SSC07-XIII-7

Wide Coverage Antennas

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ABSTRACT

Small satellites require small and lightweight antennas for telemetry and command function as well as for downlinking of data. We have during the last thirty years developed a large suite of wide coverage antennas. The basic radiator designs used are quadrifilar helices, waveguides, horns and patch excited cups (PEC) depending on frequency range, coverage requirements and application. The antenna designs range from L-band up to Ka-band frequencies. Typical coverages for the antennas are from low gain hemispherical, isoflux, fill-in, toroidal to medium gain, global and semiglobal coverage antennas.

The paper gives a brief overview of the antenna family and a selection of recently developed and interesting antennas is presented more in detail. L-band antennas have been developed for satellite-born GPS receivers and for earth observation satellite downlinks. Two recently developed GPS antennas are presented together with a complementary LNA. One is a helix antenna, an antenna type of which we have a hughe experience, the other a PEC antenna. Several PEC antennas have been designed through the years. This radiator type can be used either as a complementary fill-in antenna or as a free-standing medium-gain antenna for telemetry and command. Three S-band antenna developments are presented. An X-band helix antenna has been developed for downlinking of data from LEO satellites. This antenna has an isoflux coverage. It is a compact and light-weight design. The X-band helix antenna and some ongoing and future developments are presented.

INTRODUCTION

Saab Space has during the last thirty years developed a large family of wide coverage antennas.[1, 4, 5, 8, 11, 15] The antennas are and have been used for a number of satellite applications including telemetry and command, beacon, data downlinks, GPS reception and also for launch vehicles. In total, more than 350 wide coverage antennas have been delivered during the years. The basic radiator designs used are quadrifilar helices, waveguides, horns and patch excited cups depending on frequency range, coverage requirements and application. Typical coverages for the antennas are from low gain hemispherical, isoflux, fill-in, toroidal to medium gain, global and semiglobal coverage antennas.

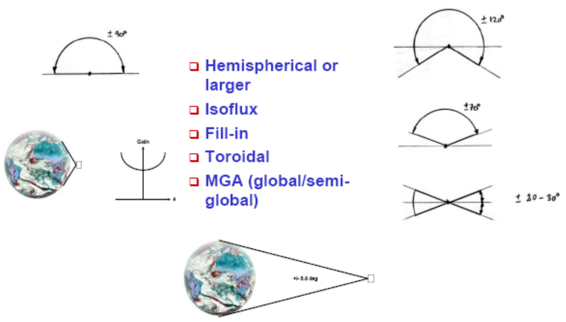


Figure 1: Typical Antenna Coverages

The antenna designs range from L-band through S,C,X and Ku-band up to Ka-band frequencies.

WIDE COVERAGE ANTENNA BACKGROUND

As an introduction to wide coverage antennas a selection of such antennas is presented in the following section.

Our first helix antenna was introduced in the late 70's.

The helix antennas are of many different types, developed during the years, in order to fit all the rf and environmental requirements imposed by the users.[2, 6, 13]

Common for all the helix designs is that they are lightweight designs, with broad coverage and low cross polarization.

A major benefit using quadrifilar helix antennas is that it is possible to shape the radiation pattern to obtain the desired coverage.[13, 16]

Depending on the coverage and bandwidth requirements, they are conical or resonant or something in between.

The helices can be realized in different ways:

- Self-supporting metallic wires
- Machined out of one metallic piece
- Metallic tubes or wires using dielectric supports
- Etched on dielectric cones or tubes

Feeding of the helices, from the antenna feed network, can be done from the top or bottom of the radiator. Top feeding of a helix is more complex, but gives in many cases better performance.

In figure 2 some helix antennas are shown.

Figure 2: Helix Antennas (S-Band Hemispherical, Isoflux and Launcher Antennas, X-Band Hemispherical Antenna Pair)

The first toroidal antennas, developed in the mid 70's, together with more recent toroidal antenna developments are shown in figure 3.[9, 14]

Figure 3: Toroidal Antennas (Ka-band Circular Polarisation, Ku-band H/H Polarisation, Ku-band H/V Polarisation, Ku-band H/H Polarisation, S-Band H pol and S-Band H-pol)

Selected horn antennas are shown in figure 4.

Figure 4: Horn Antennas (Ka-Band Circular Polarisation, Ku-Band (14 GHz) Linear Polarisation, Ku-Band (12 GHz) Linear Polarisation, Ku-Band Circular Polarisation, Ka-Band Circular Polarisation)

Different waveguide radiators are shown in figure 5.

