PARACHANT EXECUTIVE SUMMARY

PARACHANT

Internal Code:	21288/08
Version:	1.0
Date:	22-12-2008

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1. INTRODUCTION

Integrating antenna elements into the parachutes of planetary entry probes may provide benefits at system level. These probes normally use low gain antennas located in the back shell for communicating with an orbiting relay spacecraft during the descent trough the atmosphere. The mass and surface available for these antennas on the probe is typically limited. The integration of parts of the antenna on the additional surface provided by the parachute may allow for a higher gain or a reduced total mass compared to conventional solutions.

1.1. PURPOSE

This study investigates this concept and assesses the potential benefits and or new applications that may be derived. First, the different mission scenarios of interest are analysed. Then, several integrated parachute-antenna designs are discussed. Finally, the performances and implementation aspects of the preferred solution are presented.

1.2. SCOPE

The canopy of the parachutes of planetary entry probes may be used to integrate elements of the antennas in charge of the communications with the orbiter spacecraft during the descent. The additional surface provided by the parachute may allow the implementation of higher gain antennas compared to more conventional solutions where the antenna is installed on the lander. For missions where the acquired scientific data needs to be transmitted during the descent through the atmosphere, the higher gain could maximize the scientific return of the mission. In this paper, designs for a steerable S-band patch array antenna located on the canopy of a disk-gap-band parachute are presented. A retrodirective technique is used to point the antenna beam in the direction of the orbiter. The design concept is flexible and can be adapted to different mission requirements and constraints (frequency band, etc.). Different configurations are analysed in terms of the antenna performance, the aerodynamics of the parachute, the link budget, and the impact on the mission at system level. A system prototype is being built and will be dropped from a balloon for testing. Finally, recommendations on the developments required for this technology as well as on its potential applications are provided, including the analysis of the possible use of these antennas for planetary exploration balloons.

1.3. ACRONYMS

The following acronyms are used in the document and have been identified as necessary to be described:

Acronym	Definition
GPS	Global Positioning System
LHCP	Left Hand Circular Polarization
PARACHANT	Parachute-Antenna
PCB	Printed Circuit Board
RF	Radio Frequency
RHCP	Right Hand Circular Polarization
Rx	Receiving
SMA	SubMiniature version A
Tx	Transmitting
UTC	Universal Time Coordinated
Wrt	with respect to

2. REFERENCES

2.1. APPLICABLE DOCUMENTS

The following documents, of the exact issue shown, form part of this document to the extent specified herein. Applicable documents are those referenced in the Contract or approved by the Approval Authority. They are referenced in this document in the form [AD.X]:

Ref.	Title	Code	Ver.	Date
[AD. 1]	ESA's SOW AO/1-5071/06/NL/HE Antenna Elements Integrated into the Parachutes of Future Landers and Entry Probes.	TEC-EEA/2005.339	Issue: 4	07-03-2006
[AD. 2]	GMV'S proposal to ESA/ESTEC for "Antenna Elements Integrated into the Parachutes of Future Landers and Entry Probes"	GMVSA 1183/06		24-07-2006

Table 2-1- Applicable Documents

2.2. REFERENCE DOCUMENTS

The following documents, although not part of this document, amplify or clarify its contents. Reference documents are those not applicable and referenced within this document. They are referenced in this document in the form [RD.X]:

Ref.	Title	Code	Ver.	Date
[RD. 1]	PARACHANT: "Mission Scenario Review and Integrated Parachute-Antenna Solution Identification"	GMV-PARACHANT-TN1	2.0	08-03-2007
[RD. 2]	PARACHANT: "Parachute-Antenna Requirements Document"	GMV-PARACHANT-TN2	2.0	08-03-2007
[RD. 3]	PARACHANT: "Preliminary Parachute-Antenna Design and RF Link Performances"	GMV-PARACHANT-TN3	1.0	02-07-2007
[RD. 4]	PARACHANT: "PARACHANT Materials and Processes"	GMV-PARACHANT-TN4	Draft	05-12-2007
[RD. 5]	PARACHANT: "PARACHANT Antenna Design and Analysis"	GMV-PARACHANT-TN5	1.0	25-01-2008

Table 2-2- Reference Documents

3. MISSION SCENARIOS AND SYSTEM LEVEL CONSIDERATIONS

Planetary entry probes have already been sent to Venus, Mars, Jupiter and Titan. The interest in this type of missions keeps growing, and plans for new entry probes to these bodies and others, like Neptune, continuously appear. All these missions have used one or more parachutes as the main aerodynamic decelerator. The number, type and size of parachutes used and the duration and characteristics of the descent, however, depend strongly on the atmosphere of the given planet or moon. In this sense, a first classification may be already done distinguishing Mars, which has a very thin atmosphere, from the rest of bodies, which have denser atmospheres. Martian entry probes can only open their large parachutes relatively close to the ground (at altitudes around 8 or 10 km), so the descent under the parachute lasts no more than a few minutes. In the case of Venus, Jupiter, and Titan, parachutes do not need to be as large, and the descent lasts much longer (up to 2 hours for Huygens).

The communications during the descent through the atmosphere can be achieved in two different ways: direct to Earth (DTE), or through a relay spacecraft. DTE is the only possible link when there is no spacecraft that can be used as relay (like for the NASA Mars Pathfinder mission, in 1997). The weakness of the signal limits very much the amount of data that can be transmitted. Therefore, the most widely used option is to communicate through a relay spacecraft.

The contents and volume of information that needs to be transmitted during the descent depends also on the planet or moon. For Mars entry, descent and landing (EDL) missions, the amount of data transmitted is relatively small, because it consists mainly on engineering data on how the different EDL events are performed, with no or very limited science data. Conversely, for the rest of bodies considered, the main scientific return of the mission is normally achieved during the passage through the atmosphere (either because there is no landing, like in the case of the Galileo Jupiter Entry Probe, or due to the short expected lifetime on the surface of the planet, like for Venus or Huygens on the surface of Titan). Hence, all the data collected during the descent (images of the surface, atmospheric properties, and engineering data) must be transmitted right away to the Earth or to a relay satellite overhead. For these missions, the communications link performance has a strong effect on the scientific return of the mission. Clearly, the highest the data rate, the better. An antenna integrated within the parachute may have a higher gain than the antenna mounted in the probe, and thus provide important benefits at system level. Table 3-1 lists the main characteristics of the EDL communications for two examples of this type of missions.

Communications		Galileo Entry Probe	Huygens
Direct to Earth Communications		No	No
Probe-Orbiter communications	Relay Satellite	Galileo	Cassini
	Range of distances	[217500:234000] km	[30000:80000] km
	Range of PAA	[2:15] deg	[20:65] deg
	Visibility interval	~ 60 min	~ 140 min
	Tx Antenna Type	2 channels and one crossed-dipole antenna	2 redundant transmitters and antennas
	TX Antenna Gain	9.6 dBi Half Power Beam = 56 deg	+5dBi, +3dbi
	Tx Power		40.7 dBm (11.7 W)
	Frequency	L-Band (1387.0 and 1387.1MHz)	2040 and 2098 MHz
	Polarization	LCP and RCP	LCP and RCP
	Bit Rate	256 bps (128 bps per channel)	8 Kbps
	Performance	-132 dBm	Minimum end-to-end frame error rate of 10^{-5}
	Modulation	100% Phase modulated (up to 512 phase transitions per second)	Index 1.34 rad
	RX Antenna Gain	20.8 dBi Half Power Beam = 12.6 deg	34.7 dBi, 35.3 dBi
	RX System Temperature		230 K, 256 K

Table 3-1: Summary of the characteristics of the RF communications link during the EDL for the Galileo Entry Probe and Huygens.

