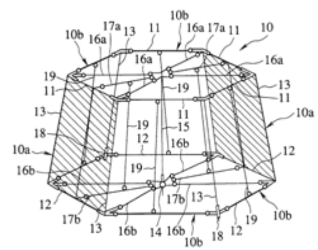
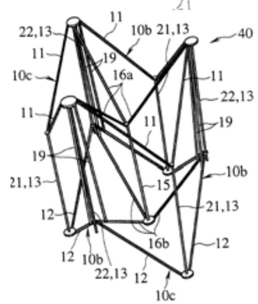


FIG. 5







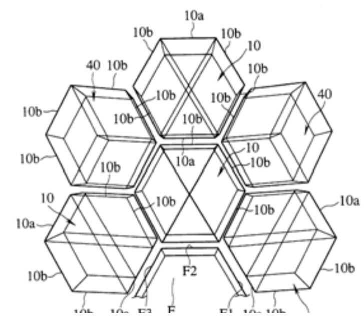
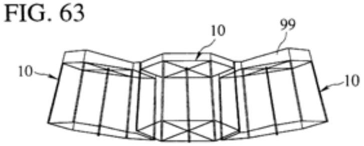
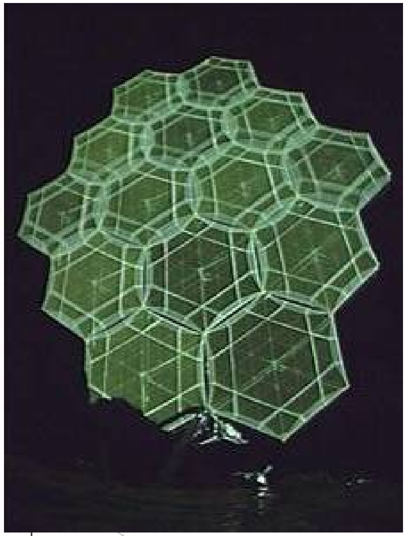
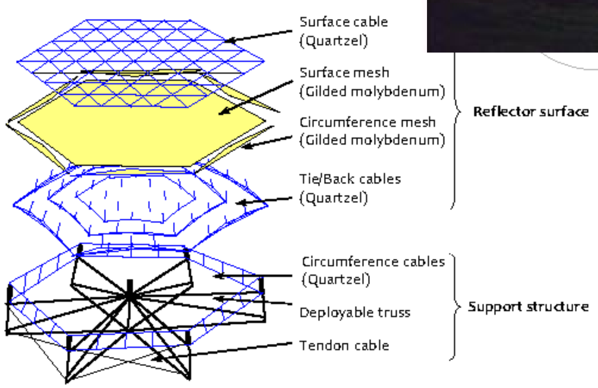


FIG. 63

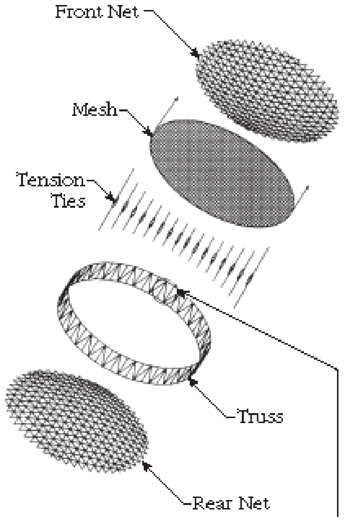


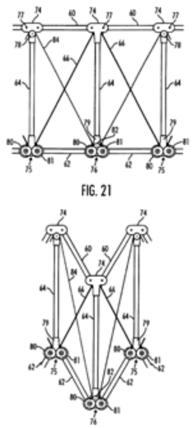


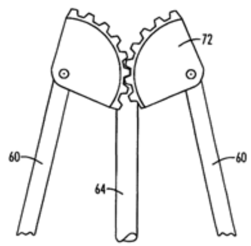


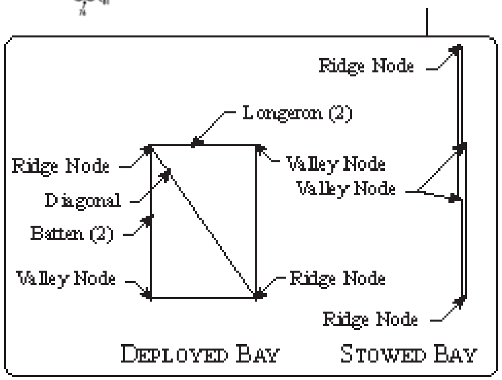
4. Critical Review of the state of the art

