SDR for space systems: overview and perspectives

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Introduction

- Software Defined Radio (SDR) is a technological concept where the processing of RF signals is implemented in re-programmable units rather than application-specific integrated circuits (ASICs)
  - Re-programmable units encompasses digital signal processors (DSP), field programmable gate arrays (FPGA) and general purpose processors (GPP or CPU)
  - It is made possible thanks to Moore's law (and a bit of science and entrepreneurship too)
- We'll discuss here about the applicability of SDR to space systems with a strong focus on satellite communications (satcom)

Introduction

- Devising satcom equipments is challenging:
  - Space is a tough environment (temperature variation, vacuum, radiations, scarce energy supply)
  - Getting there is techno-demanding (vibration, acceleration) and costly: about 1/4 of the overall satellite cost [≈ 1/4 x $500 millions]* is dedicated to launch operations
  - Once there, always there: a satellite lifetime is about 15 years*
  - And "space" can be quite far from Earth (36 000 km for the geostationary orbit)
    - At Ku-band (around 12 GHz) that makes a 200 dB free space loss

* For big satcom geostationary satellites

Introduction

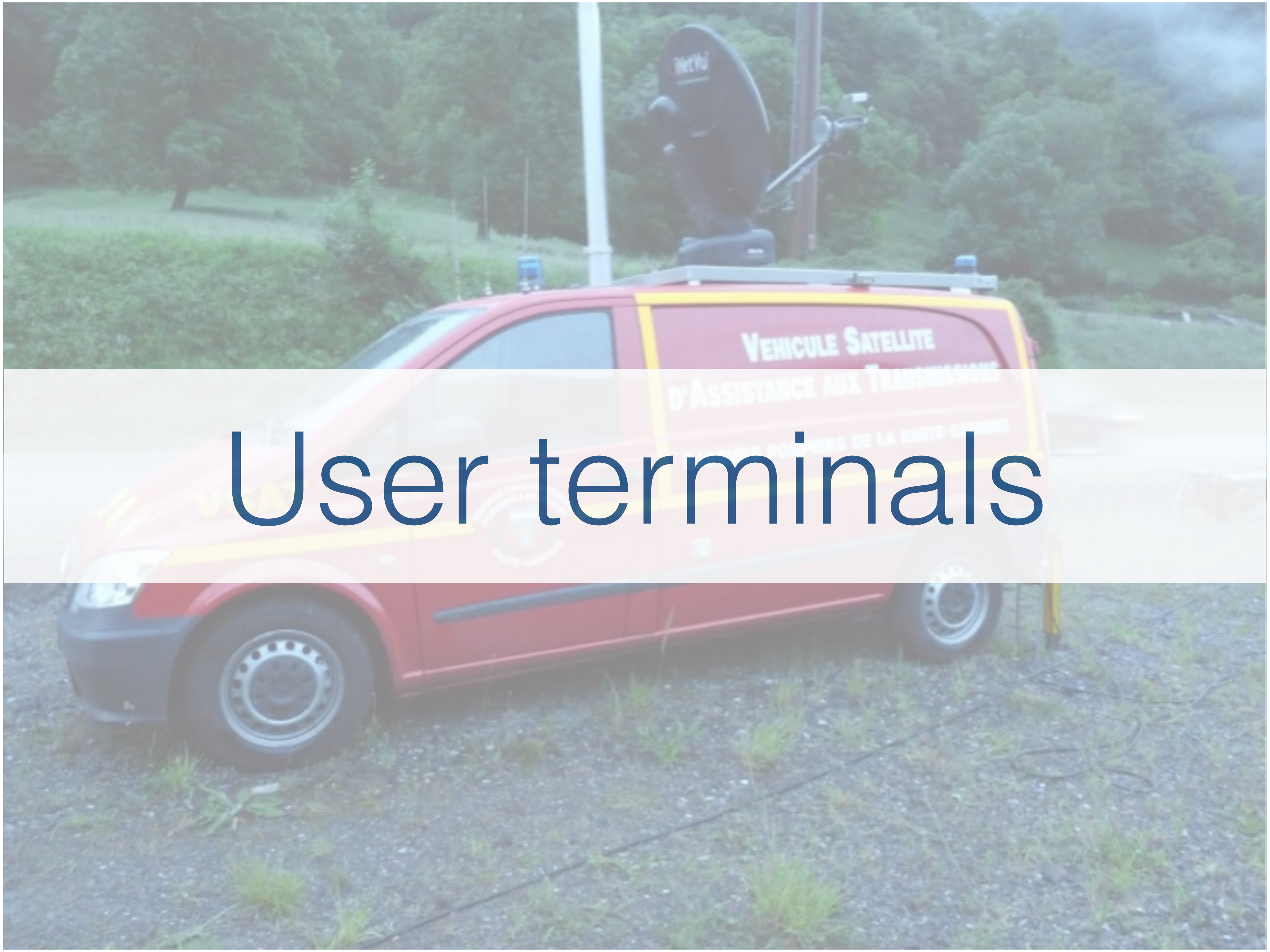
- Selling satcom services is also challenging:
  - The markets and business models are different from terrestrial telecommunications: niche and governmental markets (except for TV and radio broadcasting)
  - There is strong competition with terrestrial technologies where the satellite and terrestrial market intersect

➡ **Could SDR be the swiss army knife of satcoms ?**

SDR for satcom

"One thing to rule them all ?"

