

# Flexible Payload Technologies for Optimising Ka-band Payloads to Meet Future Business Needs

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## ABSTRACT

Interest in flexible payload technologies has grown significantly over the last two years. Astrium is at the forefront of technology developments for analog and digitally processed flexible payloads. The Generic Flexible Payload (GFP) program of work undertaken between the European Space Agency and Astrium was a flagship program run over a 6 year period. The primary goal of the program was to design, develop, and qualify an active flexible input section which allows the payload to be as transparent as possible. The GFP analog flexible payload technologies have led to conventional and flexible spin-off developments with further equipment evolution planned.

Supported by ESA, Astrium's extensive heritage in mobile processed payload missions was leveraged for the Next Generation Processor development resulting in Astrium's current processor product flying on Alphasat and now in the IOT phase. As Astrium plans and executes its research and development activities for the future processor capability the two architectures from GFP and NGP programs provide complementary capability for offering agile processed payloads providing the highest levels of flexibility and genericity. These together with flexible coverage and power flexibility enable the vision of a truly generic flexible payload.

This paper will outline the key technology developments applicable to future Ka-band payloads and includes:

- Astrium antenna technologies, both passive and active, for both wide coverage and multi-beam solutions:
  - Mechanically steerable conventional reflectors
  - Active or semi-active electronically steerable antennas.
- Astrium flexible spectrum management technologies including:
  - Use of agile converters & evolution of Generic Flexible Payload (GFP) equipment: planned future developments and current equipment capability including Ka-band multi-pack developments.
  - Flexible channelization via analog technologies: current and future developments.

➤ Digital signal processing capability and evolution.

- Astrium flexible power management technologies including:
  - Flex-MPMs for in-orbit variation of saturated power by 0-3dB.
  - Phase Combined TWTAs offering the potential to increase the power by a factor of 2.
  - Multi-port amplifiers (MPAs) offering the maximum flexibility for variation of power to beams.
  - Active transmit antennas can provide both coverage and power exchange between beams.

The level of flexibility required and commercial benefits offered vary according to mission type and payload architecture. The typical Ka-band payload types seen include:

- Multi-band missions including a Ka-band payload in conjunction with other bands e.g. C/Ku.
- Multi-mission payloads offering a range of services – broadband, broadcast, star & mesh connectivity.
- Large Ka-band broadband satellites with a high number of beams and demanding accommodation requirements.

Whilst it is clear that flexible payloads are of great commercial interest the design and implementation of the flexible payload need to ensure the optimum balance between the levels of flexibility provided and cost, mass, power etc. This is clearly also dependent on the mission type and service needs. This paper provides an overview of Astrium flexible equipment portfolio and plans for future developments. Future flexible payload technologies for spectrum, power and coverage flexibility are outlined and their applicability to meet future Ka-band payloads is discussed.

## Market Drivers: Cost Per Bit

The business cases for new communications missions are under constant pressure from both competition within the space segment and also from terrestrial solutions. We find that services continuously require more and more band-

width, whilst transponder lease rates have to remain competitive and the available spectrum is becoming scarcer due to limited orbital slots, frequency allocations and interference management issues. Such issues are currently very important drivers in C and Ku band and would be expected to progressively impact Ka band as its uptake becomes more widespread. Meanwhile satellite based solutions continue to suffer from high operational cost when compared with many terrestrial equivalents due to both the space segment and its associated terrestrial gateways being expensive to finance. Traditionally satellite links have always operated with large margins to account for rain fade, whilst still a driver (particularly in Ka band) this impact is being reduced with the application of adaptive modulation and coding schemes becoming more widespread.

The situation is shown in Figure 1.

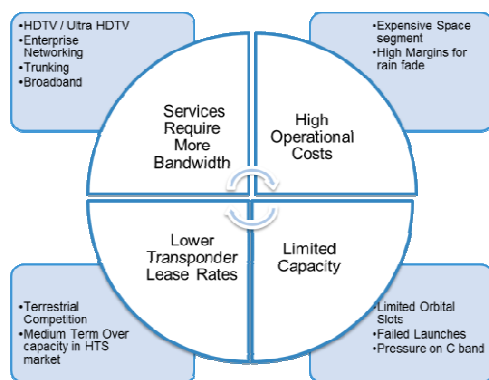


Figure 1 Business Case Drivers for Satellite Communications missions.