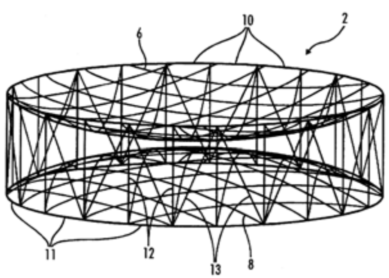
The Astromesh reflector, built by Astro (Northrop Grumman Space Technology) RD2: US5680145 A of 1997

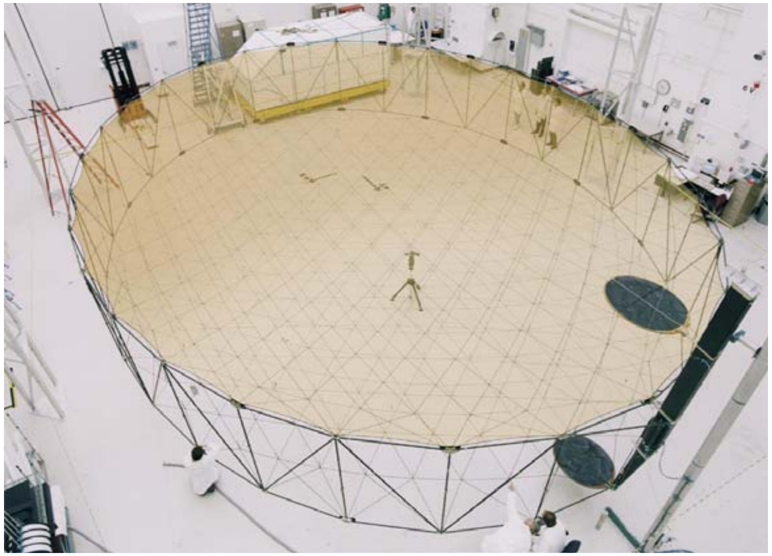












4. Critical Review of the state of the art

The hoop-truss reflector (RD3: US6618025 B2) by Harris Corporation

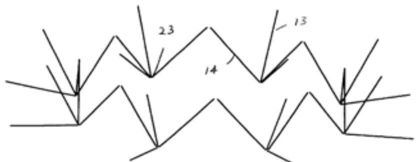


FIG. 31.

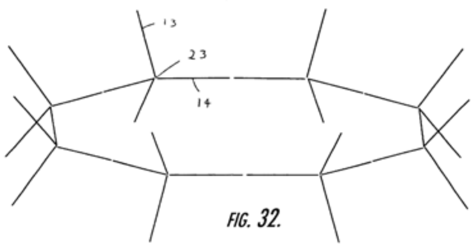
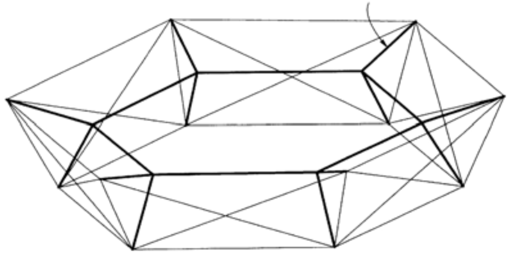


FIG. 32.