Figure 5: Waveguide Radiator Antennas (C-Band Circular Polarisation with Global Coverage, Ka-Band Circular Polarisation Antennas, C-Band Circular Polarisation Antenna Pair, Ku-Band Circular Polarisation)

Patch excited cup (PEC) antennas have been delivered through the years. This radiator type can be used either as a fill-in antenna or as a free-standing medium-gain antenna or as a radiator element in large array antennas for mobile communications as in the ICO or Thuraya payloads.[3, 7] For those projects, thousands of antenna elements have been delivered.

Some selected PEC antennas are shown in figure 6 below.

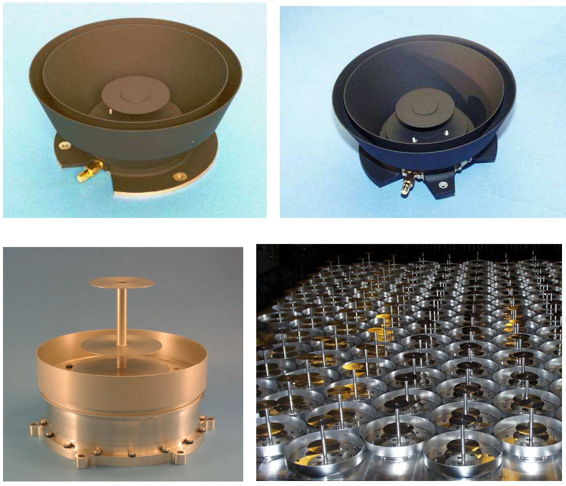


Figure 6: PEC Antennas (Artemis S-Band Fill-In, Cryosat I and Cryosat II S-Band Fill-In, S-Band Array Element with Integrated Filter, S-Band Array Elements)

ANTENNAS FOR GPS APPLICATIONS

GPS Helix Antennas

We have developed a high performance GPS receive antenna realized as a quadrifilar helix. It is shown in figure 7. The antenna operates at the GPS frequencies 1.227 GHz (L2) and 1.575 GHz (L1). It has a hemispherical coverage.

The design required extremely low back radiation in order to minimize satellite disturbances. In order to fulfil this requirement we introduced a special feeding technique of the quadrifilar helix antenna which reduced the back radiation by 5 dB - 10 dB. The antenna design is patented.

The antenna can be equipped with an atomic oxygen protective cover, a germanium coated single layer insulation (SLI) foil, to allow the use of the antenna on low orbiting satellites.

Typical measured radiation performance for the antenna is shown in figure 8 and figure 9 (gain min/max envelope over the hemisphere for co- and cross-polar radiation).