4. INTEGRATED PARACHUTE-ANTENNA CONCEPT

Several potential passive and active antenna concepts for integration with a parachute were preliminarily analysed in the first stage of the project. These antennas are supported by either the surface of the canopy of the parachute or the suspension lines. The antenna performance requirements are based on the analysis of the mission scenarios and the system level considerations. Considering that the requirements for a lander-orbiter link can greatly vary depending on the mission, the following general requirements were assumed:

- a significant increase in gain wrt conventional antennas located on the probe is to be achieved
- need to cover a wide angle sector. Complete azimuth range (0:360 deg), with azimuthally symmetric pattern. Probe aspect angle up to 70 deg.
- both UHF and S-band solutions seem in principle suited to satisfy the range of requirements at performance level

Table 4-1 summarizes the analysis performed for the different integrated parachute-antenna concepts identified (two of these concepts are illustrated in Figure 4-1).

Antenna concept	Description	Advantages	Disadvantages
Patch array	Patch array with different configurations and number of elements located on top of the canopy	- Large surface available - Azimuth symmetric patterns - Fixed or steerable beam - Flexible design	-Feeding: battery on the canopy
Microstrip constrained lens	Microstrip constrained lens with feeder and lens integrated in the parachute canopy.		-Efficiency problems in power supply (spillover) -Design complexity
Horn supported by parachute wires	A horn antenna integrated into a fabric that can be hooked up to the parachute suspending wires. A field launcher could be directly located on the probe, radiating in the horn.	- A horn antenna usually provides a high/medium gain pattern pointed at boresight	-Difficulties to obtain a shaped pattern without the maximum directed towards the boresight -Design complexity
Dual-mode "conical helix"	Cylindrical or conical helix antenna integrated into a fabric that can be hooked up to the parachute suspending wires. The helix is provided by 4 RF terminals located at its base.	- Using a suitable switch at feeding level, antenna can provide boresight or mode delta beams - Azimuth symmetric patterns - Radiating elements close to transmitter (low cable losses)	-Medium/low directivity gains -Directivity gain strongly depends on the ground plane (a small surface is not suitable) -Not suitable for steerable beam
Conical vertical array of printed antennas		- Medium gain pattern with a circular polarization, pointed at bore-sight - Azimuth symmetric patterns - Radiating elements close to transmitter	- Low/medium gain linear polarization pattern with a null at broadside -Not suitable for steerable beam

Table 4-1. Summary of the integrated parachute-antenna concepts investigated.

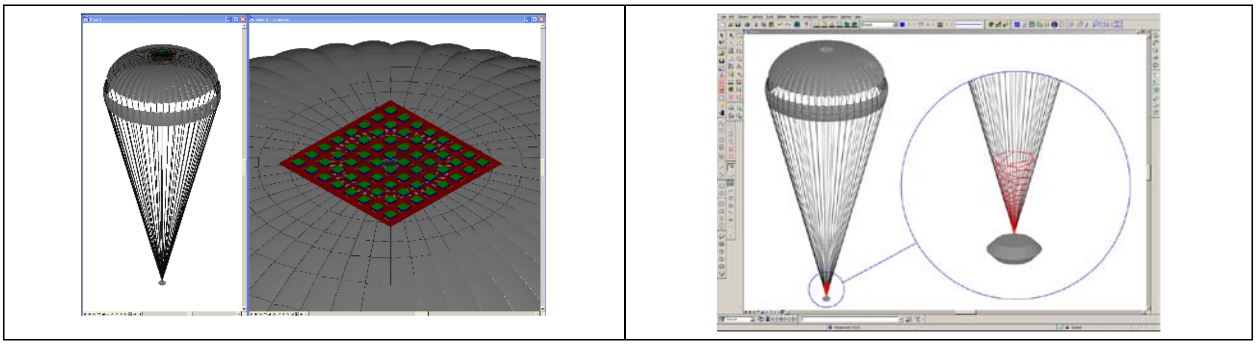


Figure 4-1: Two of the proposed integrated parachute-antenna concepts.

5. INTEGRATED PARACHUTE-ANTENNA DESIGN AND ANALYSIS

5.1. STEERABLE PATCH ARRAY DESIGN

5.1.1. RADIATING ELEMENT

The radiating element of the patch array was designed considering the requirements on:

- operating frequency: S-band, with a central frequency of 2010 MHz
- operating frequency bandwidth: about 20 - 40 MHz
- polarization: circular
- radiating element return loss: -15 dB on the operating frequency range;
- total transversal dimension of the single element: lower than the maximum inter-element distance for the steerable array

The key points of the radiating element design are:

1) selection of a dual feeding point structure to obtain a good circular polarization

2) selection of a reactive splitter-fed structure to obtain two ports with a phase shift of 90° using a simple technology

3) only one radiating patch (no stacked patches) in order to simplify manufacturing. Figure 5-1: shows the layout of the single radiating element. Electromagnetic analyses and optimizations were performed assuming an ideal ground plane (see also Figure 5-1). The robustness of the element design was verified through sensitivity analyses where the characteristics of the dielectric were varied.

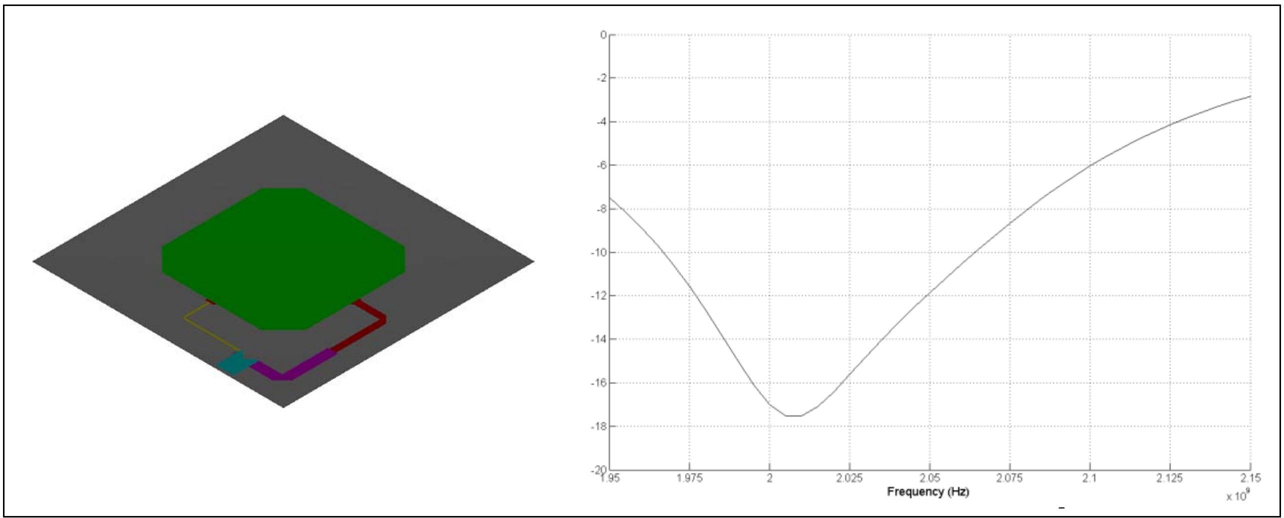


Figure 5-1: Model of the single radiating element (left). Return loss (dB) of a single radiating element.

