6th INTERNATIONAL PLANETARY PROBE WORKSHOP

ANTENNA ELEMENTS INTEGRATED INTO THE PARACHUTES OF PLANETARY ENTRY PROBES

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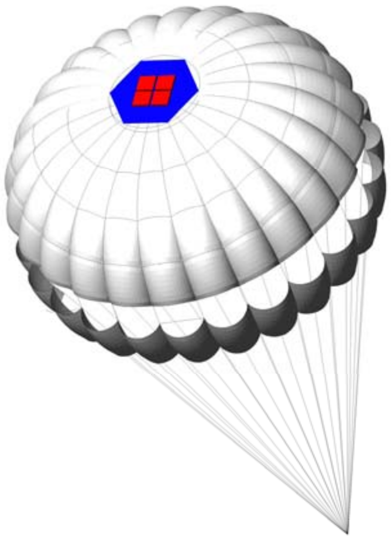
INTRODUCTION

- Integrating antenna elements into the parachutes of planetary entry probes may provide benefits at system level
  - parachutes are most common aerodynamic decelerator
  - conventional comms solution: low gain antennas located in the probe (limited mass and surface)
  - integration of parts of the antenna on the parachute may allow for potential
    - increased performances
    - size/mass reduction
    - additional applications



- Activity initiated and founded by ESA

- Multidisciplinary research
  - GMV (EDL), CIMSA (parachutes), IDS (antennas)

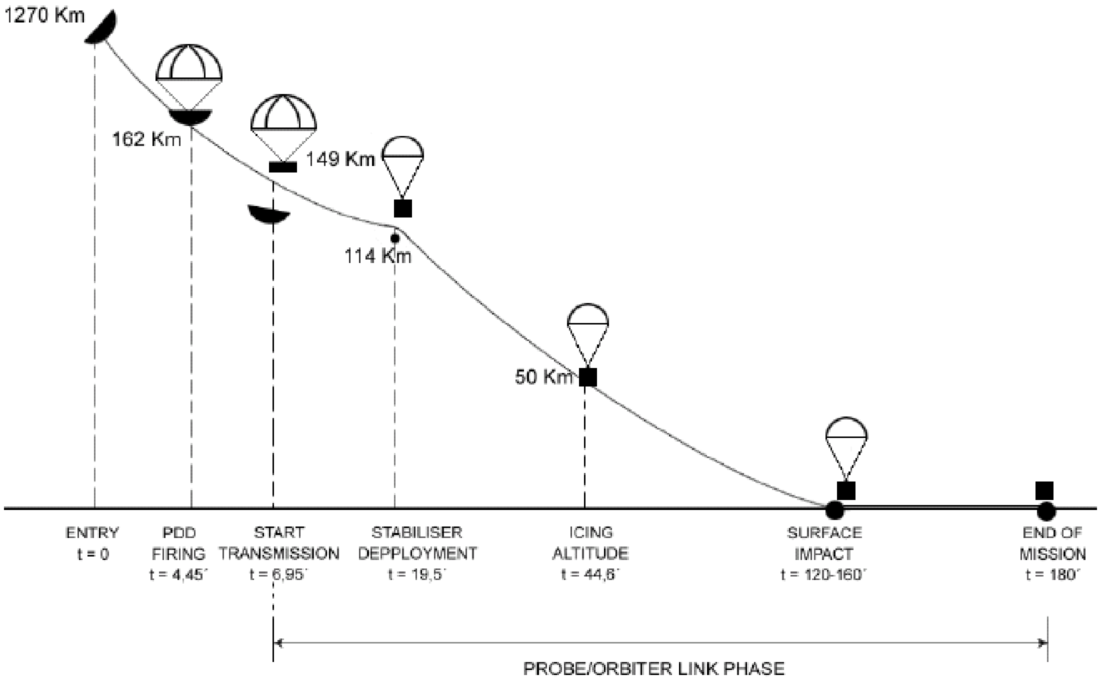
MISSION SCENARIOS AND SYSTEM CONSIDERATIONS (1)

- Classification of mission scenarios
  - Mars missions
    - Thin atmosphere ⇒ large parachutes, can be opened only close to the ground ⇒ descent under parachute lasts no more than a **few minutes**
    - Communications during descent: DTE (X-band) or UHF (through relay SC)
    - Amount of information that needs to be transmitted during the EDL is **small** (mainly engineering telemetry) ⇒ no need for high data rates
  - Missions to bodies with denser atmospheres (Venus, Jupiter,Titan...)
    - dense atmospheres ⇒ smaller parachutes ⇒ descent lasts much **longer** (up to 2 hours for Huygens)
    - main **scientific return** of the mission is achieved during the passage through the atmosphere
      - no or very short lifetime on the surface
      - all data collected during the descent (images, atmospheric properties, and engineering data) must be transmitted right away to to a relay SC overhead (DTE often not possible)
    - the highest the data rate, the better

