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From "Bent Pipes" to "Software Defined Payloads": Evolution and Trends of Satellite Communications Systems

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The paper offers an analysis of recent trends in satellite communication payloads from a system perspective. A critical discussion of advanced payload architectures based on the exploitation of Software Defined Radio techniques and technologies is presented. Software Defined Payloads are envisioned as the next evolution step in the progress of satellite communications systems.

I. Introduction

THE history of satellite communications payloads traces its roots to the year 1958, of which we mark this year the fiftieth anniversary. On the 18th December 1958 an Air Force Atlas B booster successfully carried the Advanced Research Projects Agency's SCORE (Signal Communications by Orbiting Relay Equipment) payload into low-Earth orbit, from where it delivered President Eisenhower's famous Christmas message [1].

In fifty years of satellite communications, on-board payloads experienced an extraordinary and continuous technical, architectural and technological evolution. Over these years, however, the role of satellites in telecommunications has changed substantially [2]. The first satellite communications systems were self-standing and autonomous, typically providing trunk links among a limited number of ground stations. We could say that these systems were very "spacecraft-centered".

In today's network-centric perspective, communications satellites are the elements of larger systems, or systems of systems, integrating a variety of network technologies. The technical challenge has been shifting from the compliance with multiple access, connectivity and throughput requirement to the achievement of improved payload flexibility, while minimizing complexity and cost. Flexibility features are needed not only to make satellite systems fully meshed with the global communications infrastructure, but also to adapt to unpredictable business conditions or to emergency situations.

Many in the satellite industry expect substantial benefits from the introduction of general-purpose, flexible payloads, deriving from reduced non-recurring schedule and costs and from economy of scale savings. Both satellite manufacturers and satellite operators expect delta costs associated to flexibility to be more than counterweighted by economic returns (e.g. traffic capacity increase, improved satellite fill-factor, wider addressable market, in-orbit spares reduction, lower operating expenditures, etc.). "Transparent" payload technologies aiming at flexibility are to some extent already available (e.g. digital transparent processors for frequency channelization and switching, multi-port amplifier and Flex-TWTA, reconfigurable antennas, etc.).

Together with the growing demand for flexibility, it has been gradually decreasing the attention to regenerative on-board processing payloads, mainly because of their intrinsic rigidity with respect to the physical layer interface. Despite some worth mentioning exceptions (e.g. the piggyback payloads for processing a limited number of channels of HB6 and AMERHIS as well as the renewed interest in military meshed processors), operators are skeptical about fully regenerative communications satellites, not willing to "freeze" their expensive assets in orbit for fifteen or more years, while market and technical standards experience a continuous evolution.

Net-centricity requirements and flexibility w.r.t. technological evolution explain the wide popularity of Software Defined Radios in wireless communications. Their rapid spread of popularity has been facilitated by the progress in digital signal processing techniques and technologies.

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Software Defined Radio (SDR) technologies can also be envisioned on-board communications satellites, as a promising answer to the compelling need for reconfigurable, flexible payloads over ever longer satellite lifetimes.

Software Defined Payloads (SDPs), consisting of on-board hardware and software technologies to in-flight reconfigure satellite payloads for multiple different communications scenarios, might be attractive both in alleviating the operational risks associated to rigidly configured payloads and in extending payloads capabilities (up to the inclusion of reconfigurable regenerative features).

II. Historical Perspective

Telecommunication satellites, oriented either to fixed or to mobile users, have been continuously evolving towards more sophisticated services requiring a steady development of the system architectures. A gold thread that links this evolutionary path is the increase of satellite payload complexity in terms of handled bandwidth, offered power, antenna coverage complexity, processing functionalities and flexibility.

Because of the scarcity of the available frequency spectrum for satellite communications, frequency usage efficiency has always played a central role. Two major techniques have been introduced to increase the system capacity by reusing the same frequency several times on the same satellite: spatial discrimination and polarization discrimination.

In frequency reuse by spatial discrimination a portion of the available bandwidth is allocated to a single beam and the same portion is reused multiple times over the overall multiple beam coverage provided either that the beam-to-beam isolation is consistent with certain limits or the system is robust to co-channel interference.

The second method used to achieve frequency reuse was by mean of orthogonal polarizations; two co-frequencial signals are transmitted on orthogonal polarizations on the same coverage. In this technique the antenna polarization isolation becomes a major conditioner of the co-channel interference performances. Obviously, several hybrid schemes can be conceived by mixing the two techniques.

