Parachant Summary Report

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ABSTRACT

This is the Final Summary Report of the ESA Parachant project: 20394/06/NL/HE, ‘ Antenna Elements Integrated into the Parachutes of Future Landers and Entry Probes’. The work was undertaken by BAE SYSTEMS ATC, Airborne Systems and University of Leicester.

A Parachant is an antenna which is integrated and packed within the parachute and deployed when the canopy opens. The main driver for the use of parachute antennas is to increase the data rate for communications during the entry, descent and landing stage of interplanetary probes. Parachants can be much larger than the small antennas fixed to the entry probe and hence offer the potential of providing a much higher antenna gain and consequently much higher data rates.

A number of previous and future missions relevant to parachute antenna deployment, such as missions to Mars, Venus and Titan were considered. Link budgets are compared for alternative Parachant concepts. Two Parachant antennas were selected, a single passive helix antenna for Mars landing and a seven element actively switched helix antenna for Titan descent. Two single S-Band Parachant helix elements were manufactured and measured in an anechoic chamber. Pattern measurements were in excellent agreement with predictions.

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LIST OF ACRONYMS:-

CH Cassini-Huygens

CLDA Chinese Lantern Dipole Array

CMOS Complementary metal–oxide–semiconductor

EDL entry descent and landing

EDLS entry descent and landing system

EOC edge of coverage

ESA European Space Agency

MERs Mars Exploration Rovers

MRO Mars Reconnaissance Orbiter

SoS Silicon on Sapphire (SoS)

TRL Technology Readiness Level

VEP Venus Entry Probe

VSWR voltage standing wave ratio

1 INTRODUCTION

This is the Summary Report of the ESA Parachant project: 20394/06/NL/HE, ‘ Antenna Elements Integrated into the Parachutes of Future Landers and Entry Probes’. The work was undertaken by BAE SYSTEMS ATC, Airborne Systems and University of Leicester.

A Parachant is an antenna which is integrated and packed within the parachute and deployed when the canopy opens. The main driver for the use of parachute antennas is to increase the data rate for communications during the entry, descent and landing (EDL) stage of interplanetary probes. Parachants can be much larger than the small antennas fixed to the entry probe and hence offer the potential of providing a much higher antenna gain and consequently much higher data rates.

This Summary Report covers the following work:-

Mission Review

Review of a number of previous and future missions relevant to parachute antenna deployment. Missions to Mars, Venus and Titan are considered. The relative feasibility of alternative Parachant concepts are tabulated.

Antenna Requirements

The performance requirements of the antennas are listed.

RF Link Performance

The baseline antennas for the representative Mars, Venus and Titan missions are chosen and the helix antenna is selected for the prototype parachant antenna.

Materials and Manufacturing

Suitable materials for the manufacturing of the helix antenna are selected.

Antenna Design

The electrical design of the parachute antenna for a Titan mission. The antenna is a cluster of seven identical helices. The geometry of a single helix is optimised to provide the widest possible field of view for a gain of 10 dBi. The RF switching architecture and control method are outlined. Link budgets are provided showing the expected system performance.

Prototype Tests

The construction, manufacture and test of prototype inflatable helix antennas for the Titan mission. It shows the measured pattern characteristics are in good agreement with predictions.

2 MISSION REVIEW

A review of a number of previous and future missions relevant to parachute antenna deployment was performed. The missions were chosen based on availability of data and relevance of future planetary explorations to the European Space Agency (ESA). The use of parachute antennas to increase the data rate for communications during the entry, descent and landing (EDL) stage of interplanetary probes has been a major consideration in the selection of types of parachute antenna solutions. In addition, the frequency of communication between the lander and orbiter has also constrained the types of antenna configurations relevant to the various missions.

2.1 Mission Scenarios

2.1.1 Mission Types and Context

Planetary missions attempt to examine the geology, geochemistry, environment and atmosphere, when present, of various planetary targets. Successful planetary missions include the Galileo mission to Jupiter, Cassini-Huygens to Saturn and Titan and the Mars Exploration rover missions to Mars. If one wants to either obtain a detailed atmospheric profile or perform in-situ surface analysis and measurements then an entry probe or lander is required. For all targets with atmospheres a parachute is the first choice as one of the deceleration phases due to its development status and relatively low mission resource requirements. Such missions with parachutes are potential users of an antenna integrated with the parachute. Possible planetary targets include: Venus, Mars, Jupiter, Saturn, Titan, Uranus and Neptune.

In the context of planetary landers and parachants, there are basically only two types of communications involving data relay to be considered:

- Relay in Close Orbit.
- Relay in Distant Orbit or Flyby.

A “third type” is communication to Earth. Direct to Earth Transmission during entry is currently limited to “tones” a small data rate increase might be possible with a parachant.

2.1.2 Recent Mission Scenarios

Examples of the first mission type Relay in Close Orbit include Beagle 2, the Mars Exploration Rovers (MERs) and ExoMars. As ExoMars has similar requirements to the MERs and is still undergoing its Phase B1, with little details of its entry system released to date, the MER mission was considered within this study. Drivers and requirements for this type of relay are comparatively close distances (100-1000’s km) to the relay which results in short contact times (minutes).

An example of the second mission type Relay in Distant Orbit or flyby is the Cassini-Huygens Titan lander, here distances are large (10,000’s km) with potentially long contact times (tens of minutes to hours).

A key factor is of course the atmospheric density in any mission scenario as this will dictate the descent time along with the design of the EDL system (EDLS), Mars provides a low pressure environment (~6 mbar) with the total EDL time being typically ~ 6 mins and Titan a high pressure atmosphere (~1.5bar) with an EDL phase measured in hours for a suitable EDLS.

Beagle 2/MERs

Both Beagle 2 and the MER missions featured a direct entry into the atmosphere of Mars from interplanetary space with relay of data from the surface in the case of Beagle 2 and relay of entry data in the case of the MERs by another orbiting spacecraft(s). This is a “classical” relay in close orbit scenario as defined above. The MERs also sent RF “tones” back directly to Earth during their entry phase to indicate successful completion of the various elements of the EDL sequence.

Cassini-Huygens

In the case of Cassini-Huygens the probe had an entry into the atmosphere of Titan from an orbit around Saturn with the relay spacecraft being in Saturnian orbit at some distance from Titan (~70000km), which given the orbit and distances involved was the equivalent to a “flyby” type scenario. This is a “classical” relay in distant orbit or flyby scenario as defined above.

2.1.3 Entry Descent and Landing System

A key element to be considered in any parachant system and its design is the EDLS design. These are mission specific and can involve many stages using a sequence of parachute deployments. It has been assumed in this study that the parachant would be used during the final stage of descent.

It should be noted that there is a great deal of conservatism in use of only a limited number of parachute designs in planetary EDL systems, with disk-gap band and ring sail designs being used almost exclusively for planetary entry systems (including the Earth). This is due to the costs of qualification and the desire to use a “proven” design.

The Mars mission case parachute deployment is at low altitudes ~7-9km and the time on the parachute is limited to a few minutes. In the case of MER the total time from parachute deployment to landing was 111 seconds. In contrast for the Cassini-Huygens Titan mission parachute deployment occurred at high altitude (~170km for the pilot chute) with a total descent time of 2 hours 28 mins .

It should also be noted that in the case of Cassini-Huygens the probe was spinning continuously throughout entry. This was essential to obtain data from the instruments and the probe included spin vanes to ensure continuous spinning.

In all such entries the greatest lateral travel across the surface of the planetary target is however during the deceleration phase within the aeroshell. Once the probe is on its parachutes the descent is essentially vertical with only wind induced drift causing a horizontal velocity component and a displacement. Hence, once such probes are on their parachutes, they therefore lie approximately at a fixed point in terms of longitude and latitude with only its height changing. In the case of both the Mars missions and Cassini-Huygens mission this variation is small compared to the distance to the relay spacecraft.