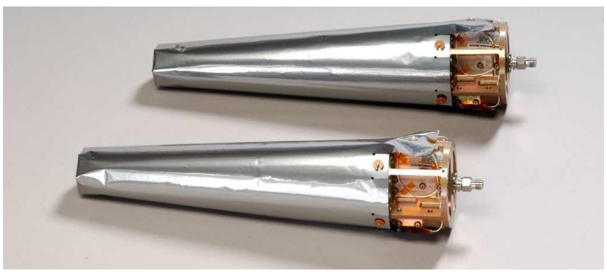


Figure 7: GPS Helix Antennas with SLI

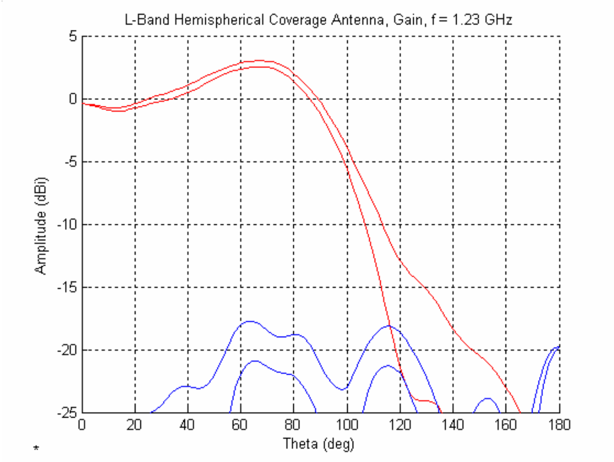


Figure 8: GPS Helix Antenna, L2 Frequency, Radiation Pattern

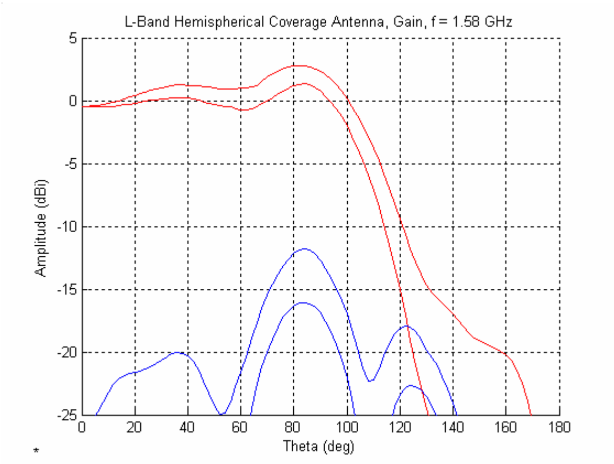


Figure 9: GPS Helix Antenna, L1 Frequency, Radiation Pattern

GPS PEC Antennas

The quadrifilar helix antenna mentioned above is, however, too high for smaller spacecrafts such as the one in the SWARM programme.

A new low profile antenna has been developed for these applications.[17] It is a PEC antenna which consists of two patches, placed in a circular cup. The bottom patch is capacitively fed by probes.

For SWARM we need a very stable antenna covering the two GPS frequency bands. This has been obtained using a four-point feed with capacitive coupling of the bottom patch, and an isolated feed network.

The interaction with the spacecraft should be minimized. The limited allowed size makes this a challenge, in particular for the lower L2 frequency band.

The antenna diameter is 160 mm and the mass is 345 g.

Coverage out to 80° zenith angle is needed, while simultaneously the crosspolar and copolar back radiation must be minimized. The characterization of the carrier phase requires a very stable antenna and a predictable environment. Considerable effort has been spent to find the best antenna location on the spacecraft and to optimise the total performance i e balancing antenna coverage against spacecraft interference and multipath errors.

The antenna has been breadboarded with very good results.

The breadboard antenna is shown in figure 10.

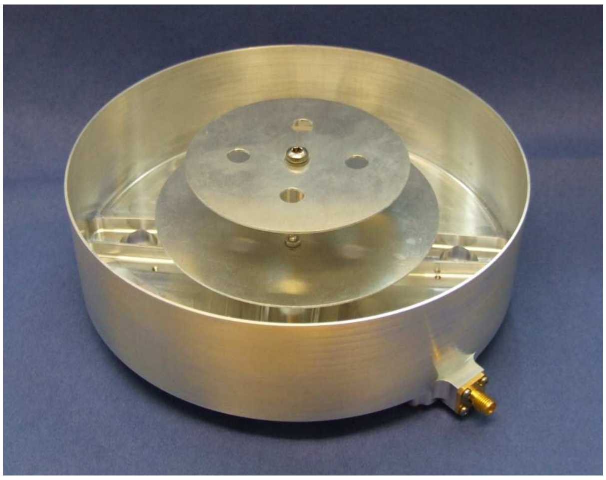


Figure 10: GPS PEC Antenna

Measured antenna patterns (gain min/max envelope for co- and cross-polar radiation) for the breadboard antenna together with the predicted performance are shown in figure 11 and figure 12.

Solid lines represents the measured performance and the dashed curves represent predicted performance.

The measured performance is in very good agreement with the predictions.

To characterize the antenna installed performance on satellite for the SWARM programme, it will be measured on a mock-up.

Since the spacecraft interference is dominated by the structure close to the antennas, a limited mock-up can be used.

The error due to the smaller mock-up has been evaluated by comparison between the calculations with the complete S/C and with the smaller mock-up.

The SWARM spacecraft and the small mock-up with the antenna accomodation are shown in figure 13 and figure 14.

