Abstract

EADS Astrium GmbH has developed a new antenna technology based on highly shaped reflectors in combination with low number multi-feed assemblies providing transmit and receive functions for several areas with high mutual isolation requirements from one reflector aperture. This advanced multibeam concept is independent of the frequency bands and can, in principle, be applied for all types of communication services minimizing the number of apertures needed. This minimization leads to a reduction of the antenna farm complexity per spacecraft. The paper describes a typical scenario applying the new technology, starting from the design and ending off with the successful qualification for space environment applications. This new technology is currently being applied for three different mixed C/Ku-Band communication satellites.

1 Introduction

Modern compression techniques in digital satellite communication systems on the technical side and the economical crisis in the communication market on the commercial side lead to a considerable overcapacity in satellite transponders currently available in orbit. Consequently the market in communication satellites has dramatically dropped, leading to an increased competition between the satellite providers with a strong pressure on cost and schedule. As a further consequence the satellite operators are forced to more efficient use of their future satellites. This itself leads to a high level of payload integration with sufficient flexibility to allow for adaptations in the market requirements, which today are nearly impossible to predict over the full duration of a satellite's life span (typically >15 years).

Concerning the payload design, in particular considering the antennas, the upper described situation demands for the following needs on the antenna design:

- Multiple use of the antenna aperture, providing multiple beams over an increased set of frequency bands from a single aperture (as reaction to the increased payload integration requirement),
- Increased RF power handling capabilities (as a consequence of the compressed use of the frequency spectrum),
- Reduced delivery times and easy integration on the spacecraft (as tribute to the commercial requirements).

In order to fulfil the above mentioned antenna requirements, EADS Astrium GmbH has developed a novel multibeam antenna concept as an interesting complementation to their classical combined multifeed technology. The concept uses a highly shaped reflector surface, fed by an assembly of a few feedsystems only. This leads to a considerable reduction of the feedsystem complexity (with the entailed design and manufacturing time) and enabling for increased RF power handling and frequency bandwidth capabilities.

2 The Concept

The novel antenna concept (see Fig. 1) is an extension of the classical "single feed per beam" multibeam architecture where each generally contoured beam is unequivocally allocated to one feed. In the extended concept the reflector surface is shaped such that each contoured beam can be allocated to two different physically separated feeds, i.e. each of these two feeds generates the same footprint of the beam.

Fig. 1 An example of the advanced multibeam antenna concept
The advantage of this novel architecture is that the second, so to say redundant, feed can be used for:

- a separate frequency band, if the frequency separation doesn't allow for a compact high performance single feed design.
- the same frequency band, if for example the RF power cannot be handled by a single feed chain due to multipaction or thermal constraints
- flexible channel switching where, depending on traffic, market or license developments during the lifetime of the satellite, channels from additional service bands can be added to a coverage without needing a complex multiplexer and channel switching matrix design.

Like the classical multifeed antenna the new concept allows for a high order of frequency re-use by achieving high isolation between different coverage regions. The limitations of the antenna concept (numbers of beams, magnitude of isolation etc.) are determined by the minimum radius of curvature of the shaped reflector surface for which current state of the art manufacturing technologies is limited to about 35 to 40 mm.

3 Design & Development Process

A block diagram showing the flow of events during the design and development process is shown below.

- Requirements:
  - Based on the given antenna specification, the basic antenna geometry is defined and optimization goals and constraints are derived. Typical requirements are:
    - Launcher and spacecraft (S/C) constraints defining maximum reflector size, focal length, stiffness and thermal requirements
    - Coverage definitions for one or more contoured beams
    - Channel allocation plan defining transmit and receive frequency bands with at least 15% bandwidth each
    - Large gain area products
    - Co-polarization Isolation or side-lobe constraints of at least 27 dB
    - Cross polarization isolation of better than 27 dB.

- Optimization:
  - The optimization of the reflector surface shape and feed horn locations are performed using TICRA’s POS4 software. This program uses physical optics (PO) method for reflector computations.

- Feasibility:
  - Checks are performed on the optimized antenna geometry:
    - The local radii of curvature of the reflector surface should be maximized to ensure low manufacturing risk and costs
    - Reflector and feed system have to be accommodated on the S/C and must comply with the launcher specifications
    - Sufficient clearance between antenna (feed system, reflector) and S/C must exist to avoid RF performance degradations due to scattering effects.

  If one or more of the above criteria are violated the antenna and/or S/C geometry have to be changed, and the optimization process must be repeated for modified or additional constraints.

  If the above criteria are fulfilled, a detailed analysis phase as described below is performed.

