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# METHODS TO INCREASE THE FLEXIBILITY OF TELECOMMUNICATION SATELLITES

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## ABSTRACT

Telecommunication satellites are acting on a very competitive and demanding market. Communication satellites have to enter a new age of flexibility or become extinct. In this study, flexibility requirements are investigated and payload architectures are proposed to meet these flexibility demands coming from satellite operators. Coverage flexibility, frequency plan flexibility and power flexibility are considered in terms hardware, software and feasibility. Hybrid flexibility figures may also be added by implementing necessary modifications. In the upcoming satellites, short term advancements will be used. Long term modifications are also studied to be used in the next generation satellite fleet.

## INTRODUCTION

Fixed-service communication satellites were designed for specific particular mission (coverage, frequency plan, linear or circular polarization, Equivalent Isotropic Radiated Power (EIRP)) until now, with no or very limited capability to re-configure the satellite during its lifetime. The evolution shall be in two ways: giant satellites or adaptation. Giant satellites are cost effective but lacks flexibility and increase risk. The first solutions to introduce some on-board flexibility were based on classic devices already used on board satellites, such as electro-mechanical RF switches and driving motors for antenna beam steering. These solutions are robust, but have very limited flexibility and require the use of additional on-board hardware. Although active antennas and digital beam-forming networks appear to be ideal solutions today, they present some drawbacks like intermodulation effects generated by multi-carrier amplification.
In this study, adequate payload solutions proposed for the short/medium term, based on mature technologies that optimize the capability for service flexibility with minimum impact on the satellite in terms of mass, power and cost. It also aims to reduce non-recurring costs and satellite delivery times.

### Payload technologies: current options and flexibility needs

All the current spacecraft solutions are based on customized designs, which result in significant nonrecurring costs and relatively long development schedules. Recent developments that led operators to consider the benefits of moving towards flexible commercial satellites are;
• The option to deploy a spacecraft in many different revenue earning roles throughout its life will enhance overall return on investment.
• An increased ability to back up satellites in the fleet by using flexible spacecraft.
• The possibility to limit the number of spacecraft designs, to shorten manufacturing time and reduce costs.
• The need to start replacing the fleet in three years.
• The increasingly rapid changes in telecommunications, together with the increasing lifetime of modern spacecraft.
• The recent initiatives of the U.S. satellite industry (Boeing, Lockheed, Loral) to commercialize technologies developed for military applications.
Typical attempts from operators for in-orbit flexibility are;
- Coverage flexibility: This is the major need for flexibility in order to achieve in-orbit capability to provide coverage adaptation as a function of the satellite orbital position, beam steering capabilities, and/or generation of new coverage,

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- Frequency plan, connectivity and routing flexibilities,
- Possible change of the channelization,
- Flexible allocation of channels to different beams,
- In-orbit EIRP flexibility,
- Polarization flexibility.

## PROPOSED METHODS

Two target architectures, channelized and non-channelized, are seen as being the most representative of the solutions that address the operators' needs.

### Flexible Payload Architectures

Channelized flexible payload:

The payload remains based on a channelized repeater (i.e. dedicated input/output filters and TWTA (Traveling Wave Tube Amplifier) per channel), with little flexibility in terms of adaptation of the frequency plans associated with passive flexible antennas. The major flexibility achievable within such an architecture consists of:

• coverage flexibility according to the use of passive flexible antennas (mechanically steerable antennas or electrically reconfigurable antennas);

• The power flexibility derived from the use of flexible TWTAs. It is also possible to amplify a few channels through a multiport amplifier architecture (MPA) to offer flexibility in terms of capacity. Figure 1 illustrates the general principle of the architecture.

Non-channelized flexible payload

The payload is based on a flexible core permitting the separation and routing of all the uplink signals (channels or subchannels) associated with a distributed amplification performed within an active antenna (Figure 2). This architecture offers a very high degree of flexibility:

• Rx coverage flexibility due to the use of passive flexible antennas;

• Tx coverage flexibility due to the use of an active antenna;

• High flexibility in the frequency plan, due to the use of a processor permitting the separation of all uplink channels and sub-channels, to route all of them from any input to any output and to recombine channels before amplification;

• Distributed amplification within the antenna, compatible with a large variety of frequency plans.