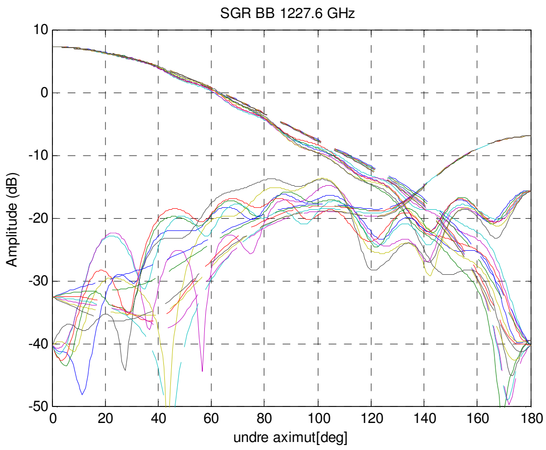


Figure 11: GPS PEC Antenna, L2 Frequency, Radiation Pattern

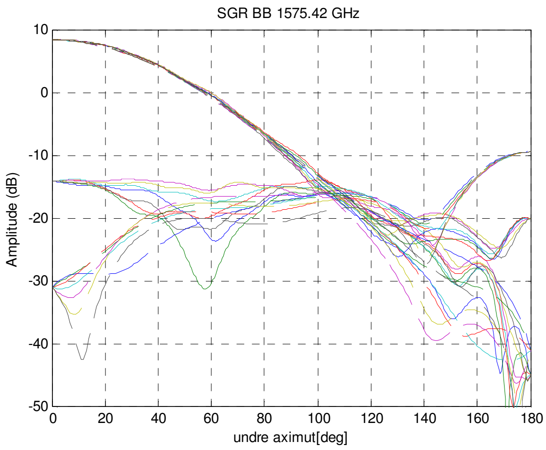


Figure 12: GPS PEC Antenna, L1 Frequency, Radiation Pattern

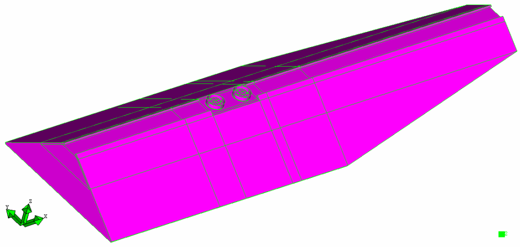
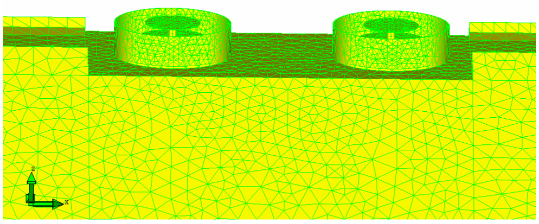


Figure 13: SWARM Spacecraft Model



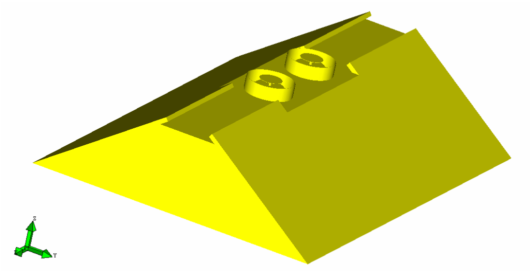


Figure 14: SWARM Spacecraft, GPS antenna accomodation and small mock-up

GPS LNA

For the SWARM programme a dual frequency (L1 and L2) LNA has been developed.

It has one common input port and one output port each for the L1 and L2 frequencies respectively.

The LNA has a very low loss diplexer integrated for separation of the L1 and L2 signals as well as for rejection of unwanted out of band signals.

The LNA can be used together with both the helix and the PEC GPS antennas described above.

The LNA breadboard is shown in figure 15.

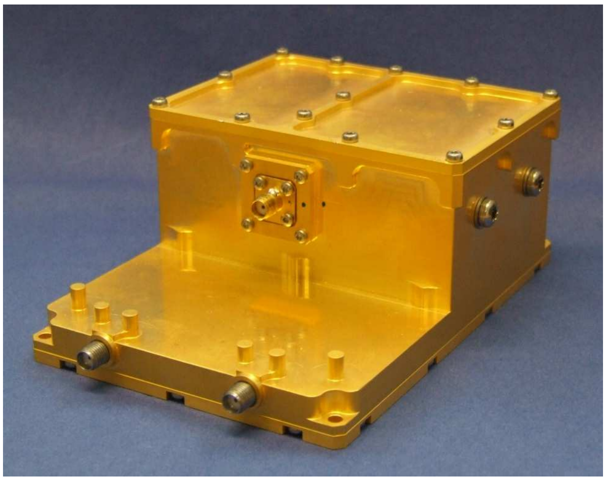


Figure 15: GPS Dual Frequency LNA

The LNA has been breadboarded with good results.

The measured gain is better than 24 dB and the measured noise figure is lower than 1.7 dB.

The mass is 300 g and the size is 142 x 100 x 56 mm^3.

S-BAND ANTENNAS

Small PEC Antennas

A recent S-band development is the GOCE programme PEC antenna.[10]

It consists of a short cylindrical cup with circular cross-section and an exciter.

The cup is excited in the TE11 mode using the stacked circular patch element. It is also narrowed in the opening to achieve a broad coverage, needed in this specific programme.

The lower patch is fed at two perpendicular points via a 90 degree hybrid for circular polarisation generation.

