Development, Realisation and Validation of a Baseband Equipment Dual-Channel

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An OHB Company

Antwerp Space

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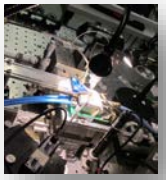
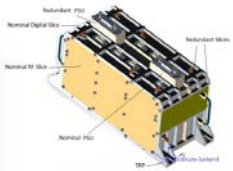
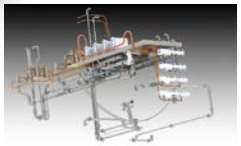
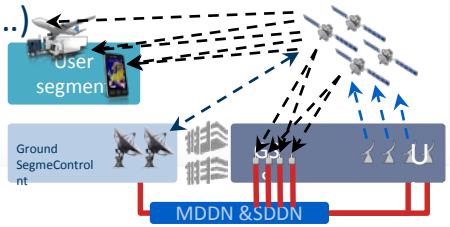
Agenda

- Antwerp Space
- Drivers for the development
- Project structure
- Key technical challenges and achievements
- Validation campaign & subco roles
- Lessons learned
- Future work

Antwerp Space

- Satellite communication experts since 1962
- An OHB company
- Both onboard and ground solution:
  - On board:
    - components for photonics
    - Modem equipment onboard ISS, RF instrument for Mars
    - Payload integration for scientific satellites
      (Exomars 2020, JUICE, …)
  - Ground:
    - Modems for TT&C and high speed telemetry,
      frequency convertors (EESS and deep space)
    - SCOE for TT&C and payload telemetry, RF suite cases
      (Solar Orbiter, MTG, Hispasat, Exomars, Columbus Orbital Facility,…)
    - Secure networks
      (design and implementation of Galileo MDDN and SDDN)

Solar Orbiter TT&C SCOE

Drivers for the Project

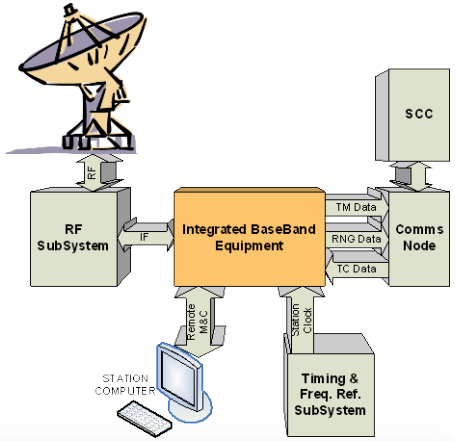
- History of IBB (Integrated BaseBand)
  - SDR platform for TT&C (physical layer and ECSS/CCSDS stack in SW)
  - Initially designed for House Keeping Telemetry (HKTM) of telecom satellites:
    - => remnant carrier
    - => bitrates up to 64kbps
    - => Tone ranging
  - Used for LEO constellations, SCOEs, etc
  - Enhanced later on with backend protocols like SLE and EDEN

- Newer satellites require more HKTM (e.g. OBP), and smaller satellites mix payload TM with HKTM

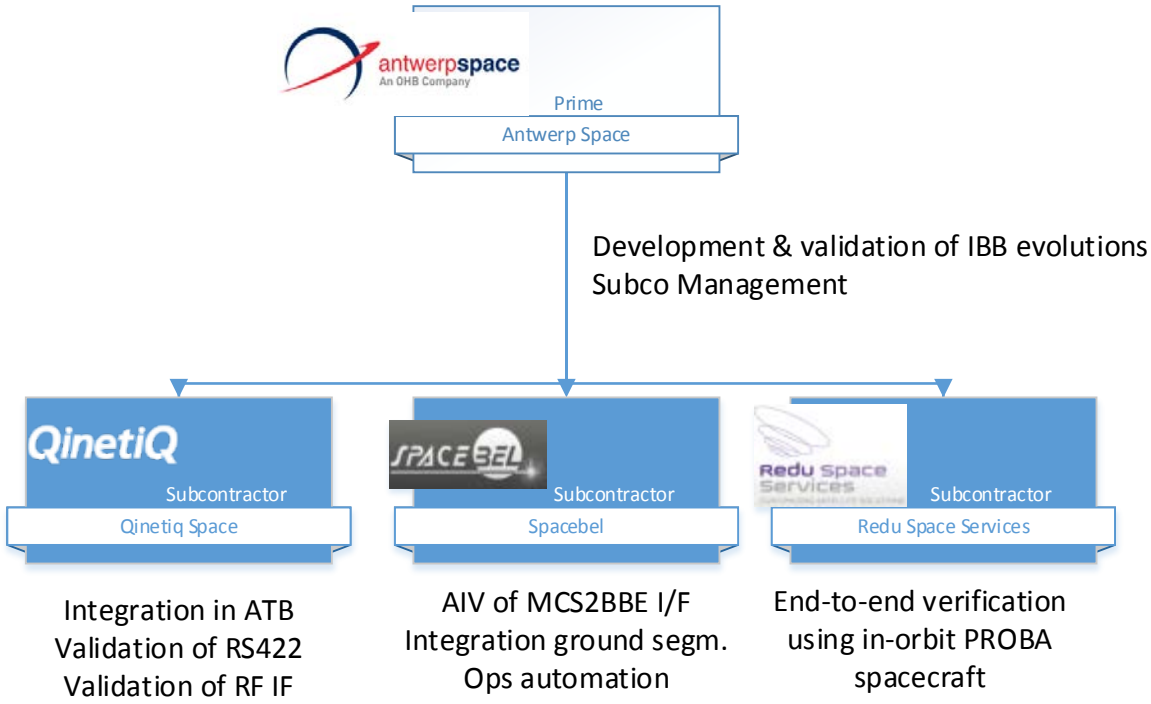
  ⇒ Need for higher symbol rates and other modulation types
- Operators require more flexibility in TM processing

  ⇒ need for better TM replay

  ⇒ Need for TM archive browsing
- Opportunity arose to validate new version with PROBA-V and PROBA-3
  - => need for MCS2BBE protocol