2.1.4 Transmission Geometries

Figure 2-1 illustrates the relay geometry for Cassini-Huygens and shows the original geometry and changed/flown geometry due to problems with the RF system. Note for the old / original trajectory a near constant aspect angle was achieved which would be good for a parachant type approach whilst for the new trajectory as flown there was a considerable variation in the probe aspect angle.

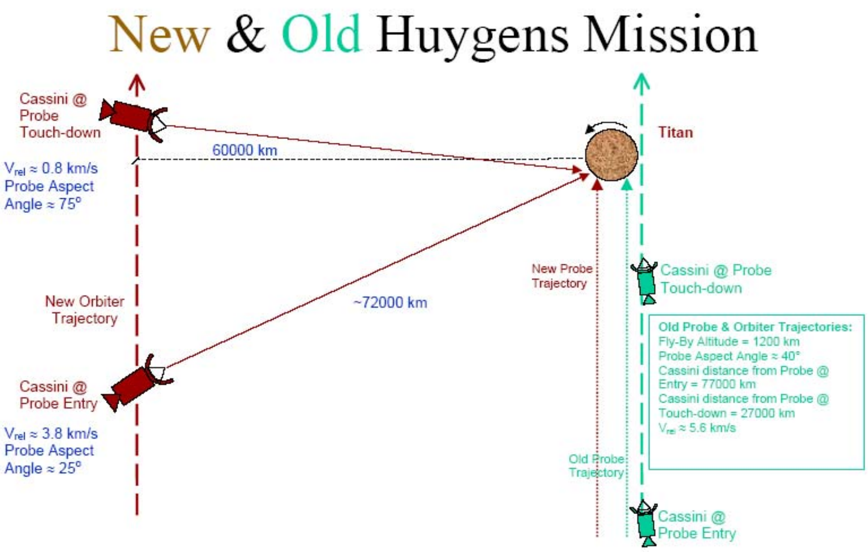

Figure 2-1 Cassini-Huygens relay configuration for original and as flown mission

2.1.5 Missions for Study

The three following missions were considered during the study:-

• Mars parachute descent, similar to MER, communication between probe and Mars orbiting satellite, at UHF frequencies.

• Venus balloon, similar to VEP, communication between probe suspended below the balloon and Venus orbiting satellite, at X-Band frequencies.

• Titan parachute descent, similar to CH, communication between the probe and Saturn orbiting satellite, at S-Band frequencies.

2.2 Integrated Parachute Antenna Solutions

The disk-gap-band parachute is one of the most popular types used for interplanetary exploration during descent and landing. Figure 2-2 depicts a disk-band-gap parachute.

Owing to the size of the parachutes for various missions, there could be space for integrating antennas in the following locations

- On the canopy
- Inside the canopy
- Below the canopy, between the rigging lines.

The size of the antennas will be dependent on the frequency of operation, the coverage requirements between the lander and orbiter and the level of functionality or adaptivity of the antenna system.

2.2.1 Parachute Antenna Configurations

A number of antenna configurations that are amenable to parachant solutions, were considered. These included:

- Fixed antennas on parachute canopy
- Reconfigurable antennas on parachute canopy
- Fixed / reconfigurable antennas on membrane surface(s) between the parachute lines or beneath the canopy

- Deployable antenna / lens balloon.
- Inflatable structures
- Fresnel lens(es) producing high gain beams from antennas situated on the lander / probe.
- Lantern geometries (antennas suspended below the canopy).

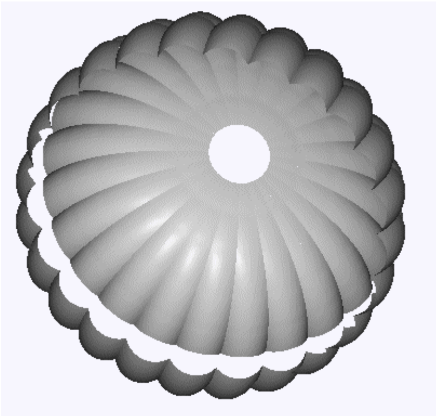

Figure 2-2 Disk-gap-band parachute

2.2.2 Summary of Integrated Parachant Solutions

A parachute canopy is flexible and not dimensionally stable for a number of reasons. Antennas require greater dimensional accuracy and stability than is normally achieved through traditional parachute manufacturing techniques. The antenna elements would have to be manufactured into the canopy using methods which achieve the accuracy and stability required. The micro and macro effects of the wind on the canopy also need to be considered to produce the required antenna performance.

Emerging materials may improve seam tolerances to within parts of a millimetre but are not sufficiently mature to be exploited on the current project. Material stretch can also be reduced to within parts of a millimetre by using emerging materials, but the consequences of this increased control mean a reduction of parachute porosity which in turn means reduced stability and increased opening forces.

Many of the parachant concepts are unfeasible because the antenna size is large compared to the size of the parachute. The lower the frequency the greater the size of antenna required for adequate performance. S-Band parachants will be much more easily integrated within a parachute because it would require antennas which are an order of magnitude smaller, in terms of both area and thickness.

The viability (yes-‘y’, no-‘n’) of each alternative parachant option is summarised below.

Proposed Solution	**Active /Passive**	**UHF**	**S-Band**
Fixed Beam Canopy Antenna	Passive	n	y
Reconfigurable Canopy Antennas, Pencil Beams	Active	n	y
Reconfigurable Canopy Antennas, Fan Beams	Active	n	y
Canopy Lens Configurations	Passive	n	y – poor
Canopy Multilens Configurations	Active	n	n
Fixed Beam Membrane Antenna	Passive	n	y
Reconfigurable Membrane Antennas	Active	n	n
Membrane Fresnel Lens	Passive	n	y - poor

Offset Membrane Lens	Active	n	n
Reconfigurable Lenses	Active	n	n
Membrane Multilens	Active	n	n
Platonic Solids Inside Balloons	Active	n	y
Chinese Lantern Dipole Array (CLDA)	Active	y	y
Yagi Lantern	Passive	y	y
Helix Lantern	Passive	y	y

Table 2-1 Summary of feasibility of solutions

3 ANTENNA REQUIREMENTS

The following table summarises the typical parachant requirements of a future mission.

Parameter	MER Mars Mission	Cassini-Huygens New Mission	Cassini-Huygens Old Mission
Frequency	401.6MHz	2.040-2.098GHz	2.040-2.098GHz
Gain EOC	7dBi	10dBi	10dBi
Polarisation	Circular	Circular	Circular
Coverage	θ=0º-90º,ϕ=0-360º	θ=25º-75º,ϕ=0-360º	θ=40º,ϕ=0-360º
Max Scan Rate	0.375 deg/s	0.004 deg/s	<0.004 deg/sec
Stowed Volume	Original Volume + 10%	Original Volume + 10%	Original Volume + 10%
Stowed Mass	Original Mass + 10%	Original Mass + 10%	Original Mass + 10%
Deployment Velocity	430m/s	Mach 1.5	Mach 1.5
Atmospheric Conditions	Mars	Titan	Titan
Final Descent Rate	68m/s	6m/s	6m/s
Oscillation Limits	±15º	±15º	±15º
Spin Rate	Requirement	2 to 10rpm	2 to 10rpm

Table 3-1 Parachant requirements

4 RF LINK PERFORMANCE

Three different mission scenarios were identified:

- Mars descent. A scenario based on a Beagle 2 type descent but with communications via a low orbiting relay and a time under the main parachute of 200 s.
- Venus atmospheric probe. A scenario derived from VEP with a small probe suspended under a balloon envelope communicating via an orbiting relay in a high orbit. This proposed mission would last up to 15 days.
- Titan descent. An atmospheric probe mission to Titan. A “strict” comparison of a parachant and the flown antenna on Huygens assumed the actual flown trajectory and no antenna steering. A “relaxed” approach was also considered where the relay trajectory was more suitable for a high-gain parachant.