In this respect INTELSAT IV-A was the first satellite providing frequency reuse by spatial discrimination between two different continental zones (2-fold theoretical capacity increase). Polarization discrimination was implemented for the first time with INTELSAT V* (4-fold theoretical capacity increase) [3,4].

The single-beam / single-repeater ideal payload of Early Bird† is nowadays a sweet remembrance that finds very limited applications (e.g. single beam coverage for high power broadcasting).

Modern payloads show multiple beam configurations with high frequency-reuse with payload architectures that may be chosen among several major options including:

- Transparent “Bent-Pipe” transponder.
- Regenerative repeater with routing capabilities.
- Transparent repeater with analog routing capabilities.
- Transparent digital repeater (“Digital Bent-Pipe”) with routing and beamforming capabilities (also known as “Translucent”).

The reader is remanded the Ref. 5 for a detailed discussion of the advantages and drawbacks of the various options. For the present discussion it is worth noting that transparent payloads based on on-board digital processors (“Digital Bent-Pipes”) have been introduced to realize the important objective of flexible resource allocation without incurring in the limitations of analog technology. Their primary functions are flexible channelisation, frequency conversion and routing; nevertheless, adoption of digital signal processing strongly suggests multibeam antennas based on Digital Beam Forming (DBF) techniques. Such techniques allow the implementation of array antennas (in configurations ranging from Array-Fed Reflector to Direct Radiating Array) with full control of their potential capabilities (i.e. power sharing, beam pointing, pattern shaping, nulling, etc.). Digital processing offers further possibilities to integrate in a seamless environment other payload functionalities, such as Automatic Level Control (ALC) or transponder gain control on a per-channel base, broadcasting/multicasting based on single channel copies, inactive channels squelching to reduce power robbing, RF sensing, RF paths calibration and equalization, in-band TT&C channel extraction and generation, etc.

The on-board processor operation on a time frame base allows also extending payload system architectures to SS-TDMA and beam hopping techniques. Finally, it is worth highlighting that a major advantage of digital

* INTELSAT V has also the record to be the first example of hybrid payload operating and cross-connecting C- and Ku-bands transponders.

† To be exact, Early Bird had two transponders but a single active TWT shared by the two.

processing stands in the fact that the same design can be easily adapted to different customer requirement reducing non-recurrent development costs.

Narrowband transparent digital processing payloads for Mobile Satellite Services (MSS) operating at L-band have been studied by ESA in late '80s and then prototyped with the ESA support in the early '90s. Narrowband MSS transparent processors found their commercial opportunity around 2000 to support the demanding requirements of the Thuraya and Inmarsat 4 MSS satellites.

Thuraya provides a capacity corresponding to a total of 628 subbands of 156.25 KHz (for each of the FL and RL). From the payload perspective such capacity is achieved through on-board digital signal processing with variable bandwidth channel capability (through reprogrammable polyphase + FFT processing), circuit switching and agile transmit/receive digital beam forming with 246 Tx and Rx beams. The processor can actually form a separate beam per subband up to 628 beams [6].

INMARSAT 4 is the fourth generation of the global mobile satellite communications system Inmarsat. The first of a series of three satellites has been recently launched and will be soon operational. These satellites will support the new Broadband Global Area Network (B-GAN), offering phone and mobile data communication at up to 432 kbits/sec. The two processors offer a capacity corresponding to 600 subbands of 200 KHz (for each of the Forward- and Return link processors) with full circuit switching possibility. Agile transmit/receive digital beam forming of 200 Tx and Rx beams completes the picture of the major functionalities (a mix high gain and low gain beams to guarantee backward compatibility with third generation satellites) [7].

Concerning broadband digital processors operating at Ku and Ka-band initial European R&D effort was focused in the early '90s to digitizing the wideband demultiplexer [8-11] in addition to possible on-board regeneration and switching that was widely investigated few years before [12]. This initial R&D effort found application in the ESA co-funded broadband satellite technological developments such as DOMINO 2 led by Thales Alenia Space [13] and WEST Early Bird (WeB) led by EADS Astrium [14]. These systems were encompassing bent-pipe payloads as well regenerative processors for hybrid mesh/star multimedia networks.

While rigidity concerns and cost issues generally didn't play in favor of regenerative payload architectures, the Boing's Spaceway spacecrafts, with their 10Gbps on-board-routers and 1500 elements active direct radiating array antennas, represent the state-of-the-art in regenerative satellites.