User terminals



Categories of user terminals

- Portable terminals

[Source: Inmarsat]

- Mobile terminals

[Source: Thuraya]

- Transportable terminals

- Fixed terminals

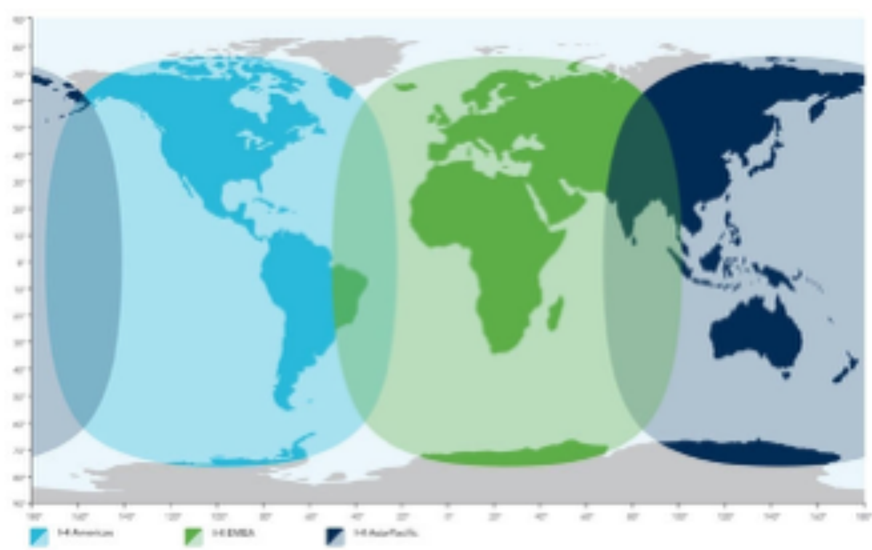
[Source: satsig.net]

User terminals

- The SDR technology is makes possible the following capabilities:
  - Cognitive radio: adaptivity to various spectrum conditions (as a result of prior sensing) in terms of frequency, bandwidth and emitted power, including the possibility to share spectrum
    - For example on the 17.7-19.7 GHz band, the fixed satellite service (FSS) and fixed service (FS) are both primary
  - Integration of multiple waveforms (i.e., transmission schemes) into a single hardware platform to (a) save space and cost, (b) ensure upgradability and (c) foster co-operative communications schemes based on ancillary terrestrial components

User terminals: example

- The Inmarsat BGAN service provides data rates up to 492 kbit/s with a worldwide coverage
  - Support for real-time (called streaming, 384 kbit/s) and non-real time IP-based services as well as voice services
- GateHouse has developed a software BGAN implementation compliant with the SCA (Software Communication Architecture) standard and the BGAN specification
  - This software can be run on SCA compliant SDR platforms



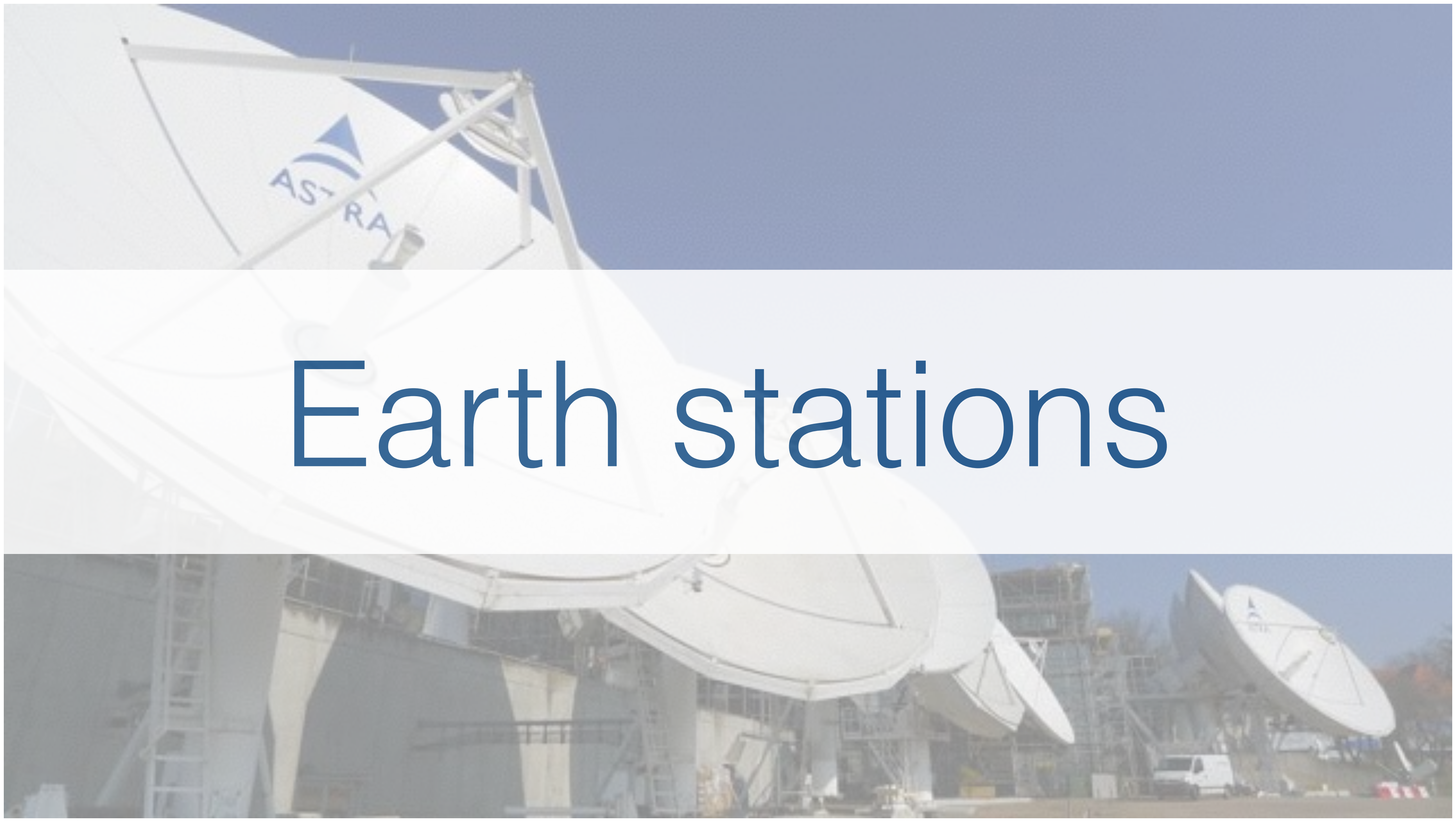
[Source: Inmarsat]