MISSION SCENARIOS AND SYSTEM CONSIDERATIONS (2)

- Main potential benefit at system level
  - increase the volume of data transmitted during the descent phase

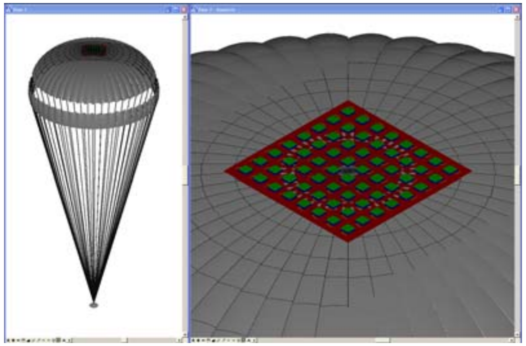
- Huygens taken as reference mission scenario
  - 3 parachutes: most part of descent under stabiliser 3-m diam. chute
  - One-way link comms to Cassini

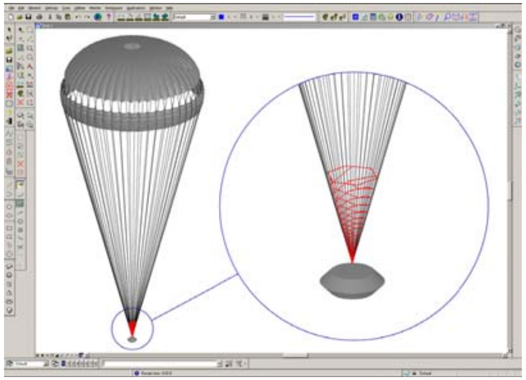


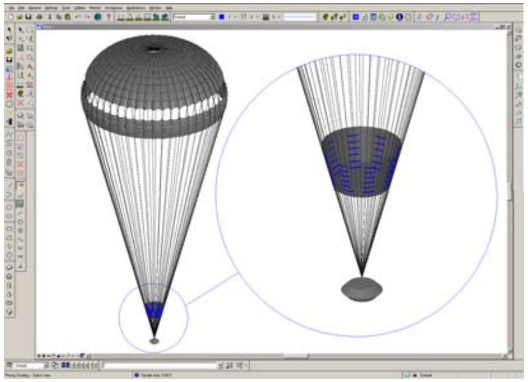
- Link geometry depends very much on the mission
  - evolution of probe aspect angle

INTEGRATED PARACHUTE-ANTENNA SOLUTIONS (1)

- Candidate antenna concepts
  - Patch array
    - different configurations and number of elements located on top of the canopy
    - large surface available, azimuth symmetric patterns, fixed or steerable beam, flexible design
  - Single circular patch
  - Microstrip constrained lens (feeder + lens)
    - efficiency problems in power supply (spillover), design complexity
  - Dual-mode conical helix supported by suspension lines
    - directivity gain strongly depends on ground plane, not suitable for steerable beam
  - Conical vertical array of printed antennas
  - Conical sleeve dipole







INTEGRATED PARACHUTE-ANTENNA SOLUTIONS (2)

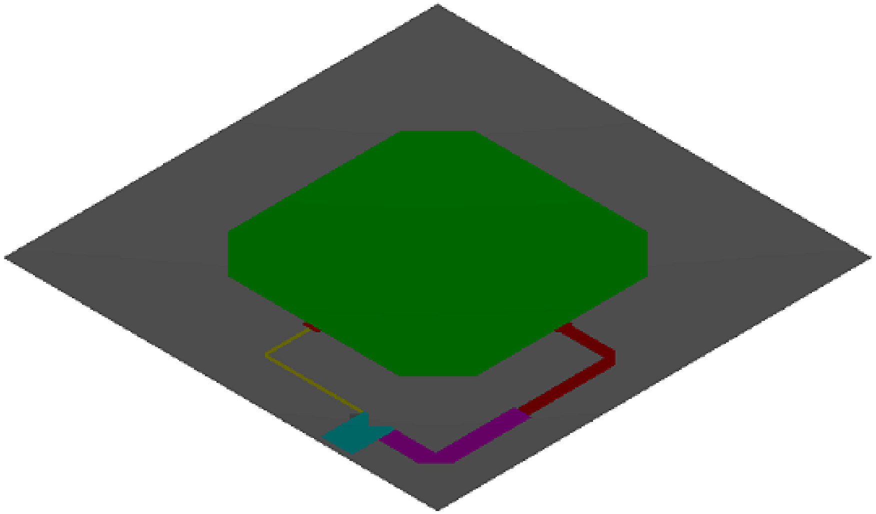
- Considerations on frequency band
  - Heritage, atmospheric attenuation, antenna sizes, etc.
  - S-band was selected because of smaller antenna