4.1 Link Budget Models

The link budgets were constructed to allow a range of different scenarios to be considered. An important requirement is that the link budget should show the time evolution of the available data rate and link margin so that the effect of different antenna patterns could be demonstrated.

4.1.1 Performance Criteria

Two performance criteria have been used. The first criterion is the evolution of the link margin based on a defined fixed data rate. If a fixed data rate is being used this shows the range of times over which the link is available. The second criterion is the evolution of cumulative data throughput through the pass. In order to take advantage of the available link margin and to compare the performance of the different systems the total data throughput assumes that the link data rate is varied in steps of 3 dB (i.e. a factor of 2) so that the link margin is maintained in the range 1-4 dB. The minimum link margin of 1 dB has been chosen rather arbitrarily but this only affects the total data throughput.

4.2 Baseline Antenna Choice

The following antennas were considered in the link budgets.

- [1] A wide beam, 10 element toroidal antenna which concentrates gain around the horizon, (6dBi) with much lower gain at the zenith.
- [2] A five turn quadrifilar helix antenna with a toroidal pattern shape, (8.3dBi towards the horizon).
- [3] A low gain quadrifilar helix antenna with uniform 0 dBi gain over a hemisphere.
- [4] A high gain helix antenna with 14.4dBi of gain on boresight and a half-power beamwidth of 32º.
- [5] Electronically switched seven high gain helix antenna with 14.4dBi peak gain.
- [6] Electronically steered planar array with 14.4 dBi peak gain.
- [7] Electronically steered CLDA with 11.1dBi peak gain.
- [8] A helix antenna optimised to maximise the 10dBi beamwidth.

A design trade-off was performed and for each of the three missions the following baseline antenna concept was chosen.

•**Mars:** Passive Helix (UHF)

The Mars mission has a quick decent. The main justification for a high data rate link is for diagnostic imaging during the landing phase. If the decent phase is sufficiently constrained to ensure a near overhead relay pass, a passive relatively high gain helix can provide the required gain over a sufficient field of view.

•**Venus:** Electronically steered planar array (X Band)

Missions such as VEP with an atmospheric balloon and a two-way link would be ideal candidates for active steering. However the Venus mission proposes to use an X-band link. For the envisaged data rate requirements, this leads to very small antenna sizes which can readily be accommodated on the gondola, negating the need to deploy it, in or on the balloon.

•**Titan:** Electronically switched high gain helix antennas (S Band)

The Titan descent mission is of significant duration and requires high gain over a wide field of view. At S-band there is sufficient space below the parachute canopy for a switched beam antenna to provide the required performance. This uses seven separate passive helices each pointing in different directions to cover a wide field of view. Helix elements are much more tolerant to mechanical distortion than phased array elements such as patches. Although larger than a phased array when deployed, it is inherently more robust and reliable, as it uses switched independent elements and does not require accurate, active, amplitude and phase control. Also, the stowed volume and mass are significantly less, than a phased array.

5 MATERIALS AND MANUFACTURING

Materials and manufacturing methods which will allow a flexible helix antenna to be folded and packed within the parachute assembly were investigated.

5.1.1 Helical Conductor

Four different types of copper material were considered: Table 5-1 compares the mass of the conductor required for the antenna. Note that the Litz wire results in the lowest mass.

	Solid wire	Litz wire	Non-Insulated multi strands	Flat tape
Diameter /width (mm)	1.24	0.04	0.04	2
No. of strands	1	31	958	1
Mass/m (g)	9.939	0.321	9.908	0.576
Total Mass (g)	90.890	2.932	90.606	5.268

Table 5-1. Antenna Conductor Mass Comparison

5.1.2 Helix Tube

The review of the materials to manufacture the inflatable elements of the antenna showed that of the film materials available Kapton (Polyimde) has the most suitable material properties. If a ram-air type design were used then traditional nylon fabric may also be a suitable material selection.

5.1.3 Helix Ground Plane

For the prototypes it is proposed to use a knitted metallised mesh which is manufactured by metallising a knitted nylon mesh with silver. The mesh can be stretched flat and crinkle free due to its knitted construction. The metallised layer is sufficiently thick such that high frequency signals can be transmitted without significant losses. The mesh is of a square cell configuration providing a diamond pattern.

5.1.4 Whole Antenna

Figure 5-1 shows the seven element helix antenna beneath a parachute.

Figure 5-1 Antenna concept design within parachute

5.2 Aerodynamic Assessment

5.2.1 Aerodynamic Effect of Antenna on Parachute Performance

The antenna system to be attached to the parachute must not significantly adversely affect the aerodynamic performance of the parachute.

The single helix antenna has a cross sectional area of 1.02 x $10^{-3}m^2$ which is negligible when compared with the cross sectional area of a parachute canopy. This single helix would be approximately 0.01% of the drag area of the final stage parachute for the Cassini-Huygens probe. The array of seven helical antennas will also be small in comparison with the area of a parachute. The seven helix array would be approximately 0.8% of the drag area of the final stage parachute of Cassini-Huygens. Since either antenna system is small in comparison with the drag area of a parachute any change in airflow into the parachute will be negligible.

5.2.2 Aerodynamic Effects on Antenna Performance

In order to assess the effect on antenna performance of distortions caused by aerodynamic effects during parachute descent, models were manufactured to test in a representative air flow. The air flow was sufficient to fill the cylinders with air, but not to provide sufficient pressure to maintain a cylindrical shape. So a gas inflation system would be used to both inflate the antenna and maintain shape during descent.

5.3 Bulk/Volume Impact On Parachute System

The mass budget calculations for S-Band antenna systems for use on Titan type missions indicate that the introduction of a 7 Helix antenna into a Cassini-Huygens type parachute system would increase the mass of the parachute system by approximately 9%

The mass budget calculations for a compressed gas inflated UHF antenna system for use on Mars type missions indicate that the introduction of a compressed gas inflated single Helix antenna into a Mars type parachute system would increase the mass of the parachute system by approximately 8%. This can be reduced to approximately 2% for a ram-air inflation system. Whilst this Task has shown that ram-air inflation of an S-Band antenna is not practical it is thought likely that a ram-air inflated UHF antenna system would be successful due to the increased diameter of the helix.

Figure 5-2 (left) shows a series of photos showing the packing of a lightweight inflatable manufactured as part of a research programme. The inflatable has a central body with five legs attached to it. Each leg is approximately 5m long. The photos show the sequence of taking the inflatable from a deflated state through the packing process required to pack it into its deployment bag. For this programme it was required to pack the inflatable body in an annulus around a central cylindrical body. The inflatable only occupies a 25mm thick annulus surrounding a central cylindrical body within the pack shown in the final two photos.

Figure 5-2 (right) shows a series of photos showing some of the stages during the packing of a parachute used for vehicle recovery. A lightweight inflatable such as that shown could be packed within this parachute pack making a negligible difference to the overall packed mass and volume of the parachute system. The inflatable antenna element of the proposed Parachant concept design is much smaller than the inflatable shown but of a similar configuration.

Figure 5-2 Inflatable and Parachute packing sequence

6 ANTENNA DESIGN

A cluster of identical S-band helices was chosen as the antenna solution for the Titan mission. A UHF helix was also recommended for the Mars mission. The design presented here can also be used for that mission, providing that dimensions are scaled according to the ratio of operating frequencies.

The necessary RF switching and control for the seven element design was also examined. Link budgets are provided, showing the expected system performance.

6.1 Modelling of Single Helix

The antenna was modelled using a Method of Moments code. The in-built optimisation routine was used to design a helix with the widest possible field of view for an edge of coverage realised gain of 10 dBi. As the operating band is narrow (2.040 – 2.098 GHz), optimisation was carried out at mid band only. The ground plane was fixed to be 0.15 m in diameter. Figure 6-1 shows the single helix pattern.

