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CEAS Space Journal
An Official Journal of the Council of European Aerospace Societies

ISSN 1868-2502
Volume 2
Combined 1-4

CEAS Space J (2011) 2:67-73
DOI 10.1007/s12567-011-0010-1

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ORIGINAL PAPER

Verification of new technologies as main task of the communication payload of the Heinrich-Hertz mission

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Received: 1 April 2011 / Revised: 4 July 2011 / Accepted: 8 July 2011 / Published online: 10 August 2011

Abstract In the space business, there is typically a quite long period from the design and development of new technologies to their commercial use. Even comprehensive tests on ground cannot replace long-lasting experiments and tests in space. Such IOV (In Orbit Verification) activities provide the scientific basis for the introduction and application of new technologies and the necessary heritage for commercial satellite programs. The Heinrich-Hertz mission of a geostationary communication satellite with a planned life time of 15 years lead by the German Space Administration (DLR) establishes a valuable basis to verify new technologies scientifically in orbit over a long period of time and to gain heritage regarding their performance in space [1]. In addition, research institutes and the industry are enabled to perform numerous scientific and technological experiments over the full life time of 15 years. With this approach of the mission, the German Space Administration offers to the German satellite industry an outstanding advantage and gain in knowledge for the development of new communication technologies and their applications. The launch of the satellite is envisaged for 2016. The technical feasibility of the overall program was successfully demonstrated within a Phase A study. The major tasks for the payload responsible during Phase A have been: (1) survey and assessment of all proposed IOV-technologies, (2) development of a payload concept for the scientific-technical verification of the IOV-technologies.

This paper is based on a presentation at the German Aerospace Congress, September 27–29, 2011, Bremen, Germany.

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Keywords In orbit verification · Technologies · Communication payload

1 Proposed technologies

1.1 Overview

About 30 technologies have been proposed, mainly out of the national program COMED NG (Communications and Multimedia Development and Demonstration Program Next Generation). Nearly all of them are related to Ka-Band applications and a variety of relevant technical issues are covered. Figure 1 gives an overview about all proposed technologies and project partners, where the link between the proposed technology and the related main project partner is indicated.

All proposed technologies and their related abbreviations are given in Table 1 in alphabetical order.

None of the proposed technologies is in direct competition to each other and all of them can coexist within the same payload in a proper way. The variety of the proposals is very large and ranges:

- From proposals of single companies or institutes up to large consortiums,
- From parts and components to complete units and up to subsystems,
- From concepts to technologies matured to a large extent,
- From technology experiments with a lifetime of less than 15 years to commercial usability,
- From communication experiments (only temporarily used) to commercial usability.