5.1.2. STEERABLE PATCH ARRAY

As result of the trade off performed, a 12-element configuration with layout as shown in Figure 5-2 was selected. This choice was based on the fact that this design presents a small number of elements with a small reduction in radiation performance. In order to reduce the pattern of the cross polar component a sequential rotation of step 90° is applied to antenna elements (3 by 3). The result is an antenna ideally composed by 4 identical sub-panels. This array configuration can provide a radiation pattern steerable both in azimuth and theta angles with a Directive Gain better than about 12 dBi. The system works on the basis of implicit or explicit DOA (direction of arrival) knowledge: once an evaluation has been made of the azimuth and theta angles between the parachute and the orbiter, the phase of the excitations of the 12 single elements can be varied to steer the antenna beam. Figure 5-3 shows the directivity gain of the patch array antenna for different antenna bearing directions (assuming a local ground plane for each radiating element).

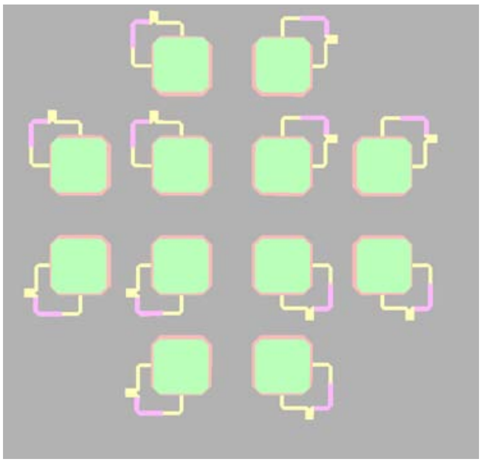


Figure 5-2: 12-elements patch array with square grid operating in S band.

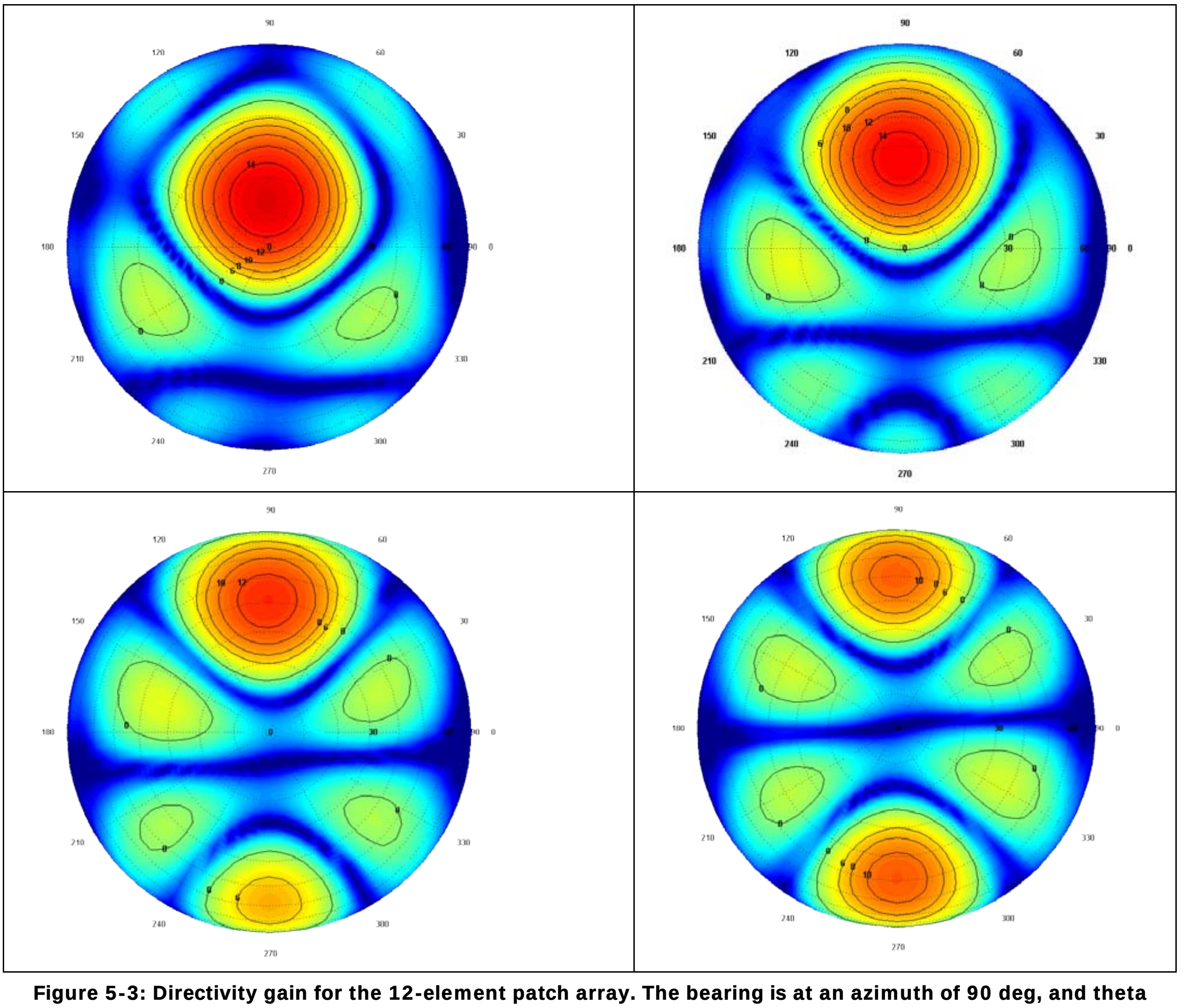


Figure 5-3: Directivity gain for the 12-element patch array. The bearing is at an azimuth of 90 deg, and theta varying: 15 deg, 30 deg, 50 deg, 70 deg.

5.1.3. RETRO-DIRECTIVE ARRAY

The retro-directive array is a system that automatically transmits in the direction of the source radiator by re-transmitting the phase conjugate of the received signal at each element of the array. This system is able to automatically track the communicating platforms and to transmit a directive return signal without the use of phase shifters and no explicit DOA evaluation.