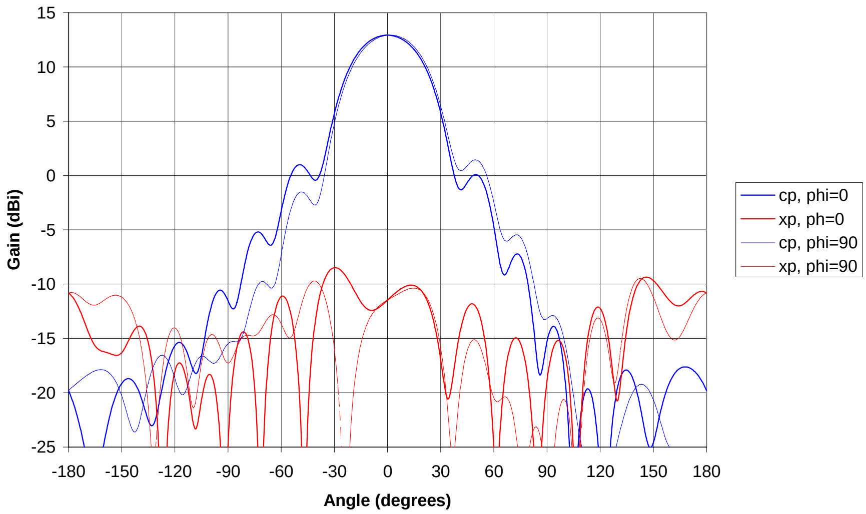

Figure 6-1 Helix above meshed ground

6.2 Antenna Cluster Coverage

Seven helices are arranged so that their combined field of view is as wide as possible. This is the chosen solution for the Titan mission.

In use the elements are switched, so that at any instant only one helix is transmitting or receiving. Two views of the antenna are shown in Figure 6-2. The outer elements are tilted 30° outwards from the central one.

Looking down on the antenna, the seven beams will overlap as indicated in Figure 6-3. From this it is clear that only two helix patterns (those for elements 1 and 2 in Figure 6-2) are required to determine the extremes of coverage, and that only the ϕ=0° and 30° cuts need be considered.

The predicted patterns are shown in Figure 6-4. The first thing to note is that the pattern of the central element is significantly different from that of a single isolated element. This is due to coupling to the nearby elements. Secondly, the field of view is smallest in the ϕ=30° plane. This is to be expected, as the pattern cut does not pass through the beam peak of element 2 (see Figure 6-3). The antenna field of view varies between a minimum of ±40.5° in the ϕ=±30°,90° planes, and a maximum of ±50.5° in the ϕ=0°, ±60° planes.

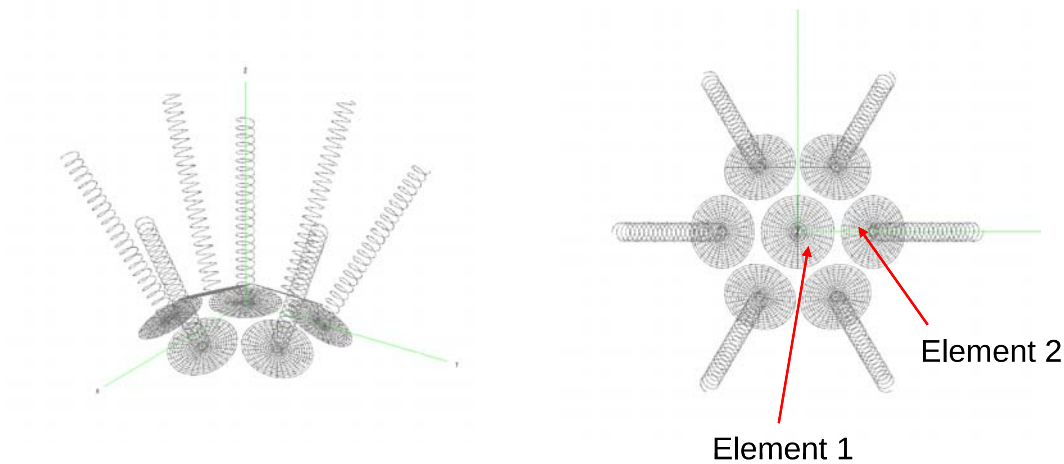

Figure 6-2 Configuration

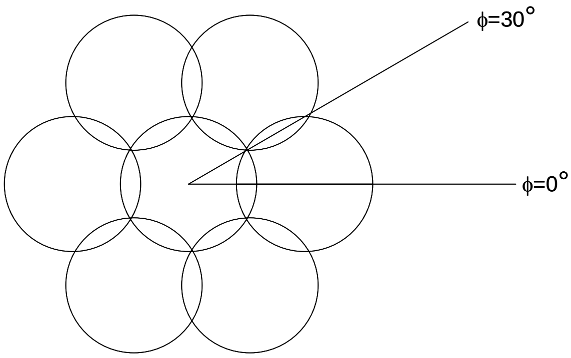

Figure 6-3 Beam set

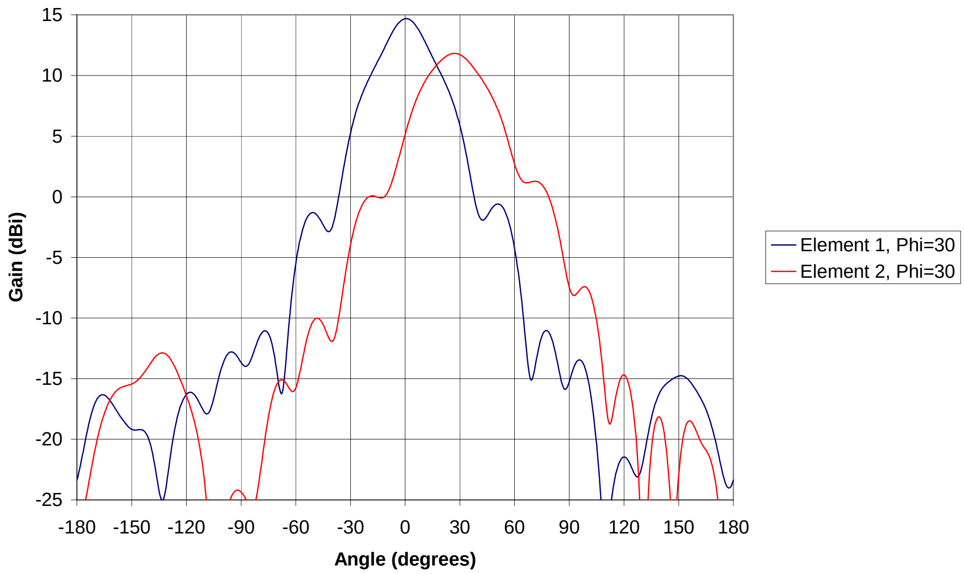

Figure 6-4 Patterns for seven element antenna

6.3 RF Switching

A communications link between the probe and the orbiting relay is required to pass the instrumented data back to Earth. The RF switching system will select the element on the parachant that provides maximum gain in the direction of the orbiting relay. The following assumptions have been made.

a) A beacon will be implemented on the orbiting relay to enable beam selection.

b) Beam selection will be based on selecting the Helix element receiving the highest power from the beacon as the uplink antenna.

c) A single receiver system will be used to monitor the beacon power.

d) Parachute motion, probe motion, and the orbiting relay motion are the prime drivers for why the antenna selection needs to be made.

Figure 6-5 illustrates the basic switched element parachant.