- Selected concept $\Rightarrow$ patch array with steerable pattern, both in elevation and azimuth
  - significant increase in gain
  - flexible design for easy adaptation to different missions, parachutes
    - operating frequency, number of radiating elements and inter element distance can be varied according to mission requirements
  - signal must be modulated and amplified on the canopy and not on the probe (avoid transmission losses)
  - a bidirectional link is necessary to evaluate the direction to the orbiter

RADIATING ELEMENT DESIGN

- Radiation requirements
  - operating frequency (S-band), bandwidth (about 40 MHz)
  - polarization (circular)
  - radiating element return loss (-10 dB)

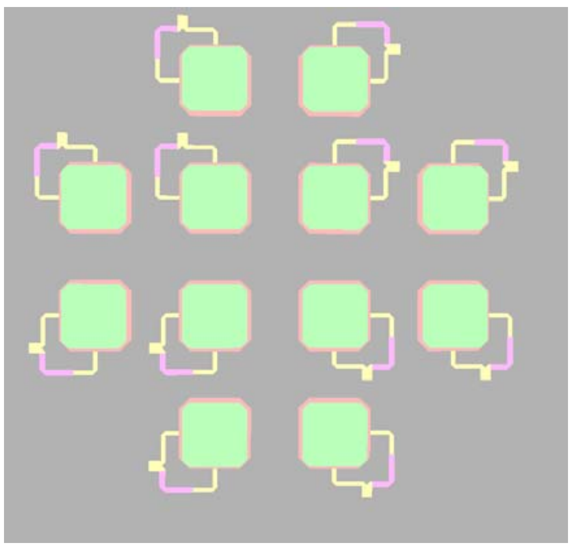
- Design optimized for robustness
  - ground plane + dielectric + radiating patch
  - dual feeding point structure (good circular polarization)
  - reactive splitter-fed structure to obtain two ports with a phase shift of 90°
  - only one radiating patch (no stacked patches) in order to simplify manufacturing

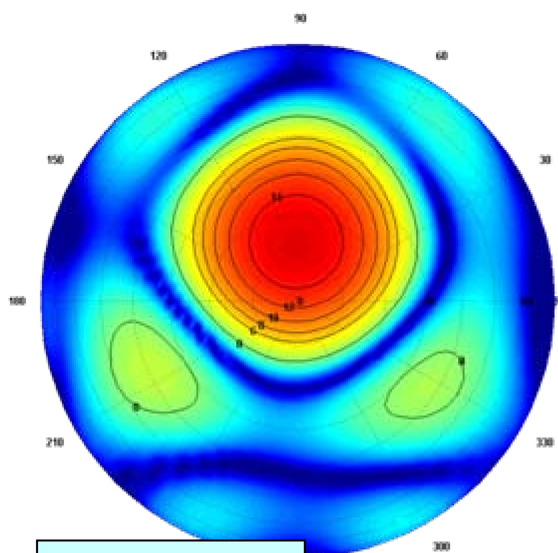


Dimensions: 75 x 75 x 3 mm

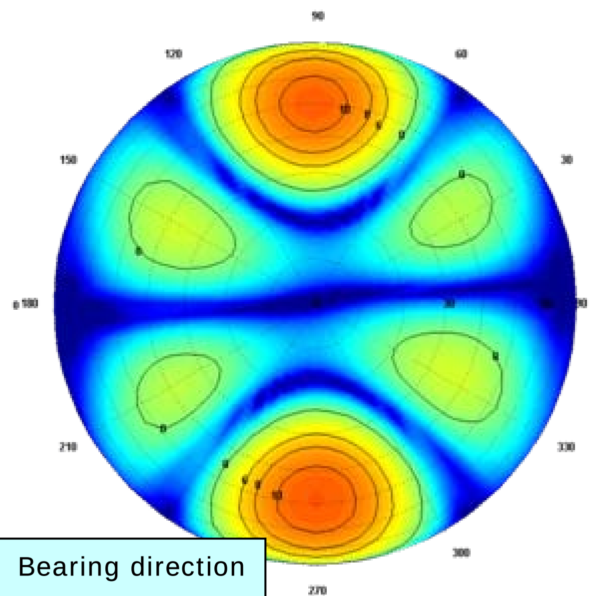
STEERABLE PATCH ARRAY DESIGN (1)