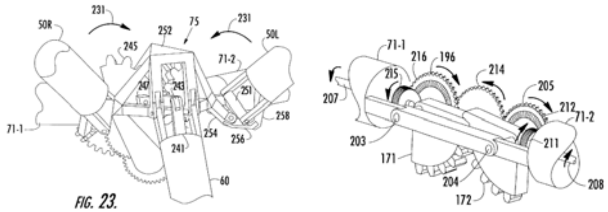
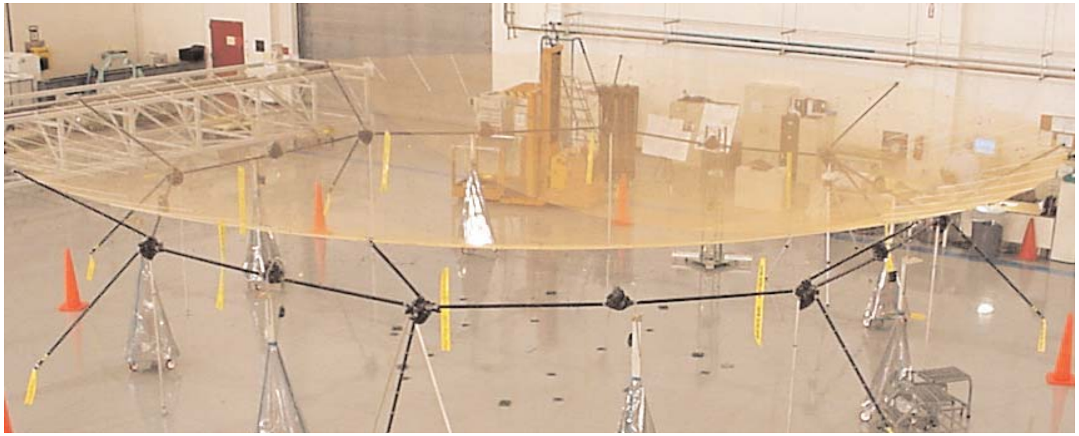
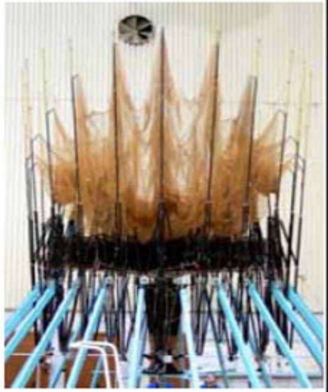
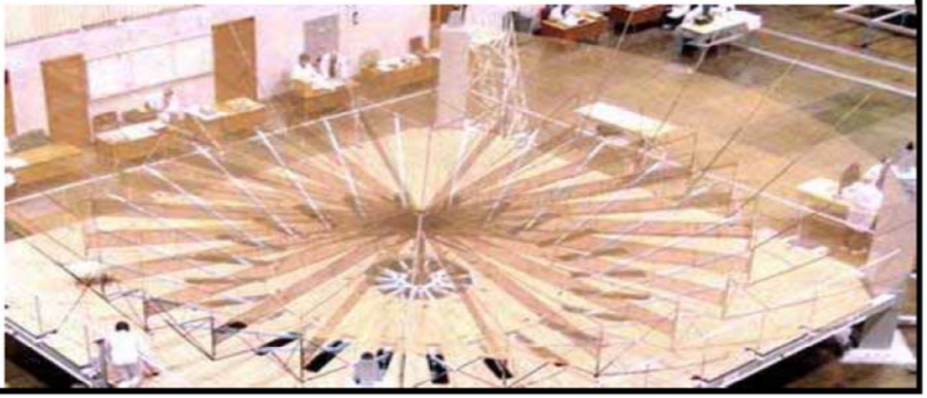


FIG. 23.



4. Critical Review of the state of the art

The TAS-I / EGS reflector (developed under ESA contract)

LDR stowed	LDR semideployed	LDR fully deployed
		

5. A New Concept of Deployable Structure

- The novelty introduced by the present invention is a **simplified architecture** of the deployable structure, generated by **articulated struts**, allowing for a modular construction of doubly curved surfaces.

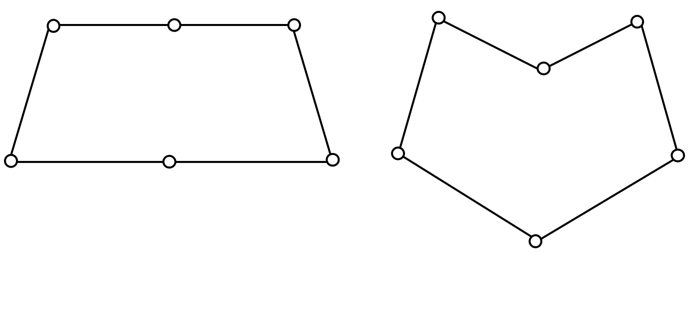
- **Increased flexibility** of the design as compared to the prior art. Either a single or multiple-cell architecture can be chosen.

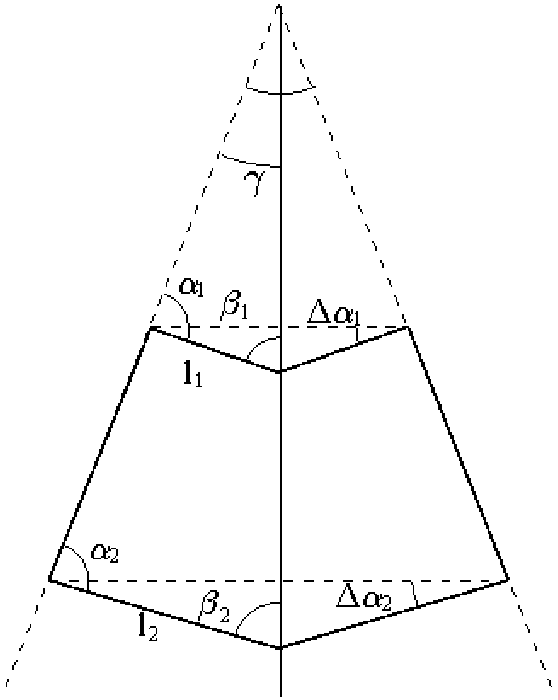
- Each module has **simple kinematics**, that allow stowing efficiently and also guarantees a controlled deployment, reduced mass and improved stability and reliability.