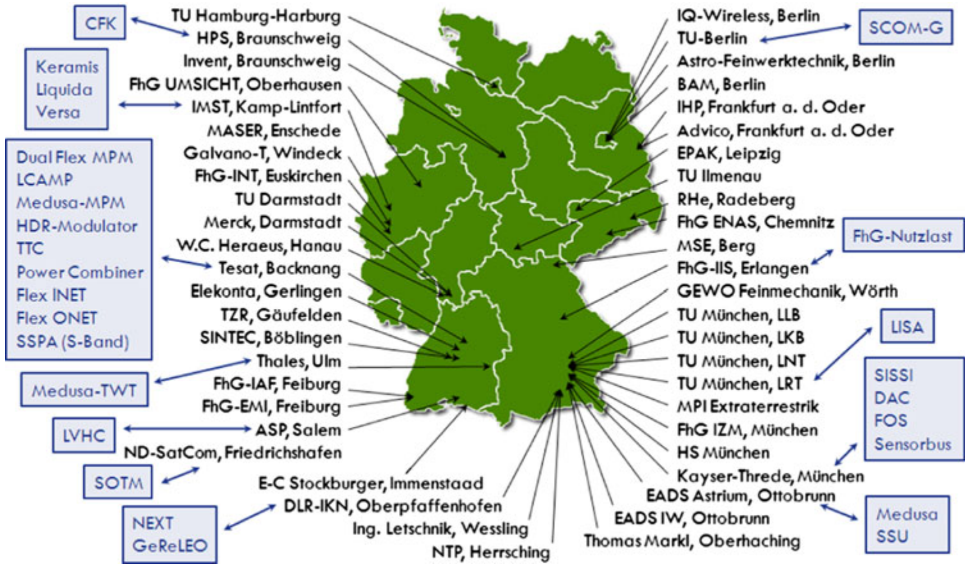

Fig. 1 Overview about all proposed technologies and project partners

Table 1 Abbreviations and titles of the proposed technologies

CFK	Carbon fibre reinforced polymer for antennas and other structures.
DAC	Digital analogue converter
Dual-Flex MPM	Dual flexible adjustable microwave power module
Flex INET	Flexible input multiplexer network
Flex ONET	Flexible output multiplexer network
FhG-Nutzlast	Payload of the Fraunhofer Society
FOS[a]	Fibre optical sensor
GeReLEO	Geostationary earth orbit (GEO) data relay for low earth orbit (LEO) satellites
HDR Modulator	High data rate modulator
KERAMIS	Ceramic microwave circuits for satellite communications
LISA	Lightweight inter-satellite antenna
LCAMP	Linearized channel amplifier
LIQUIDA	Liquid crystal for microwave applications
LVHC	Low-voltage high-current DC/DC converter
MEDUSA	Multimode multi spot-beam-antenna
Medusa MPM	Microwave power module for medusa antenna (200 W FPM)
Medusa TWT	Travelling wave tube medusa MPM (200 W TWT)
NEXT-OBP	On board processing unit for a network coding satellite experiment
Power Combining	Output power combining
SCOM-G	S-band transceiver for GEO-satellites (S-band)
SENSORBUS[a]	Electrical serial data bus
SISSI	SiGe integrated space synthesizer
SOTM	Satcom on the move with dynamic IF switching unit
SSPA	Solid-state power amplifier (S-band)
SSU	Store 'n' stream unit
TTC-Transponder[a]	Tracking, telemetry and command-transponder
Versa	Satellite distribution networks

[a] Not part of the communication payload

1.2 Classification of the proposed technologies

The proposed technologies have been classified regarding their relevance to the overall communication system in four groups, as depicted in Fig. 2.

- *Antenna systems (high relevance for the overall communication system)* The main characteristics are the antenna gains (or EIRPs and G/Ts, respectively, taking the performance of the output and input repeater sections into account) together with the related

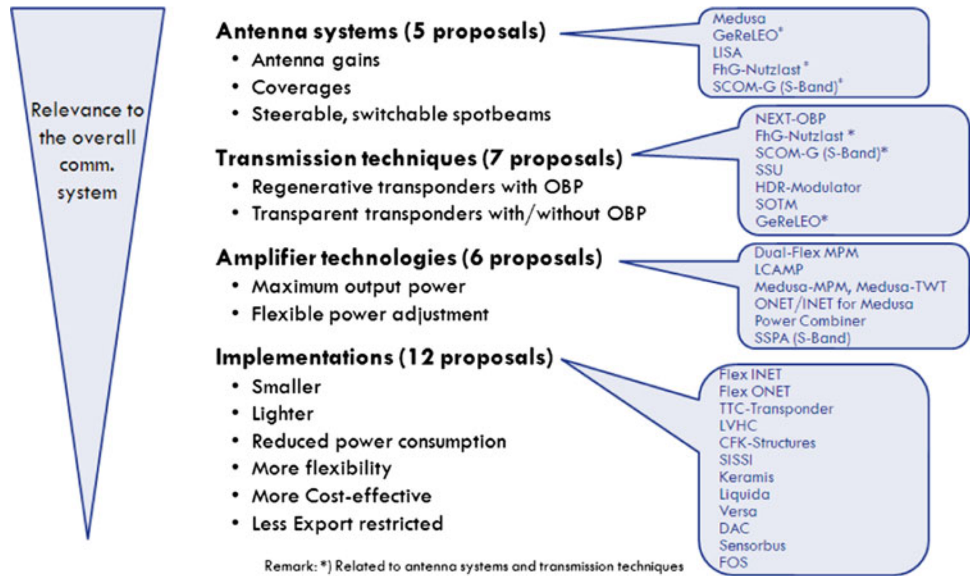

Fig. 2 Classification of the proposed technologies regarding their relevance to the overall communication system

coverages in combination with steerable antennas and switchable spot-beams antennas.