[Source: GateHouse]

Conclusions on user terminals

- The use of SDR for user terminals is a promising direction
  - The signal bandwidth to process is usually limited
  - For terminals, the exposure to changing standards, hence the need to adapt is strong
- Using SDR for user terminals adresses the following stakes:
  - To decrease the CAPEX of accessing satellite services by favouring convergence between terrestrial and satellite terminal hardware technologies
  - To decrease the OPEX of accessing satellite services by favouring seamless hybridisation of terrestrial and satellite access

Earth stations



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Categories of Earth stations

- Gateways / hubs / teleports

[Source: groundcontrol.com]

- TTC stations

[Source: Elta]

Earth stations

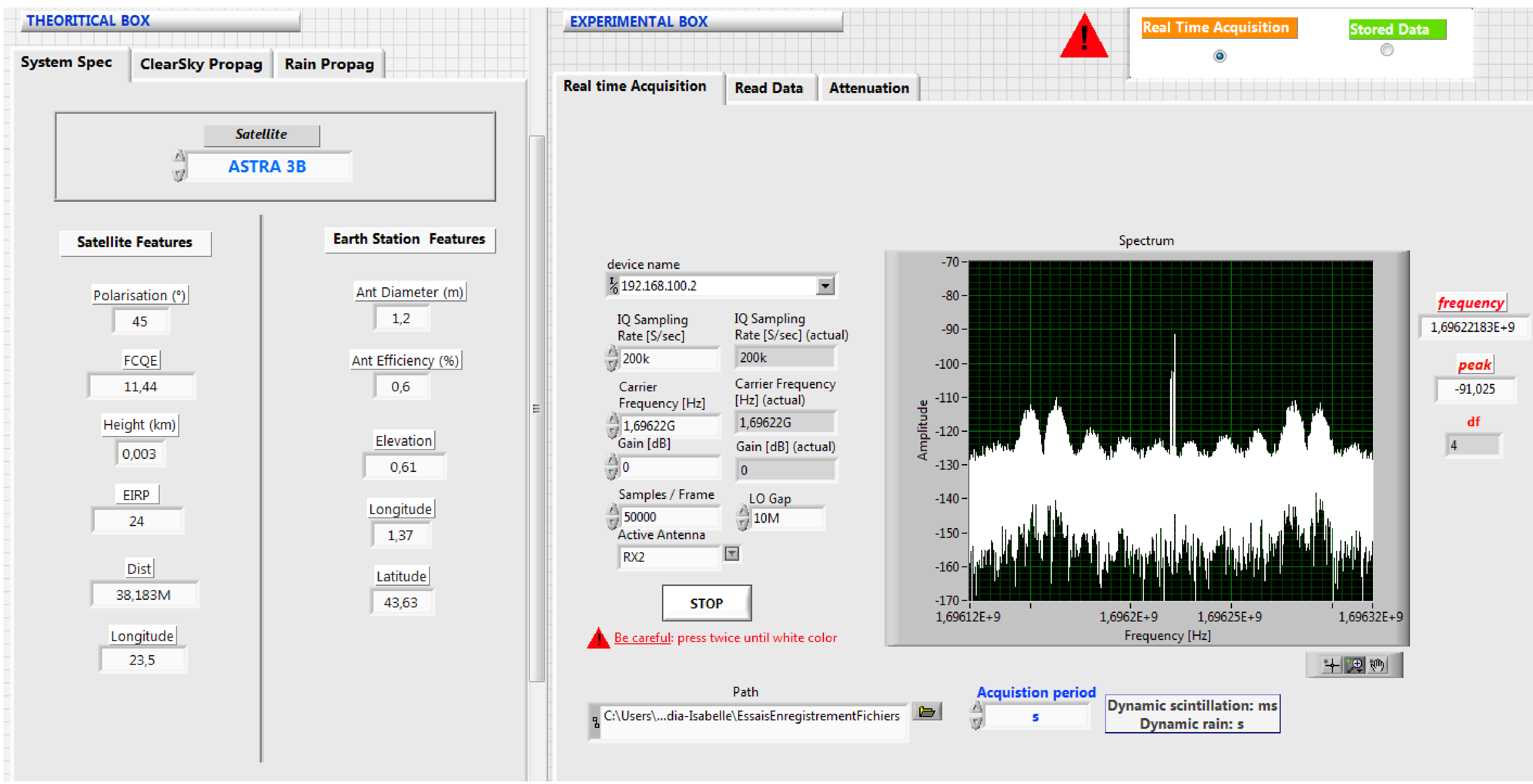
- Gateways/hubs and teleports deal with complex processing of large bandwidth of spectrum
  - Possibly not the best case for SDR
- On the other hand, SDR technology is well positioned for the development of specialised receivers that are tailored to situations where a dedicated ASIC development would be too costly
  - Example: in the DIGIDSAT ESA project, an antenna tracking system is developed for end-of-line geo satellites that drift to inclined orbit. SDR is used for a building a dedicated beacon receiver that actuates antenna pointing

Earth stations

- For small satellites (typically low earth orbit) such as cubesats, amateur sats or nanosats, SDR-based Earth stations are popular
  - From an SDR standpoint, it is a favourable case since (a) signals are narrowband and (b) transmission schemes are simple (AFSK, BPSK modulations)
- Example: the OSAGS ground station network is based on Ettus Research USRPs