Three different types of retro-directive architectures are possible. The first type is characterized by transmitted and received signals operating at different frequencies (frequency division technique); in the second type, both signals are at the same frequency and a time division technique is used; in the third one (hybrid technique), transmitted and received signals are at different frequencies and, in addition, a time division technique is used.

The frequency division technique has several drawbacks. The most important is related to the difficulty to control the unwanted phase shift caused by the whole electronic chain for each radiating element. Besides, the simultaneous transmitting and receiving operations can involve the desentisization and blocking of the receiver. These problems are not present if a time division technique is used. Besides, the time division technique has the advantage of allowing for a self phase calibration of the antenna: a calibration period could be foreseen at regular intervals where the system would work simultaneously in transmitting and receiving modes with the receiving chain disconnected from the antenna, so that the phase contributions of the whole path (transmitting and receiving chain) could be measured. This would clearly increase the robustness of the system. The main downside of the time division technique is related to the use of the same frequency for transmitting and receiving signals can produce some difficulties for the system at orbiter level, which has to continuously transmit and receive. A possible solution is to implement a hybrid technique, where the transmitting and receiving signals are at differently frequencies.

5.2. ANTENNA CONFIGURATIONS

Two baseline integrated parachute-antenna configurations were selected:

- one single patch array antenna located on the top of the canopy, near the vent
- one antenna with three patch arrays located with radial symmetry in the lower part of the canopy, that work in diversity mode

Figure 5-4 illustrates the two configurations. The two solutions have been selected considering key aspects such as: geometry, materials, mass, performance, implementation, aerodynamic behaviour and system level considerations.

The configuration with a single patch array is not symmetric, since the central part of the canopy is occupied in most cases of interest by the vent of the parachute (which provides stability). However, this is not so important since the shape of the canopy is almost flat in the region closest to the vent. The directivity is very good at boresight, but it decreases sharply for probe aspect angles greater than 70 deg.

For mission scenarios where the antenna will need to cover the full range of aspect angles (from the horizon to the boresight), the configuration with three patch arrays provide better performances. The three arrays are located on a circumference of the surface of the parachute every 120°, forming an angle between the normal of the antenna and the parachute axis of about 45°. They will operate in “diversity mode”, that is, only one array will transmit at a given time. A central unit will select the transmitting array at every instant. Several selection criteria are possible; the simplest one is to use the amplitude of the received signal (for instance, the amplitude of the incoming signal received by one of the central elements of each array can be compared). The configuration with three patch arrays has the main drawback of an increased mass and complexity.

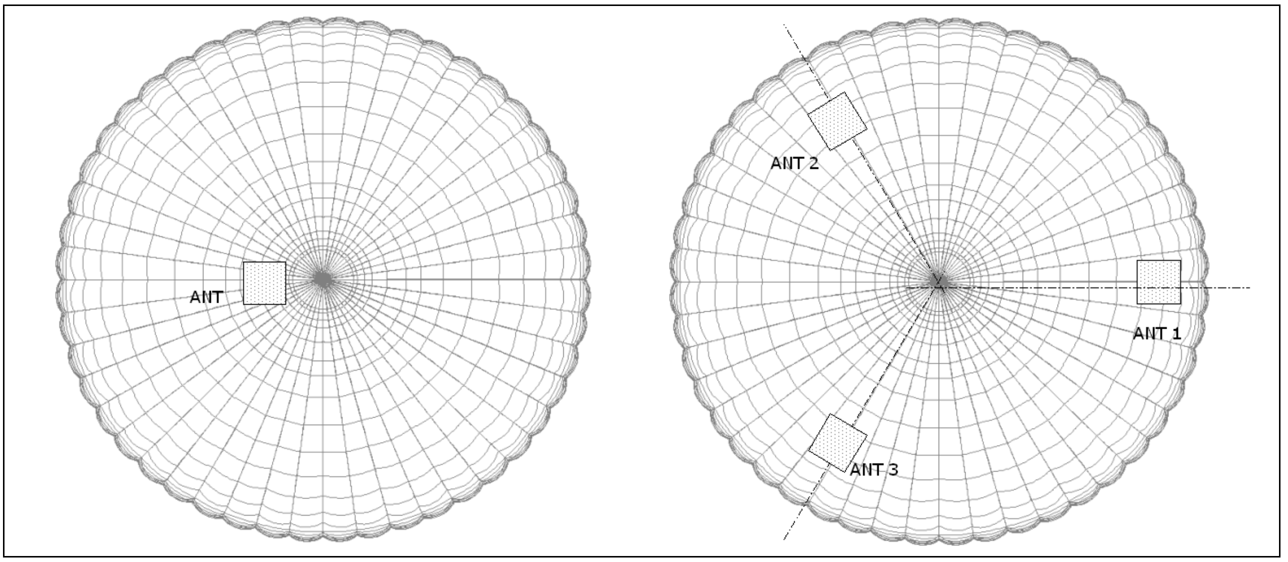


Figure 5-4: Two baseline integrated parachute-antenna configurations: one single patch antenna located on the top of the canopy (left), and three patch arrays located with radial symmetry in the lower part of the canopy (right).

5.3. MATERIALS AND PROCESSES

5.3.1. ANTENNA MATERIALS

Extensive research was conducted to identify the best material for acting as dielectric. The main requirements for the selection of the dielectric material are: 1) permittivity constant (ε) = 2.2, 2) low density, 3) proper range of operational temperature, 4) flexibility (a rigid material will complicate the integration with the parachute). The first option was to use textile materials. However, it was discarded due to the low values of the thickness of the fabric (<0.1mm for Nylon 6-6, a common fabrics for the canopy of parachutes) and to the difficulty to avoid air cavities during the sewing process of a high number of layers, which would lead to an important decrease of the permittivity constant. For instance, in case of Nylon fabric (permittivity constant of 4-5), 2000 layers should be joined together in order to get a 2 cm thickness dielectric. Consequently, the dielectric material selection was directed towards soft plastics (like resin polymer) and epoxy (like gel). Finally, RT/duroid 6002 (from Rogers Corporation) was identified as the most suitable candidate material for the dielectric.

Conductive fabrics were investigated for manufacturing the ground plane and the radiating patches. Although some of the solutions were promising, the reference design is based on the use of Printed Circuit Board (PCB) technology.

5.3.2. ANTENNA INTEGRATION

The antenna elements must be covered and protected against friction during the parachute extraction sequence. Therefore, mechanical integrity during packing and deployment must be ensured. Individual pockets per antenna element could be a solution, but since the inter-element distance is very low (less than 1 cm gap distance between 2 adjacent elements), the implementation of individual adjacent pockets is not feasible due to sewing difficulties. Consequently, one main pocket covering the 12 elements antenna is baselined. It will shield the antenna and avoid entanglement with the rest of the fabrics and lines. The pocket material could also be Nylon type 6.6 fabrics.

In order to minimize the shape distortion on the canopy due to the antenna, additional reinforcement tapes can be added. These reinforcement tapes (Kevlar 49 or Vectran HS type 97) protect also the canopy fabric from too high stress bypassing the forces to other structural parts (radial structure).