### Coverage flexibility

If no frequency plan flexibility is required, the simplest and most economical solution consists of keeping the classic channelized repeater. In this case, the antenna solutions are passive ones, mechanically or electrically reconfigurable.

Mechanically reconfigurable passive antennas

Mechanically steerable and zoomable passive antennas (Figure 3) are already available in Turksat fleet. The antenna (Gregorian architecture) generates one beam (circular or elliptic) per polarization, and beam-pointing can be achieved by the two rotation axes (N/S+E/W) of the antenna. In case of an elliptical spot, the ellipse orientation is made possible by the rotation of the sub-reflector.Zooming capability (for example, spot size extension from 1°to 7°) is achievable by the mechanical translation of the main reflector on the focal axis.

A new solution consists of the use of a printed reflectarray(a flat panel reflector composed of reflecting cells fed by the antenna feed). Each cell receives radiating power from the feed, and reflects the wave with a given phase permitting contoured beam coverage. Only one contoured beam can be generated by one passive reflect array, but as the panel is flat, it is possible to superpose several panels dedicated to particular coverage areas (like the pages in a book), and to select in orbit the panel corresponding to the desired coverage.

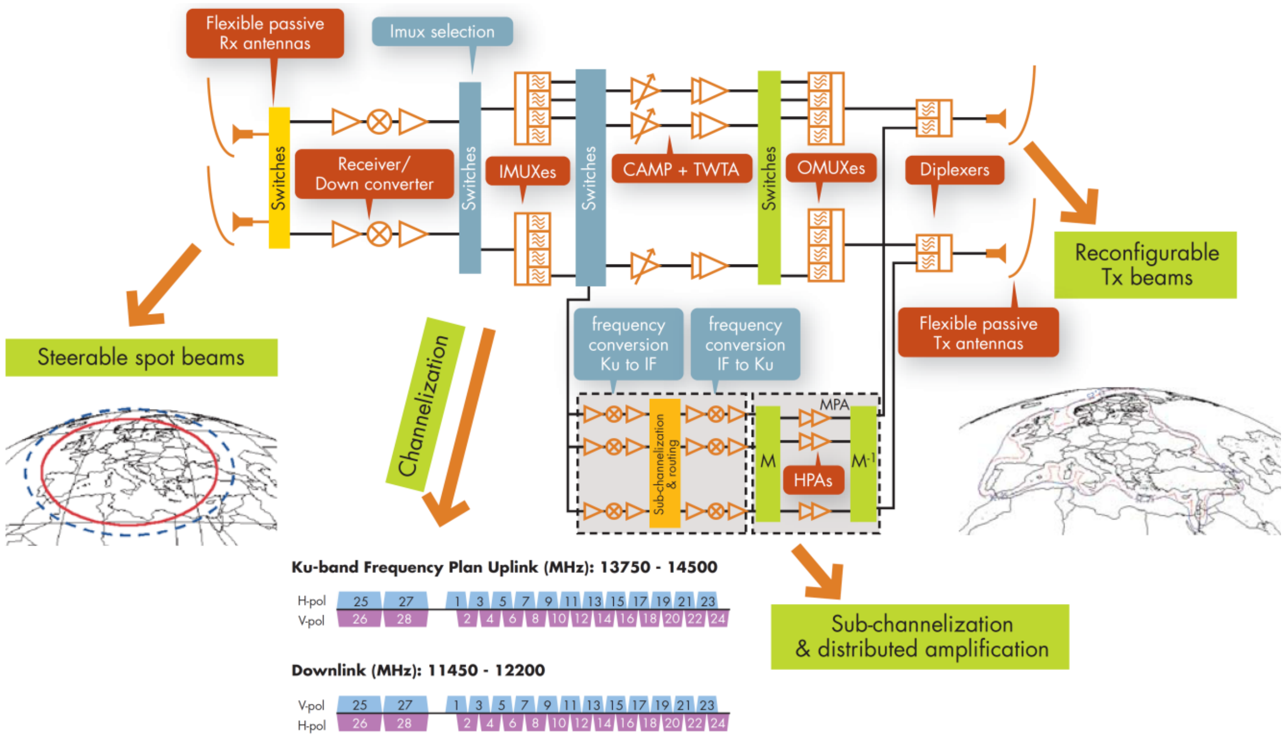


Figure 1: *Channelized flexible payload*

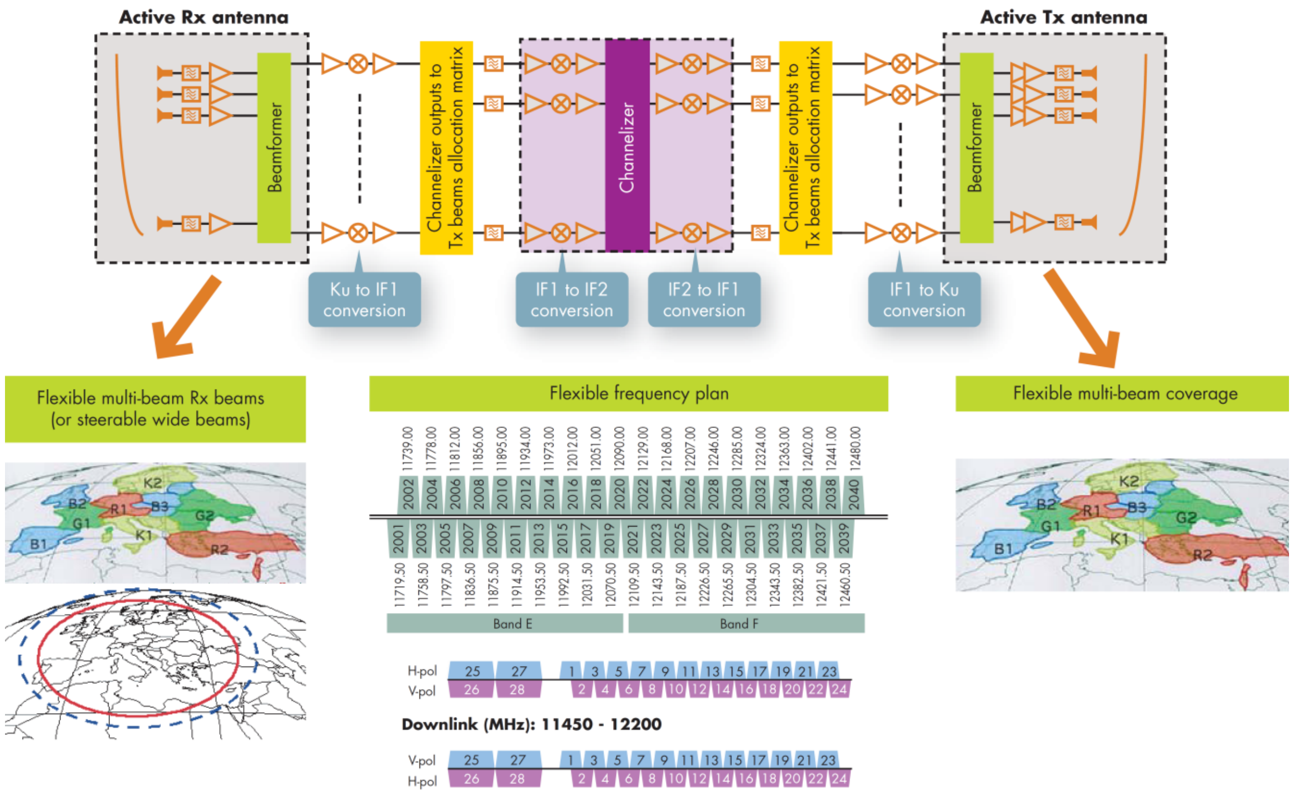


Figure 2: *Non-channelized flexible payload*

Electrically reconfigurable passive antennas
Two solutions are under development: a lens antenna (Figure 4-a) and a passive array-fed shaped reflector (AFSR) .They are both based on the use of ferrite phase shifters to control the beam shaping electrically. Ferrite phase shifter technology is a mature technology widely used in US military communication satellites,