- *Transmission techniques (medium relevance for the overall communication system)* Transparent transponders with and without OBPs (On-board Processing Units) and regenerative transponders with OBPs including switching and routing functionalities.
- *Amplifier technologies (of medium relevance for the overall communication system as well)* The main focus is on maximum RF power in combination with high efficiency and flexible adjustment of the output power in orbit.
- *Implementations* This generic term is used for a large variety of different proposals that are of low relevance with respect to the overall communication system but have significant advantages and are very important to improve the competitiveness like smaller, lighter, reduced power consumption, more flexible, more cost-effective or less export restricted.

In a first step, all technologies have been assessed and reviewed in a comprehensive process. For incorporating the proposed technologies to a functional payload, all technologies that are of lower functional level than payload unit level like parts or modules have been combined and integrated into units on payload unit level in a next step.

2 Communication payload

The development of the payload concept was performed in several steps. In a first step, all proposed technologies were integrated in a reasonable payload ("bottom-up"). A consolidation of proposed communications experiments as defined by the system responsible ("top-down") and implementation in payload concepts was done in a second step followed by an intensive optimization and iteration process in order to achieve an agreed payload concept.

The block diagram of the agreed version of the communication payload for IOV (In Orbit Verification) is shown in Fig. 3. This diagram includes different types of devices:

- *IOV equipment* These devices shall be verified in orbit. The payload is designed to support the verification of these devices. The IOV equipment is marked in orange for units with a lifetime by design of 15 years and marked in green for units not specifically designed to have a lifetime of 15 years.
- *Standard equipment* Due to the fact that the IOV equipment do not lead to a complete operational payload, standard equipment have to be added to get a functional payload (marked in white)
- *Equipment which has to be developed* These are special devices which are needed to get a functional payload and which are neither available as IOV equipment nor as standard equipment (marked in red).

The result of the related accommodation study is depicted in Figs. 4, 5, respectively.

2.1 Description of the payload

The main function of the payload is described in the following paragraphs, whereas IOV technologies are highlighted in italic letters at their first mention.

30 GHz Receive Section (top, left) The 30 GHz receive antenna is a multi spot-beam antenna and consists of a Multi-Feedsystem and a main reflector. The Multi-Feedsystem