Earth stations: example

- A simple SDR Ku-band beacon receiver
  - The receiver includes frequency tracking to cope with cheap COTS components in the LNB



Conclusions on Earth stations

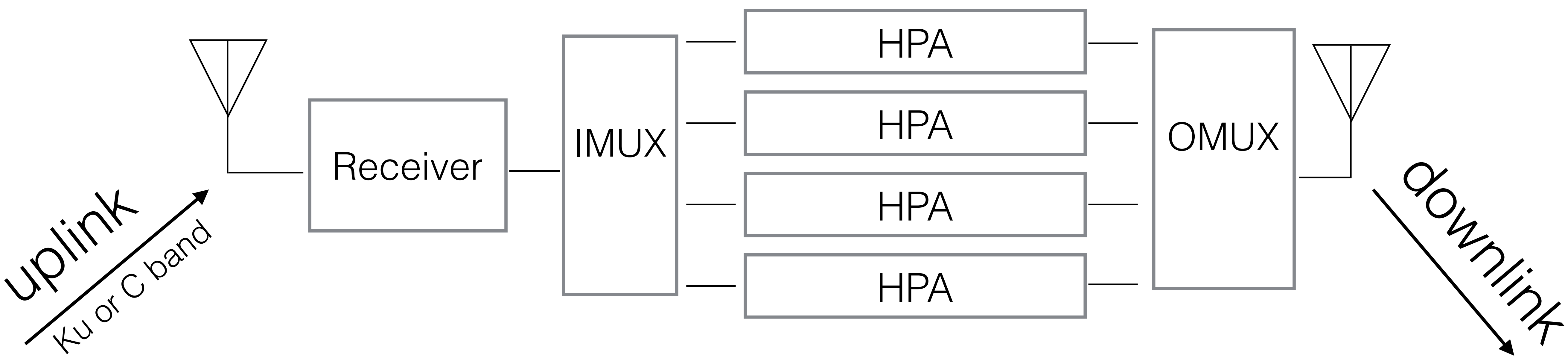
- SDR best suited to design of dedicated receivers or ground instrumentation for controlling facilities
- Or for LEO small satellites Earth stations

Payloads

[Source : O3b networks]

Telecommunication payloads

- Transparent "Bent pipe" payload architectures are an heritage from broadcast services (e.g., TV and radio broadcast):



Transponder = channels of fixed 36 or 72 MHz bandwidth
One "fat" carrier per transponder

The HPA can be operated close to the saturation point

➡ **Current usage is shifting away from this paradigm**

Telecommunication payloads

- Current usages and satellites display the following characteristics :
  - *Directed to "telecom" (i.e., bi-directional, point-to-point) services*
    - The business model changes dramatically and the cost of transmitted Mbit is a strategic issue
    - The rate of change of terrestrial standards for networks and services is higher than the typical lifetime of a satellite
    - Forward and return link show different constraints and characteristics
  - *Based on multi-beam architectures*
    - For example, KA-SAT features 82 user spot beams over Europe at large
  - *Operating in the Ka-band band and above*
    - The Ka-band suffers from tougher environment impairments (than the Ku-band). These may vary on a carrier by carrier basis

Telecommunication payloads

- These characteristics are summarised in two challenges:
  - Increasing payload capabilities
    - In terms of technology figure of merits (e.g., mass, consumption and thermal characteristics)
    - In terms of transmission figure of merits (e.g., spectral efficiency)
  - Increasing payload flexibility
    - In terms of adaptivity to evolving trafic geographic distribution
    - In terms of adaptivity to evolving trafic characteristics

➡ **Onboard processing contributes to tackling these challenges**

Telecommunication payloads

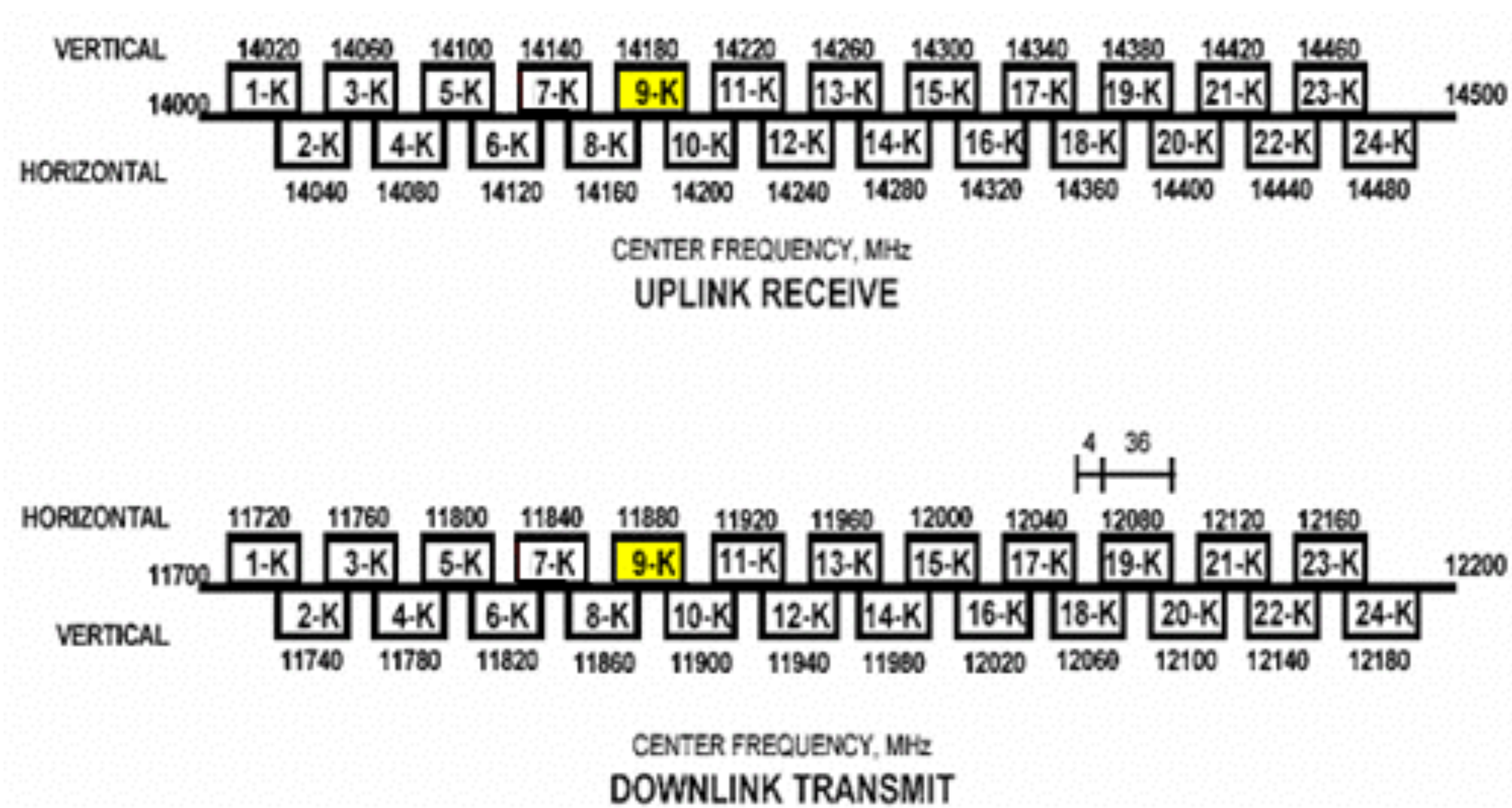
- Categorisation of onboard processing:
  - Digital signal processing of the incoming carriers to optimise subsequent channelised HPA operations (e.g., digital transparent processors implementing filtering and carrier routing)
  - Digital signal processing of the incoming carriers to accommodate to a flexible definition of channels (in terms of bandwidth and central frequency)
  - On-board demodulation for regenerative processing (e.g., different modulations on the uplink and downlink) or higher layer switching (i.e., mesh architectures)