- **The shape of each module can be chosen** to conform to the reflector shape or remain as a standard module.

5. A New Concept of Deployable Structure

Six-bar linkage with special kinematics and trapeze shape when deployed





Patented concept

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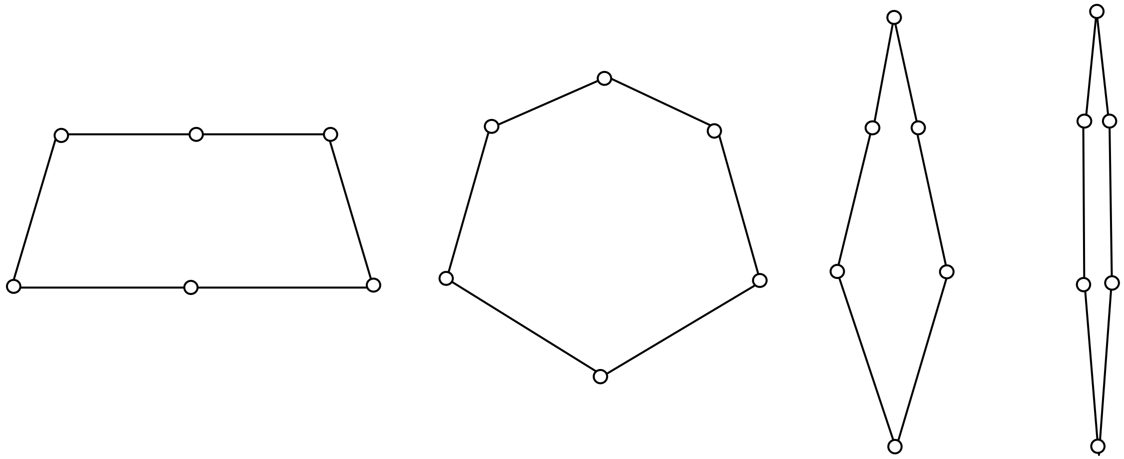

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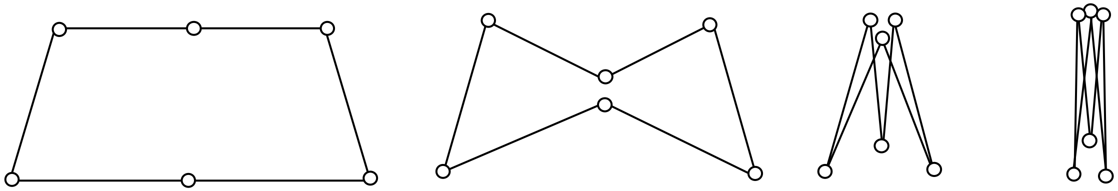

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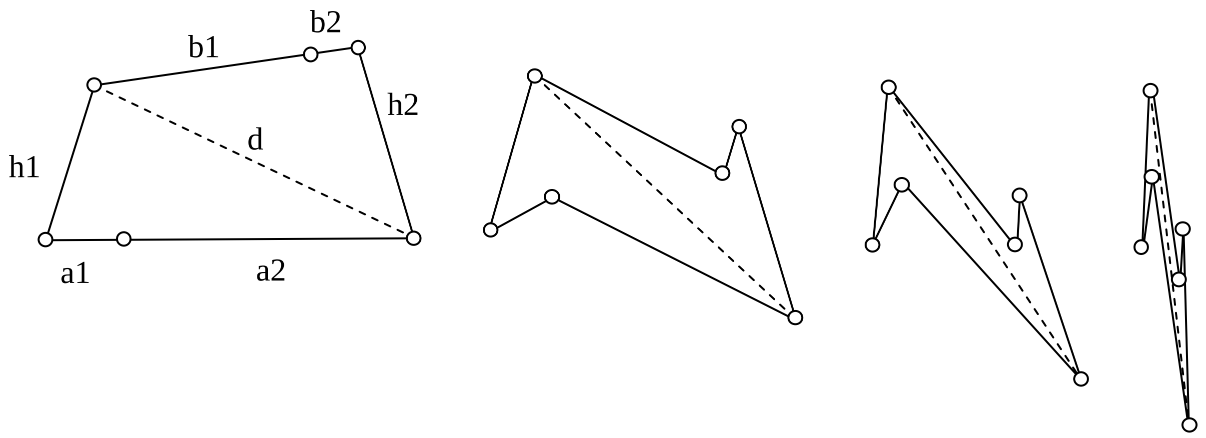
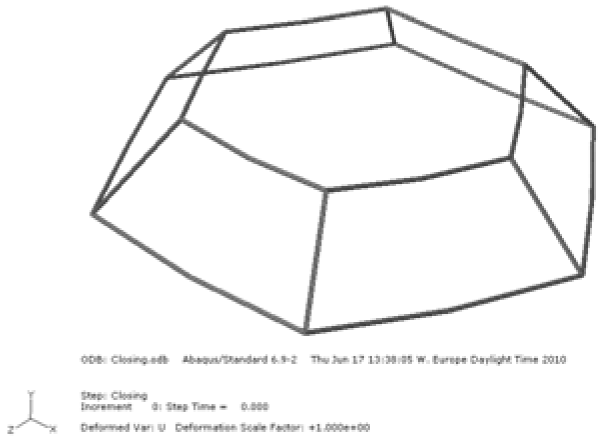