5.3.3. CABLING

Cables should be routed either through the parachute suspension lines (for connecting elements from the canopy down to the probe), or through reinforcement tapes for connecting antenna elements located in the canopy fabric. In the first case, the cabling configuration consists in a regular electrical twisted cable inserted as core in a braided suspension line. The relative thickness (electrical cable and suspension line) should be such to allow the insertion, as illustrated in Figure 5-5.

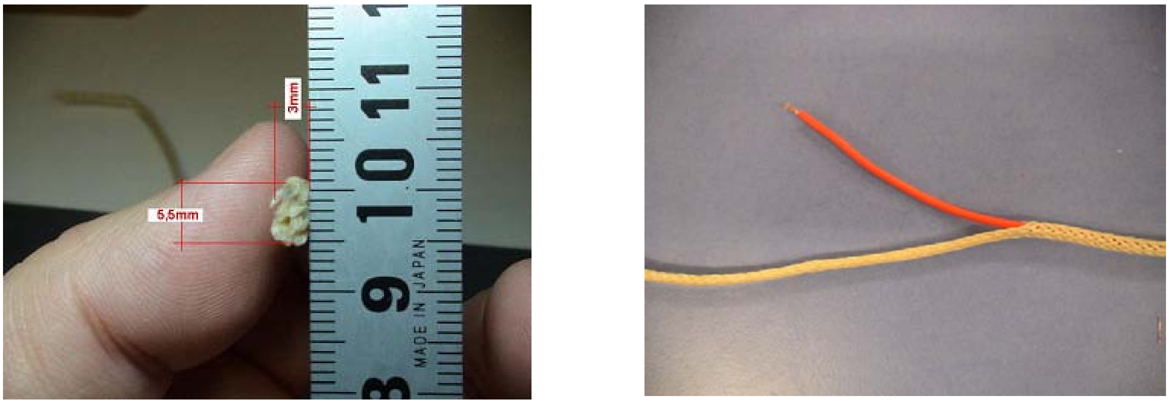


Figure 5-5: The thickness of the parachute suspension lines shall allow the insertion of a twisted cable.

5.3.4. INTEGRATED PARACHUTE-ANTENNA PACKING

The integrated parachute-antenna shall be packed in a limited volume inside the backshell of the probe. The packing process will be similar to a conventional round parachute, although the antenna location inside the container should be considered with care in order to avoid damages during the extraction. If the antenna is located close to the container wall, a narrow extraction angle will be required for a safe extraction. If the antenna elements are located on the centre of the container and closer to the extraction port, the angle range leading to the safe extraction area is wider.

5.4. AERODYNAMIC ANALYSIS

The impact on the parachute performance of the antenna elements located on the canopy was assessed from the structural, dynamic and aerodynamic points of view. For this analysis, a uniform mass distribution was assumed for the area occupied by the antenna on top of the canopy.

In terms of drag, the integrated antenna has a low effect, due to the fact that the antenna to parachute area ratio is low and the parachute projected area is not affected.

From the structural point of view, the antenna represents an extra static force acting down on the canopy surface, attempting to concave it. For minimizing the deformations in steady-state descent, the antenna local load per surface unit should be much lower than the aerodynamic load on the parachute, which itself depends on the mission (parachute size, probe mass) and on the planet (gravity, density). For some of the cases analysed in this paper this was not the case, so that deformations appeared around the location of the antenna (see Figure 5-6, left). One possible solution for reducing the concavity in these cases would be the installation of reinforcement tapes at different locations of the canopy, such as the border of the antenna (Figure 5-6, right).

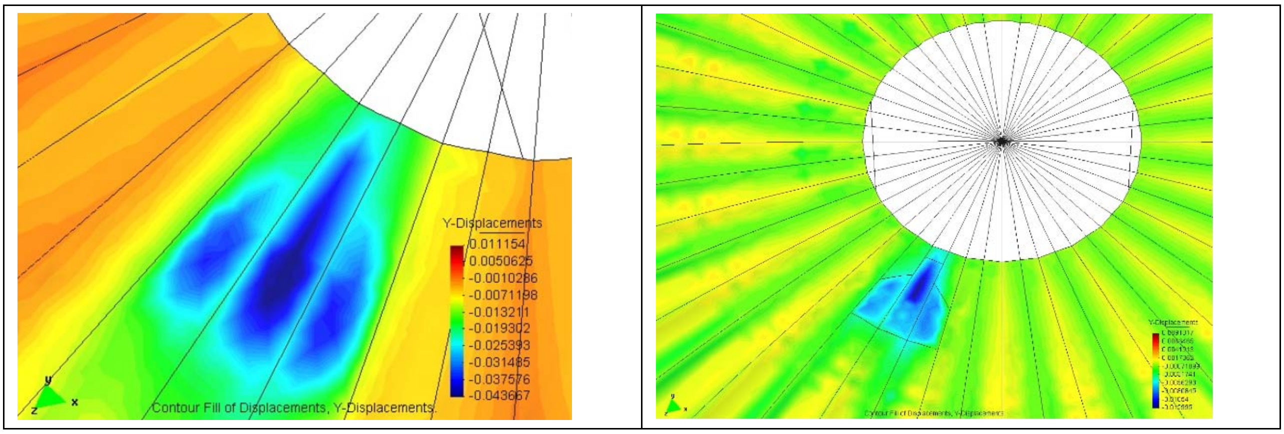


Figure 5-6: Deformations on the canopy of the parachute for a patch array antenna located close to the vent without (left) and with (right) reinforcement tapes.

Atmospheric disturbances encountered during the descent may produce oscillations of the parachute canopy and local deformations. In order to assess the dynamic behaviour of the parachute, a dynamic structural analysis of the integrated parachute antenna system was performed in order to evaluate frequency and modes of oscillations. For the analysis, the parachute is forced to inflate or deflate by adding an apparent mass of fluid with the corresponding atmospheric density, increasing or decreasing the pressure by 30% (see Figure 5-7). The frequencies and deformations obtained (although greater in some cases than for parachutes of similar size in the Earth) are acceptable.