By increasing requirement on reconfigurability

➡ **SDR contributes to reconfigurable digital processing for flexible payloads and favours reusability, cutting down costs**

Telecommunication payloads: example

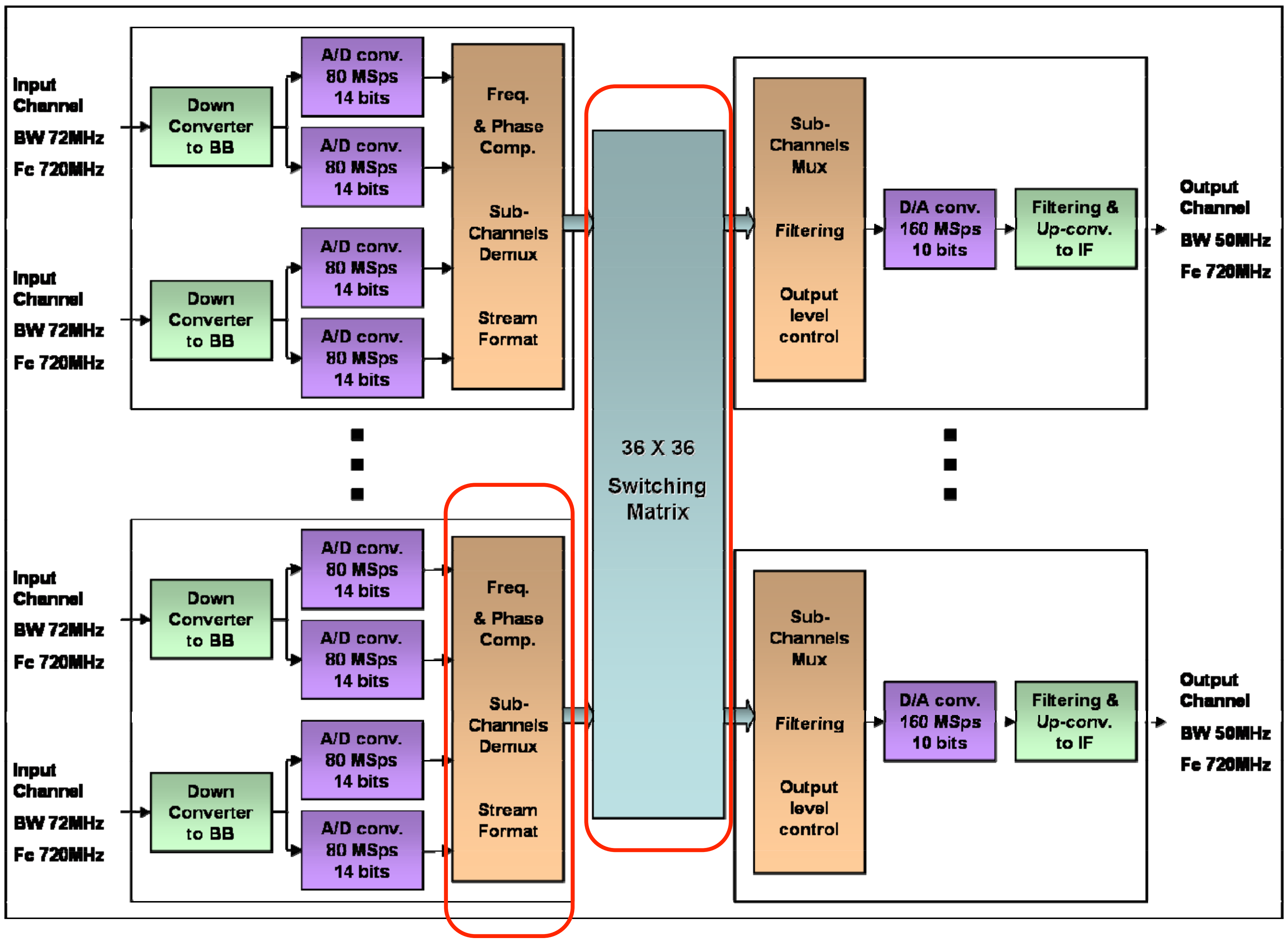
- Legacy payloads: the frequency plan determines the (fixed) switching policy among uplink and downlink channels