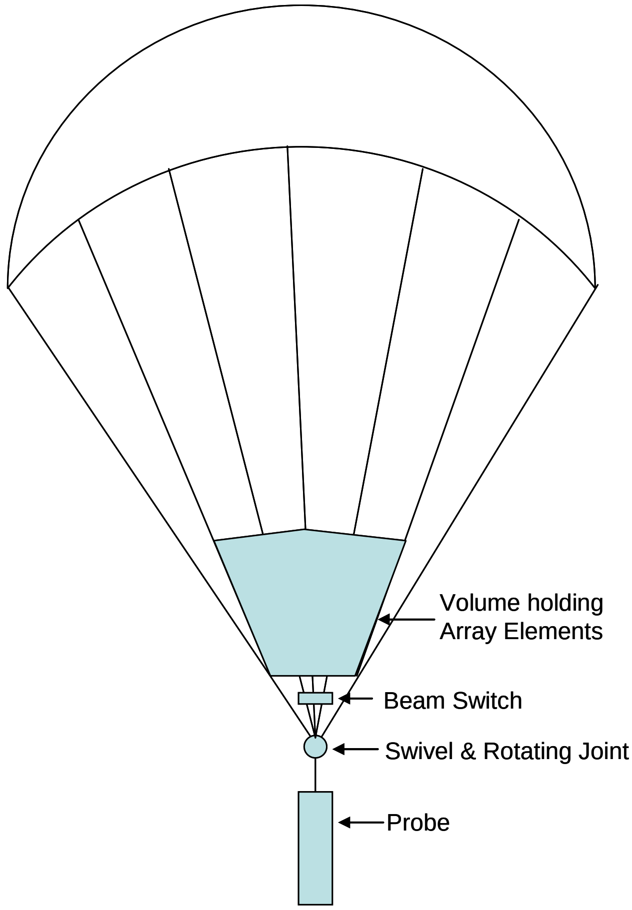

Figure 6-5 Basic switched element Parachant approach

Parachute motion includes both rotation and pendulum swing effects. For the Cassini/Huygens mission the probe spin rate was initially +7.5 rpm at release, and the probe included spin vanes to ensure that it continued to spin during decent. The spin was necessary to obtain data from the instruments. The probe spin rate peaked at close to -10 rpm. Additionally the parachute may oscillate (pendulum swing) up to ±5 degrees with a period of about 15 seconds.

The switch needs to be low loss and capable of handling the RF transmitter power. Transmit power for CH was ~10 watts. The performance of alternative switch technologies was compared. Taking switching speed into account an electo-mechanical switch gives a transmission duty ratio of ~62.2% where as the CMOS (SoS) switch offers a ratio of ~99.9%.

The most critical area for beam switching is the intersection point of three beams. Taking helix pointing errors into account, a decision to switch the beam has to be made within a 3º circle centred on the intersection point. A power measurement system has been proposed that poles round each element in turn, measures the beacon power received and switches to the element with the highest power. It is estimated that using the proposed receiver system a 95.3 % data transmission duty ratio can be achieved.

6.4 Antenna Link Performance Simulations

6.4.1 Mars Entry

The first scenario is Mars entry where the geometry is selected so that a relay in a low orbit (2000 km) passes at or near the zenith as seen by the lander.. Time evolved link budgets for an overhead pass at 3.2 Mbit/s are shown in Figure 6-6. Figure 6-7 shows the situation for a 1 Mbit/s link and a pass 20° from the zenith. The plots also show the effect on margin due to wind-induced tilt of the antenna by up to 5° from the local vertical. It can be seen that for near zenith passes the helix gives a considerable improvement over the reference antenna, (the reference was the flown Cassini/Huygens antenna).

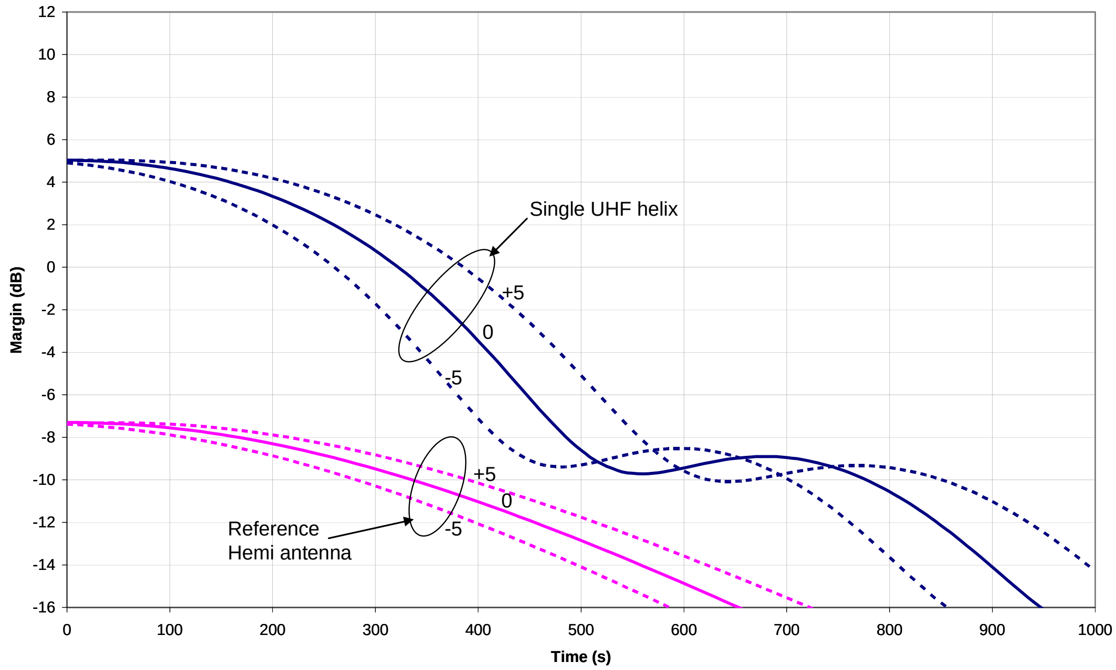

Figure 6-6 Overhead pass. Mars entry UHF single helix. Margin for 3.2 Mbit/s information rate. Reference hemispherical antenna shown for comparison. T = 0 corresponds to highest elevation of relay as seen by lander. The effect of a ±5° tilt due to wind is show

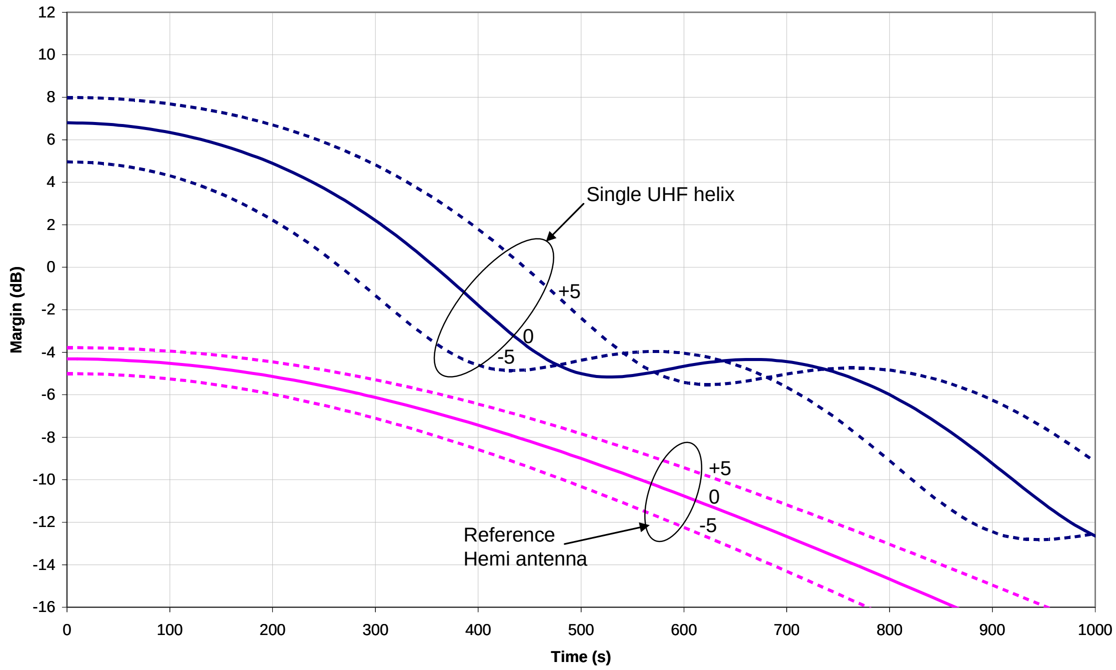

Figure 6-7 Pass 20° from zenith. Mars entry UHF single helix. Margin for 1 Mbit/s information rate. Reference hemispherical antenna shown for comparison. T = 0 corresponds to highest elevation of relay as seen by lander. The effect of a ±5° tilt due to wind is shown.