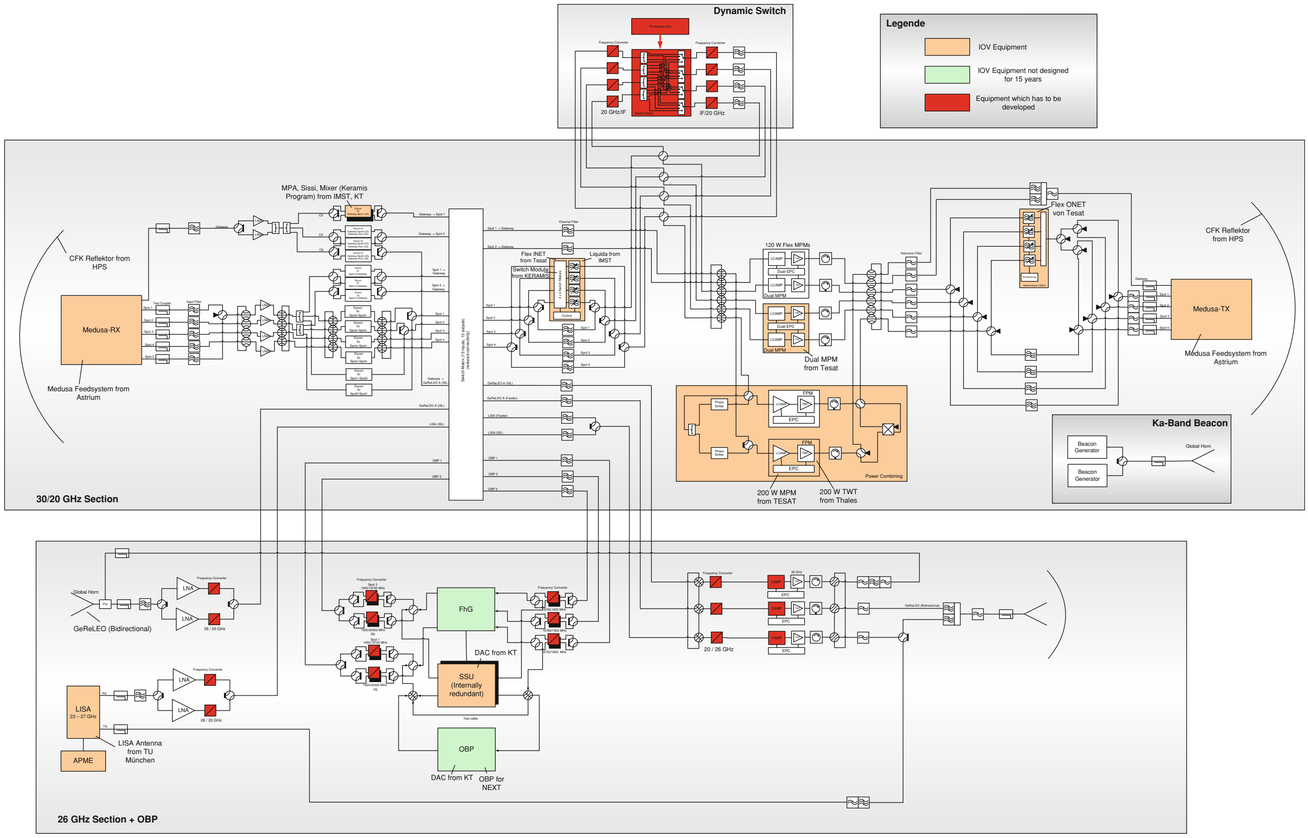

Fig. 3 Phase A version of the communication payload for in orbit verification

is designed and developed within the *MEDUSA* program and the reflector is a *CFK* reflector out of the related program. The received signals are fed via test couplers and input filters to the LNA (Low Noise Amplifier) and Down-converter section, whereas a separate output is envisaged for a gateway beam. One of the down-converter is an IOV-unit comprising different components from the *KERAMIS* and *SISSI* program.

A conventional switch matrix consisting of power splitters and coax switches will be implemented. After the switch matrix the signals pass the channel filters, where a *Flexible INET* including a 4 × 4 switch module and four tuneable channel filters, based on technologies out of the KERAMIS and *LIQUIDA* programs is integrated. Here, the centre frequency can be varied over a certain range. For reliability reasons the Flex INET can be bypassed using conventional filters.

20 GHz Transmit Section (top, right) To achieve the required transmit power *Dual Flex MPMs* are used to amplify the signals. A Dual MPM consists of a common EPC, two *LCAMPs* and two TWTs. The saturated output power of the MPM is adjustable over a range of 4 dB. The maximum saturated output power of the MPM is 120 W.

Two Dual Flex MPMs are implemented within the IOV payload. In case of a failure the *200 W FPMs* (including *200 W TWTs*) used within the *Power Combining* technology can be utilized to replace the failed MPM. Within the Power Combining it is possible to generate a power combined signal. In that case, the input signal of the Power Combiner is split into two parts, amplified and combined afterwards. With that an output power of up to 400 W is achievable. Consequently, the amplified transmit signals are adjustable to power levels between approx 50 and 400 W.

The amplified signals are filtered by the *Flex ONET* or combined in case of the gateway beam. The centre frequencies of the Flex ONET can be varied over a certain range. For reliability reasons, the Flex ONET can be bypassed using conventional filters. The signals are then transmitted using a multi spot-beam antenna (*MEDUSA, CFK*) similar to the receiving antenna.

For the alignment of the ground station antennas a beacon is generated using a separate horn.

26 GHz ISL Receive Section (bottom, left) For the communication with satellites in the low earth orbit (LEO) the communication payload offers two possibilities for the use as relay satellite. For low data rates a global horn is implemented (*GeReLEO*) whereas for higher data rates a steerable horn array from the *LISA* program can be used. The received signals are filtered, frequency converted and fed to the static switch matrix.