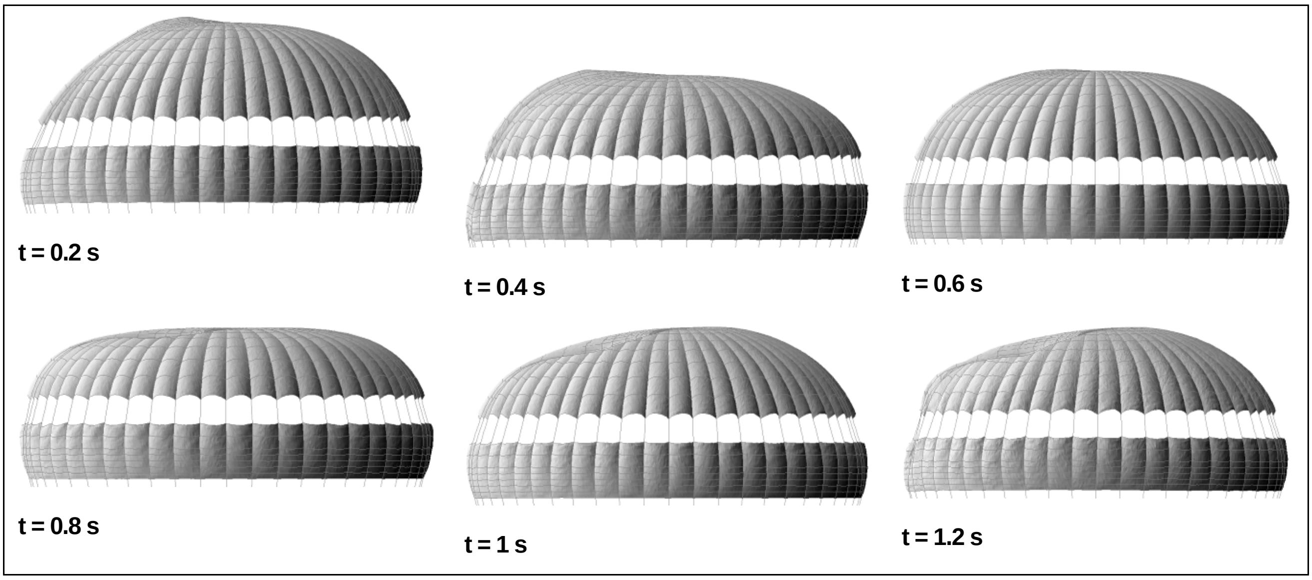


Figure 5-7: Dynamic structural analysis of the integrated parachute-antenna (Titan atmosphere).

The pendulum oscillations of the integrated parachute/antenna system were also considered. The amplitude (angle) and frequency of the oscillations with respect to the flight trajectory were computed. The extraction, deployment and inflation of the parachute system were not taken into consideration.

5.5. LINK PERFORMANCE

The performance of the RF-link between the probe and the orbiter with the new integrated parachute-antenna design was analysed for a reference scenario similar to the Huygens mission. The results obtained were compared to those obtained with the actual antennas onboard Huygens.

The nominal Huygens entry and descent trajectory was assumed. The evolution of the two most important variables for the link (Probe Aspect Angle and distance from probe to orbiter) is illustrated in Figure 5-8. Only the part of the trajectory corresponding to the descent under the stabiliser parachute is relevant, since the integrated parachute-antenna would only be active during that phase.

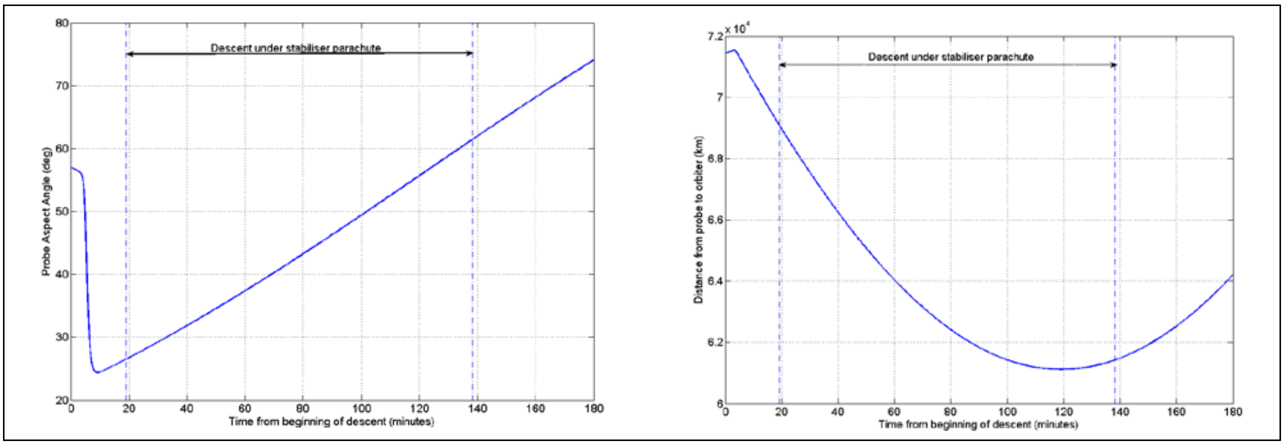


Figure 5-8: Evolution of the PAA (Probe Aspect Angle, left) and of the distance between the orbiter and the probe (right) for the nominal Huygens descent through the atmosphere of Titan.

All the original link parameters (transmitter RF power, receiver, etc.) were kept constant except for the updated antenna gain, which was computed from the directivity data by estimating the losses (mismatching, ohmic, dielectric, and phase errors). Figure 5-9 shows the gain of the novel configuration with 3 patch arrays compared to the gain of the original Huygens antennas as a function of the probe aspect angle. The gains also depend on the azimuth angle; the maximum and minimum values of the gain for the complete range of azimuths are presented.

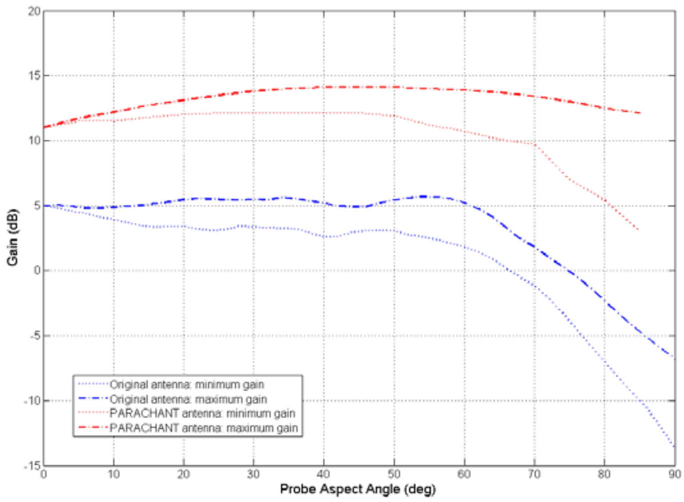


Figure 5-9: Integrated parachute-antenna (PARACHANT) gain with three patch arrays compared to the gain of the original Huygens channel A antenna.

The data bit rate has been varied to assess the link performance. The original data bit rate used by Huygens was 8192. With the new antenna, simulations have been run for a set of possible values of the data bit rate: 8 Kbps, 32 Kbps, 64 Kbps, and 128 Kbps. The results of these simulations, in terms of the evolution with time of the signal to noise ratio (measured through the energy per symbol to noise spectral density ratio) through the Huygens descent are shown in Figure 5-10. For the sake of comparison, the best and worst expected performance of the original link is also shown. The results show that a data bit rate of 64 Kbps would involve, with the new integrated parachute-antenna with 3 patch arrays, signal to noise ratios that are better, throughout all the descent, than those expected nominally for the Huygens mission. For a data rate of 128 Kbps, however, the signal to noise ratio would be close to the original, but lower.