6.4.2 Titan Entry

The link budgets for the Titan entry scenario have been run for the trajectory as flown (approx 68000 km miss distance with the relay at an elevation of around 50° to start with then slowly setting), and for a modified close flyby trajectory of 6000 km where the relay lingers near the zenith for a long period. The antenna patterns correspond to the switched helix with cuts through the peak gain of the adjacent beams and through the minimum gain of the adjacent beams.

Figure 6-8 shows the link margin for the flown trajectory assuming an information rate of 16384 bit/s. Limits due to ±5° wind-induced tilt are shown. A comparative plots for the relaxed scenario is shown in Figure 6-9 . All of the link budgets include the effect of pointing error, ohmic and switching losses.

It can be seen that the performance of the switched helix is significantly better than the reference antenna in the case of the relaxed trajectory since the relay spends much of its time in the high gain region of the antenna. The improvement is not so marked in the flown trajectory since the relay is not optimally placed for the antenna pattern.

A set of link budgets have been computed for several different mission scenarios. The selected parachants show a significant performance improvement over hemispherical antennas if the mission geometry is optimised so that the relay is situated in the high-gain part of the antenna pattern. The performance improvement is not so marked for unconstrained geometries and it is clear that the benefits of parachants will only be achieved if the mission can accept some restrictions on the relay geometry.

One of the disadvantages of the switched beam approach used for the Titan entry scenario is discontinuities in the uplink carrier. This will have significant effects on the use of the carrier for radio science and integrated Doppler measurement. A future study is recommended to investigate this aspect of the design.

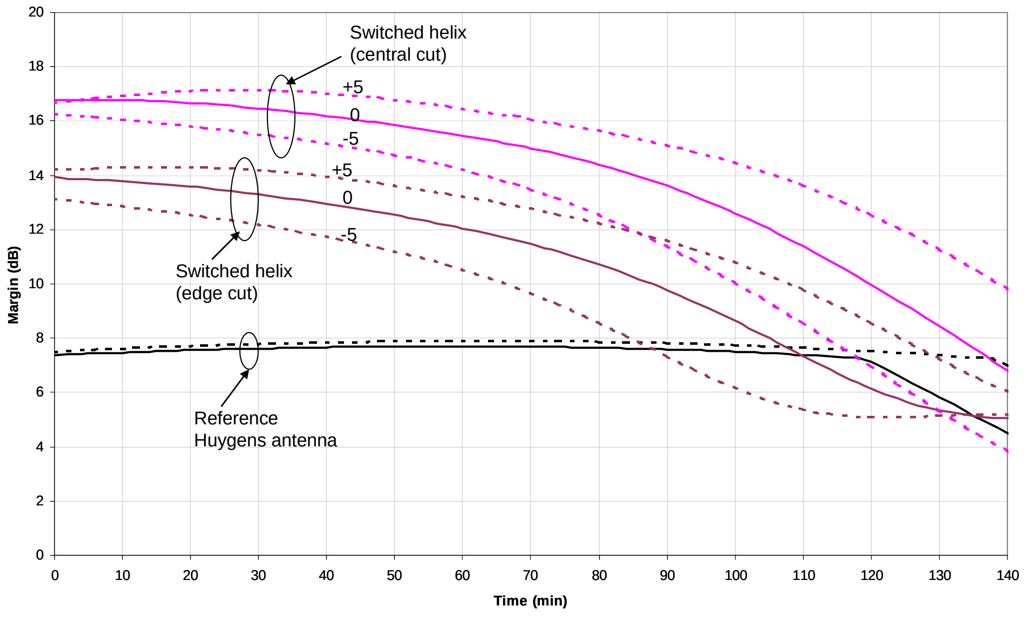

Figure 6-8 Titan entry scenario using as flown Huygens trajectory (Relay passing 68,000 km from the lander at closest approach). Switched helix antenna using central and edge beam cuts. The original Huygens hemispherical antenna is shown for comparison. The effect of a ±5° tilt due to wind is shown.

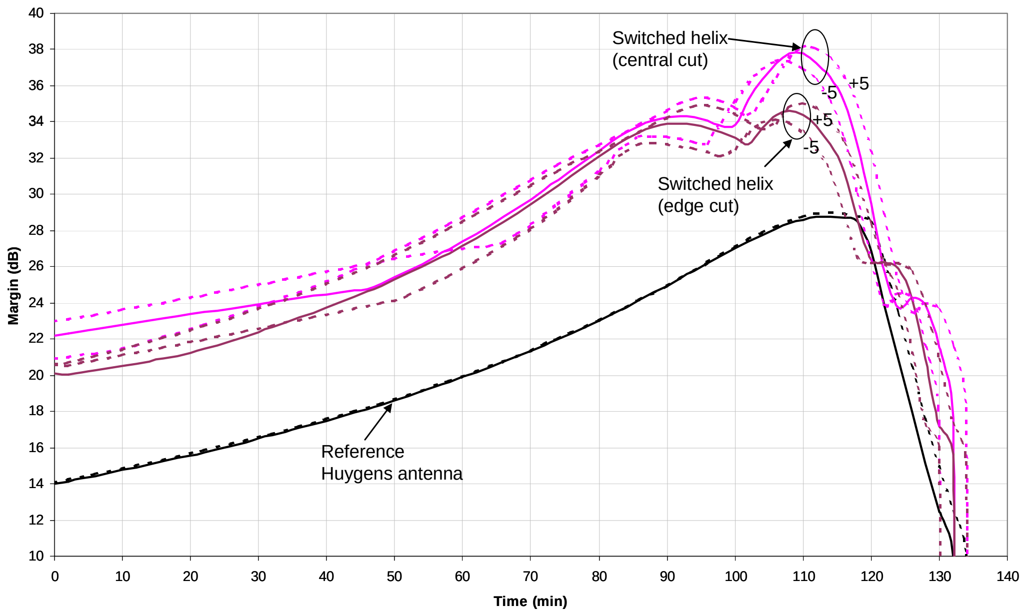

Figure 6-9 Titan entry scenario using relaxed trajectory (Relay passing 6,000 km from the lander at closest approach with trajectory designed for maximum period near zenith). Switched helix antenna using central and edge beam cuts. The original Huygens hemispherical antenna is shown for comparison. The effect of a ±5° tilt due to wind is shown.

7 PROTOTYPE TESTS

The objective was to manufacture and test a prototype to demonstrate the feasibility of the concept antenna. The prototype is not intended to be a fully designed production ready sample, but a model which can be used to determine if the required performance can be achieved from an antenna which can be folded and packaged within a parachute.

7.1 Development

A two stage approach was used to demonstrate the feasibility of the inflatable antenna concept

1. Construct, test and compare the performance of helices manufactured from a selected number of conductor types.
2. Construct and test the performance of helices formed around a compressed air inflated Mylar tube.
    a. The helix is attached to a solid aluminium disc ground.
    b. The helix is attached to a ground plane made from metallised mesh material.

7.1.1 Stage 1

Each prototype helix was wound on an expanded polystyrene cylinder core and used a solid aluminium ground plane. The prototype antennas are shown in Figure 7-1 and a close up view showing the details of the conductors in Figure 7-2.