- A 12-element configuration selected
  - small number of elements with small reduction in radiation performance
  - 4 identical sub-panels: sequential rotation of step 90° is applied to antenna elements (3 by 3), to reduce the pattern of the cross polar component
  - System works on the basis of implicit or explicit DOA (direction of arrival) knowledge
    - phase of the excitations of the 12 elements can be varied to steer the antenna beam





Bearing direction
Phi 90° Theta 15°



Bearing direction
Phi 90° Theta 70°

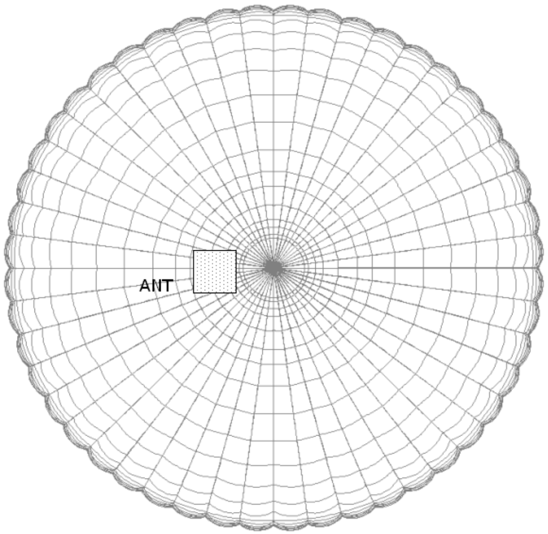
STEERABLE PATCH ARRAY DESIGN (2)

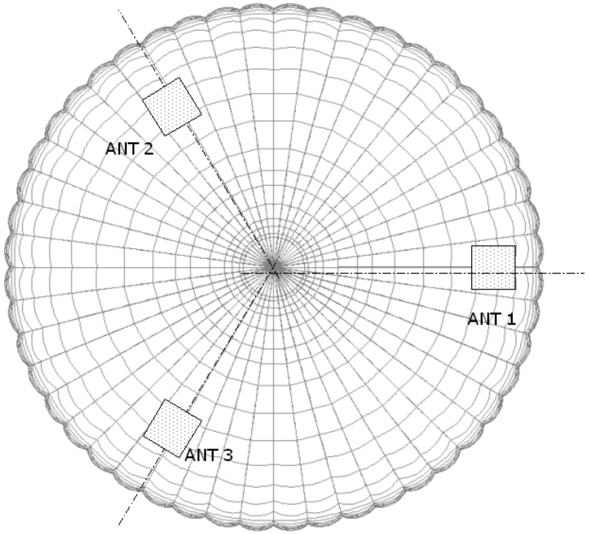
- Retro-directive technique
  - array automatically transmits in the direction of the source by re-transmitting the phase conjugate of the received signal
  - no need for phase shifters and no explicit DOA evaluation

- Three types of retro-directive arrays
  - Frequency division: transmitted and received signals operating at different frequencies
    - Drawbacks: blocking of the receiver, difficulty to control unwanted phase shift for each radiating element
  - Time division: both signals at the same frequency using a time division technique
    - Advantage: allows for a self phase calibration of the antenna
    - Drawback: same frequency for transmitting and receiving signals at the orbiter
  - Hybrid technique: signals operating at different frequencies + time division

ANTENNA CONFIGURATIONS

- 2 integrated parachute-antenna configurations
  - one single patch array antenna located on the top of the canopy, near the vent
    - not symmetric (central part of the canopy is occupied by the vent) ⇒ canopy shape almost flat in region closest to the vent
    - Directivity very good at boresight, decreasing sharply for probe aspect angles > 70º
  - one antenna with three patch arrays located in the lower part of the canopy, that work in diversity mode
    - symmetric
    - angle between the normal of the antenna and the parachute axis around 45º
    - only one array transmits at a given time
    - for mission scenarios where the antenna will need to cover the full range of aspect angles





MATERIALS AND PROCESSES (1)

- Research conducted to identify best materials for dielectric and ground plane and radiating patches
  - Requirements for dielectric
    - required permittivity constant
    - low density
    - proper range of operational temperature
    - flexibility
  - Use of textile materials for dielectric discarded due to
    - very high number of layers required (more than 2000 for Nylon 6-6)
    - difficulty to avoid air cavities during the sewing process
  - High-frequency circuit material RO6002 selected
  - Conductive fabrics also investigated for ground plane and radiating patches, but reference design based on Printed Circuit Board (PCB)

- Mass budget
  - 12 radiating elements: ~600 g
  - Common unit electronic devices, cabling: ~400 g