and selected for its low loss characteristics. The lens antenna consists of an offset parabolic reflector fed by a single feed, and a reconfigurable electromagnetic lens located between the feed and the reflector. The lens comprises an RX and TX array of radiating elements, with ferrite phase
shifters connecting the RX and TX elements. The beam shaping is achieved according to the phase control of the RF paths connecting the RX and TX elements. The passive AFSR consists of an array of feeds illuminating a shaped reflector. The reflector shaping is designed so that all radiating elements contribute to the beam shaping. The antenna input is distributed to all radiating
elements. The illumination can be controlled to form the beam according to the phase control of each RF path performed by ferrite phase shifters.A printed reflect array antenna (Figure 4-b) is another solution for passive electrically reconfigurable antennas.MEMS technology (Micro Electro-Mechanical Systems) allows low loss and miniaturized implementation of micro switches. They are introduced in the reflecting cells to control the phase shift, and thus the antenna foot-print.

Active antennas
If frequency plan flexibility is required (flexibility of channel bandwidth and channel spacing), it is not possible to use a channelized repeater architecture, because no solution exists for flexible Omux filters. In this case, it is necessary to select a non- channelized (wideband / multi-channel amplification) architecture. Active antennas perform wideband/multi-channel amplification by design, and are consequently compatible with coverage and frequency plan flexibility.In order to deal with the poor power efficiency of Solid State Power Amplifiers, the preferred solution for transmit applications is to use an Array Fed Shaped Reflector with one TWTA per radiating element (Figure 5). In this case, the coverage flexibility is performed at a low level in the analog Beam Forming Network (BFN).

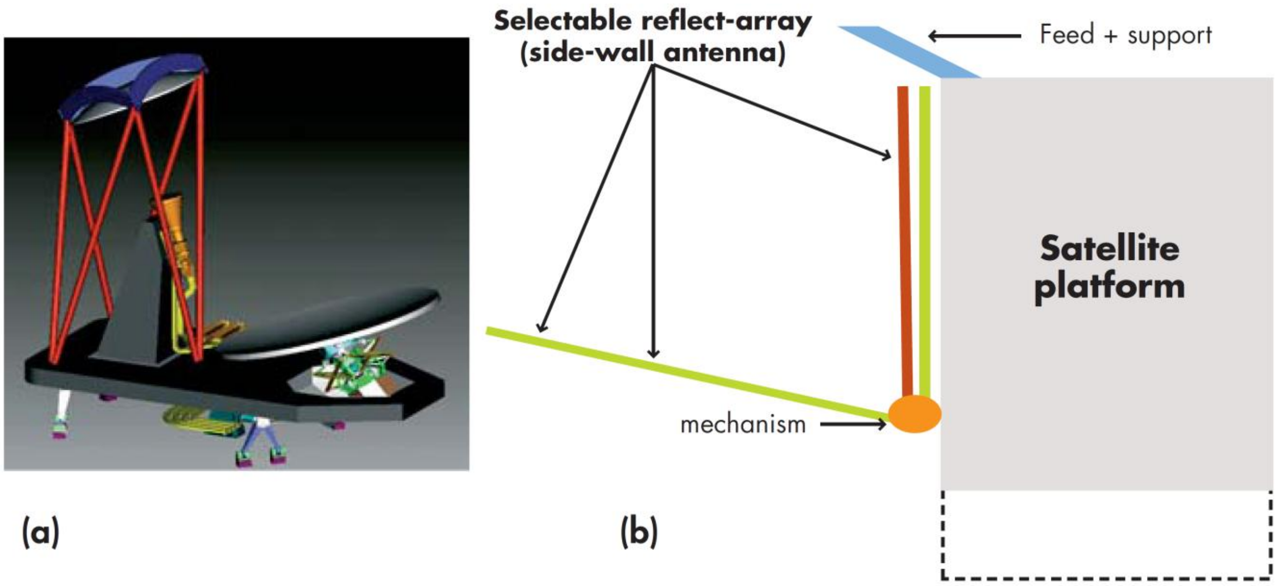


Figure 3: *Mechanically reconfigurable passive antennas; a) 3-D view, b) side-view*

**Power Flexibility**
Microwave Power Module
With passive mechanically or electrically reconfigurable antennas, the antenna gain and, consequently, EIRP (Equivalent Isotropic Radiated Power) will change with the coverage modification. The concept of a flexible power MPM (Microwave Power Module) composed of the Linearized Channel Amplifier (L-Camp) associated with the TWTA is an elegant solution in order to adjust the EIRP to mission requirements. This concept is designed to change the saturated output power of the TWT (by acting on the anode voltage) to keep its power efficiency quasi-constant for different output power levels, typically in the
range of 3 dB variation. The flexible LCamp is designed to compensate the TWT gain drift and non-linearity over the saturated output power range.This concept achieves linearity improvement and a significant gain (~10%) in satellite power.