- RF Analyses:
  - The different analysis tasks are performed using TICRA’s GRASP8 software. This program is very flexible and allows for a wide range of sources and multiple geometries of scatterers made from conductive, as well as dielectric material. The computation methods range from PO, physical theory of diffraction (PTD) through geometrical theory of diffraction (GTD).
    - Convergence must be ensured for the PO calculations
    - Manufacturing tolerances of feed components and reflector surface are analysed, and their impacts on RF performance have to be considered

Fig. 2 Antenna Design Flow
RF performance degradations due to thermoelastic distortions of feed components and reflector surface must be evaluated.

Impacts of certain elements of the antenna structure have to be assessed.

Parts of the S/C structure are modelled in order to ensure that interactions between antenna and S/C do not considerably degrade RF performance. Initially the above discussed contributions are considered using uncertainty budgets derived from heritage programs. With progressing component design status (see below) more accurate data is fed into the RF analyses, so that realistic RF performance predictions are obtained.

If the above analyses show considerable RF performance degradations the antenna and/or S/C geometry have to be changed, and the optimization process must be repeated for modified or additional constraints.

• Component Design:
The feed components (e.g. horns, transitions, polarizer, etc.), reflector, and assembly structures must be designed to fulfil the requirements derived from the RF optimizations (surface shape, mechanical tolerances, thermo-elastic deformations), as well as mechanical and thermal constraints (mass, stiffness, interface specifications, thermal stability)

• Predicted Performance:
Finally the antenna performance based on verified uncertainties derived from analyses performed during component design phase is predicted. These predictions have to comply with the RF specifications. Furthermore the predicted thermal and mechanical behaviour of the antenna has to ensure that all elements function properly after launch and under the harsh space environment encountered during the on orbit lifetime of the spacecraft.

A typical RF gain contour plot overlaying predicted and measured performance is shown in Fig. 6.

4 Manufacturing

After the successful closure of the design and development phase, the various elements of the antenna can be manufactured.

4.1 Reflectors:
The typical manufacturing time span for the reflectors is of the order 8 months. One of the most challenging requirements for the reflector manufacturer of shaped surfaces is the radius of curvature. To date, values as low as 35 mm are feasible. The typical size, mass and achievable manufacturing tolerances of the reflectors are listed in Tab. 1 below.

Two representative examples of manufactured highly shaped reflectors for applications in C-band are shown in Fig. 3 and Fig. 4.

| Mass: | 20-30 Kg |
| Aperture size: | < 3.2 x 2.7m |
| Manufacturing tolerances: | < 0.15 mm RMS |
| Radius of Curvature | > 35 mm |

Tab. 1 Key manufactured reflector data

4.2 Feed assemblies:
The feed assembly (FAS) consists of a feed support structure and the various feedsystems. Depending on the given design requirements, a typical feedsystem consists of a horn, transition, polarizer or diplexer and waveguide run or co-axial cables. Fig. 5 shows an example of a complete integrated feed assembly. Certain key characteristic data related to previously manufactured feed assemblies can be found in Tab. 2.

| Manufacturing time: | < 7 months |
| Mass of feed assembly: | 20-35Kg |
| Size (LxWxH): | 1.6x1.3x1.0 m |

Tab. 2 Key manufactured Feed assembly data

Fig. 3 An example of a manufactured highly shaped single shell reflector (Min. radius of curvature = 37 mm)

Fig. 4 An example of a manufactured highly shaped dual gridded reflector (Min. radius of curvature = 50 mm)
5 Testing

The test sequences antennas are subjected to consist out of functional testing and environmental testing. The aim of the functional test is to ensure that the antenna or elements of it perform as expected in terms of the designed for RF performance characteristics. An illustrative example of the antenna level EOC gain functional test is shown in Fig. 6. As can be seen, an excellent correlation exists between the design for and measured performance. The beams given in the figure stem from one transmit feed aperture. For this particular application, a similar receive function result is generated by a separate feed aperture within the given feed assembly.

The emphasis of environmental testing on the other hand is to ensure that the thermal and mechanical integrity of the antenna system remains intact during launch and expected in orbit lifetime.

The exact test plan and philosophy followed varies largely from one program to another. An illustration of the tests which have been performed together with the achieved test levels of a space qualified C-band antenna are outline in Tab. 3 below. The given levels tested to stem from either the given system level requirements or detailed analysis performed during the Design and Development phase mentioned in section 3 of this paper.

The complete test campaign can last anything between 2 to 4 months depending on the complexity of the testing philosophy followed. The total delivery time for the complete antenna ranges between 18 to 24 months.

Tab. 3 Summary Table of Environmental and Functional test sequence performed

![Fig. 5 A complete manufactured and integrated feed assembly for a C-band application](image)

![Fig. 6 Functional testing: Measured EOC Gain (Predicted versus Measured)](image)

5 Conclusion

EADS Astrium GmbH has developed a new novel multibeam antenna concept as an interesting complement to their classical combined multifeed technology. This novel concept is currently being applied to three different mixed C/Ku band communication satellites.