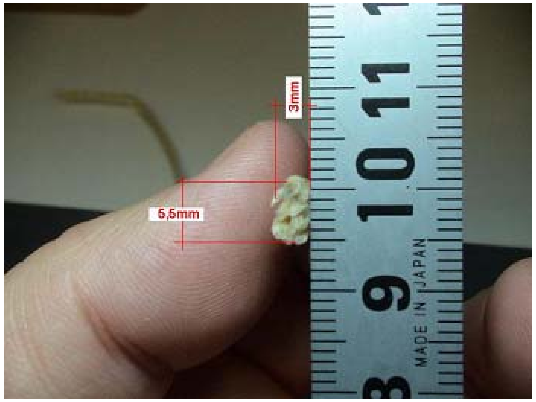
MATERIALS AND PROCESSES (2)

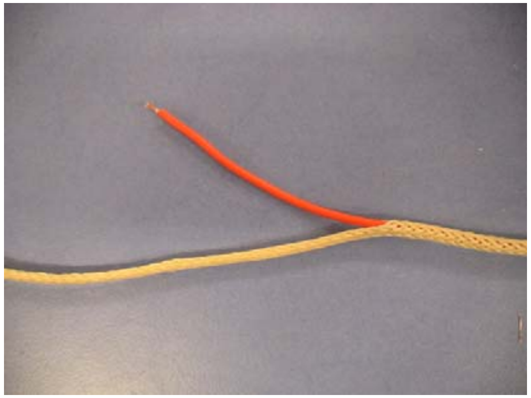
- Single array substrate (easier integration) or separated dielectric pieces for each radiating element sewed to the fabrics

- One pocket to cover and protect the antenna and avoid entanglement during the parachute extraction sequence

- Connection between probe and antenna located on the canopy through cables for signal, control and power
  - Signal is transmitted in base-band to reduce RF losses
  - Cables routed through parachute suspension lines

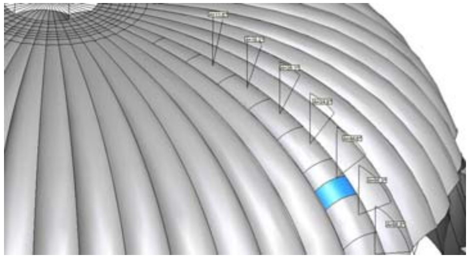
- Integrated parachute-antenna packing
  - similar process to conventional parachutes
  - extraction angle determined by position of antenna



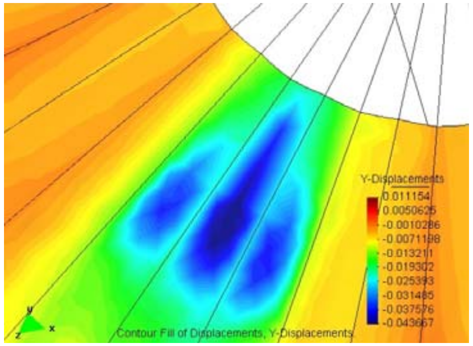


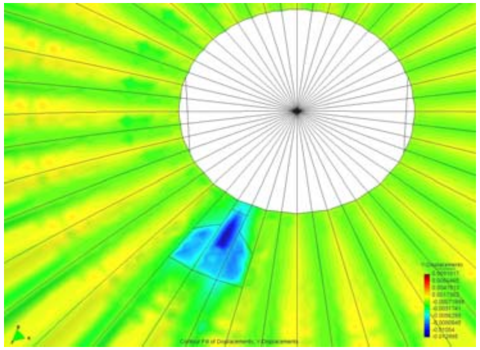
AERODYNAMIC ANALYSIS

- Disk-gap-band parachute

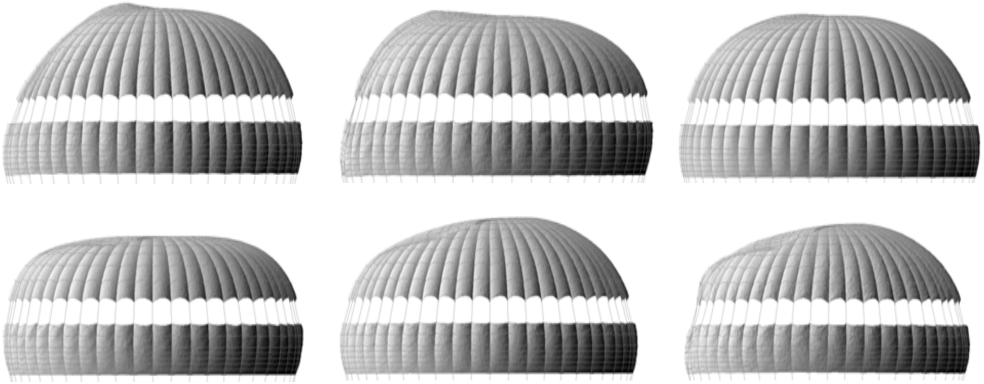


- Antenna local load per surface unit compared to aerodynamic load on parachute determines deformations in steady-state descent
  - aerodynamic load depends on mission (parachute size, probe mass) and planet (gravity, density)
  - preferred locations for the antenna on the canopy
  - reinforcement tapes on the canopy reduce the concavity