III. Reconfigurability, Flexibility and Responsiveness in Satellite Payloads

The need for reconfigurable payloads arose as soon as they became more complex. Contoured and multiple beam antenna coverages allow to obtain higher gain and to reduce interference from and to other systems, but also limit the freedom to assign bandwidth and RF power resources. In multiple beams payloads, beam to beam connectivity has also to be achieved.

In order to catch the evolving requirements of a very unpredictable market over a satellite lifetime, a number of techniques and technologies have been developed over the years, as briefly discussed in previous sections.

But the evolution of the mission requirements is not the only reason for aiming at flexibility: another very serious problem is that of technological obsolescence, made ever more evident by the advent of digital communications.

One evident characteristic of digital communications is the continuous evolution of air interfaces (i.e. encompassing from physical layer to higher OSI layers' protocols and formats). What on ground can be at worst the cause of an expensive upgrading of the software and possibly of the physical components of a network, in satellite systems, unless based on transparent payloads, can translate in much cruder reality: obsolescence.

Satellites are nowadays designed and built with a fifteen years on-orbit expected lifetime. As a matter of fact, fifteen years correspond to several generations of software and hardware evolution. Let us think of our PC, its peripherals and its software: nothing that we used fifteen years ago could today be easily operated and even data files could be difficult to retrieve if stored on no longer utilized physical supports.

The rapid evolution of digital hardware technologies, software, modulation and coding standards, communications protocols and formats is one of the reasons for the scarce appeal of regenerative payloads. Transparent ("Bent-Pipe") transponder architectures or transparent digital signal processing transponders (a.k.a. "Digital Bent-Pipe" transponders, i.e. transponders where signals are analog-to-digital converted to allow the use of digital signal processing - DSP - techniques, but are not demodulated/modulated on board) are by definition able to cope with evolving modulations, protocols and formats, provided that operating frequencies and channel bandwidths are not drastically modified.

The answer to the obsolescence problem could then be twofold: (relatively) simple payloads or flexible payloads.

The need for flexibility, however, originates from many other circumstances, also characterizing the satellite communications market.

Satellite operators are today more concerned about capital investment, flexibility and reliability rather than about technological advancement. The concerns of space insurance companies about the reliability of newly designed components and fancy technologies further enforce this trend. In-orbit flexibility is required to adapt to evolving business conditions, as seen before, or to crisis situations; reconfigurable payloads would also allow the elimination of dedicated in-orbit spare satellites. Customer needs are oriented toward higher EIRP's, broader bandwidths, reconfigurable coverage areas, higher reliability, and flexibility to adapt to evolving digital standards. The challenge is achieving improved payload flexibility and performance without dramatically increasing complexity and cost. On the other hand, satellite manufacturers expect substantial benefits from the adoption of modular, "general-purpose" payloads, mainly in terms of development schedule and non-recurring cost reduction.

The original concepts of reconfigurability and flexibility have been evolving and merging into a more general one: that of responsiveness. Responsiveness in satellite communications payloads can be defined as the ability to react to various forms of uncertainty, ranging from geopolitical operational requirements to technological obsolescence to technical failures.

The responsiveness requirement could lead to a revolution in the design of satellite payloads. Rather than focusing, as it happened so far, on technical requirements, developing highly customized (and costly) solutions, architectures encompassing built-in reconfigurability and flexibility features could be adopted.

The technological progress could this time come to the rescue: should the on-board digital microelectronic technology advance at the 18 months performance doubling rate conjectured by Moore's law for commercial on-ground applications, we will experience in the next few years a rapid diffusion of digital bent-pipe payloads also for broadband applications. Similarly, we could expect that the now operationally introduced Software Defined Radios (SDR), consisting on a collection of hardware and software technologies to reconfigure radios for multiple different communication systems, will revitalize regenerative payloads by overcoming technical obsolescence and/or lack of adaptability to evolving air interfaces.

IV. Software Defined Payloads: Myths and Realities

Software Defined Radio is a hot topic since more than one decade [15-19] and has found several interpretations in the past years. IEEE has recently giving the following definition of SDR: *A radio is considered to be a software defined radio if some or all of the baseband or RF signal processing is accomplished through the use of digital signal processing software and can be modified post manufacturing* [20]. This definition is considered more open in terms of technical solutions compared to more canonic approaches whereby SDR was requiring a truly software technological approach which finds limited applicability to space telecommunication systems. The IEEE definition is also focusing SDR to the physical/MAC layer avoiding considering upper layers which appears very appropriate. Layers above 2 are already using software technology and will not be considered part of the SDR discussion.