The only significant difference between the prototype antennas is the conductor cross section. To provide a relative comparison of the ohmic loss introduced by the helix wire, the boresight gains of the prototype antennas were measured. The mismatch loss was compensated for in the gain comparison. The differences in gain are negligible. The Litz wire was selected as the best conductor material to use, as it is light weight and highly flexible, with the advantage of being the least susceptible material to kinking and creasing during folding and packing.

Figure 7-1 Stage 1 polystyrene prototype antennas

Solid Copper Wire	Multi-strand copper wire with plastic sheath	Multi strand copper wire	Copper tape	Litz wire

Figure 7-2 Helix conductors

A matching circuit was designed, using a microstrip impedance transformer placed on the ground plane, near the helix feed point. The results for the Litz wire helix are shown in Figure 7-3.

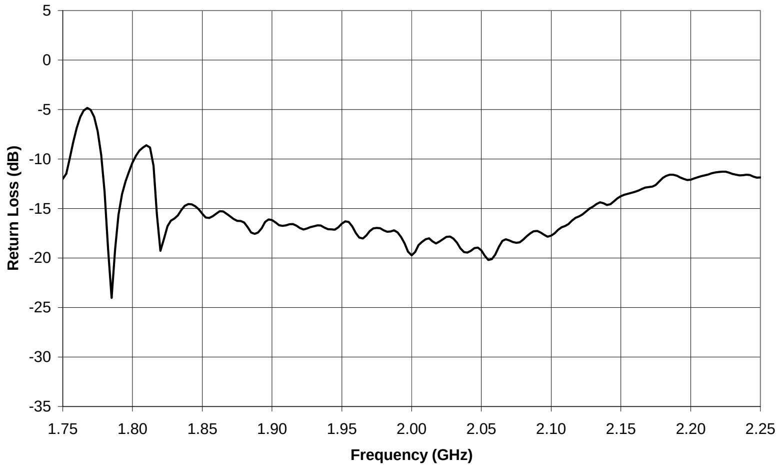

Figure 7-3 Measured match of Litz wire helix including matching circuit

7.1.2 Stage 2

A prototype inflatable antenna using a solid conducting ground plane was constructed. The prototype is shown in Figure 7-4 and consists of a compressed air inflated Mylar tube, onto which the Litz helix conductor is attached. The expanded polystyrene disc end cap controls the circularity of the helix at its base and ensures that the antenna axis remains perpendicular to the ground plane. A microstrip matching circuit was etched onto an aluminium backed dielectric sheet. The aluminium also acts as the antenna ground plane.

The helix was inflated using compressed air through a connection made in the base of the helix which passed through a small hole in the centre of the ground plane.

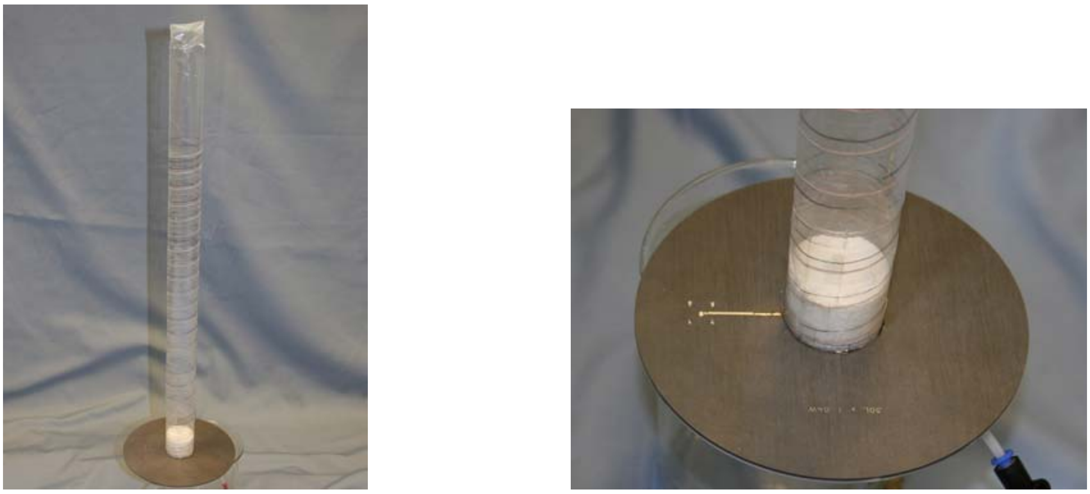

Figure 7-4 Stage 2 prototype antenna

An alternative method of construction using an inflatable structure at the base of the helix was put forward as an option. The inflatable base forms the antenna ground plane and therefore must be conducting and should be crease-free when deployed. A conducting mesh which adheres to the inflatable structure meets these criteria. To test the electrical properties, an inflatable helix was manufactured with a mesh ground plane. To provide a direct comparison, the helix is identical to that using the solid ground plane. The mesh was stretched over a circular Perspex disc. The antenna including matching circuit is shown in Figure 7-5. It is aluminium backed, and clamped to the top surface of the mesh to provide good electrical contact.

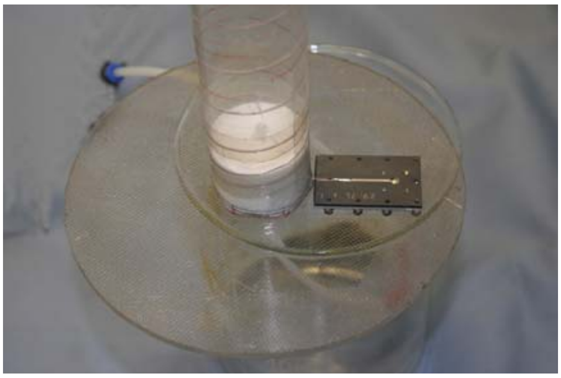

Figure 7-5 Inflatable antenna using mesh ground plane

The two inflatable helices were measured in a cylindrical near field test facility. The gain of the antennas was measured by comparison with a standard gain horn.

The measured pattern for the helix with a solid ground plane is compared against the prediction in Figure 7-6. As can be seen, there is good agreement. The predicted gain is 12.9 dBi, whilst the measured value is 13.0 dBi. The field of view for a gain of 10 dBi is predicted to be 41.2°, compared with the measured value of 39.0°.

The measured pattern for the helix with a solid ground plane is compared against that of the helix with a mesh ground plane in Figure 7-7. The difference between the two is negligible, both having gains of 13.0 dBi. The results confirm that a mesh is as effective as a solid ground plane. It has no detrimental effect on the antenna pattern performance and does not introduce additional ohmic loss.