Multi-port Amplifier (MPA)
This is a relevant solution for wideband/multi-channel amplification. Associated with passive flexible antennas, this concept is compatible with coverage plus frequency plan flexibility. MPA is a concept permitting the amplification of multiple channels in parallelized TWTAs, and is a way to send various number of channels to every transmit beam,depending on traffic demands. The total transmit power remains constant independent of the power distribution to the beams.

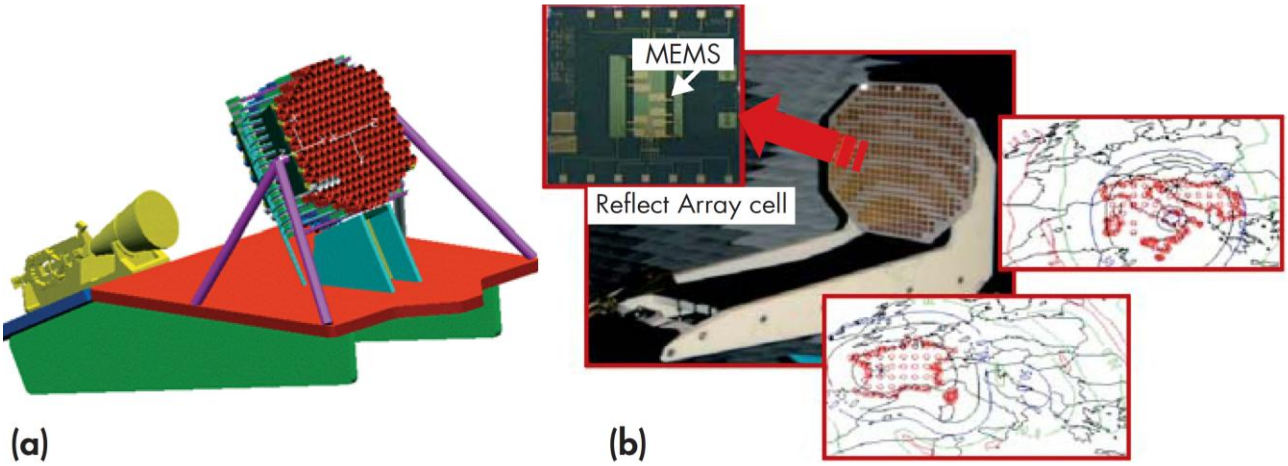


Figure 4: *Electrically reconfigurable passive antennas; a) lens antenna, b) printed reflect array*

**Frequency plan flexibility**
Channel routing between coverage
The aim of this concept is to modify the interconnection between receive and transmit coverage in the case of multi-coverage missions.Channel filters (IMUX and OMUX) are fixed, and the RX signal is translated to the TX frequency range corresponding to the wanted TX coverage. One mature solution uses a wide-band down-converter able to change the RX to TX frequency conversion with a programmable Local Oscillator (synthesizer), or by switching an external Local Oscillator reference.Another advanced solution is based on the opto-microwave technology associated with RF filtering. RF signal modulates an optical carrier (around 1550 nm); then opto-microwave technology can be used to implement the switching function efficiently. RF down conversion can be obtained through the modulation of the optical carrier by a Local Oscillator. Finally, the channel is filtered after down conversion to C band and Optical to Electrical conversion. The design is generic, and can be used for any RF frequency range, from C to Q-V Band (3-50 GHz) with 3 GHz bandwidth.The switching function uses integrated micro mirrors in OMEMS technology.