Clearly SDR in terrestrial applications is finding a more natural application path in base stations where power consumption and size constraints are much less than in a mobile terminal. For operators investing large capitals in terrestrial wireless networks the infrastructure scalability, future proofness are key factors that SDR can make more attractive (refer to Figure 1 for a pictorial view of SDR expected advantages in terrestrial cellular networks). The fast growing capabilities of modern DSP devices are also enhancing the chances of SDR adoption in user terminals. However, when the low power consumption is a premium and signal processing is very pushed more "hard wired" solutions such as ASICs with embedded DSP are still representing the preferred implementer solution.

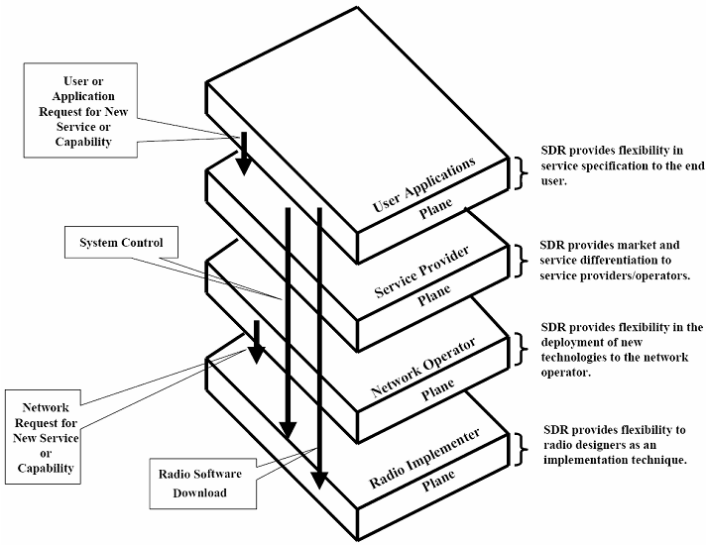


Figure 1 – The Multidimensional Perspective of Software Based Radio. (Source: Cingular Wireless)

For space applications the "pure" SDR concept of a truly software based DSP remains limited to simple or low rate functionalities as it can be for example for space explorations applications. In this frame NASA is active in the development of SDR technologies. More specifically NASA is developing an open architecture framework to evaluate SDR architectures the most efficient (especially for telemetry links). NASA is also financing space radiation tests of SRAM-based FPGA (from Xilinx). The Electra Radio to be flown to Mars will implement a SDR approach for the TT&C system.

But when considering modern telecom satellite payloads the SDR perspective is by far more challenging. First one can ask himself what is the added value of SDR in telecom satellite networks:

- SDR can be exploited in Telecom payloads to allow adapting the on-board processor to new waveform specs → Future proof;
- SDR allows implementing reconfigurable satellite payloads, terminals and gateways → Flexibility, Re-configurability;
- SDR allows easier integration of terrestrial and satellite networks where several standards are co-existing.

In the following we will focus on the SDR applicability to telecom satellite payloads.

In mobile satellite networks Geostationary satellites are already exploiting flexible DSP-based transparent processors. More SDR opportunities will become available with on-ground BFN architectures supporting MUD, MIMO and other advanced DSP techniques that can be implemented at the gateway. Broadband satellite networks may largely benefit from highly flexible (multi-beam) payloads:

- To achieve high re-configurability (frequency plan, connectivity etc...) of transparent broadband payloads;
- To allow highly reprogrammable (small scale) regenerative SDR OBP:
  - for security/governmental/professional application requiring meshed configurations
  - Potentially high interesting to mitigate the "rigidity" of current on-board regenerative processors (waveform will be frozen for satellite lifetime)
- To support header-based packet switched high throughput transparent processor:
  - Header-only on-board demodulator to route packets w/o regeneration for higher throughput and waveform flexibility
  - Possibility to have SDR implementation of the header processor.

This short review brings the point of what can be a *Software Defined Payload (SDP).* Clearly a canonical SDR interpretation is not applicable to a broadband satellite payload because of technological constraints i.e. on-board processing power requirement incompatible with mass, power and mid-term processor capabilities. However the IEEE SDR definition may be implemented through a mix of technologies fulfilling the needs listed above with affordable power consumption and mass compatible with current platform capabilities. The first SDP enabler is to have a flexible RF front-end followed by an analogue-to-digital conversion. In fact, baseband flexibility alone can not be exploited fully if not matched by a corresponding RF front-end flexibility. The issue of RF front-end flexibility is discussed in a companion paper [21] and will not be detailed in this contribution. Here we just recall that the most difficult flexibility to achieve is the transmit one being the satellite payload able to accommodate a finite number of high-power elements such as High Power Amplifiers (HPAs). A high level functional block diagram of a SDP is shown in Figure 2.