[Source: JSAT int'l]

Telecommunication payloads: example

- Digital transparent processing enables programmable switching & duplicating at carrier granularity among uplink and downlink spots



[Source : Le Pera et al. 1-4244-0525-4/07, IEEE 2007]

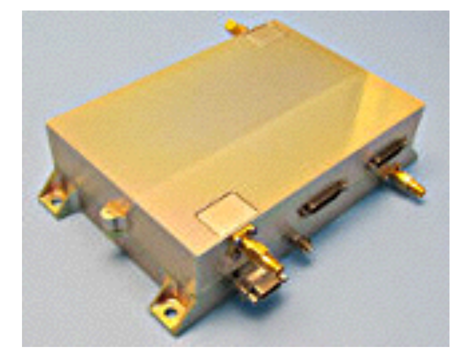
SDR makes it possible to have reconfigurable processing in the digital realm

Speciality payloads

- Speciality payloads implement missions that are different from the typical “receive, amplify and transmit” telecom payloads
- For example, Telemetry & Telecommand (TM/TC) is present in every satellite and sends health information (TM) about the satellite to Earth and receives orders from the control centre (TC)
- Other examples may be embarked as primary/secondary payloads in geostationary or non-geostationary platforms
  - Telemetry data links for observation satellites, scientific payloads, search and rescue, …
- These payloads are also candidates for using SDR technology in order to benefit from its flexibility

Speciality payloads: examples

- The following example is a Telemetry, Tracking and Control (TT&C) transceiver developed from Com Dev and embarked by the FORMOSAT-7 satellite series (LEO satellites for weather prediction through atmospheric sounding)
  - Communication modulation is implemented in an FPGA to offer flexibility depending on the mission and mission phases



[Source : ESA]

- The SCAN NASA testbed aims to test three SDR-based payloads that are compatible with NASA's TDRSS system

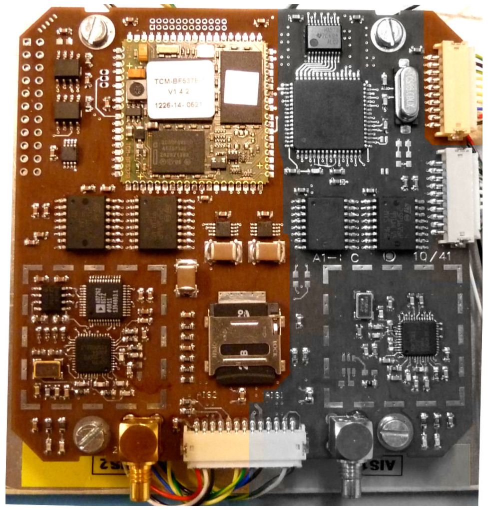
[Source: NASA]

[Source: NASA]

[Source: NASA]

Speciality payloads: example

- AIS (Automatic Identification System) is beaconing system for tracking ships
  - Beacons are broadcasted (≈ 160 MHz at 9.6 kbit/s) by ships and collected by land stations located
- While it was not initially designed for, it turned out that beacons could be collected by LEO satellites in order to provide a more global coverage
  - Collisions among beacons and weak signals are the two main challenges
- The Aalborg University has devised an SDR AIS receiver which is onboard the AAUSAT3 cubesat



[Source: Aalborg University]

Conclusions on payloads

- As far as payloads are concerned, the role of SDR is a two-fold question
  - Where to put the boundary between analog and digital processing ?
  - What is the added value of SDR for onboard (digital) processing ?
- The answers depend on the available technology and the mission requirements
  - The present opportunity for SDR-enabled payloads is where the requirements show a combination of limited throughput and complex processing
- Note: antenna processing is not covered here