Patented concept

5. A New Concept of Deployable Structure

Scalable Unit Cell for modular construction (pyramidal architecture)



Patented concept

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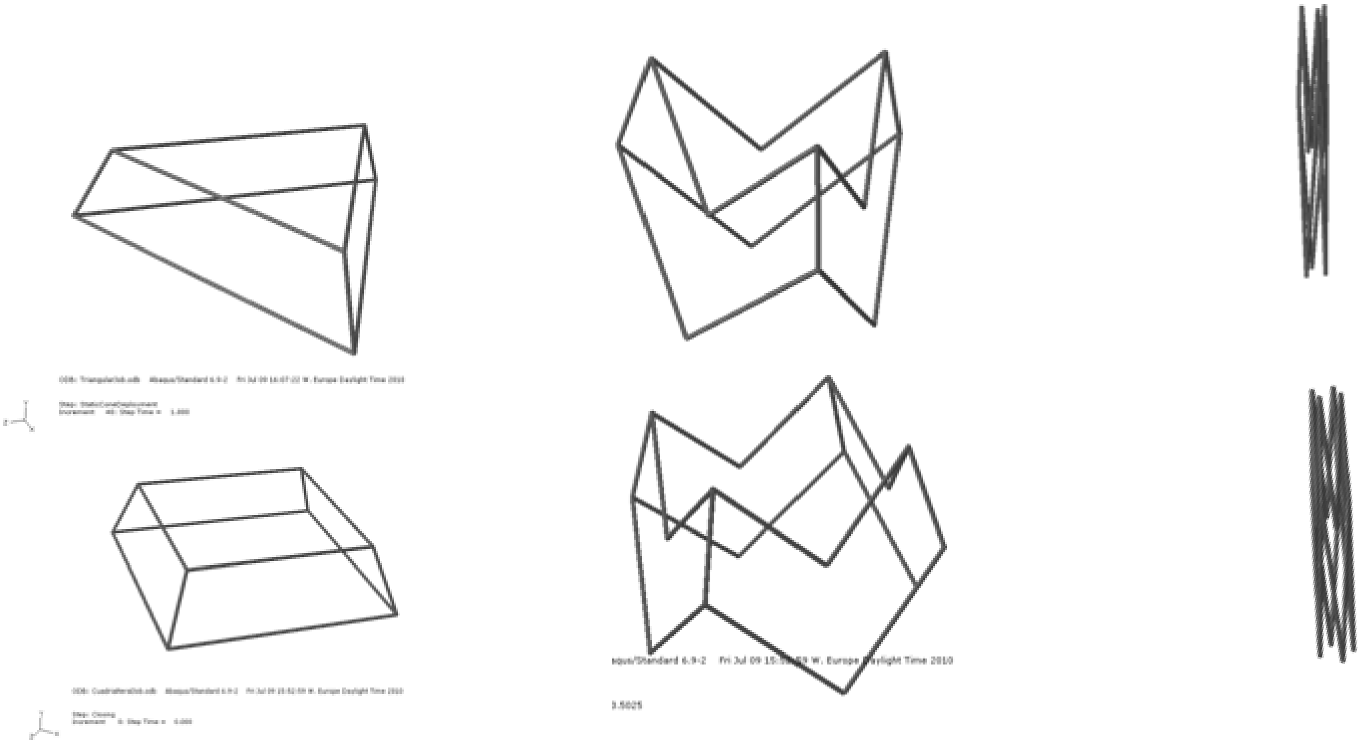