The reconfigurable receive antenna front-end allows to match the coverage needs and beam shape to the intended traffic and services to be supported. In the most advanced scenario an active antenna front-end will allow high beams shape and coverage re-configurability. After down-conversion to a suitable IF frequency Analogue to Digital conversion takes place. At this point in time SDR technologies enter into play however with adaptations required by the specifics of SDP space operations. First the digital beam forming (DBF) and channelization functionalities do not need a complete re-configurability. This allows to efficiently implementing these functionalities in ASIC technology. Despite the ASIC implementation, the DSP algorithm design embedded in the ASIC elements can provide the required level of in-flight re-configurability thanks to telecommand ground control of the payload configuration. More specifically although the ASIC design can not be modified in flight, the ground control of the DBF coefficients and the frequency demultiplexer settings will allow modifying the satellite beam layout, the frequency reuse scheme as well the beam frequency allocation. The DBF Network (DBFN) can also be exploited to support electronic antenna mispointing corrections. This partial DSP digital front-end re-configurability is considered fully satisfactory for the specific SDP needs.

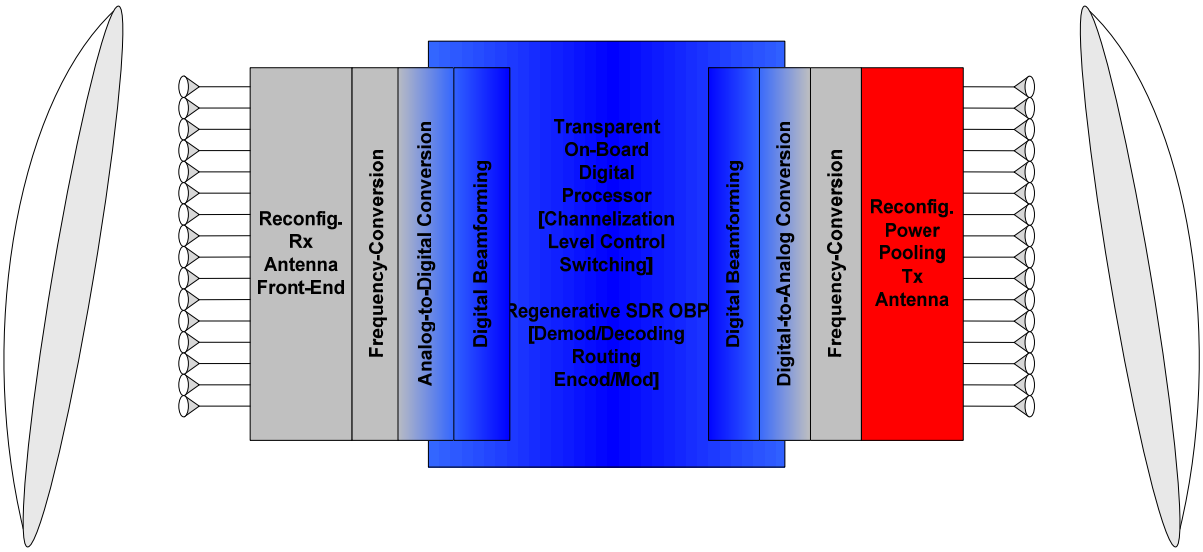


Figure 2 – Functional Block Diagram of a Telecom Payload Architecture Supporting SDP

It is well known that operators currently prefer the exploitation of transparent (bent-pipe) satellite transponders to have the maximum of payload future proofness. It is also generally recognized that the multi-star type of satellite networks with bent-pipe transponders are fulfilling the needs of the vast majority of applications (i.e. broadband access networks as well point-to-point and point-to-multipoint applications). Despite the wide applicability of flexible transparent payload architecture there are cases where meshed network architectures are required. In this case packets have to be routed on-board through a proper payload processing capability. Two distinct ways for achieving waveform re-configurability can be envisaged. The first one consists of implementing on-board processing (OBP) regeneration through a SDR processor. This can be envisaged for a relatively small scale OBP which is processing one (small) part of the overall satellite payload bandwidth. The flexible satellite analogue and digital front-end allows to full in-flight re-configurability of the beams and the bandwidth associated to the meshed OBP. This meshed processor can be implemented through FPGA technologies to allow SDR functionality within the limit of the FPGA capabilities. The second approach for achieving SDR for the meshed payload is to exploit the approach outlined in Ref. 22. According to this processor architecture uplinked packets are switched on-board according to the on-board demodulation of the packet header but not of the packet payload. In this way the payload is switched on-board transparently. For the packet header processing an SDR approach can be envisaged if required for adding further flexibility. The core processor can also support auxiliary functions such as the receive and transmit chains self-calibration required in a payload featuring an active antenna.