Teaching activities

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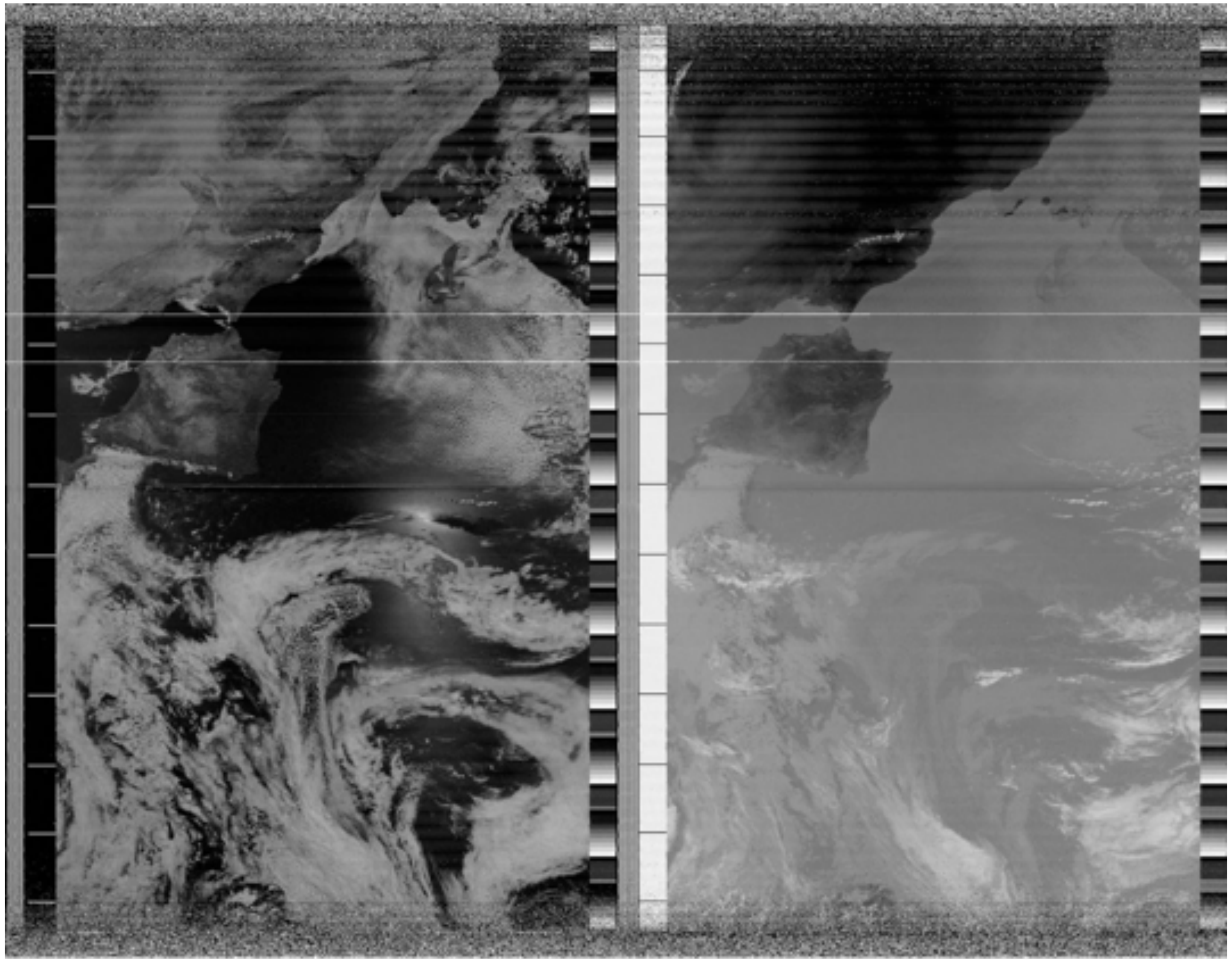
Teaching activities

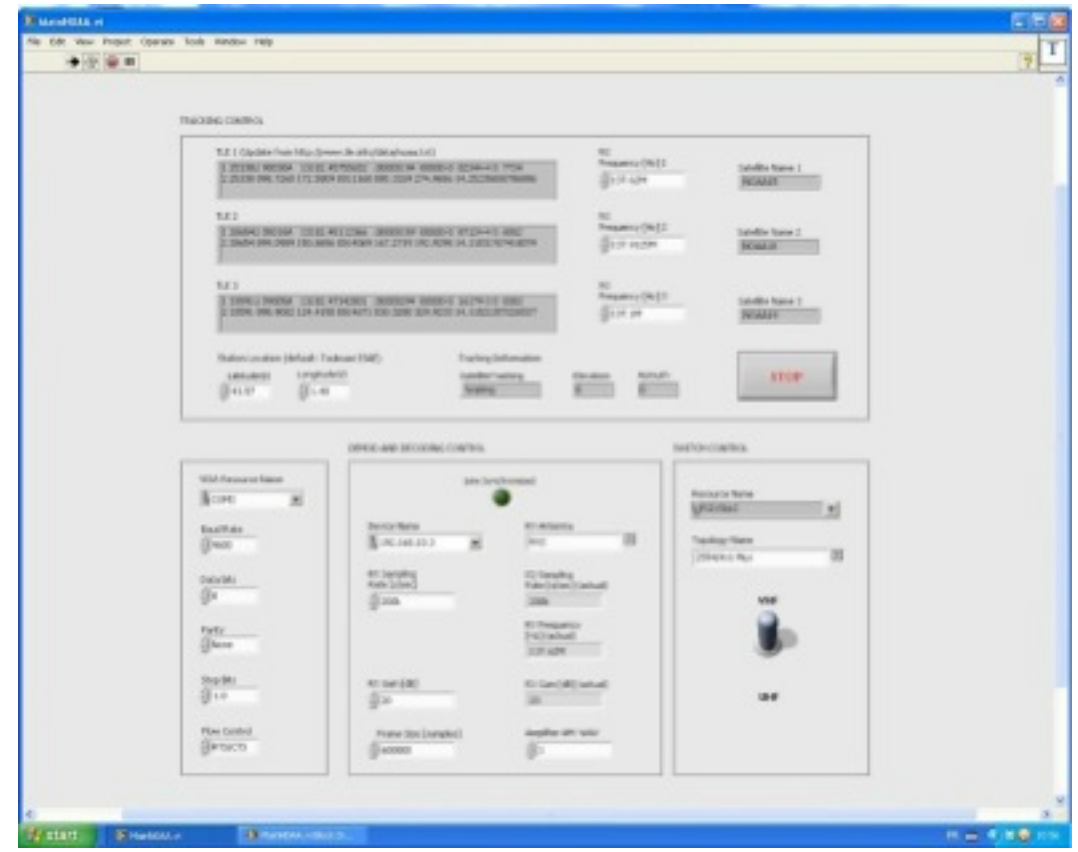
- Context: "Space Communication Systems" programme for the 3rd (last) year of engineering degree & advanced master
- SDR devices used for small projects (teams of two students working during 70 h) and workshops
- Our SDR platforms
  - 4 x National Instruments USRP 2920 (50-2200 MHz, 20 MHz of bandwidth, Gigabit Ethernet transport)
  - 2 x National Instruments VST 5644R (65-6000 MHz, 80 MHz of bandwidth, instrument grade, PXIe transport)
  - Programmable with LabVIEW