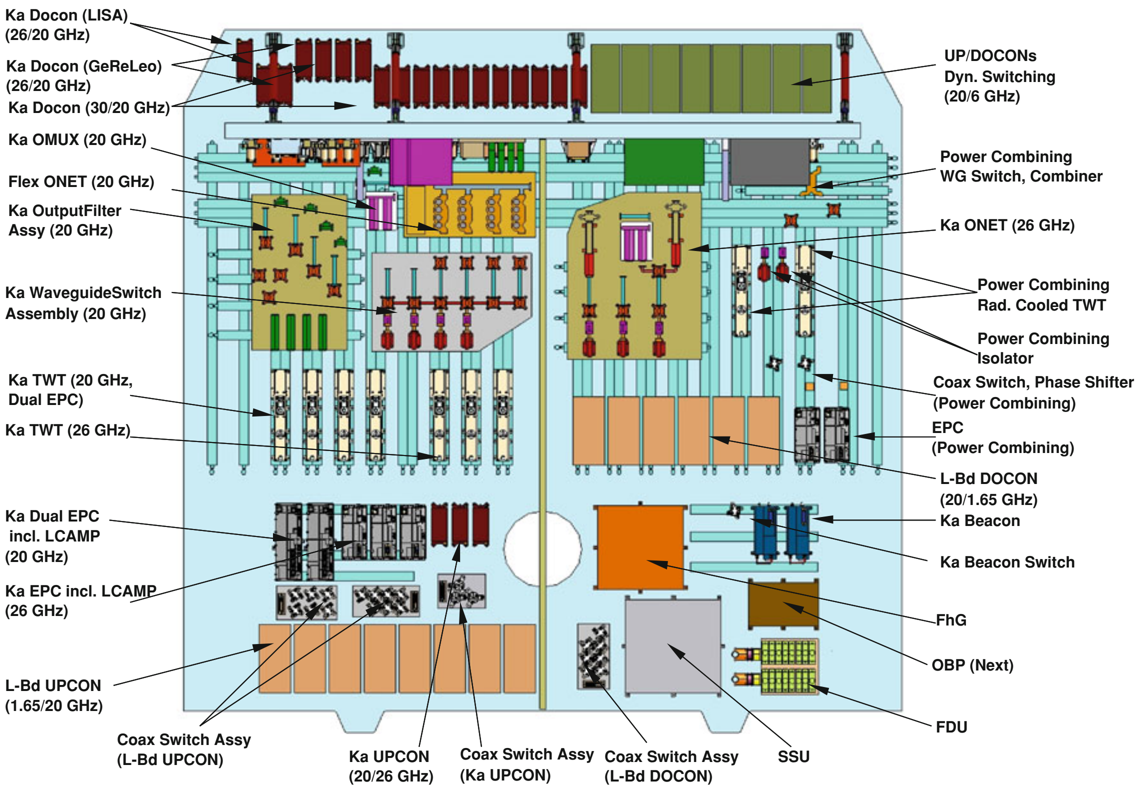

Fig. 4 Accommodation of the payload on the north panel

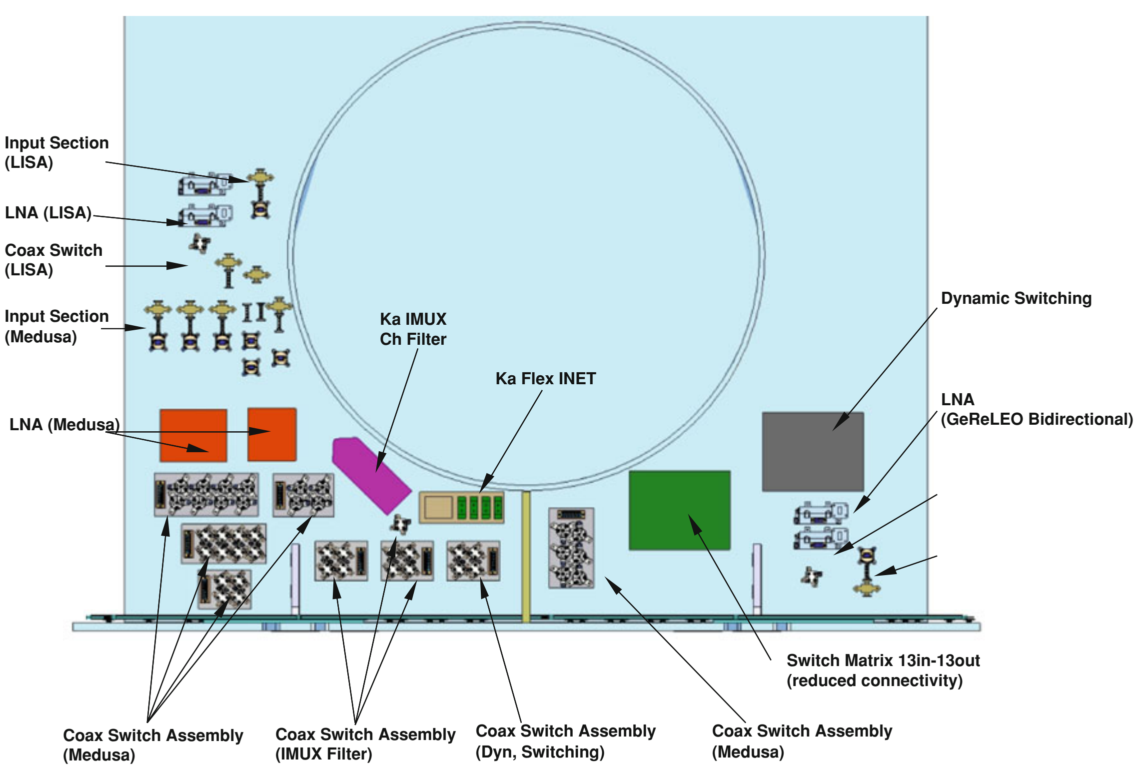

Fig. 5 Accommodation of the payload on the earth panel

26 GHz ISL Transmit Section (bottom, right) Three different applications can be served by this section:

- Transmission to LEO satellites via a global horn for low data rate connections (GeReLEO).
- Transmission to ground stations via a dedicated transmit antenna as relay function for LEO satellites (GeReLEO. LISA).
- Transmission to LEO satellites via the steerable LISA antenna.

Processing Section (bottom, middle) Three different OBPs (*FhG-OBP, SSU, NEXT-OBP*) can be switched into the transponder paths. The scopes of the OBPs varies to large extend and ranges from transparent operation to regenerative operation including switching and routing functionalities.

Dynamic Switch (top, middle) The dynamic IF switch for Satcom On The Move applications (*SOTM*) offers the possibility to switch all inputs to all outputs using burst operation and dynamic switching. In addition, the realisation allows broadcast functionality from one receiving spot to certain or all transmitting spots.

2.2 Payload summary

The total mass of the payload is approx. 250 kg, whereas a portion of about 50% is related to the IOV units. The DC power consumption is estimated to approx. 1.5 kW, taking into account that not all units are powered on at the same time to perform specific communication experiments. All IOV units that are relevant to the overall payload are either build with internal redundancy or can be switched to conventional units. The proposed communication repeater can be accommodated on one of the satellite panels and on approximately one-half of the earth deck of the satellite as depicted in Figs. 4, 5.