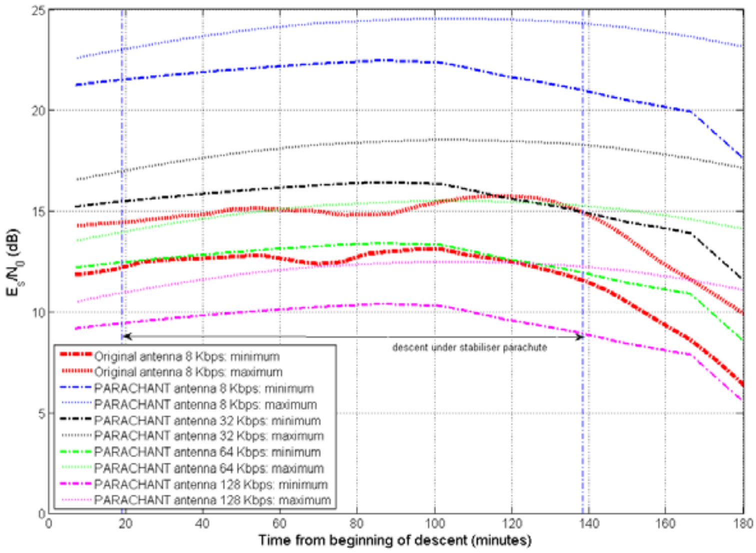


Figure 5-10: Evolution of the signal-to-noise ratio during the nominal Huygens descent for different data rates for the integrated parachute-antenna (PARACHANT) configuration with 3 patch arrays on top of the canopy. The maximum and minimum signal-to-noise ratio (corresponding to max. and min. gain per PAA) are shown.

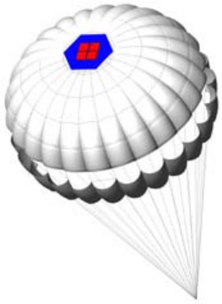
5.6. PROTOTYPE AND TESTING

A prototype of the integrated parachute-antenna was designed, implemented, and tested in-flight. The basic objective of the prototype manufacturing and testing was to proof the feasibility of the concept by: 1) verifying the proposed methods for the manufacturing of the antenna and its integration within the parachute, 2) testing the aerodynamic behaviour of a parachute with an antenna on the top, and 3) testing the performance of an antenna on top of a parachute during a real descent.

The concept of the test was to drop the parachute from a balloon at an altitude of 2000 m. The performance of the antenna was measured from a receiver on-board the balloon. GPS measurements taken from the parachute and the balloon were used to reconstruct the relative trajectory. The prototype was a simpler, reduced version of the reference design, since the prototype size and configuration were determined by the constraints imposed by the test procedure (size of the parachute, maximum payload mass, geometry, etc.).

An antenna prototype was designed by IDS specifically for the test flights: it consisted of an array composed of 4 radiating elements which transmitted a signal at 2001 MHz with a fixed radiation beam. Four sample prototypes of the antenna were manufactured using PCB technology and RO6002 as dielectric material: two were used for measurements purpose, and the other two for the test flights. The mass of each antenna prototype was 265.6 g, and its dimensions were 17 x 17 cm. Figure 5-11 shows the lookout of the antenna prototype.

The antennas were stitched on the canopy of the parachute prototypes, beside the apex vent. The battery was installed in a bag representative of the lander hooked at the parachute, with the routing of the connecting cables inside a suspending line. A calibrated receiving antenna was installed on the balloon, together with a portable spectrum analyser. GPS sensors and additional instruments (including altimeters, accelerometers and video cameras) were installed on the parachute, the payload and the balloon, in order to provide the data needed for reconstructing the trajectories of the parachute and the balloon, and derive the evolution of the relative link geometry during the tests. The parachutes were dropped from an approximate altitude of 4500 ft.



Apex vent radius (m)	0.10
Canopy disk radius (m)	1.00
Canopy gap (m)	0.11
Canopy skirt height (m)	0.26
Number of gores	24
Suspension lines length (m)	2.11
Parachute area (m^2)	4.72
Parachute projected area (m^2)	1.973
Parachute mass (kg)	0.33
Payload mass (kg)	5
Antenna mass (kg)	0.5

Table 5-1. Main characteristics of the PARACHANT prototype.

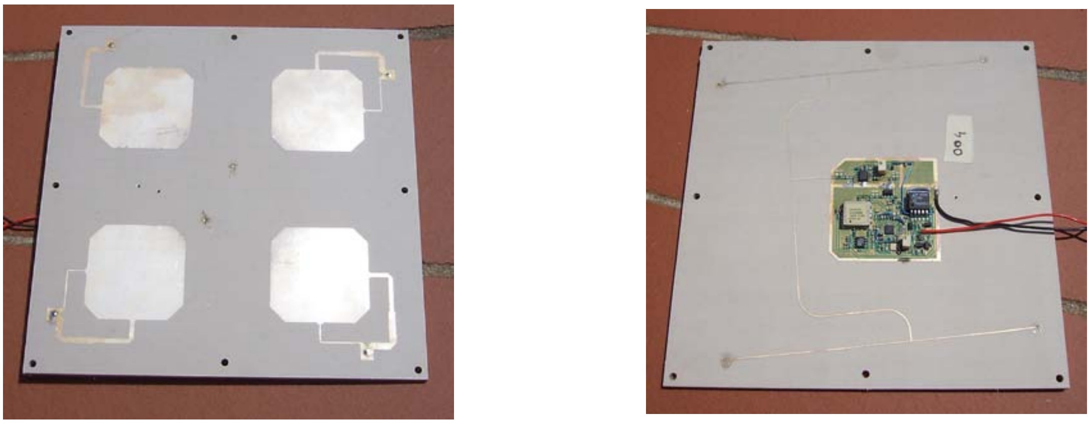


Figure 5-11. Top and bottom view of the antenna prototype.

Figure 5-12 shows the moment when one of the parachute prototypes was dropped from the balloon. The vertical velocity and the altitude were measured by the GPS. Other instruments recorded the total acceleration and the angular velocity, from which the frequency and the amplitude of the pendulum motion were derived. These data were processed in order to estimate the gain of the PARACHANT prototype, and check the signal that was received on-board the balloon. The results were successful are presented in Figure 5-13.

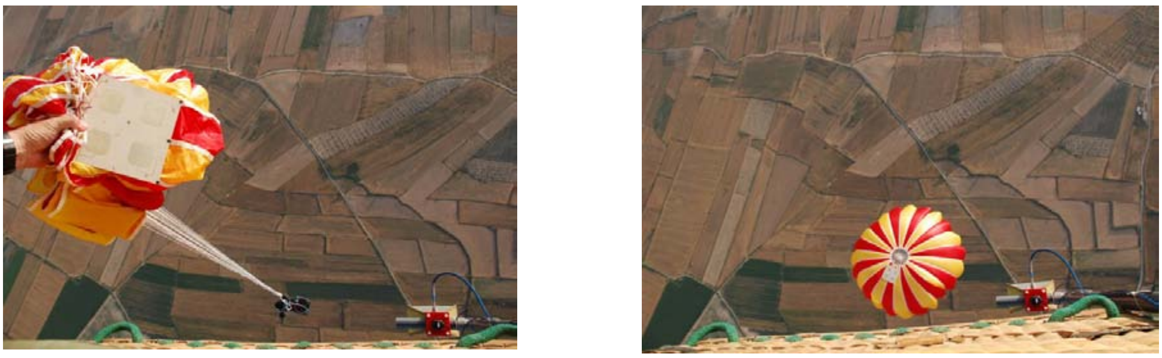


Figure 5-12: Dropping a PARACHANT prototype from a balloon.