Teaching activities: example

- Receiving weather images from space
  - Based on NOAA polar orbiting satellites (APT mode)
  - Weather images (line by line scans) are downlinked to Earth at 137 MHz with an FM + AM modulation
    - One line = 2 x 909 pixels, 1 pixel = 16 km^2
  - Extending our LEO/amateur satellite station, the students developed an SDR-based receiver and decoder for weather images
    - Pointing/tracking of the satellite
    - Signal RX and demodulation
    - Image processing

Teaching activities: example

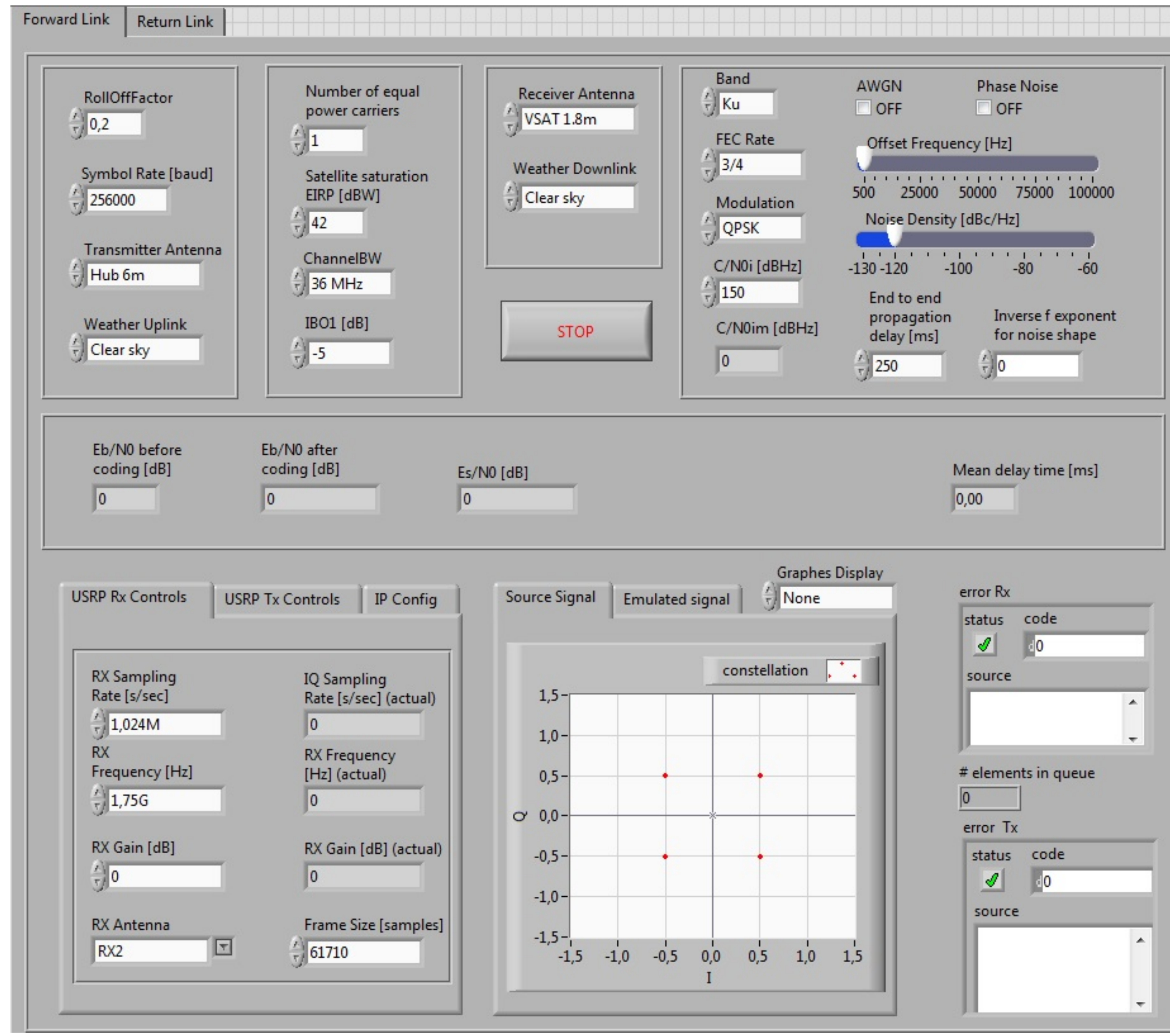




Teaching activities: example

- Flipped teaching for DVB/S2 lectures
  - Prior to attending lectures on DVB/S2, students go through an introductory workshop
  - The workshop is extensively based on our lab DVB/S2 platform:
    - Co-located DVB/S2 modems for remote and hub sites
    - An SDR-based channel emulator for geostationary link [covered in a separate presentation]
  - The topics covered are: spectral efficiency, C/N0 calculation and measurement, protocol overhead, TCP performance over geostationary links
    - Conditions similar to “real transmission” are reproduced thanks to SDR channel emulation

Teaching activities: example



Conclusions on teaching activities

- It creates “creates opportunities for projects not possible before” and it “contributes to a better understanding of the lectures” (students say)
- Having to choose between MATLAB **or** USRP + LavVIEW, 40 % of our students would go for USRPs
- It also calls for multi-disciplinary teaching teams
  - SDR = RF instrumentation + (real-time) programming

Overall conclusions

- Software defined radio offer many opportunities for satcom applications:
  - Cognitive or advanced RF processing
  - Reconfiguration during operations
  - Reusability of existing hardware/software (from similar products or by favouring convergence with terrestrial technologies)
  - Specific developments not affordable by means of ASIC technology

- The associated challenges are
  - To bridge the gap between terrestrial and space qualified SDR technology
    - Including for ADCs & DACs
  - To devise powerful development frameworks and methodologies
  - To be adventurous

Thank you