Project Structure

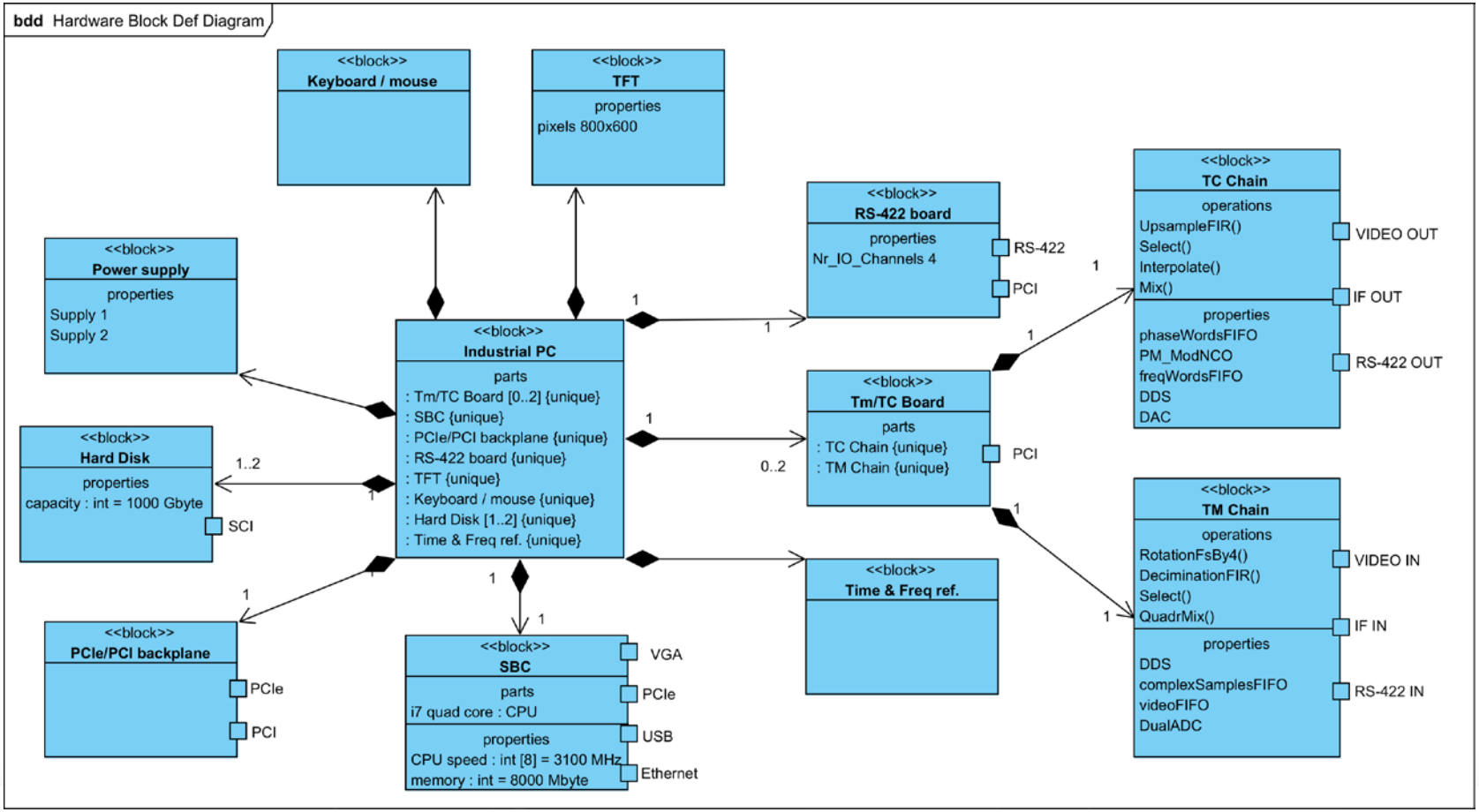


Key Technical Challenges & Achievements

- Integrated BaseBand (IBB) Philosophy
  - Hardware minimized
    - Industrial computer platform
    - Antwerp Space sampling Board (TMTC board)
  - Software maximized
    - DSP software
    - TM handling
    - TC handling
    - Monitoring and Control
    - Graphical User Interface
    - Custom software upon user demand (e.g. interfaces)
  - Advantages
    - Flexibility (extra modules at minimal cost, configurability, SW switch matrix)
    - No added noise during mod / demod
  - Disadvantages
    - Speed depends on CPU (is also and advantage, with increasing CPU power each year)

Key Technical Challenges & Achievements

- IBB hardware (just a computer ?)



Key Technical Challenges & Achievements

- Hardware challenges
  - Previous IBB (3d generation)
    - HW developed in 2008/2009
    - Direct sampling @ 70 MHz, down sampling to 1 MHz
  - Changes needed for new IBB
    - PCI or PCIe backplane
    - CPU usage => SBC quad core i7 + hyperthreading
    - Solid State hard Disks (capacity 1TB)
    - Redundant power supply
    - FPGA changes for higher resolution and BW of 4 MHz
  - What didn't change
    - TMTC boards
    - RS422 board
    - Time and Frequency board