In response to this, satellite solutions must continually strive to reduce cost per bit. Cost per bit can be reduced by either:

- Reducing the procurement cost of the satellite system
- Increasing the operational revenue of the satellite system.

Historically reductions in cost per bit have been achieved through increasing payload power or increasing satellite design life. A recent trend has also been towards multi-beam missions with increased mission capacity through the application of frequency re-use in multi-beam antennas. These trends are summarized in Figure 2

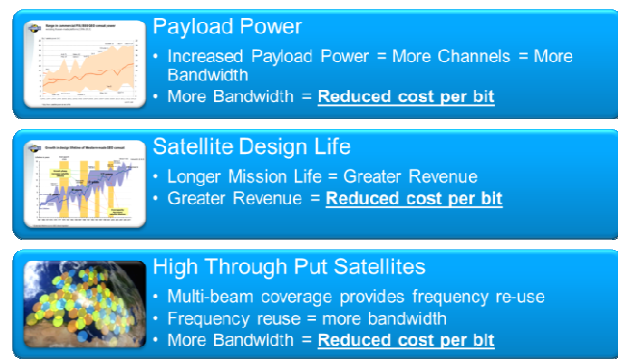


Figure 2 Historic Approaches to Reducing Cost Per Bit

However these historic approaches to reducing cost per bit are now indirectly leading to a new wave of commercial drivers for payload flexibility. For example cost per bit can be reduced by increasing mission design life (greater revenue earning potential). However, with many communications missions now specified at 18 years design life it becomes very difficult for the operator to plan a robust business case over such a long period. This situation is further complicated by the trend to reduce cost per bit by increasing the payload power or number of communications channels. This trend means that the initial investment in the spacecraft is higher and the need to accurately predict the business case correspondingly greater.

These market drivers are increasingly becoming manifested in many operators “hedging their bets” by adding many more conventional payload equipment’s (antennas, down converters, IMUX and OMUX) than can be operated at any given time simply to provide some degree of flexibility in modifying the configuration of the spacecraft during its long life. However, this approach has limitations in commercial effectiveness due to the need for additional spacecraft resources and accommodation, which become potentially cost-drivers especially when coupled with launcher constraints. On this basis the business case for flexible payload equipment’s is becoming increasingly important.

### Market Synthesis

In order to define the most important business drivers for flexible payloads it is important to take stock of market trends. Market analysis predicts that the yearly demand for Geo communications missions will be roughly 20 units per year over the next 10 years. This market is roughly split into two types of mission. The first type which represents roughly 75% of the market is the classical wide coverage mission within which the major services provided are television broadcasting, video distribution, enterprise networking, trunking, backhaul and VSAT. The major growth in this segment is considered to come from TV particularly in emerging markets such as Asia and South America. The need for flexibility in this market is more strongly driven by services such as video distribution, enterprise networking, and governmental applications. This “flexible wide coverage market” represents roughly 7 satellites per year.

The second major market segment is the High Throughput Satellite or HTS mission segment. These missions are often characterized by multi-beam antenna configurations employing frequency re-use to increase operational capacity. These types of mission can offer capacity increases of up to 10 times compared to a conventional wide coverage mission with many on-going programs targeting capacities of over 100Gbps. The majority of these missions have in the past been limited to broadband applications in Ka band. Such systems have not typically required a large amount of flexibility as the relationship between the gateways and the users within the coverage is easily known and planned for. However the market has seen a recent trend to targets the introduction of multi-beam technology in traditional Ku band for conventional services. Whilst such an approach provides major increases in capacity, retaining backwards compatibility with conventional services for flexible services such as VSAT requires that the this type of mission includes a highly flexible payload able to provide beam to beam connectivity. Typically, this connectivity must be provided with high spectrum efficiency (i.e. a few MHz granularity) necessitating the need for an on board digital processor. This market whilst highly valuable remains limited to roughly 5 spacecraft per year but could be expected to grow.