3 Innovations

The IOV payload is innovative in many respects. On one hand, the payload is based on a variety of new and innovative IOV technologies (mainly on subsystem and equipment levels but partly also on the parts level). The main purpose is to demonstrate the function and performance of these equipments and to achieve heritage in order to pave the way for success on the market for commercial payloads. These units are interconnected in a reasonable manner to allow for maximum testing as well as to limit the impact on other technologies in case that one of the new IOV technologies suffers from a limited performance.

On the other hand, the payload is very flexible in terms of re-configurability and interconnectivity.

The main purpose is to demonstrate the feasibility of a variety of communication experiments where different RX antennas (or RX antenna beams) are connected to other TX antennas (or TX antenna beams) or with different OBP units within the transponder path. In addition to point-to-point connections between antenna ports also broadcast connectivity is possible where one RX port is connected to more than one TX port. The payload contains specific IOV equipments to enable flexible interconnectivity. However, the payload as a whole is to be considered as innovative even though the methods to achieve flexible interconnectivity could be restricted to the use of standard technology only.

Furthermore, the proposed IOV-payload allows for the setting of different priorities of the Heinrich-Hertz mission.

3.1 Innovation of technologies

The proposed payload includes innovative technologies with a large potential for later commercial use.

Antennas:

Three different types of antennas are used for verification purposes.