In the design a patented crosspolar suppression technique is implemented.

Flight antennas are shown in figure 16 together with a test cap.

The test cap is used for on ground testing of the antenna and the telemetry and command system, when installed on the spacecraft.

Figure 16: S-Band PEC Antenna

Typical measured antenna patterns (gain min/max envelope for co- and cross-polar radiation) for the antenna are shown in figure 17 and figure 18.

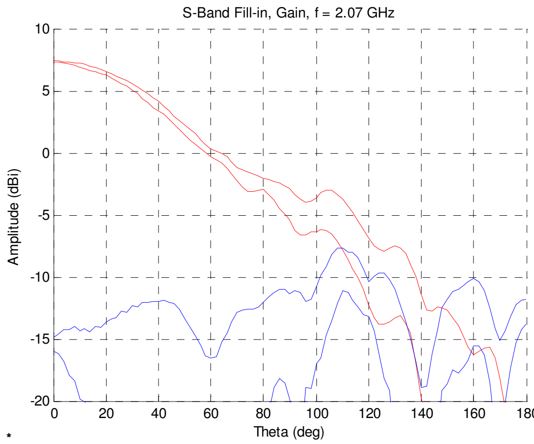


Figure 17: S-Band PEC Antenna, RX Frequency, Radiation Pattern

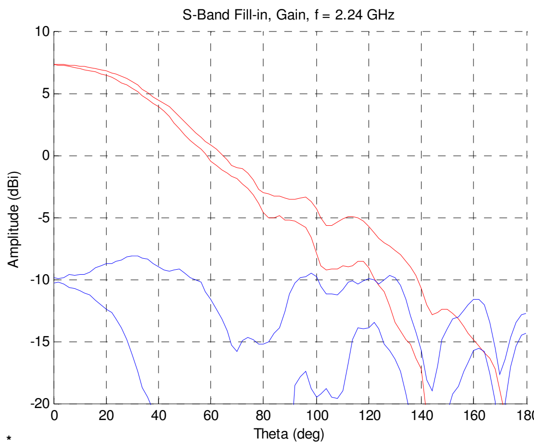


Figure 18: S-Band PEC Antenna, TX Frequency, Radiation Pattern

Large PEC Antennas

Another PEC antenna development was done for the SMART-1 programme, European Space Agency´s (ESA´s) first lunar mission.

It is a medium gain antenna (MGA) which is of the PEC type with three patches. The element design consists of a patch tower with the three patches which is mounted within an thin aluminium cup with a rim height of about a quarter of a wavelength. The two lower patches form a resonant cavity, allowing broadband or double tuning. The upper patch acts mainly as a reflector that affects the illumination of the aperture and is used to improve the aperture efficiency and thereby the gain. The lower patch is fed in phase quadrature at four points by a stripline feed network to give circular polarisation.

The qualification antenna is shown in figure 19.

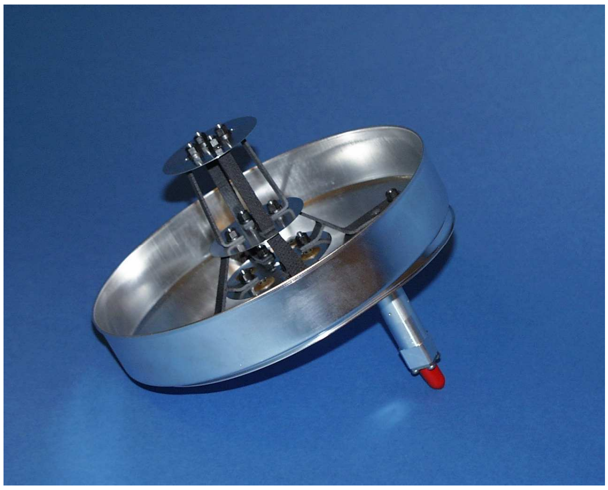


Figure 19: SMART-1, S-Band PEC Antenna

A typical measured antenna pattern (gain min/max envelope for co- and cross-polar radiation) for the antenna is shown in figure 20.