### Three Axes of Flexibility

Having considered the primary market drivers for payload flexibility it remains to categorise and discuss the available technologies applicable to these market segments. Payload flexibility can be broken into three primary capabilities, each of which is complementary to and interdependent on the others. This is conceptually shown in Figure 3

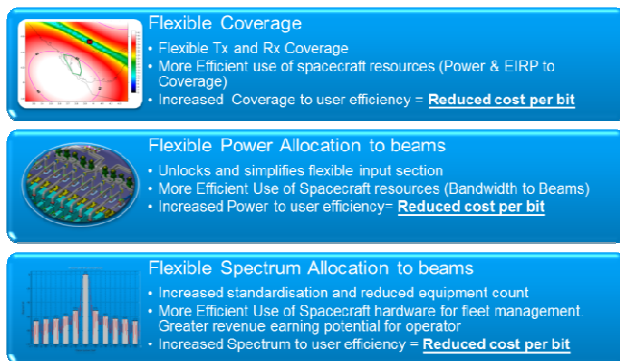


Figure 3 Three Axes of Payload Flexibility

Each of the three primary flexible payload capabilities is discussed.

### Flexible Coverage Solutions

Flexible coverage is perhaps the most important of all three flexible capabilities because the mission coverage effectively determines what geographical regions of the earth the satellites key resources (G/T and EIRP) are targeted at. Hence flexible coverage has the biggest overall impact on mission planning and the ability of the mission

to service new emerging markets. Within the wide coverage market segment, flexible coverage is also becoming increasingly important to generate value in new services such as governmental UAV which by their very nature require high performance flexible spots beams. An additional driver within this market is interference management where a flexible antenna can be essential to ensuring that the operational mission is not compromised by either intentional or un-intentional signals.

Flexible coverage is further segmented into receive and transmit capabilities and within both transmit and receive various technical solutions can be proposed including:

- **Direct Radiating Arrays (DRA):** Characterised by an array of antenna elements and a corresponding beam former.
- **Imaging phased arrays (IPA):** Characterised by an array of antenna elements, a beam former and an additional reflector system the purpose of which is to provide optical magnification thereby augmenting the size of the primary array to produce improved directivity.
- **Array Fed Reflectors (AFR):** Which are flexible multi-feed per beam antenna's that operate using multipoint amplifiers to allow inter beam power exchange. A further benefit is that both phase and gain tapering within the beam-former is possible without compromising amplifier efficiency. Note such solution could be implemented using either analogue or digital beam-forming technologies.
- **Confocal antennas:** Which are special cases of imaging phased arrays making use of two reflectors to provide optical magnification thereby offering additional flexibility for accommodation.
- **Lens Antennas:** Are a special case of direct radiating array (DRA). Characterised by an array of elements supplemented by a RF spatial lens beam-former built of a series of back to back feeds.

Examples of active antennas developed by Astrium are shown in Figure 4, Figure 5 and Figure 6

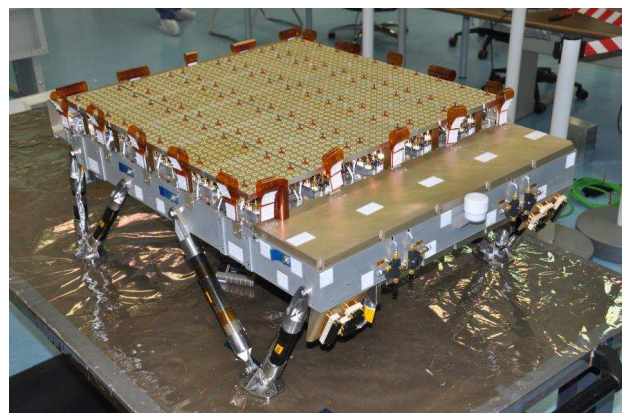


Figure 4 Example of Astrium Receive Direct Radiating Array Technology (CASA)





Figure 5 Example of Astrium Ka band Lens Antenna (Space Engineering)



Figure 6 Example of Astrium AFR technology

Flexible coverage in the multi-beam market is currently less in demand than flexible coverage in wide coverage markets nevertheless Astrium can provide solutions ranging from conventional steerable spots to multi-feed per beam antennas such as the so called MEDUSA feed array shown in Figure 7.