The proposed architecture allows fully flexible sharing of the payload capabilities between the bent-pipe multistar and meshed on-board routed payloads. Furthermore, the combination of the core digital processor with the flexible transmit RF front-end allows to achieve flexibility in power to beam, frequency to beam, frequency reuse and coverage capabilities in transmission. As discussed[21] the power to beam allocation flexibility may face limitations due to the intrinsic RF transmit front-end architecture limitations. Also the applicability of active antennas in the transmit side may face limitations due to technological and efficiency considerations.

V. SDP for Digital Bent-Pipes and for Regenerative Payloads: Architectural and Technological Issues

In SDP implementing *Digital Bent-Pipe* payloads each up-link beam channel is divided in several sub-channels that can be individually routed to down-link beams. In the down-link of the forward link, beam load sharing capability can be achieved considering the use of advanced RF power section and antenna architectures exploiting DBF.

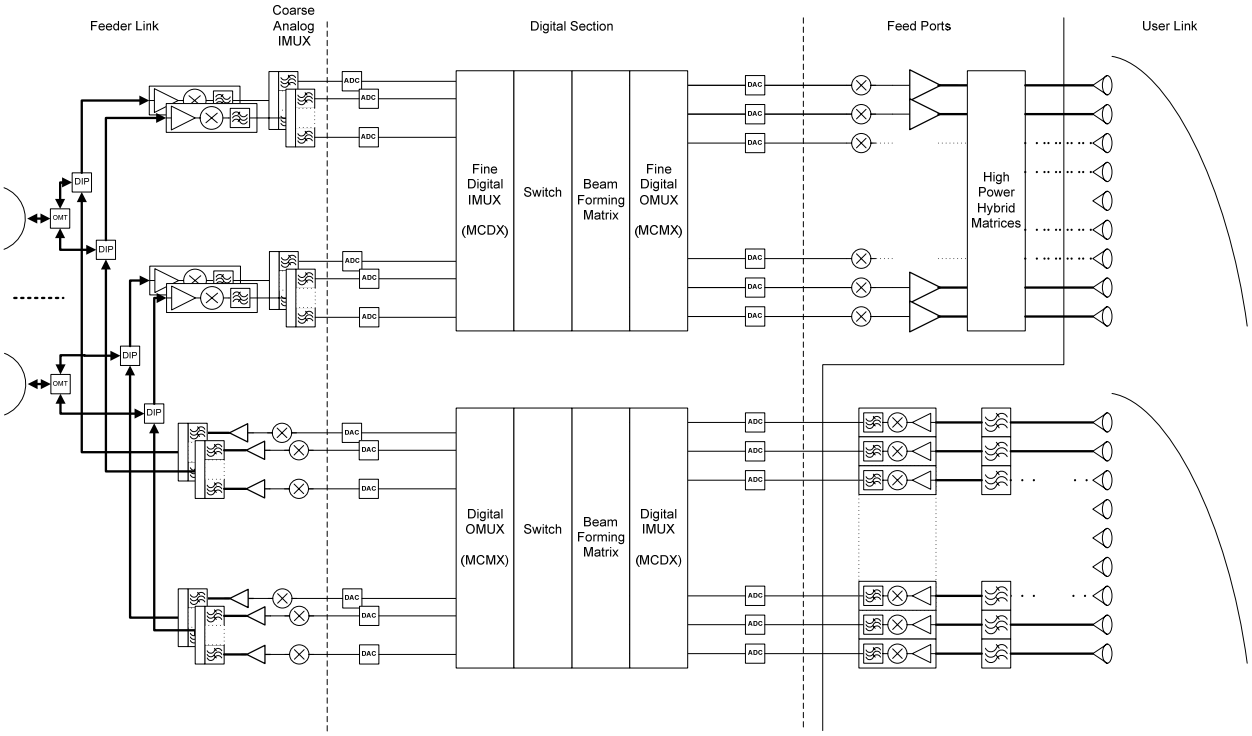


Figure 3 –Block Diagram of a Digital Bent-Pipe SDP

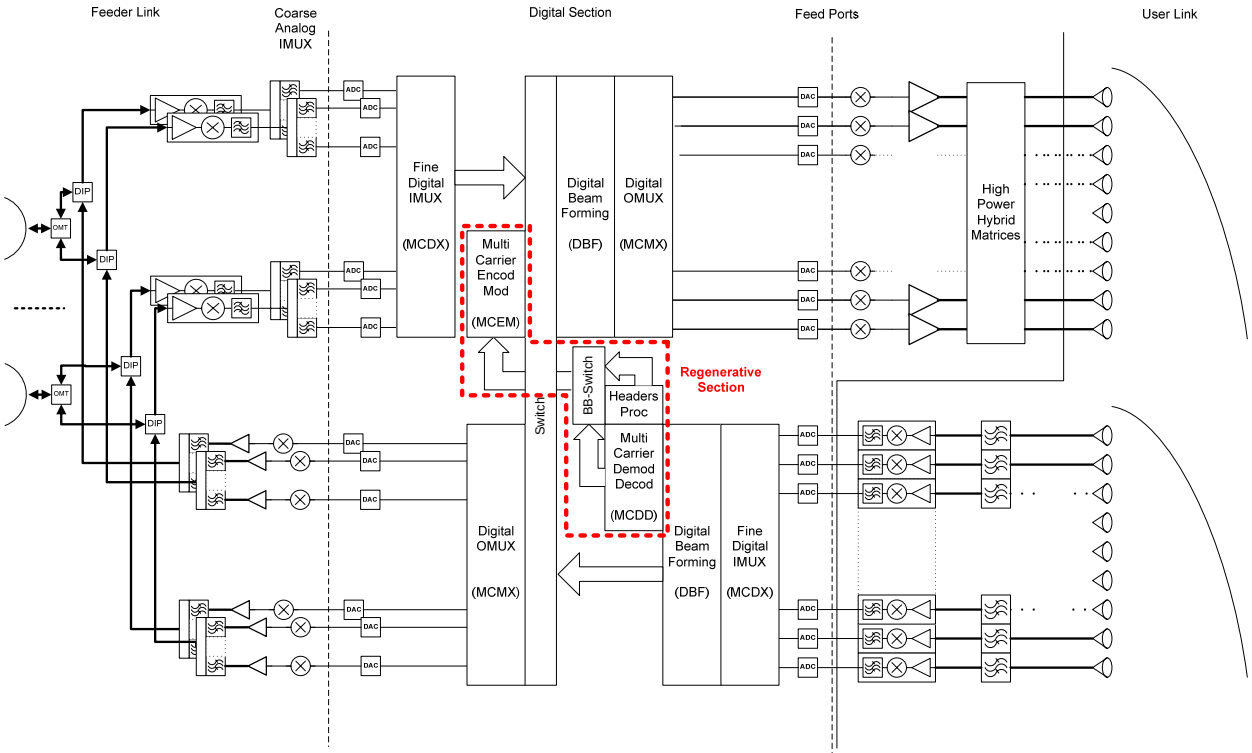


Figure 4 – Block Diagram of a Hybrid Digital Bent-Pipe / Regenerative SDP

The reference payload model reported in Figure 3 assumes separated forward (FWD) and return (RTN) processors. Forward repeater creates the path from the gateway beams to the user beams and viceversa for return repeater. In the distributed access scenario, feeder-link bandwidth is higher than user link bandwidth; in a medium/long term perspective it could be possible to adjust gateways ports conversion rates to match feeder-link bandwidths. Nonetheless, for the adopted reference architectures input and output ports of both FWD and RTN processors have been maintained at same processing bandwidths providing building blocks reusability in both the processors (i.e. the feeder-link bandwidth is segmented by analog IMUXs into chunks of width comparable to the user-link band).

Software defined implementation of on-board demodulators, decoders, encoders, and modulators open the possibility for Regenerative SDP, nevertheless the tremendous complexity load of a full reconfigurable digital processor for a mesh network regenerative payload shift its feasibility to long terms.

Hybrid solutions in which part of the traffic is served by simple bent-pipe star network topology and a regenerative meshed network is implemented for limited user-to-user amount of traffic may be realizable in shorter terms. Such Hybrid Digital Bent-Pipe / Regenerative SDP solution is shown in Figure 4.

The feasibility of the digital section of a SDP relies on technological advances in a number of key areas.