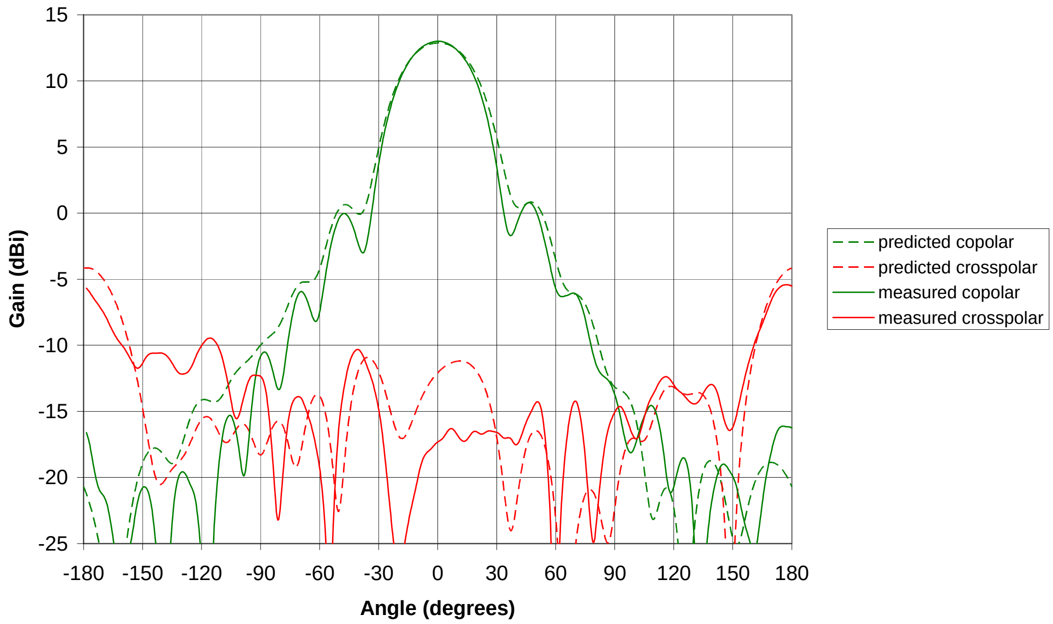

Figure 7-6 Radiation pattern of Helix above solid ground

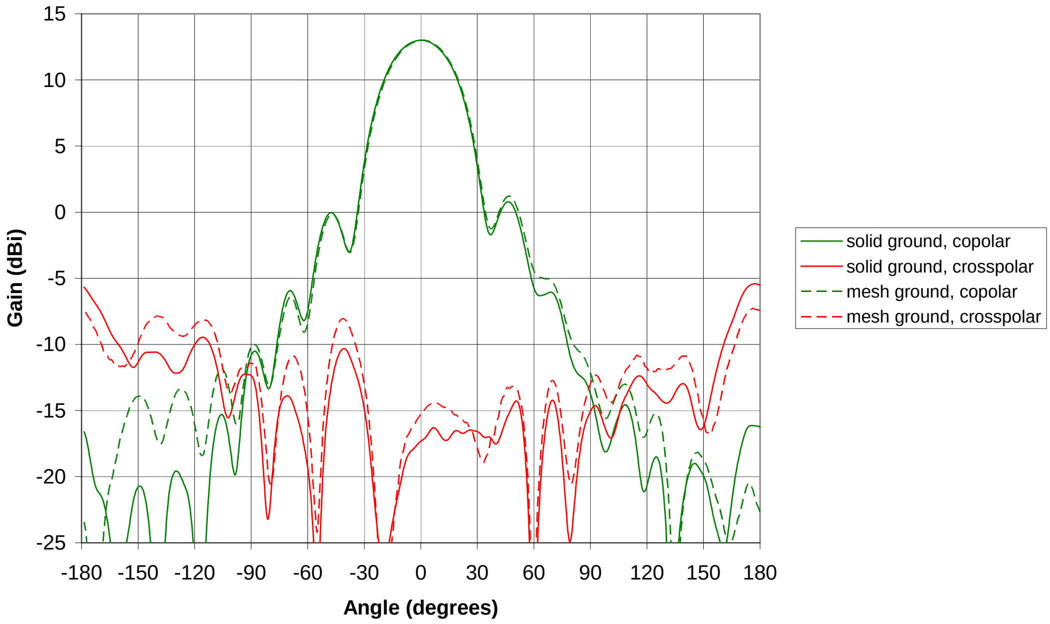

Figure 7-7 Pattern comparison for Helix with solid and mesh ground planes

7.2 Packaging and Deployment

Testing has shown that it is possible to manufacture an inflatable / deployable antenna which gives the required antenna performance. The exact design of an antenna would have to be considered for a specific mission and integrated into the specific parachute system.

Figure 7-8 shows one of the inflatable helices used for the prototypes packaged into the centre of a polystyrene collar. The hole in the polystyrene collar is 38 mm in diameter and 25 mm high. The helix easily packed into this space. It is envisaged that the bottom of the helix could be designed to utilise a collar in place of the short polystyrene cylinders used for the prototypes. The collar could then provide the interface between the helix and the ground plane and also provide a protected space to pack the helix into.

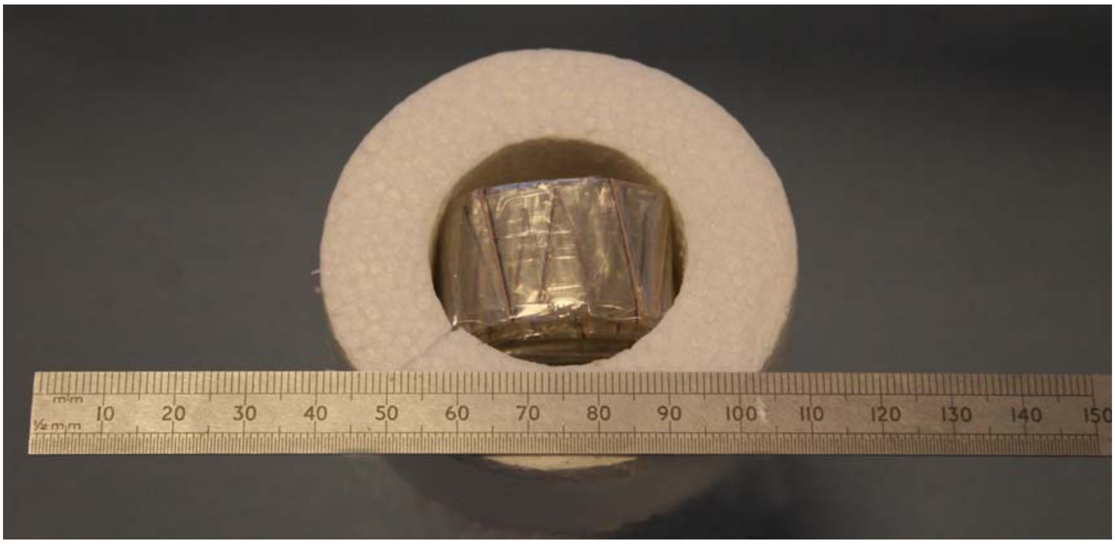

Figure 7-8 Inflatable Helix packed into polystyrene collar

The ground planes for the helical antennas designed to operate at S-Band frequencies are relatively small, i.e. only 150 mm in diameter. Since the ground planes are small it is possible that the benefit in designing a deployable mesh ground plane is not sufficiently significant and that a solid ground plane might be used.

The antenna system uses 7 identical helices. Assuming each uses a solid ground plane 150 mm in diameter and 3 mm thick, the increase in volume for a parachute system for a CH type mission would be approximately 4%. Some volume saving could be made by designing a deployable ground plane, perhaps reducing this increase in volume to 2.5%.

If the concept were expanded to UHF frequencies the antenna would need to be approximately 5 times bigger in all dimensions and therefore the use of a mesh ground plane would be essential.

8 CONCLUSIONS

Parachants have been considered for improving data link communications, to the relay satellite, for future landers and entry probes.

Missions to Mars and Titan have been identified as suitable candidates for parachant use. Antennas suspended below the parachute were chosen in favour of ones within the canopy. The canopy is relatively unstable and only has small areas between chord lines. Below the canopy there is a large volume to suspend the antenna. It also has the advantage of the antenna being closer to the probe, reducing RF feed paths.

For Mars a single high gain UHF helix was selected for transmission of high resolution photographic images of the landing terrain, during the last phase of descent.

For Titan a seven element, S Band, switched helix was chosen for transmission of the mission data during descent.

Parachants have the potential to increase data rates by ~10dB, compared to conventional low gain antennas mounted on the probe.

For the Titan mission the parachute/parachant mass increase is ~9% and the volume increase is ~4%.

Five prototype helices with alternative conductors were compared. Litz wire was selected as the most suitable. It has low mass and can be packed and deployed without kinking.

Two inflatable helix prototypes were made, one with a solid ground plane and the other using mesh. Both were measured in an anechoic chamber. Pattern measurements show that the performance of the two inflatable helices is nearly identical, and in good agreement with predictions. The results also prove that the mesh ground plane does not degrade performance in any way. The benefits of a mesh ground plane at S-Band are debatable. For a much larger UHF system however, an inflatable mesh ground plane provides significant savings in terms of mass and stowed volume.

The prototype demonstrates that the RF performance can be achieved from an antenna which could be folded and packaged within a parachute.

END OF DOCUMENT