Patented concept

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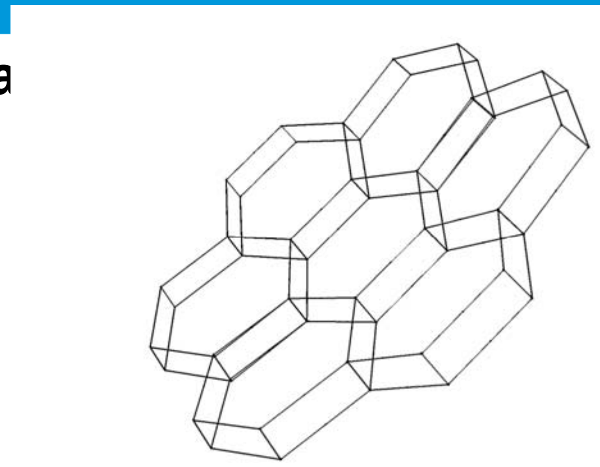

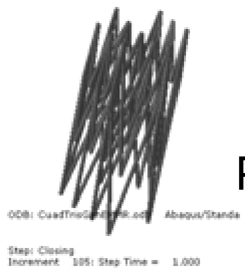

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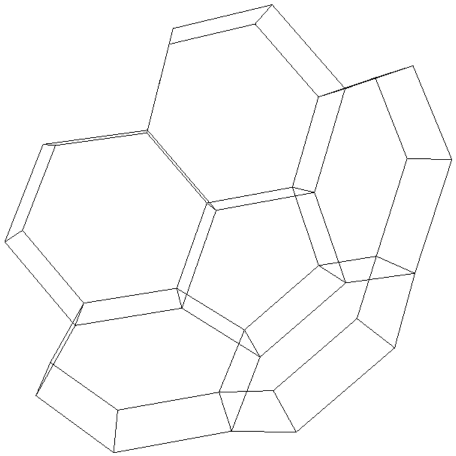
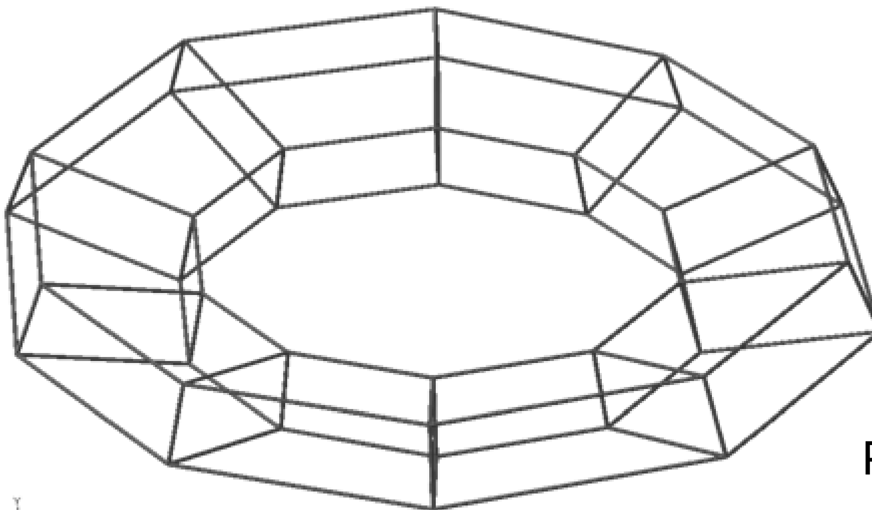
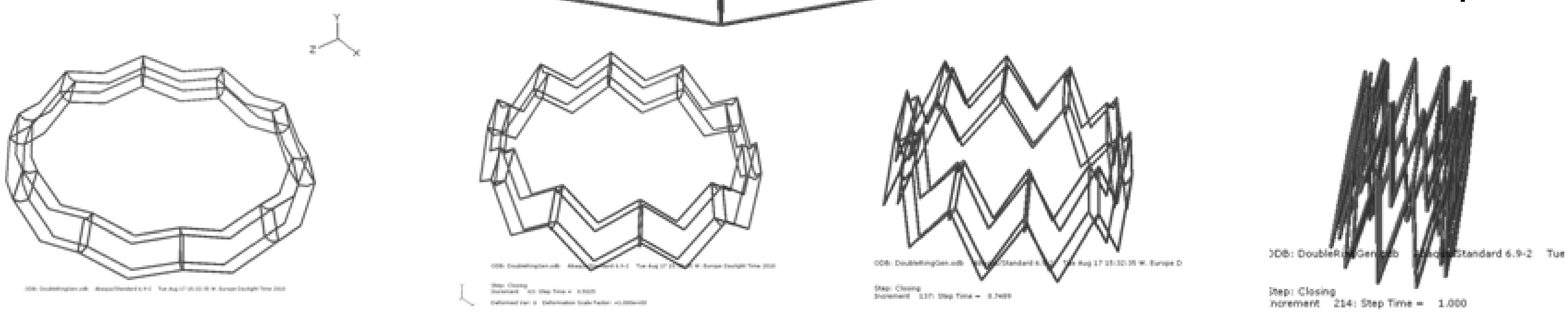