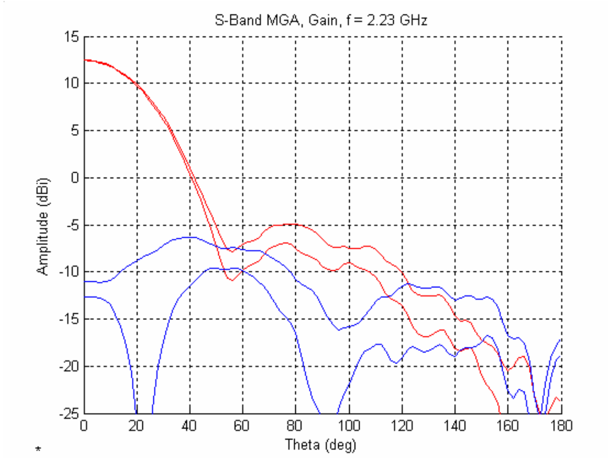


Figure 20: SMART-1, S-Band PEC Antenna, TX Frequency, Radiation Pattern

A new and ongoing PEC antenna development is the transmit antenna intended for the LCROSS mission.

This antenna is an update of the SMART-1 antenna design. It has a modified radiator tower, now an all metal design and a new feed network configuration, an isolated four-point feed design.

It is also, to a large extent, based on the building technique developed for and used in the SWARM antenna mentioned earlier.

A 3D CAD model of the new antenna is shown in figure 21.

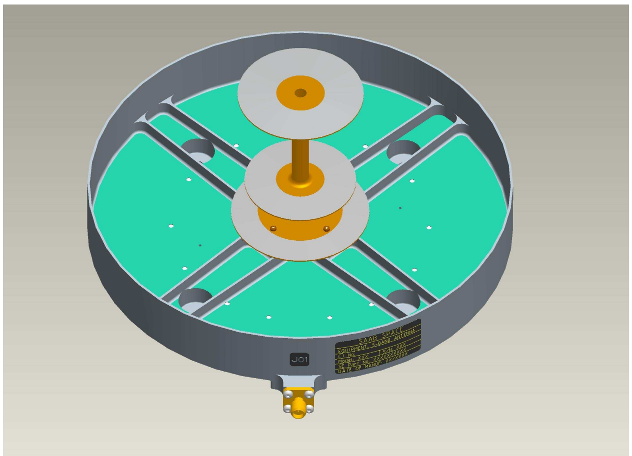


Figure 21: LCROSS, S-Band PEC Antenna

The antenna diameter is 175 mm and the mass is 325 g.

The predicted radiation pattern is shown in figure 22.

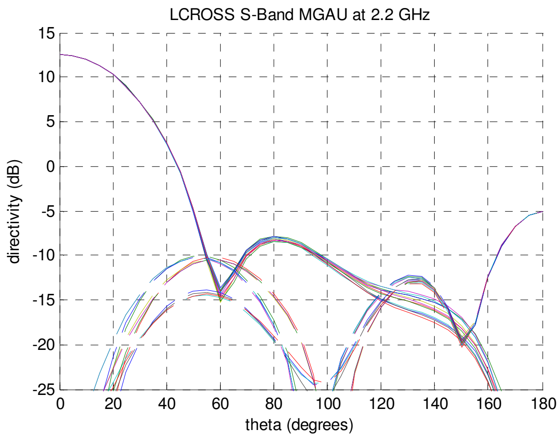


Figure 22: LCROSS, S-Band PEC Antenna, TX Frequency, Radiation Pattern

X-BAND ANTENNAS

Data Downlink Antennas

Saab Space has recently developed an innovative new X-band helix antenna design for isoflux coverage. It is a small, compact and lightweight antenna solution.

It has been developed under an ESA contract to respond to the need for cost effective antennas for down linking of data from low earth orbit (LEO) satellites.[12]

The antenna features a novel, waveguide-fed helix design that has very few parts and therefore offers low-cost production and stable performance with small production variations. It features an innovative all-metal design of the radiator part which can be adapted to a specific customer requirement regarding gain, coverage, polarisation and frequency band. This part is then combined with a radome and a generic septum polarizer, creating a modular system.

While reducing the size and weight compared to the normally used reflector or bicone antennas, the new antenna retains the favourable characteristics of the traditional helix antenna, large bandwidth and good RF performance and it also has high power handling capability.

As the antenna has only a few parts, the assembly sequence is much simplified compared to traditional helix antenna designs.

The standard septum polarizer design has an easily adaptable coaxial or waveguide interface incorporated.

This antenna will be able to replace much larger and heavier designs for data link applications on LEO spacecrafts. The weight is less than 400 g.

A typical flight antenna is shown in figure 23.

Figure 23: X-Band Helix Antenna

Currently, one radiator for 60° edge of coverage (EOC) and several ones for 70° EOC are available in X-band.

More than 15 flight antennas are delivered until now and further antennas are in production.

The antenna type is well suited for frequencies ranging from C-band up to Ku-band.