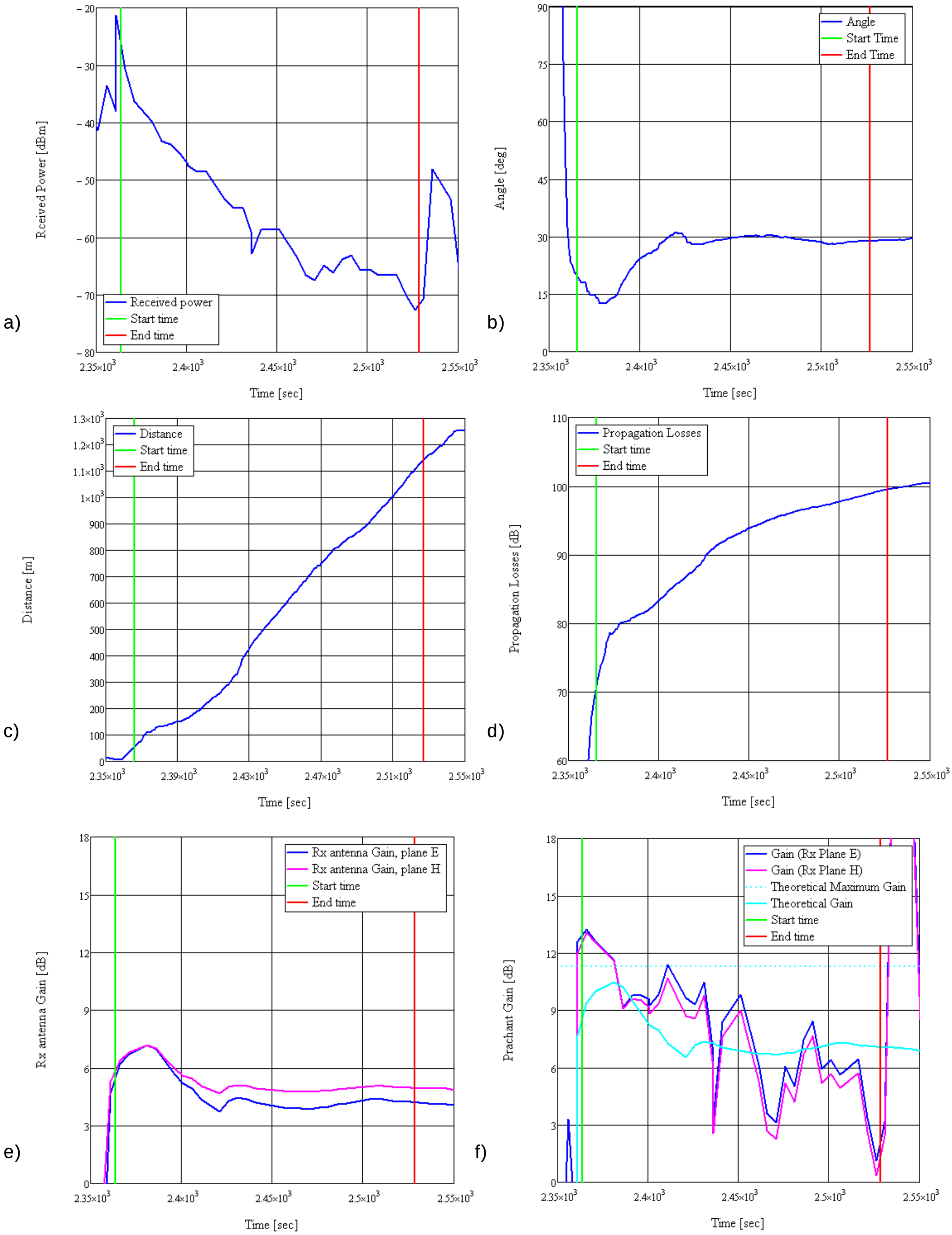


Figure 5-13. Test results for one of the prototypes: a) received power; b) angle; c) distance; d) propagation losses; e) Rx antenna gain, f) PARACHANT antenna gain.

6. CONCLUSIONS

The activities carried out during the project have led to the design of a retro-directive array operating in S-band that can be stitched on the canopy of the parachutes used for planetary entry probes. Depending on mechanical/aerodynamic constraints, this antenna can be installed in two configurations:

- a configuration with only one array located close to the top of the parachute
- a configuration of three arrays located on the external region of the canopy and operating in diversity mode

Both configurations allow gain better than 10 dBi on almost of the coverage region. The proposed design is easily customisable as a function of the mission. Variations can be made to the operating frequencies, the number of radiating elements and the inter element distance according to the specific requirements of the mission (especially in terms of coverage region and parachute dimensions).

The feasibility of the PARACHANT concept and design has been demonstrated through test flights. Prototype parachutes and antennas were designed, manufactured, integrated and tested. The main objectives of the tests were successfully achieved:

- We have demonstrated that a patch array antenna can be manufactured within the planned mass and dimensions, and that it can be indeed installed on top of the canopy of a disk-gap-band parachute by stitching procedures. In addition, we confirmed that a battery located on the lander or entry probe can be used to feed power to the antenna on top of the canopy by means of connecting cables that go through the parachute suspension lines.
- The aerodynamic behaviour of the parachute with a patch array integrated on top of the canopy has been demonstrated to be satisfactory. Specific tests with dummy antennas were performed to guarantee this. No deformations on the canopy were observed in the tests.
- We have demonstrated that the signal from the PARACHANT antenna is indeed transmitted during the descent and that it can be received from another vehicle.

Concerning the benefits from the concept, it has been demonstrated that the appreciable increase in gain with respect to *standard* antennas would allow a remarkable increase of bit rate performance. For the Huygens mission, the PARACHANT antenna design would have allowed a constant data bit rate of 64 Kbps throughout the descent under the stabiliser parachute. This would have increased significantly the scientific return of the mission, since it would have allowed to return a data volume almost one order of magnitude higher than the data actually received by the Cassini spacecraft. For missions such as Huygens or the Galileo entry probe, this increase in science data would have been essential. However, the potential increase in the scientific return of the missions with the PARACHANT antenna must be traded-off considering the impact of the antenna at system level. The increase in mass and complexity is the main drawback.

Slight variations of the PARACHANT concept could be of special interest, including the possibility of applying the concept for DTE communications for Venus entry probes (for missions without an orbiter) and, especially, for comms through a relay spacecraft (or DTE) for **balloons**, either in Venus or Titan.

The most promising option for a technological demonstrator would be to implement a full-functional PARACHANT antenna on the surface of a high-altitude balloon, and perform a flight test.