average time = 309 us; max time = 346 us; min time =

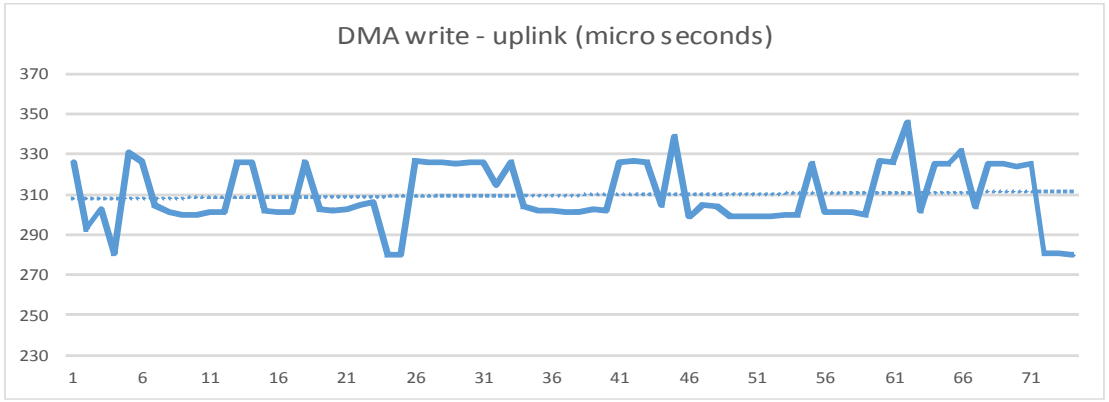
Key Technical Challenges & Achievements

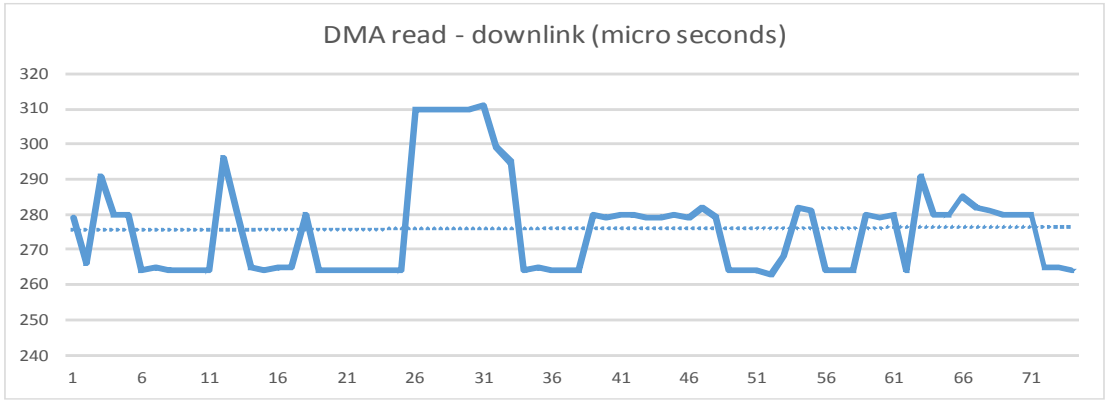
- Hardware benchmarks
  - Old IBB:
    - 1 Msample / s
    - 16384 samples / buffer (FPGA FIFO of 32 kbyte)
    - Rx 8 bit I and 8 bit Q – Tx 16 bit real : 64 kbyte per transfer per chain
    - New buffer is needed every 16.384 ms (1 Msample) in up and in down link
    - The old PC had 16 ms to handle an IRQ as it appears for 1 chain.
  - New IBB:
    - 4 Msample / s
    - 16384 samples / buffer
    - Rx 16 bit I and 16 bit Q – Tx 16 bit real or 8 bit I and 8 bit Q: 96 kbyte /chain
    - New buffer is needed every 4.096 ms (4 Msample) in up and down link per chain
    - So 2 chains means only 2 ms available to handle IRQ's and mandatory calculations.
  - Max transfer speed of data over PCI bus = 264 Mbyte/s (32 bit x 66 MHz)
    - Time to transfer 32 kbyte over PCI bus > 0.12 ms
    - For 2 chains and 96 kbyte this means 2 x 3 x 0.12 = 0.73 ms **BEST CASE !**
  - Average time to calculate 4096 point FFT: 110 µs (carrier acquisition) < 2ms

average time = 309 us; max time = 346 us; min time =

Key Technical Challenges & Achievements

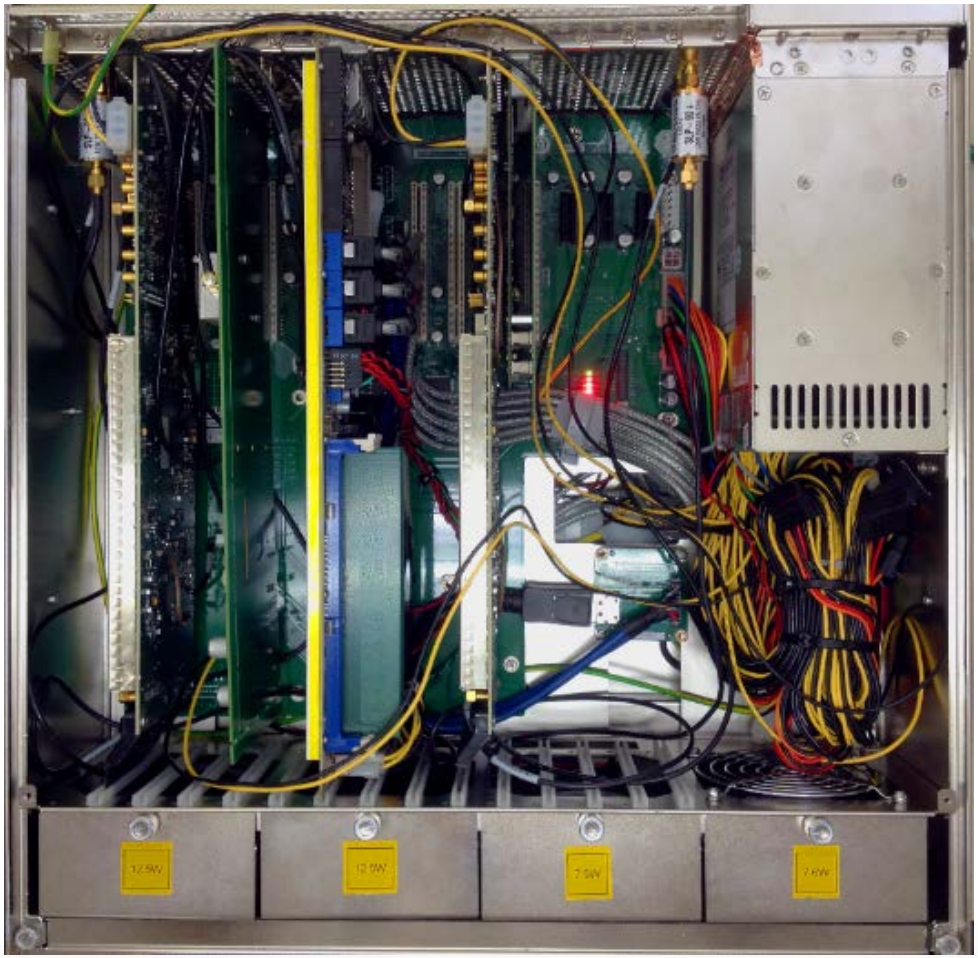
- Hardware benchmarks 32 Kbyte transfer
  - Uplink throughput
    - Average: 309 µs
    - Max : 346 µs
    - Min: 280 µ
  - Downlink throughput
    - Average: 276 µs
    - Max : 311 µs
    - Min: 263 µs
  - Total (2 DL + 1 UL):
    - Average: 861 µs / chain
    - Max: 968 µs / chain
    - Min: 806 µs / chain
  - Reason for delay / diff:
    - PCIe – PCI bridge chips
  - Remark: additional transfers for IRIG-B needed !