- Multi spot-beam antennas are used on RX and TX for the coverage of Germany and the neighbouring area. The re-use of carriers in non-adjacent cells (based on the four-colour coverage scheme similar as used typically for terrestrial mobile radio systems) allows for high spectral efficiency, high gain and high throughput without the need for a bulky farm of antenna reflectors on the satellite.
- Steerable antennas, based on mechanical or electronic shifts, allow for higher antenna gains while the coverage area can be changed during the lifetime of the satellite according to the operators needs. Electronic shifting allows also for rapid and frequent changes.
- ISL antennas can be either steerable as described above or fixed providing hemispherical coverage. An interesting data relay service for LEO satellites or other applications is offered with data rates up to 50 Mb.

High power amplifiers:

- Different types of amplifiers offer a wide range of possible output power from 50 to 400 W by flexible setting of the saturated output power and using power combining.
- The Dual-Flex approach allows for a power reduction of 4 dB, where additionally one EPC is serving two TWTs in order to reduce the mass.
- The FPM (Flexible Programmable MPM) approach allows in addition to the Flex approach for a fine-tuning in orbit of the LCAMP characteristics, e.g. in order to adapt to specific bandwidth of the signal.

On board processing (OBP):

- Three different units are intended by different contributors aiming at different characteristics like regeneration, routing, digital filtering, data compression, support of broadcast applications, network coding, testing of new waveforms, processing of sensor data, etc.
- The three units are separated, but they have a common analogue interface (in order to increase flexibility with regard to interconnectivity) and also a digital interface for cross-sharing of the mass-memories in order to increase the flexibility even more.
- The OBP units are re-programmable to host a variety of different communication and other experiments. It is also possible to develop and implement new OBP applications after the launch of the satellite. This includes also new waveforms expected to be developed in the future.

Other Equipment:

- Down-converter: evolution to in orbit adjustable conversion frequency.
- Flex INET: including 4×4 switching module and channel filters with in orbit adjustable centre frequencies.
- Flex ONET: in orbit adjustable centre frequencies of the output filters including a frequency independent manifold.
- Dynamic switch: enables for flexible routing with transparent transponders.

3.2 Flexibility and interconnectivity of the payload

The Payload is flexible in many respects and enables a large variety of adjustable interconnections based on the following methods:

- *(Static) Switch matrices* Both electronic matrices as well as conventional matrices with discrete switching elements are included. The transponders remain transparent and as such no limitations for future waveforms are imposed.
- *Dynamic switching* Different signal streams are down-converted to a common (low IF) frequency where the signal handling is done time based and finally the signals are up-converted to the original RF frequencies. The transponders remain transparent as for static switch matrices. Flexible routing is possible. Broadcast functionality is enabled without additional effort.
- *On board processing (OBP)* with routing capability enables for unlimited flexibility with respect to connectivity. Regeneration of data, allowing for improved link budgets and for separated link budgets, throughputs and bandwidths between uplink and downlink. An extension to IP routing is possible.
- *Variable filter banks* are also contributing to the flexible payload approach. Analogue filter networks are incorporated in the input and output section with adjustable centre frequencies. In addition, digital or/and analogue filter networks in the OBPs are included, especially needed for low-power narrow band signals.

4 Summary

The proposed payload includes a large variety of new and innovative technologies. It is designed for best possible testing and enables the verification of new technologies in orbit based on functionality and performance tests. Consequently, the new technologies are gaining heritage as basis for subsequent commercial marked entry. The payload ensures a remaining basic functionality even in cases where IOV-units fail or have reduced performance.

In addition, the payload supports re-configurability and flexible connectivity. It enables interconnectivity of different receive and transmit antennas (or beams), including dynamic interconnectivity and broadcast functionality. Different OBP units can be included in the transponders allowing for a large variety of additional features.

Furthermore, the proposed payload is designed to perform a lot of different communication experiments and to support ground technologies like mobile terminals as well as data relay functions for low earth orbit satellites.

The adopted IOV-payload approach provides a realistic and convincing concept which demonstrates a universal payload for the Heinrich-Hertz mission:

- All selected IOV-technologies can be integrated into the payload in a reasonable way.
- All selected communication experiments can be performed.

Furthermore, the proposed IOV-payload allows for the setting of different priorities of the Heinrich-Hertz mission and the innovative technologies enable potentials for all participants from industry and research.

Acknowledgments This work was funded by the German Space Administration (DLR) on behalf of the German Federal Ministry of Economics and Technology (BMWi) under research contract 50YB0903.

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