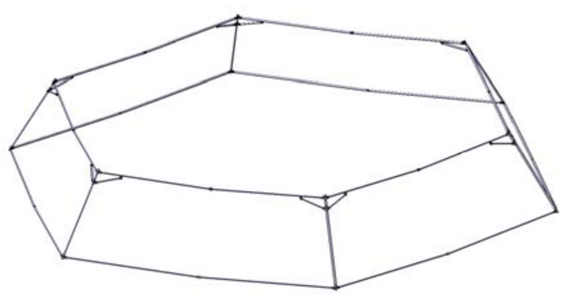
5. A New Concept of Deployable Structure

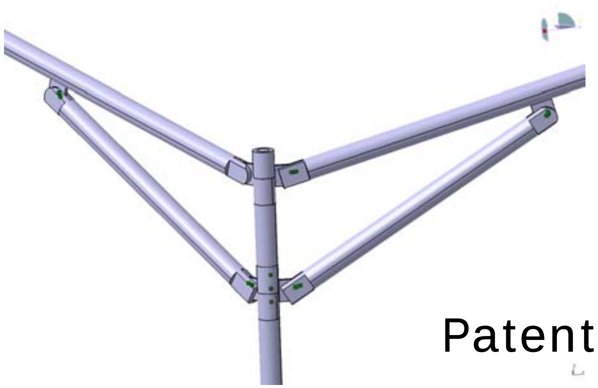


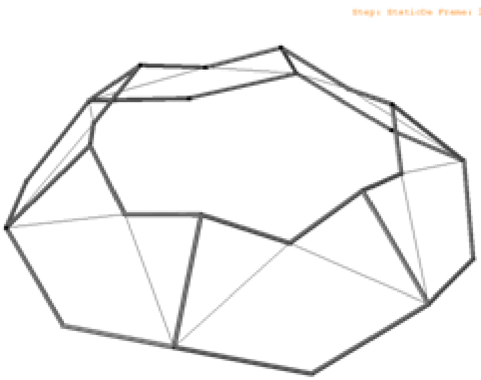
Patented concept

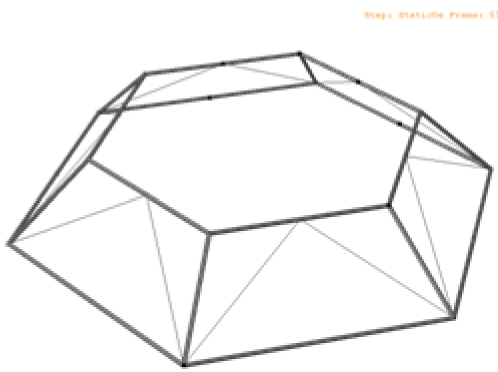


5. A New Concept of Deployable Structure









Patented concept

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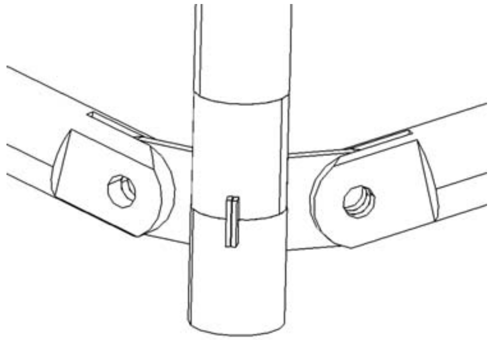
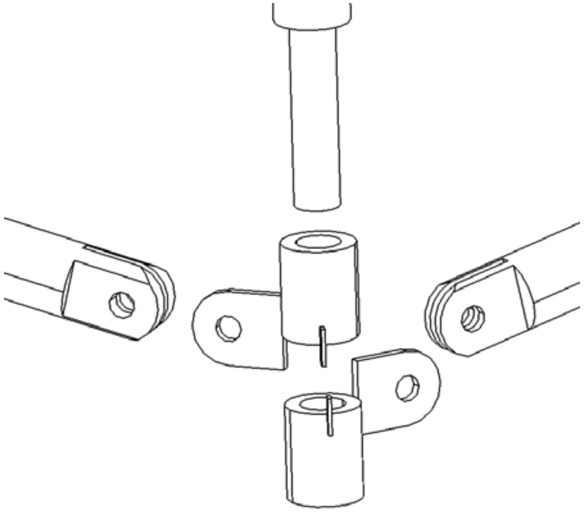
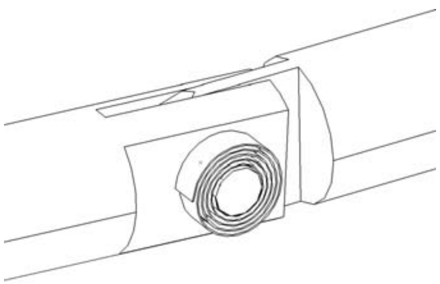