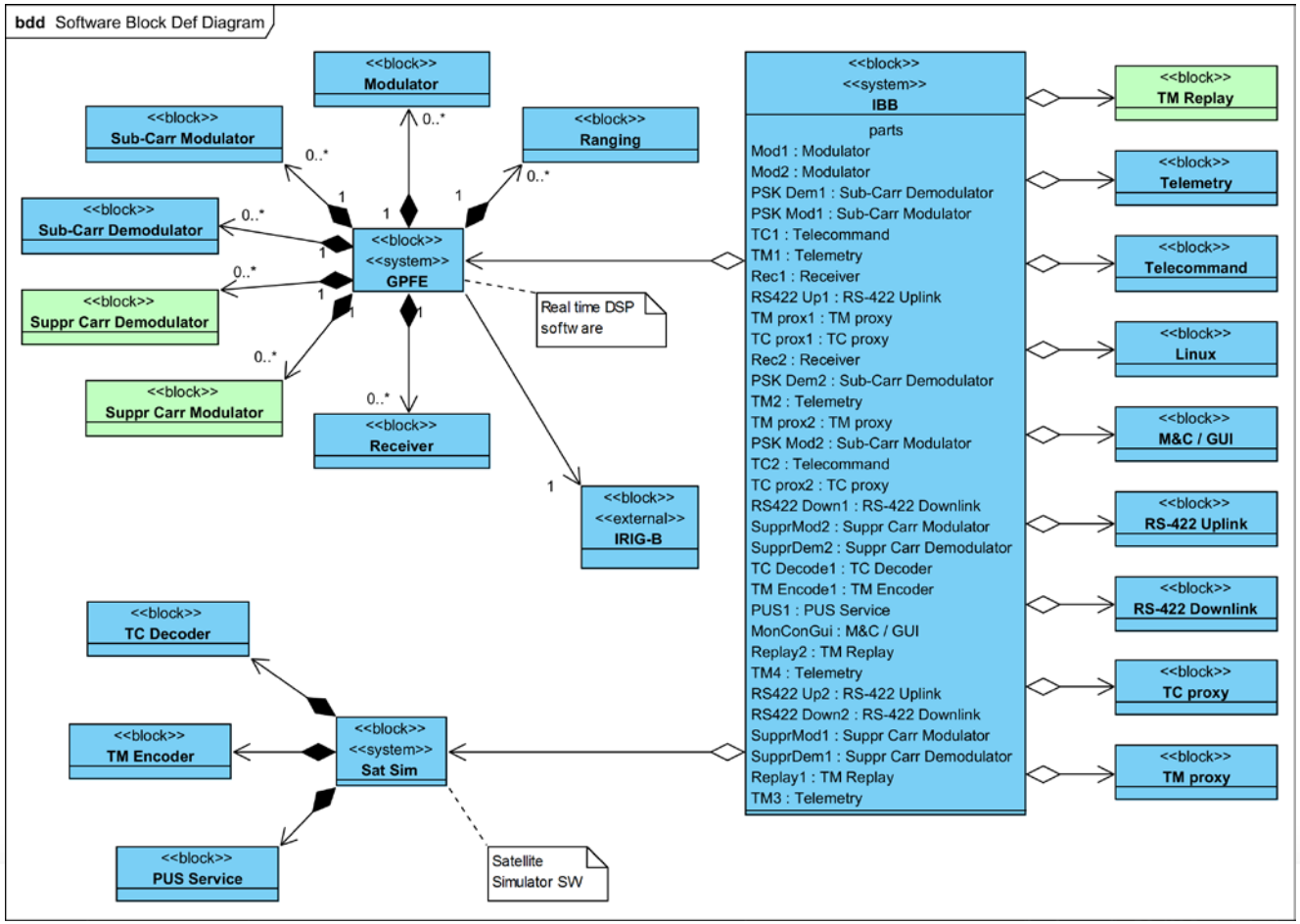
Key Technical Challenges & Achievements

- Hardware challenges (continued)
  - Problems encountered
    - EMC problems
    - Backplanes (PCI-PCIe bridge)
    - BIOS update
    - RS-422