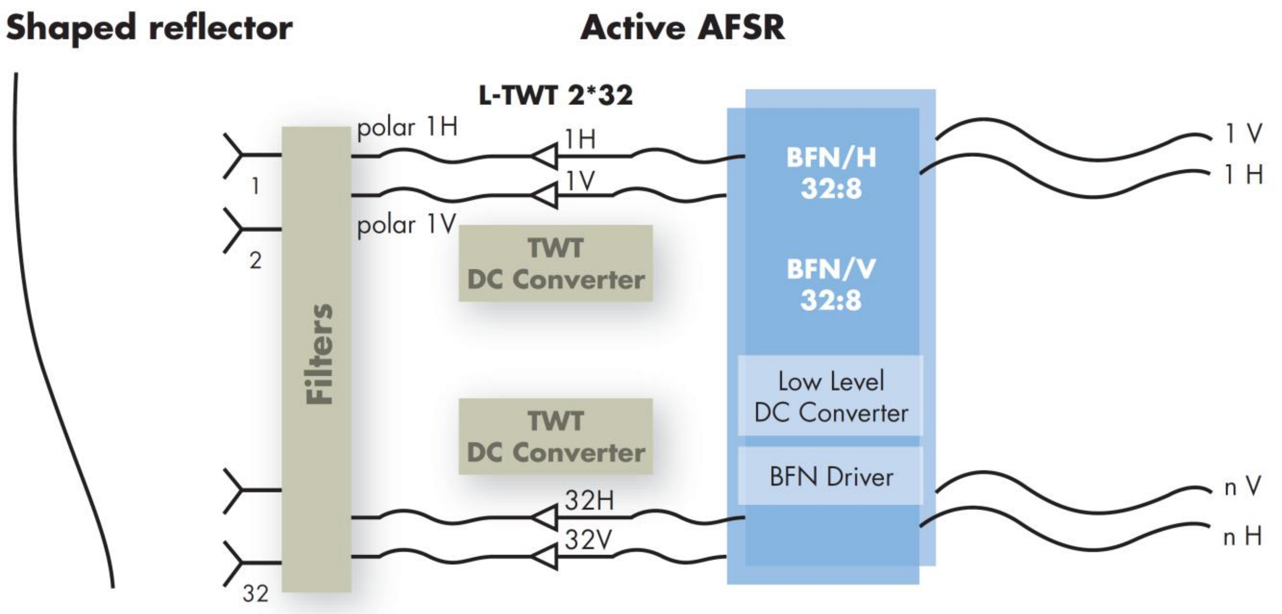


Figure 5: *Active array-fed-shaped-reflector*

Flexible frequency plan

The objective is the modification of the bandwidth of the channels and spacing between channels in orbit. Three technologies could answer this demand depending on the requirements:

1) The first solution consists of an RF filter bank in association with a switch matrix to manage and modify the channel filtering. This solution offers a very low level of flexibility, because the number of filters in the bank is limited by their size and mass.

2) An Intermediate Frequency Processor is a second solution which is based on Surface Acoustic Wave (SAW) filters working in the 200-1000 MHz frequency range. The RF channels (typically up to 16 channels) are first translated to Intermediate Frequency. The IF processor is composed of power dividers, microwave switches and power combiners, followed by SAW channel filters. Any sub-channel (minimum bandwidth of 6 MHz) of any input channel (up to 125 MHz bandwidth) is routed to any output channel and any channel or sub-channel is gain controlled (Figure 6).