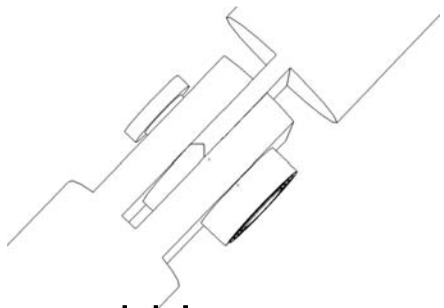




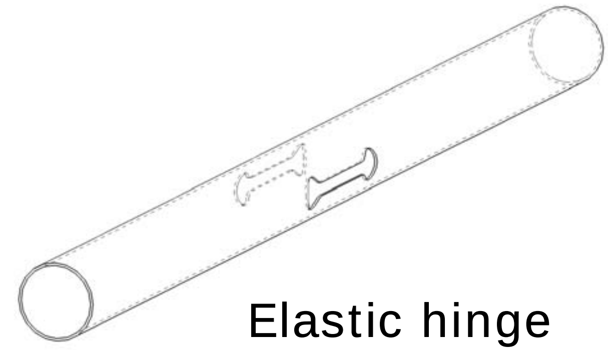
Patented concept

5. A New Concept of Deployable Structure

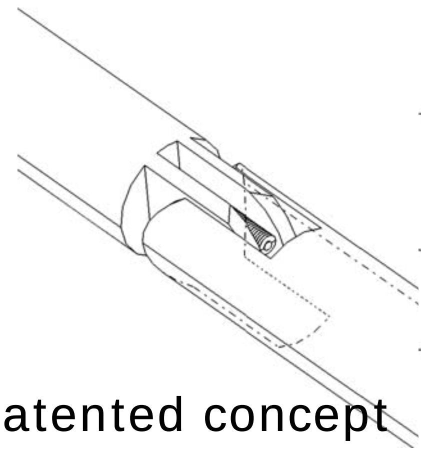




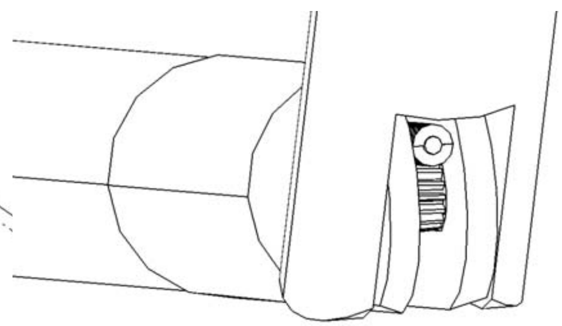
Spring actuated hinge

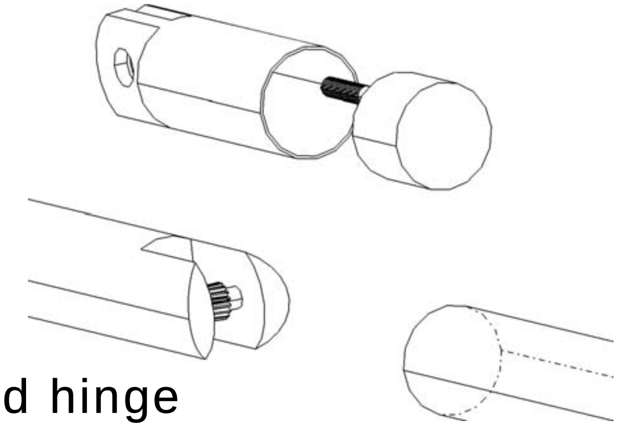


Elastic hinge



Patented concept





Electrically motorised hinge

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For the kind invitation