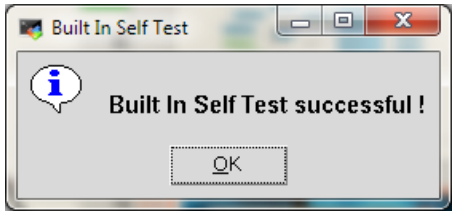
Key Technical Challenges & Achievements

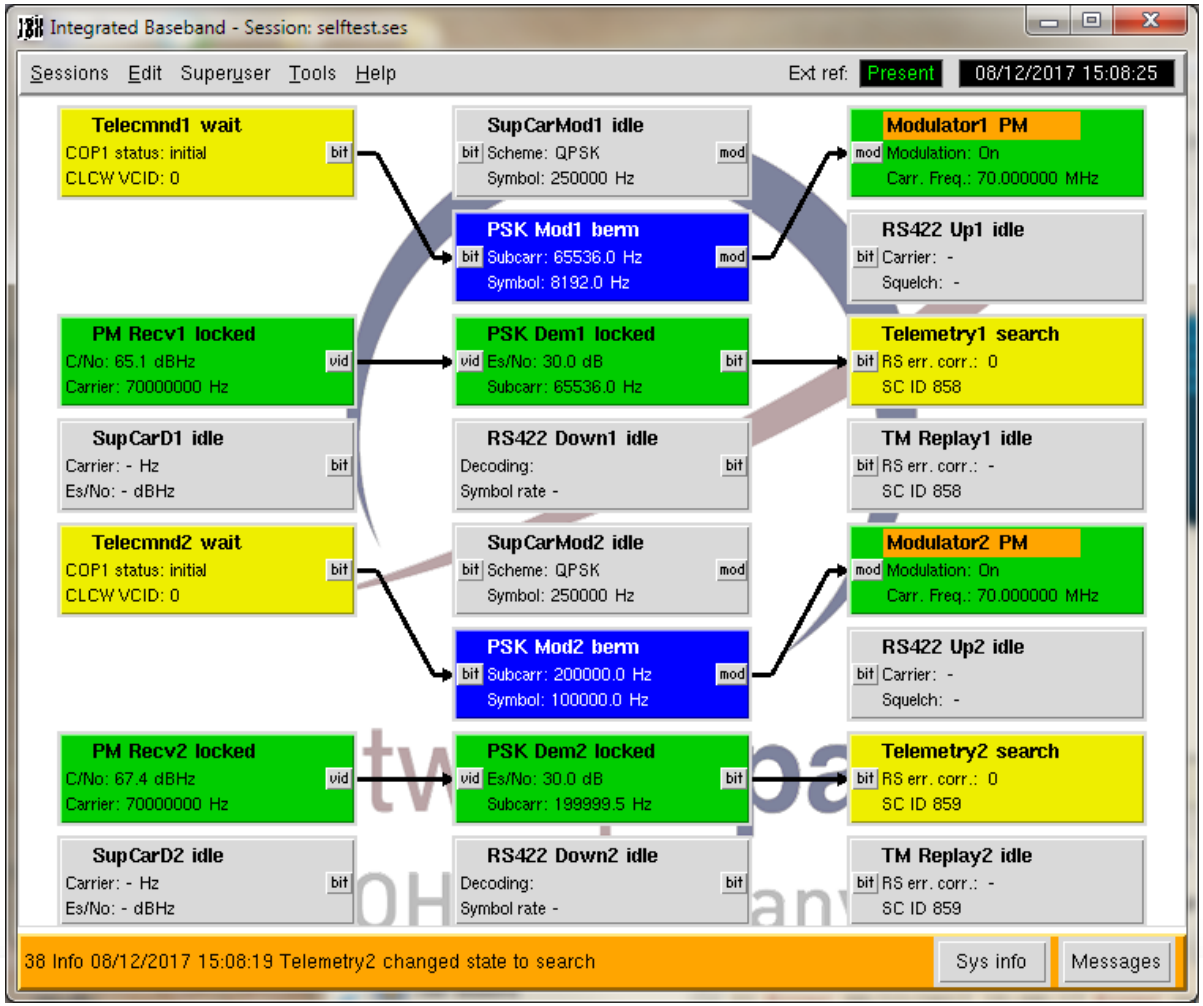
- Software challenges



Key Technical Challenges & Achievements

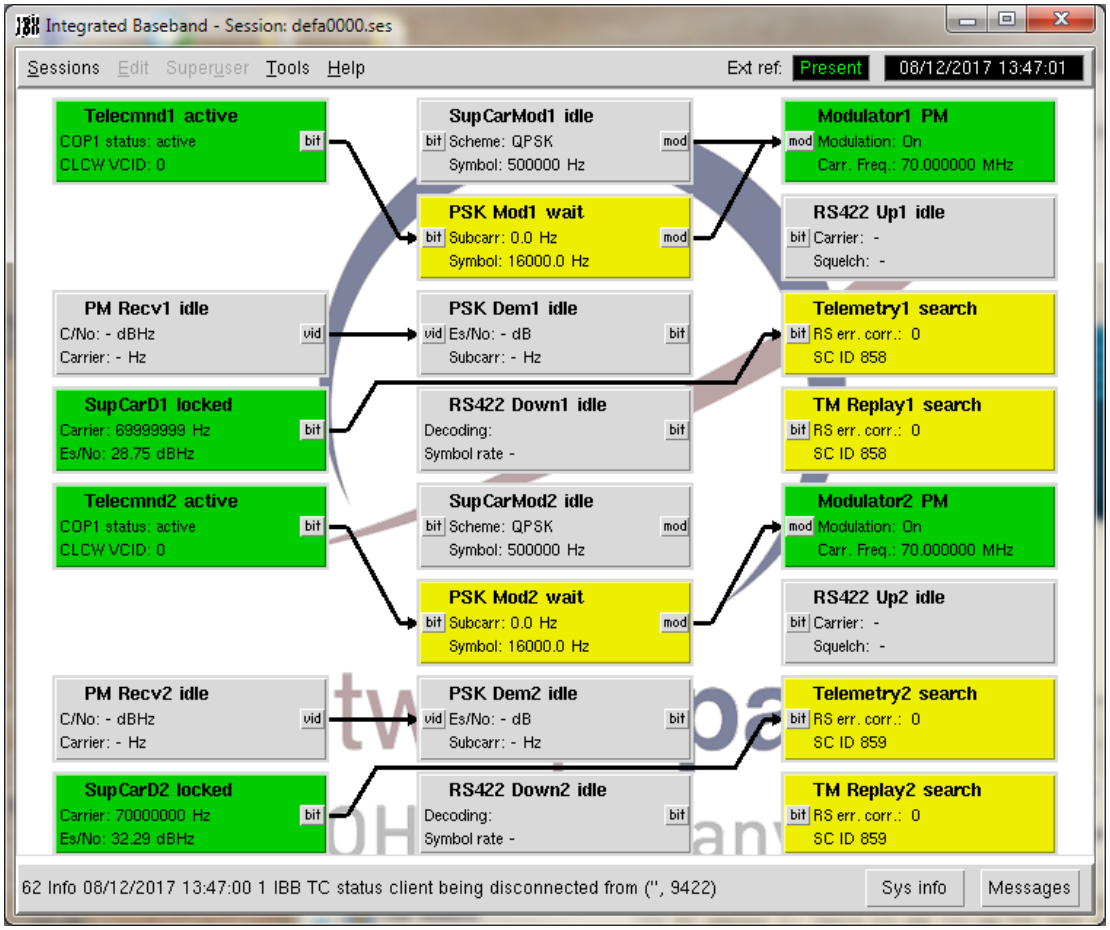
- IBB Software
  - Quick overview of the IBB User interface
  - sessions, configurations, modules, connections, …





Key Technical Challenges & Achievements

- Software challenges
  - Number of modules
  - QPSK/BPSK Mod/Demod
  - Update TM and TC modules to ECSS standards
  - MCS2BBE interface
  - Archiving
  - TM replay
  - Memory and CPU budget
  - Verification



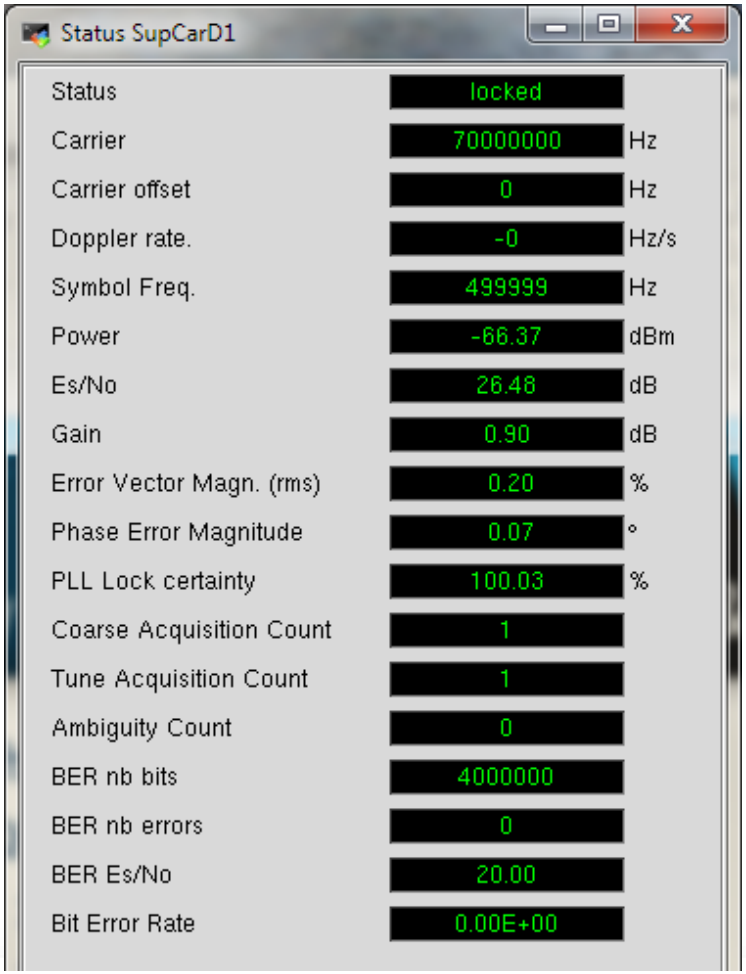
Key Technical Challenges & Achievements

- Software challenges (continued)
  - QPSK Modulator
    - Previously phase words (real signal 16 bit)
    - Now complex signal (I and Q 8 bit words)