Typical measured radiation performance in X-band (gain min/max envelope for co- and cross-polar radiation) for the two types (60° and 70° EOC) are shown in figure 24 and figure 25.

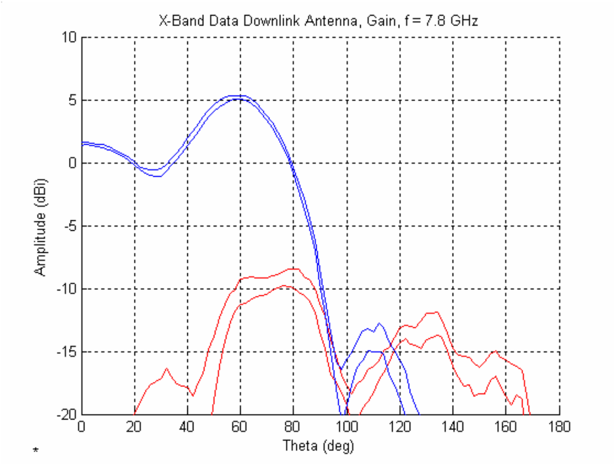


Figure 24: X-Band Helix Antenna, 60° EOC, Radiation Pattern

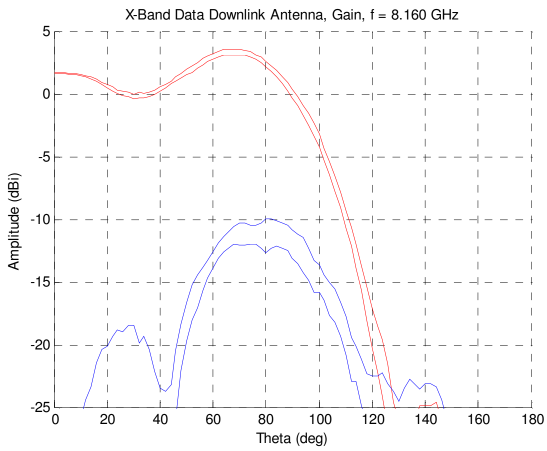


Figure 25: X-Band Helix Antenna, 70° EOC, Radiation Pattern

Dual Frequency Hemispherical Coverage Telemetry and Command Antenna

To respond to the need for dual frequency antennas, combined RX and TX function, a new waveguide antenna has been developed. It uses the generic septum polariser mentioned earlier in combination with a waveguide radiator. The dual frequency hemispherical antenna has been breadboarded with very good results.

The breadboard antenna is shown in figure 26.

Typical measured radiation performance for RX and TX frequencies (gain min/max envelope for co- and cross-polar radiation) are shown in figure 27 and figure 28.

Figure 26: Dual Frequency Hemispherical Coverage X-Band Antenna

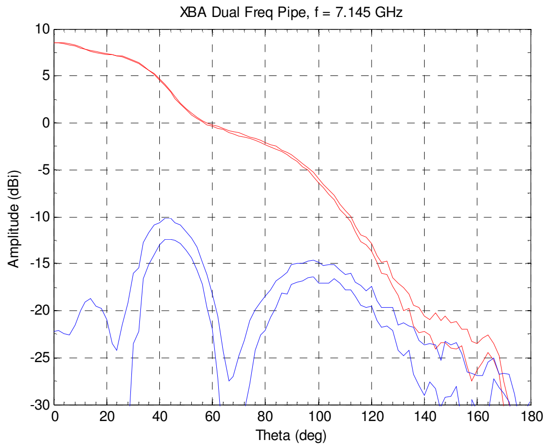


Figure 27: Dual Frequency X-Band Antenna, RX Frequency, Radiation Pattern

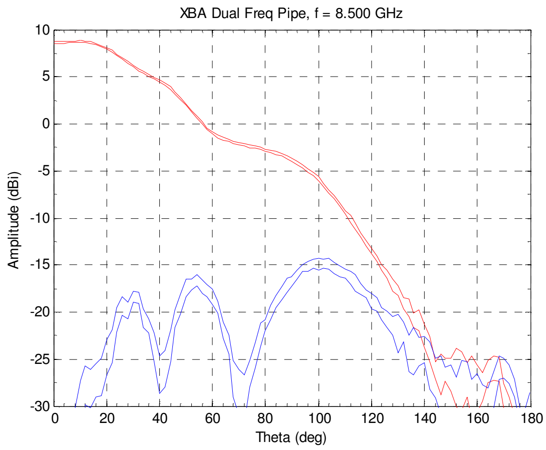


Figure 28: Dual Frequency X-Band Antenna, TX Frequency, Radiation Pattern

Single Frequency Hemispherical Coverage Telemetry or Command Antennas

To respond to the need for single frequency low profile low weight hemispherical or near hemispherical antennas two new PEC antennas are being developed in an ongoing programme.