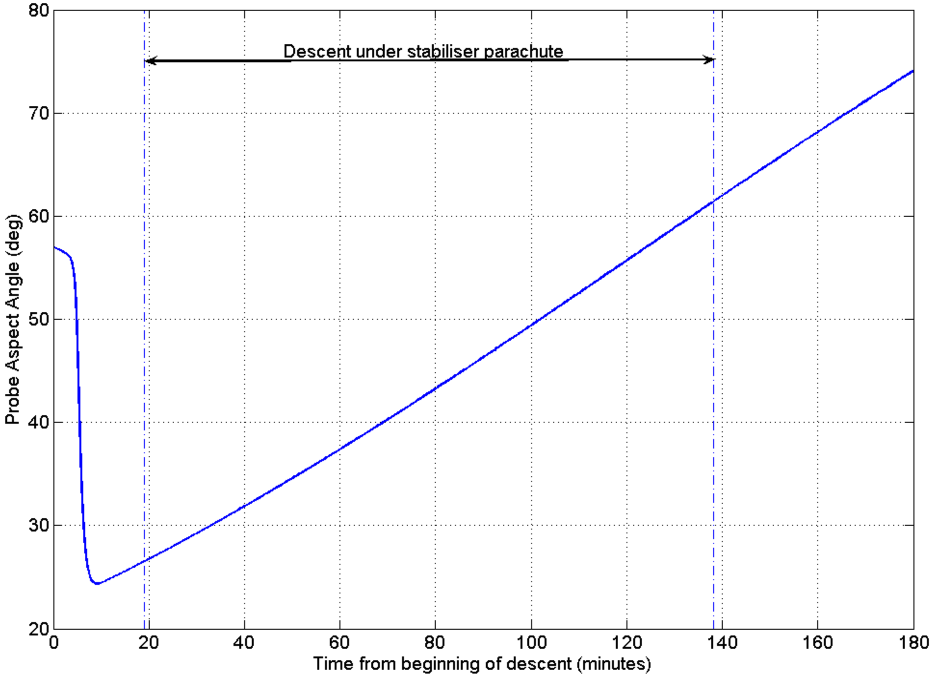


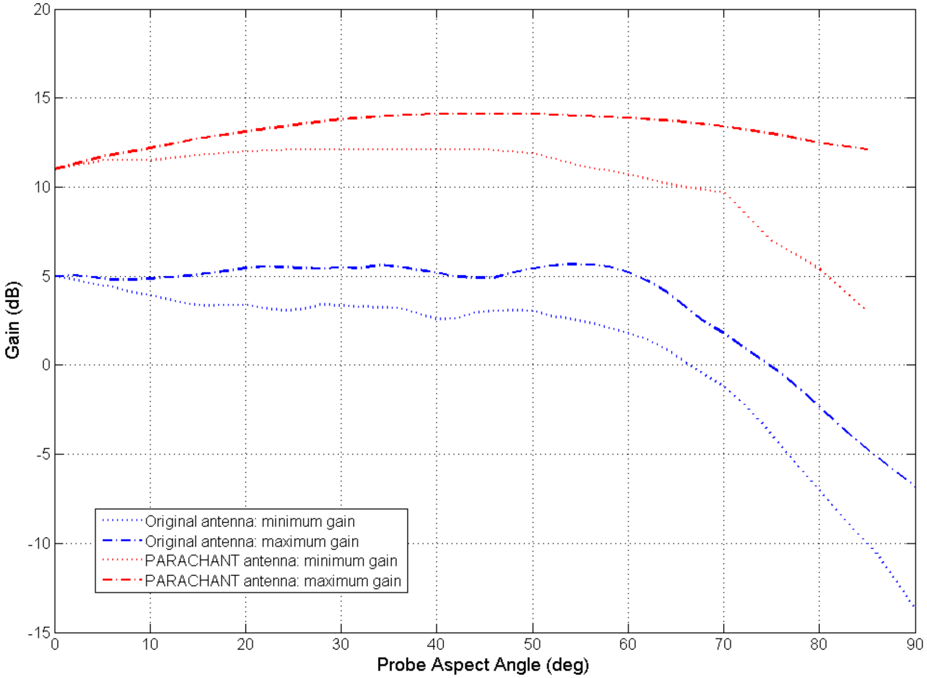
- Dynamic analysis to determine frequency and modes of oscillation