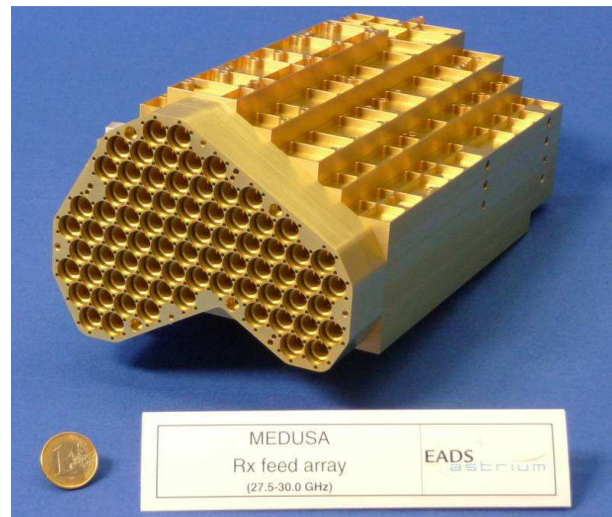


Figure 7 Example of Astrium Ka band Multi-feed per beam antenna technology.

### Flexible Spectrum Management Solutions

Flexible Spectrum management is the second major category of payload flexibility and is inherently related to both flexible coverage and flexible power. Indeed once flexible coverage capability is established flexible spectrum management capabilities are called for due to the inherent coupling between the allowable frequency allocations in different orbital slots, meaning that the frequency plan is modified as the coverage is modified. Flexible coverage also implies modification to the amount of capacity directed to geographical regions.

For a fixed modulation scheme if we vary the amount of capacity directed to a certain region we also implicitly imply a variation of the corresponding spectrum directed to that region. Furthermore if the enabling features of flexible coverage such as interference management are to be fully utilised a flexible frequency plan can be very beneficial to allow features such as spectrum notching and flexible routing of spectrum between up and downlink beams.

It is also important to note the implicit link between flexible output section and the cost models for flexible input sections. For example an active antenna provides a flexible pool of downlink power which can be directed to any given coverage. The generation of this power does not require a fixed downlink frequency plan derived through IMUX / OMUX solutions as implemented in conventional missions. This has three primary benefits, the first is essentially an unlocking of input section flexibility, the second is a potentially major increase in standardisation and reduction in equipment count within the input section. This reduction in equipment count is because the non-channelized output section does not require the input section spectrum to be channelized into, for example, 36MHz transponders, but could in principle be routed to the antenna ports in wideband block-converted chunks of 250MHz. Thus a substantial reduction in the quantity of

input section units is possible. This reduction means that technologies such as Astrium's generic flexible payload become a very efficient means to route large amounts of flexible spectrum to downlink antenna ports. The third major benefit is that the removal of the channelization process essentially improves spectral efficiency by enabling the spectrum previously lost to IMUX / OMUX guard bands to be recovered. The removal of the channelization process also acts to reduce group delay variation a parameter which is shown to have detrimental impact to higher order modulation schemes.

Astrium has provided various technical solutions for flexible spectrum management ranging from agile down converters RD[3] to flexible analogue processors (Generic Flexible Payload) to flexible digital processors. Examples of these technologies are shown in Figure 8, Figure 9 and Figure 10.

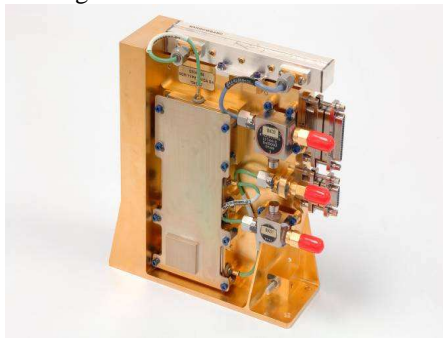


Figure 8 Example of Astrium Agile Converter Technology

A functional block diagram of the generic flexible payload architecture is shown in Figure 9 RD[1,2]. The Generic Flexible payload architecture takes a similar form to a conventional payload.