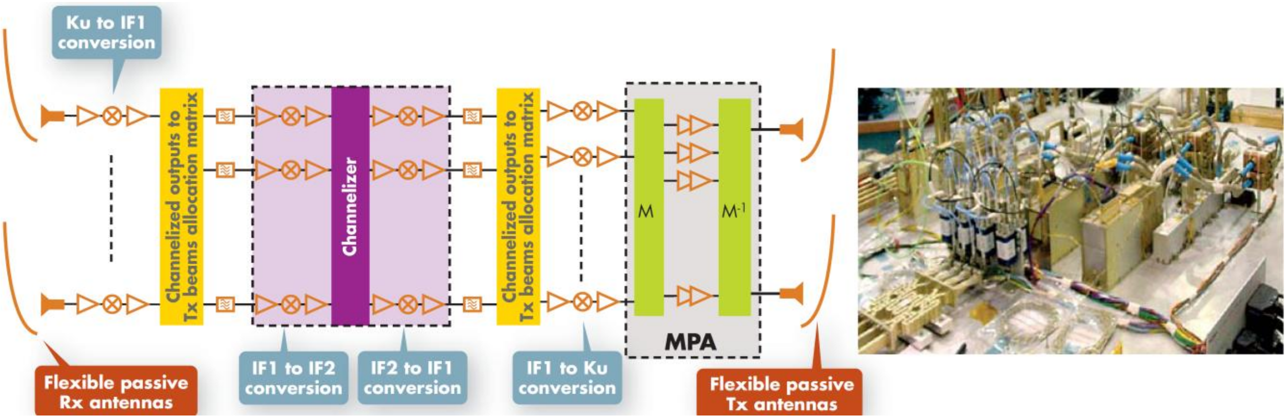


Figure 6: *Flexible frequency plan; an intermediate frequency processor*

• Digital Transparent Processor (DTP) is a third solution providing high frequency plan flexibility. The DTP performs on-board digital processing of the signal without demodulation and decoding. It is implemented between pre- and postprocessors, assuring RF-to-baseband and baseband-to-RF conversions.

Table-1 presents the range of solutions for payload flexibility and their application domain.

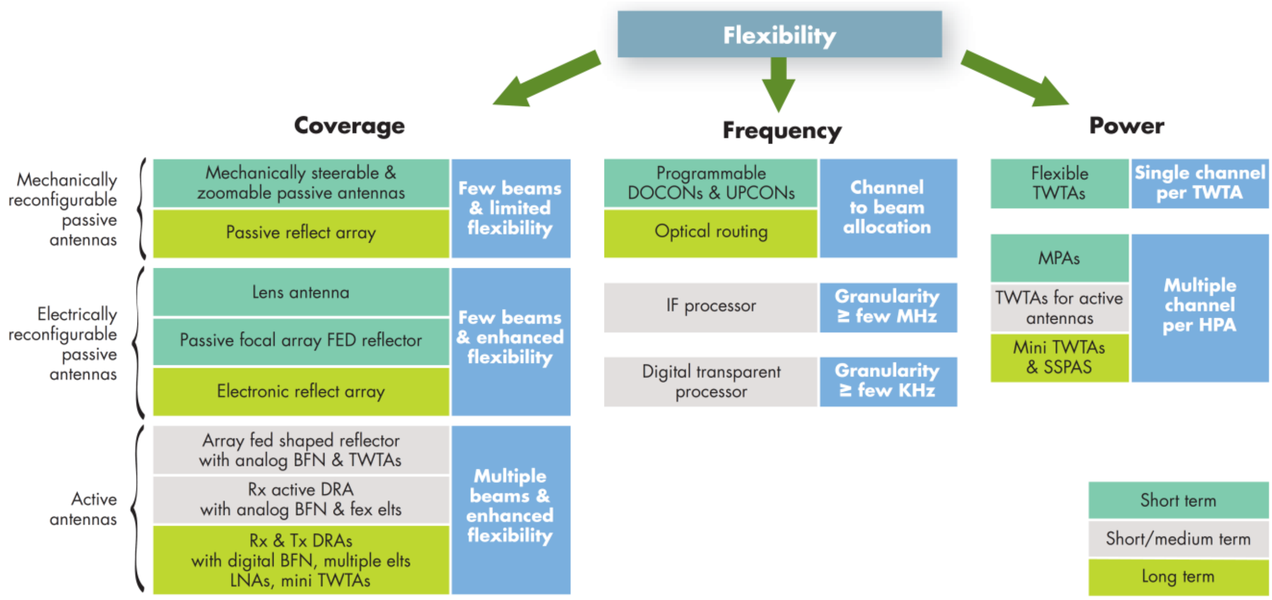


Table 1: Flexibility requirements and implementation methods

## CONCLUSION

New payload concepts are studied to be deployed during the satellite fleet renewal. It is aimed to answer satellite operators' dual needs for future flexibility while maintaining current transparent missions in the X and Ku bands.This ongoing R&D effort aims to make fleet management much easier, by offering in-orbit reconfiguration of satellite missions.This means that standardized satellites can be reconfigured to carry out different missions from different orbital positions. In turn, this standardization should reduce satellite

development costs and production lead times. Capacity needs can be met by design advancements instead of giant satellites. The technology of the telecommunication satellites is evolving towards smaller size satellites with payload architectures allowing flexibility.

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