RF LINK PERFORMANCE (1)

- Probe-orbiter link performance with new integrated parachute-antenna design was analyzed for a Huygens mission scenario
  - Atmospheric descent lasted for some 140 min
    - Range varied between 60000 - 70000 km
    - Probe aspect angle varied between 20 and 70 deg
  - All original link parameters (transmitter RF power, receiver, etc.) were kept constant except for the updated antenna gain



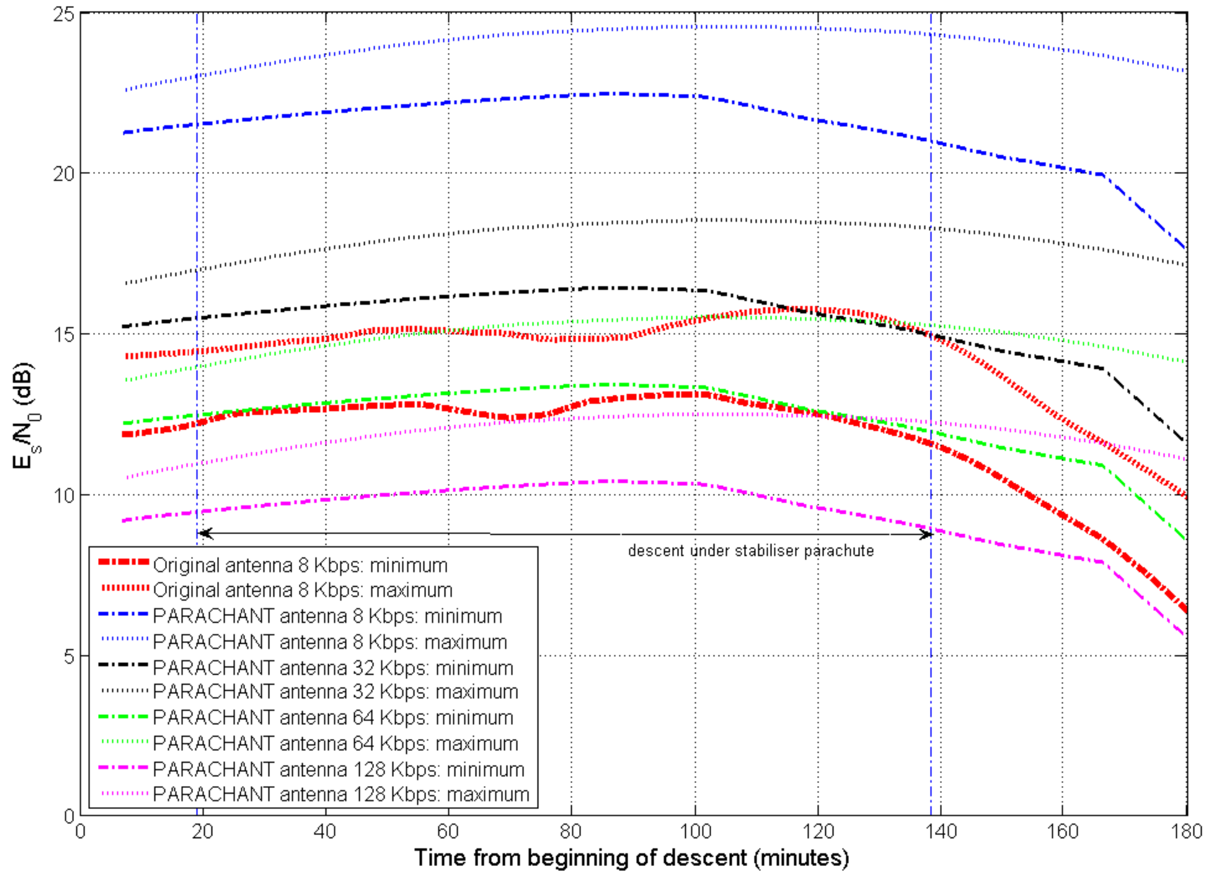


RF LINK PERFORMANCE (2)

- Data bit rate varied to assess link performance
  - Original data bit rate used by Huygens was 8 Kbps