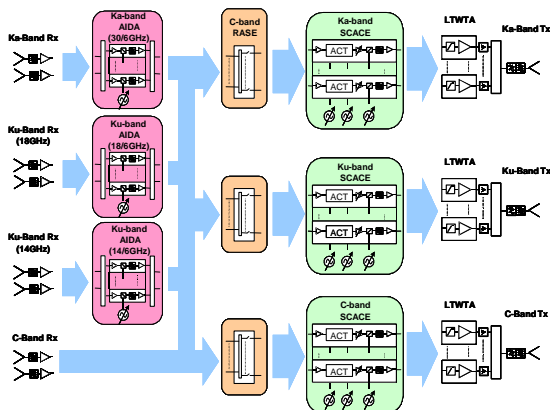


Figure 9 Generic Flexible Payload

The GFP architecture is essentially a fully generic “software defined” input section capable of replicating the frequency plan of any conventional mission by telecommand, either on ground or in orbit. The GFP design is compatible with all communications uplink and downlink bands (C, Ku and Ka bands) and when paired with a suitable output section (MPA or active antenna) allows fully flexible spectrum management with very few equipment's. The GFP design is compatible with full beam to beam connectivity but also provides full cross

connectivity potential between frequency bands. An additional benefit of the GFP design is that it can provide “hosted payload” like capability for governmental or military Ka band simply by tele-command with no additional hardware needed. This could allow the ability to seamlessly share the spacecraft's resources between traditional communications applications and new emerging or time varying markets.

For conventional wide coverage missions, technologies such as GFP can provide a highly flexible input section solution with low equipment count. This technology is likely to be an optimum solution for all but the most demanding requirements for input section spectrum management. However, analysis has shown that if input spectrum is required to be channelized and routed at bandwidths of less than a few 10's of MHz, digital processing becomes a more efficient solution than analogue processing. For most wide coverage applications this appears not to be a major driver, however multi-beam missions serving applications such as flexible FSS services are likely to require narrowband mesh channelization to maintain backwards compatibility with existing wide coverage missions. Astrium is therefore able to offer a state of the art solution for digital processing which is applicable to multi-beam C, Ku or Ka band missions serving FSS applications.

Figure 10 shows Astrium's current generation of digital channelizer RD[4]. This product now has heritage on the Inmarsat ALPHASAT mission and offers 14 (12 active) ports each capable of processing 250MHz bandwidth or a total processed bandwidth of circa 3GHz.

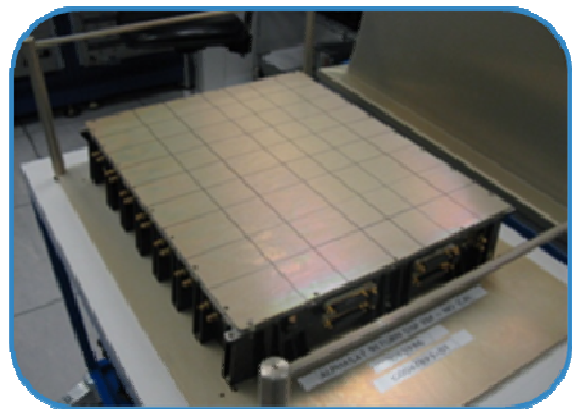


Figure 10 Example of Astrium Digital Processor Technology

Clearly digital processing requires that the RF spectrum is downconverted to baseband or IF for digital sampling. The RF converters needed for this purpose can be major cost drivers. Astrium continues to develop this product along with a new generation of digital processor aiming to minimize the cost, mass and accommodation impact of the RF converter units by implementing IF sampling, and direct agile conversion.