    ⇒ FPGA changes
    - Upconverter frequency issues …
  - QPSK Demodulator
    - Previously complex signal was already used
    - Resolution problems 16 bit I and Q needed

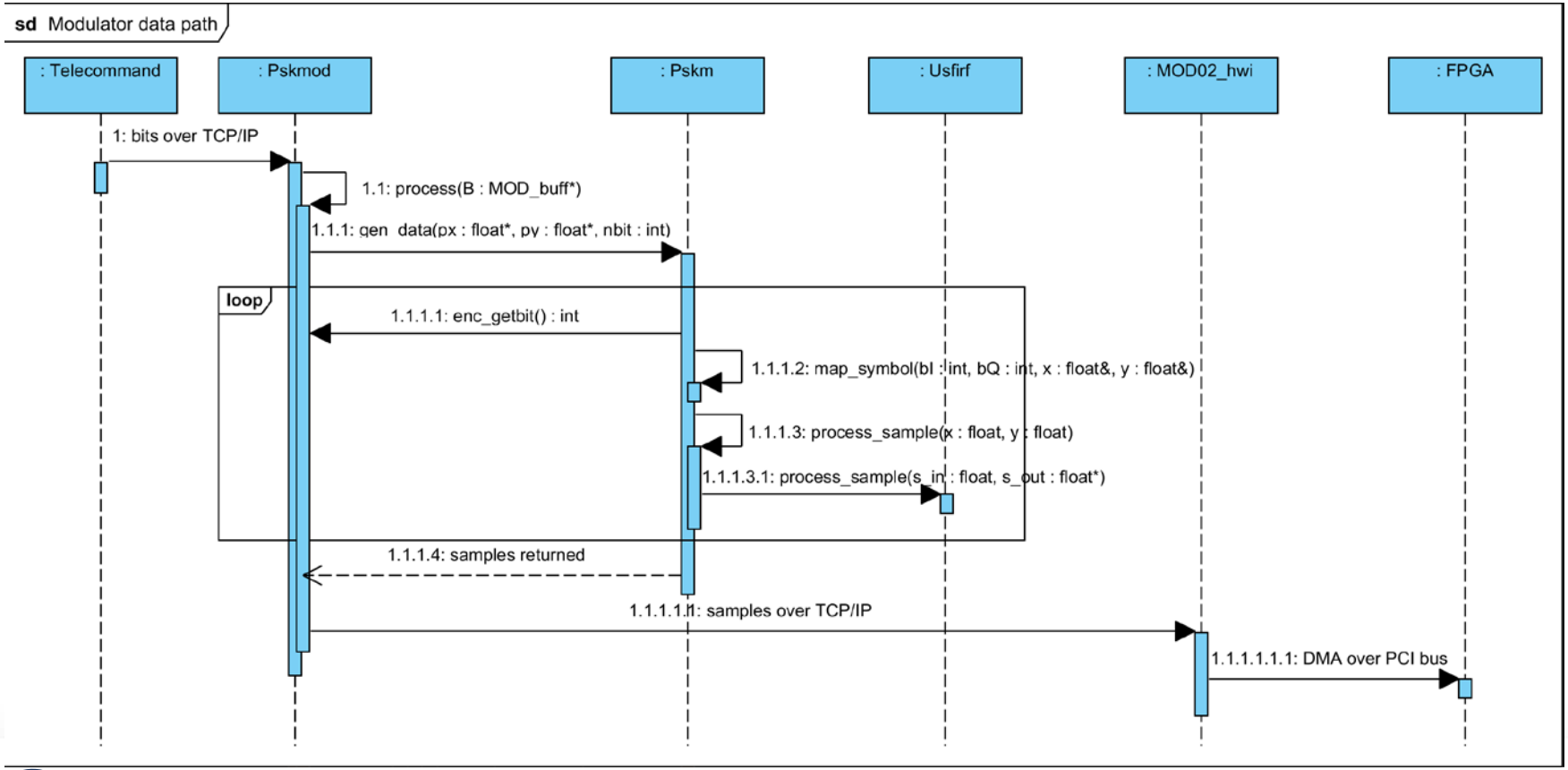
    ⇒ FPGA changes

    ⇒ Throughput changes (8 Msam -> 4 Msam)
  - SRRC filter (FIR, nb taps & roll-off cfg)