- **Deep submicron, radiation-hardened Application Specific Integrated Circuits (ASIC) technology**

  In accordance to the forecasts of the International Technology Roadmap for Semiconductors (ITRS) [23], CMOS scaling exhibits a continuous shrinking of gate lengths from micrometer to nanometer regimes (which in turn implies an increase of the number of gates per device, till to now, in accordance to the Moore's Law). As drawback, the supply voltage is now approaching the 1 Volt floor which leads to: reduced DC-DC conversion efficiencies (with respect to the 50/100 Volt values of typical satellite platforms), increased Ohmic losses and higher sensitivity to noise. As well, as dimensions scale downward the photolithographic masks costs are becoming dramatically high.

- **Digital Signal Processors (DSP) and Field Programmable Gate Arrays (FPGA) Technology**

  DSPs, intended as fully software programmable processors, provide the capability for implementing an unlimited number of functions at he cost of a limited speed and complexity (per device). As well, FPGAs solutions can be considered a bridging solution between fully programmable DSPs and hard-wired ASICs.

  Reconfigurability of on-board DSP/FPGA implies operating, managing and control functionalities such as: Software transfer (Download), Storage, Installation, Testing, Failures reporting, etc..

  It is note worth that substantial payload reconfigurations may require repeating an in-depth in-orbit-test for validating and commissioning the renewed payload.

- **High-speed and low-power A/D and D/A converters,**

  Analog to Digital (A/D) and Digital to Analog (D/A) converters play the key role of translators from one domain to the other.

  Unfortunately converters technology exhibits a slower rate of development than ASIC technology [24]:
  - Number of levels (2^{bits}) times sampling frequency (F_s) doubles approximately every 5 years;
  - Effective number of levels (2^{ENOB}) times sampling frequency (F_s) doubles approximately every 10 years;
  - 3dB RF Bandwidth doubles approximately every 5 years.

- **High-speed serial links**

  Together with the ASICs' core processing capabilities it is mandatory to improve the efficiency of data transportation (between ASICs, boards and equipments) by mean of High-Speed-Serial-Link (HSSL). Stand-alone SerDes chips or embedded HSSL IPs provide very high speed, analogue and flow control functions of serializing/de-serializing, clock recovery, Rx code synchronization, elastic buffering and encoding/decoding.

  To bridge larger distances it can be envisaged to connect the serial, high speed, electrical interface with an optical transmitter and receiver and to replace copper cable by optical fibers.

- **High density modular packaging**

  High density and thermal efficient packaging is required to respond to the demand for integration of ever increasing functions into one chip. The request is further enforced by the rate of growth of the number of gates per ASIC which is unmatched by an equivalent growth in available IN/OUT pins.

Packaging technology criticality is augmented by the need for keeping under control parasitic effects for embedded HSSL interconnections.

- **Architecture/Algorithm Co-Design/Optimization**

  It is clear that SDP reconfigurability may come at the cost of power, mass, and complexity. Therefore a full exploitation of the design degrees of freedom is mandatory. This objective can only be obtained co-designing the SPD overall architecture, functionalities and algorithms with particular care to the partitioning of the digital section in reusable, modular and scalar building blocks and to the interconnect layout for guaranteeing reconfigurability (e.g. non-blocking) while reducing the throughput between the stages.

VI. Conclusion

In a fast evolving telecommunication world, payload and overall system flexibility assume great importance in overcoming difficulties to predict service requirements and user demand with adequate accuracy and sufficiently in advance. These uncertainties call for a high capability of reconfigurability, unfortunately not easily matching telecommunication payload technological simplicity and satellite's long operational life.

Transparent, conventional bent-pipe payloads are, at this regard, less risky. However regenerative satellites, based on On-Board-Processing (OBP), would certainly provide a better efficiency at the risk of a rapid obsolescence with the emersion of new transmission standards not fitting the frozen on-board capabilities.

Alternative approaches based on Software Defined Radio techniques and reconfigurability of the on-board functions, may be attractive in both alleviating the operational risks associated to regenerative payload, and in extending the capabilities of bent-pipe payloads.

The reduction of operational risks may surely attract the attention of the final satellite operator; nonetheless, telecommunication payload manufacturers may equally well benefit by the introduction of Software Radio technologies.

Indeed it is expected that *Software Defined Payload* implementations, using common RF front-ends in conjunction with a modular signal processing architectures, will reduce the new products design cycles making less mission specific the required non-recurring-engineering (NRE) effort.

The move to digital hardware with the relative reduction of components performance spreading (typical of analog devices) could further reduce manufacturing, assembly, integrating and testing costs.

The final outcome would be a reduction of the time required to develop a marketable product (development schedule reduction and certainty) and an augmented confidence for successive builds.

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