For Ka band multi-beam missions ASTRIUM is also developing a “multi-pack” Ka band receiver and down con-



verter equipment's. These equipment's offer multiple benefits including:

- Mass power and cost reduction due to centralized "service section"
- Wideband operation due to application of novel mixer technologies capable of offering improved carrier related spurious performance.
- Flexibility in translation frequency by utilising a centralized Master Local Oscillator (MLO) based architecture allowing different frequency local oscillators to be switched to different converter chains.

The EQM Ka band multipack equipment is shown in Figure 11

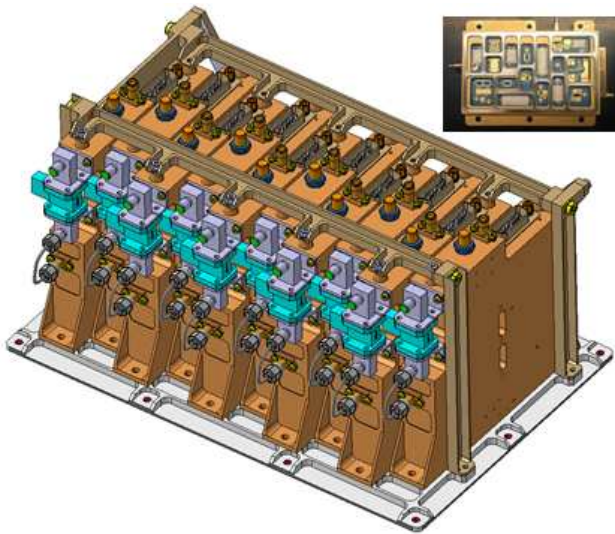


Figure 11 Ka band Multi-pack EQM equipment.

### Flexible Power Management Solutions

In some applications full coverage flexibility may not be required. In these cases the operator may prefer to implement the coverage using conventional antennas. In such situations multi-port amplifiers (MPA) are a key technology which offers benefits to payload design RD[5]. The multiport amplifier acts as a flexible "power pool" able to direct anything between no power and the combined sum of the power of all its amplifiers to a given output port. In essence the MPA provides the flexibility to exchange power between its ports (or beams when connected to antenna ports). Furthermore the MPA (in common with active Tx antennas) also removes the need for channelization thereby providing the benefits to input section units previously mentioned. The removal of the process of channelization can also provide major benefits to the output section design simplifying layout of waveguide runs and in some instances even reducing reflector count. On this basis Astrium continues to develop its MPA capability both internally and with partners. Figure 12 shows an image of Astrium's Ka band MPA INET/ ONET breadboard developed by MM Microwave.

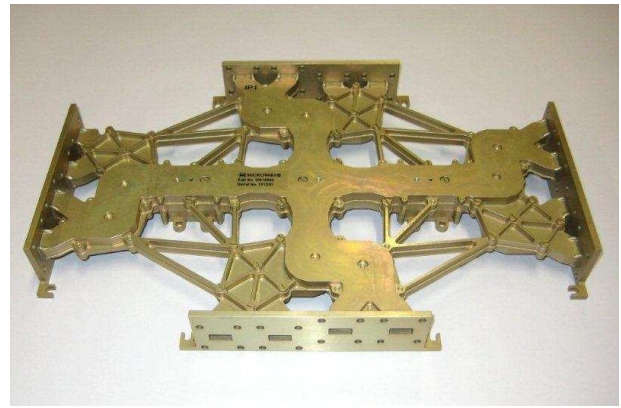


Figure 12 Example of Ka Band INET / ONET Technology

Figure 13 shows an image of a Ka band phase shifter developed by Astrium and MESL. This phase shifter is an important part of the MPA allowing calibration of the phase shift within each path thereby ensuring that port to port isolation specifications can be achieved.



Figure 13 Example of Phase Shifter Technology developed by MESL for Astrium

### Summary & Conclusions

This paper has discussed the market drivers leading to an increasing demand for flexible payloads. It has been shown that payload flexibility can be broadly categorised into 3 major axes: coverage, spectrum and power. Astrium's technical solutions within each of these domains have been summarised along with the potential benefits provided.

### Acknowledgements

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