They both consist of a short cylindrical cup with circular cross-section and an exciter. The cup is excited using a stacked circular dual patch element or a single patch. The lower patch or the single patch is fed in one point and the patch has two opposite perturbations for circular polarisation generation.

The antennas have special features to minimize their coupling to the surrounding spacecraft environment as this is a common problem for low gain antennas of this type and have effect on the installed performance.

3D CAD models of the new antennas are shown in figure 29 and figure 30.

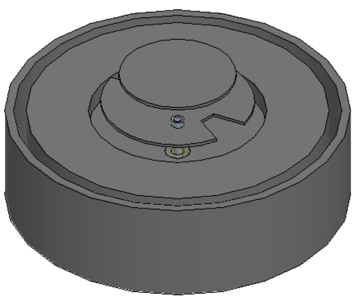


Figure 29: Hemispherical Coverage X-Band PEC Antenna, RX Frequency

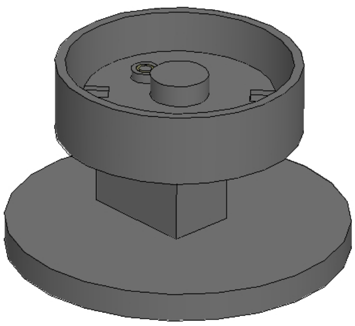


Figure 30: Hemispherical Coverage X-Band PEC Antenna, TX Frequency

The antenna diameter is 60 mm for the RX antenna and 40 mm for the TX antenna.

Both antennas have a mass less than 90 g each.

The predicted radiation patterns for the two antennas (gain min/max envelope for co- and cross-polar radiation) are shown in figure 31 and figure 32.

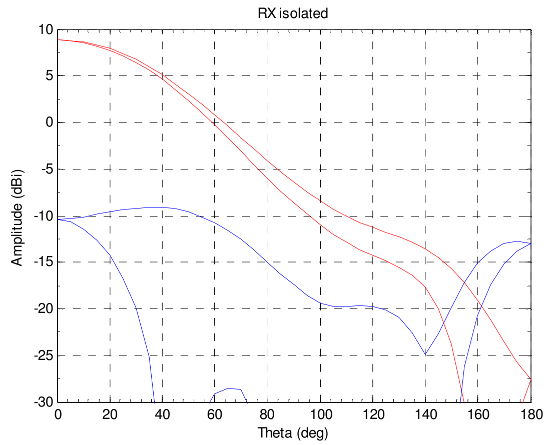


Figure 31: Hemispherical Coverage X-Band PEC Antenna, RX Frequency, Radiation Pattern

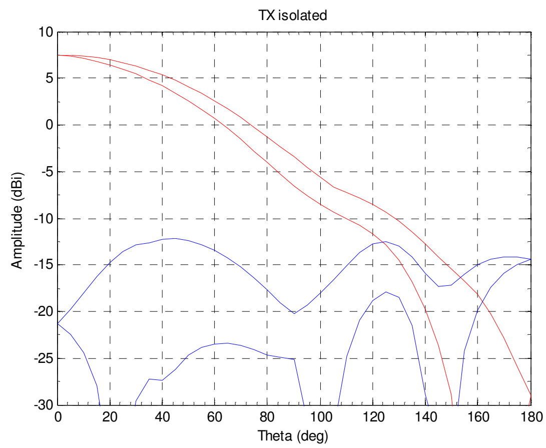


Figure 32: Hemispherical Coverage X-Band PEC Antenna, TX Frequency, Radiation Pattern

ENVIRONMENTAL DESIGN ASPECTS

The normal thermal design for wide coverage antennas is passive. No MLI or other thermal hardware are used. They are designed to perform over a wide temperature range, typically from - 150°C to + 150°C. Some designs even down to below - 200°C.

The wide coverage antennas also need to survive a very harsh mechanical environment during launch, both random vibration and shock. An example of this is the

GPS helix antenna, described above, which needed to sustain and survive a random vibration level of globally at least 36.8 g rms.

Atomic oxygen is also a factor to consider for LEO applications. This can be handled in a variety of ways, for example by using a germanium coted SLI protective cover as in the GPS helix antenna design or by using a resistant surface treatment directly on the antenna.

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