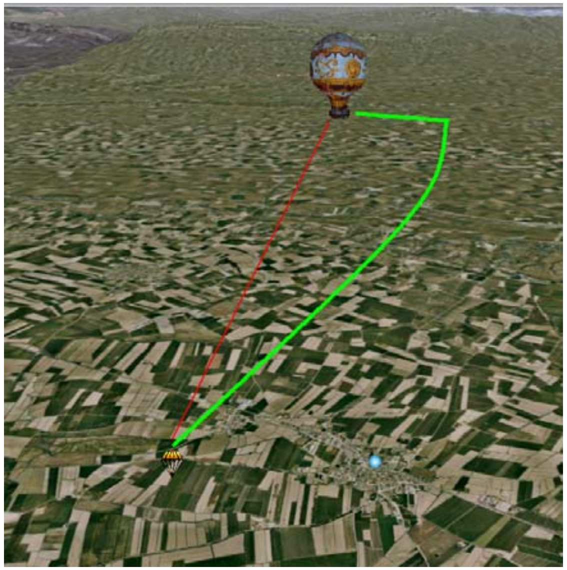
- New antenna would allow for **64 Kbps** ⇒ increase in data volume returned
  - More and higher resolution images

- Increase in scientific return to be traded-off with impact at system level
  - Mass increase
  - Another antenna will be needed in the probe



PROTOTYPE AND TESTING (1)

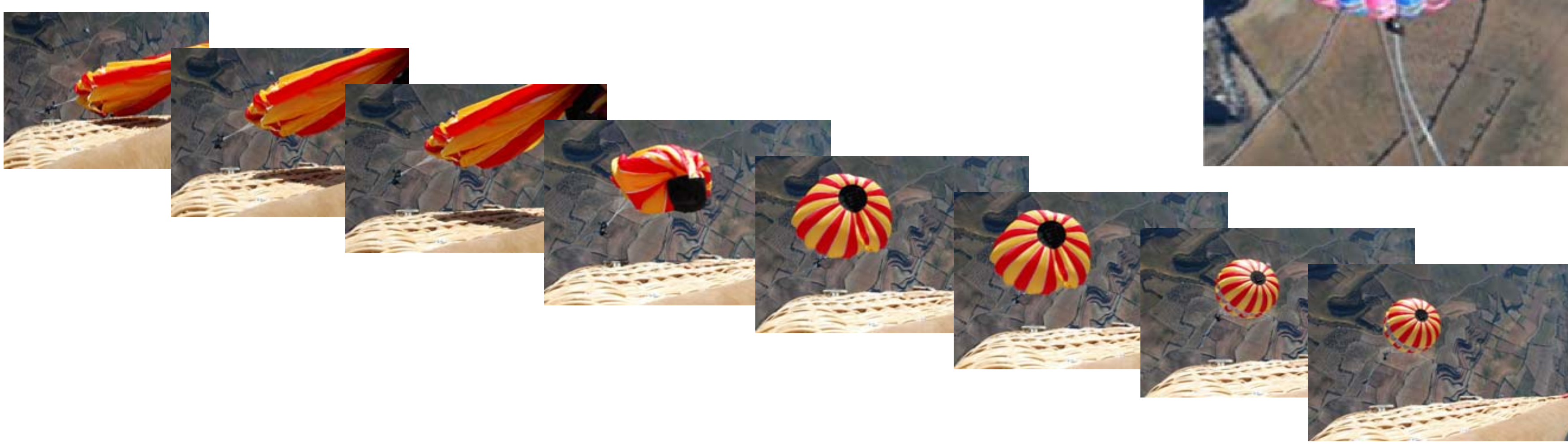
- A **prototype** of the integrated parachute-antenna will be implemented and tested in-flight
- Objective: proof the feasibility of the concept
  - verify manufacturing and integration methods
  - test integrated parachute-antenna aerodynamic behavior
  - test antenna performances during a real descent
- Test concept: drop the parachute from a balloon at 2 km altitude
  - prototype size and configuration determined by constraints imposed by test procedure (parachute size, max. payload mass, geometry, etc.)
  - tests not representative of real mission scenarios



PROTOTYPE AND TESTING (2)

- 2 parachute prototypes already built and dropped from a balloon with 2 dummy antennas (same properties as planned antenna prototype)

- Tests were successful $\Rightarrow$ conditions for antenna test (relative geometry, oscillations, etc.) as planned



CONCLUSIONS

- Integrated parachute-antenna concept investigated
  - Design proposed for a retro-directive patch array (S-band) located on top of the canopy
  - Easily customizable as a function of the mission
  - Prototype being built and tested for proof of concept

- Significant increase in gain wrt conventional antennas for entry probes allows for a increase of bit rate performance
  - potential increase in scientific return

- Improved link performance to be traded-off at system level
  - A bi-directional link is required with the orbiter
  - Increased mass and complexity

- Promising application to **balloons**
  - Scientific missions, high volume of data return, constantly changing link geometry
  - Antenna on top of balloon, similar implementation processes

Thank you

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