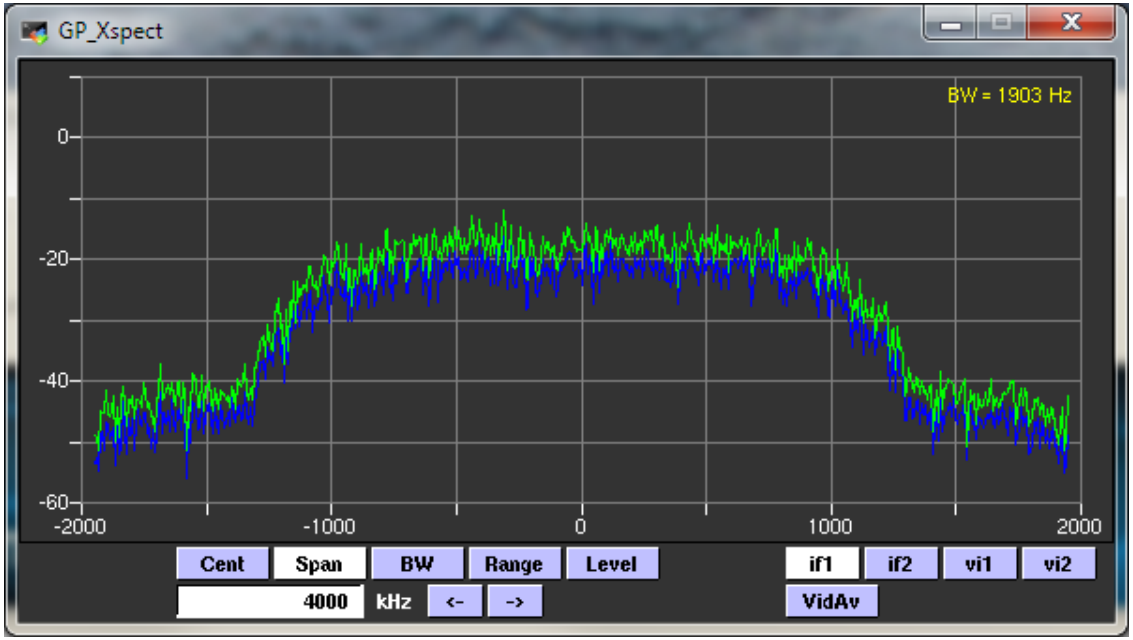
Key Technical Challenges & Achievements

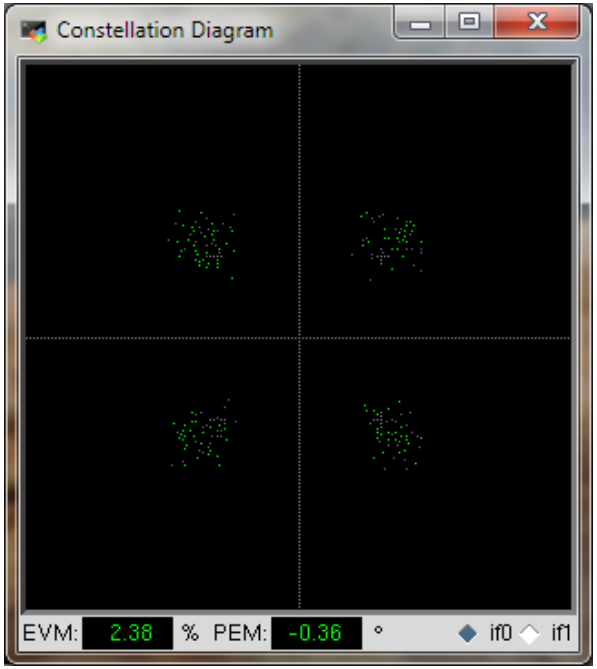
- Software challenges (continued)
  - QPSK Modulator context



Key Technical Challenges & Achievements

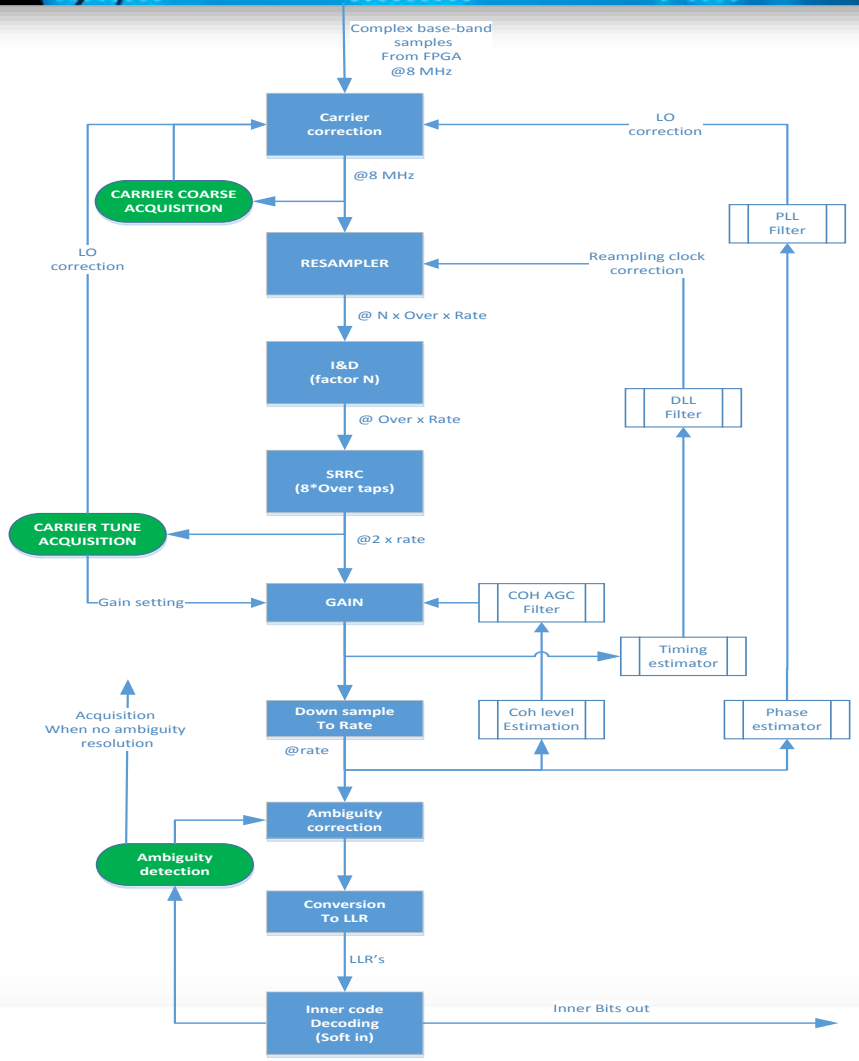
- Software challenges (continued)
  - QPSK Demod @ 2Msym/s SRRC roll-off 0.35





Key Technical Challenges & Achievements

- Software challenges (continued)
  - QPSK Demod
    - Design for highest possible Doppler rate (LEO)
    - Acquisition decision dependent on PLL, DLL and Convolutional



Key Technical Challenges & Achievements

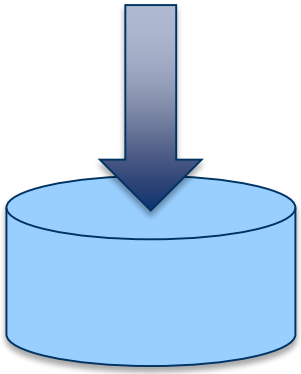
- Software challenges
  - Update TM and TC modules to match updated ECSS standards
    - Update TC segmentation
    - Improved timestamping of TM (2 bytes => 0,015 ms resolution)
    - Time correlation (onboard – ground time)
    - Provide RS error info in real time (latency)

Key Technical Challenges & Achievements

- Software challenges
  - MCS2BBE interface
    - Addition to existing SLE and EDEN interface
    - Extension of propriety CCCOM interface of IBB for M&C

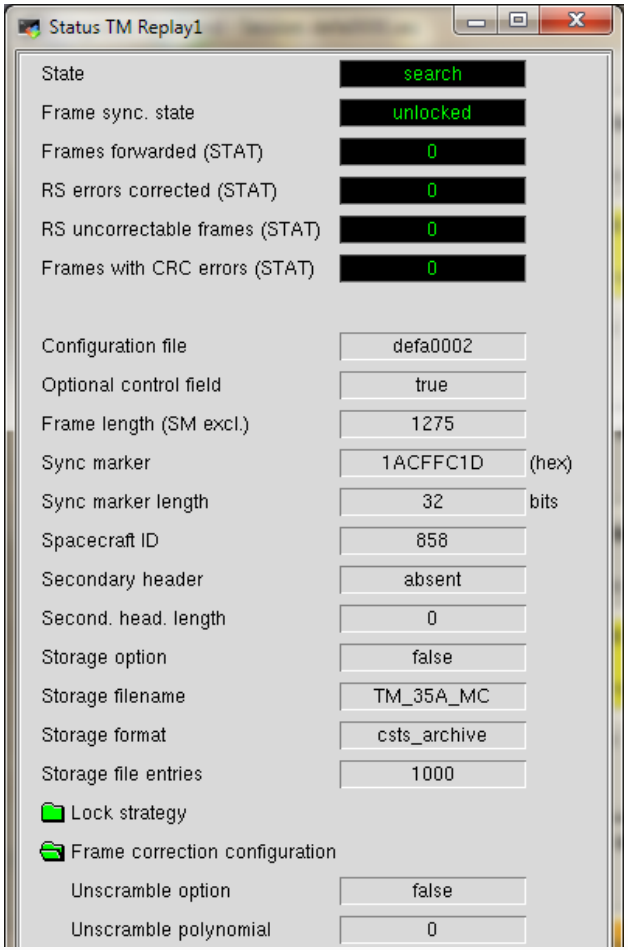
Key Technical Challenges & Achievements

- Software challenges
  - Archiving
    - Format based on archiving already in use by potential customers
    - Adaptation of existing archiving: frames, packets (all of 1 VC or specific ID)
    - TC and TM modules (per chain)



Key Technical Challenges & Achievements

- Software challenges
  - TM replay
    - Simultaneous Real time and Replayed TM
    - TM replay proxy – TM archive player – TM module
    - Remote start and stop, VC selection
    - Usage of archived TM frames
    - Generation of timestamped bit blocks
    - TM handling identical to real time TM (VC, packets)



Key Technical Challenges & Achievements

- Software challenges (continued)
  - Memory and CPU budget
    - Memory is not a problem
    - CPU is a problem

Key Technical Challenges & Achievements

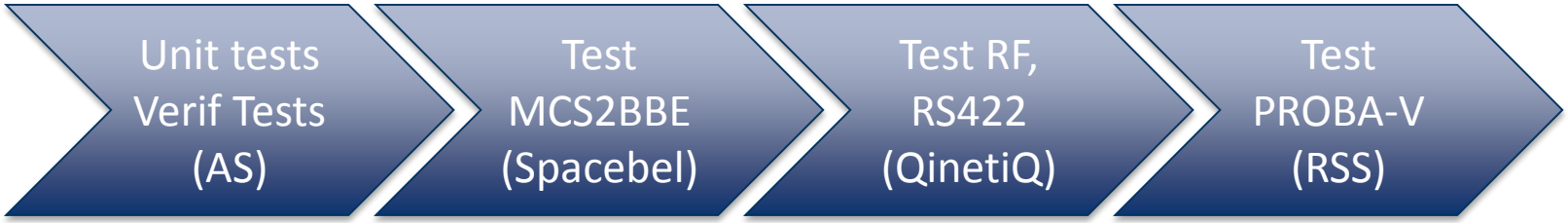
- Software challenges
  - Verification
    - Oscilloscope + VSA software (EVM, PEM, constellation diagram)
    - Spectrum analyzer (spurious frequencies)
    - Omnisat G3 Modulator + Demodulator @ > 1 Msym
    - Internal Loopback:
      - Different bitrates
      - BER measurement
      - File replay + TM statistics (frame sync, VC extraction, Reed Solomon, …)
    - Satellite simulator I2B2 (with De Lande Long library) for ECSS TC and TM
    - MCS2BBE automated test suite
    - EGSE Router simulator (2 chains)
    - Celestia Archive browser

Key Technical Challenges & Achievements

- Remaining software problem areas
  - Demod unlock problem
  - Performance convolutional decoding (Intel instruction set)
- SW solution for EM issue
  - I/Q swap detection need (QPSK implementation Proba 3 EM)

Test & Validation Campaign - General

- General Approach:



- Tests at Antwerp Space (AS):
  - Unit tests of extra code
  - Verification tests of complete IBB:
    - Using automated test framework of Antwerp Space
    - Emulator of MCS & EGSERouter for MCS2BBE tests
  - 12 test cases, using 21 test procedures (14 automated)
  - Some test procedures contain hundreds of scenario's (e.g. MCS2BBE tests)

Test & Validation Campaign - Spacebel

- Tests at Spacebel:
  - Main focus was integration and verification of MCS2BBE
  - 30 test cases
  - Issues:
    - 3 minor, 6 major
    - All resolved (TBC by testing)
    - Main Issues encountered:
      - Minor ICD changes during project
      - TM replay issues

Test & Validation Campaign – QinetiQ Space

- Tests at QinetiQ Space:
  - Focus:
    - RS422 tests
    - RF tests
    - Integration in ATB of PROBA-3
  - 36 test cases
  - Issues:
    - 36 minor, 25 major
    - Only 2 issues remaining
    - Major issues encountered:
      - RS-422 board throughput
      - EM module of PROBA-3 satellite (I/Q swap, wrong bitrate)

Test & Validation Campaign – Redu Space Services

- Tests at Redu Space Services (RSS):
  - Focus:
    - Validation of integration in operational environment
    - Compatibility test PROBA-V
  - 14 test cases
  - Issues:
    - 3 minor, 3 major
    - 2 issues remaining
    - Major issues encountered:
      - Loss of lock during PROBA-V pass
      - TM replay

Lessons Learned

- Foresee enough slack in the integration tests at subcontractors
- Foresee more than 1 platform for testing
  - In order to provide support to subcontractor testing
  - For non-regression testing in parallel by subcontractors
- Try to obtain (a simulator) of the external components
- Automated testing platform proved to be invaluable
- The person who estimates should do the task

Future Work

- Hardware evolution to increase the symbol rate even more
  - New modulation schemes OQPSK, 8-PSK, …
  - New sampling HW

- Software evolutions to increase the number of simultaneous channels

Conclusion

- Main objectives of the activity:
  - Increase the bandwidth of the IBB baseband SDR platform to 2 x 2Msym/s
  - Enhance IBB with suppressed carrier modulation types (besides remnant carrier)
  - Enhance IBB with MCS2BBE protocol (besides SLE and EDEN)
  - Enhance TM/TC archive browsing and TM replay
- Main objectives have been achieved:
  - Implementation is validated
  - Demonstrated new capabilities of IBB on PROBA-V and PROBA-3 mission

Thank you !

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