Need for Common Interfaces in EO Satellites

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Why Common Electrical Interfaces

Interfaces: **infrastructure to support**/enable the user-driven goal of the mission:

i.e. delivery science data

–interfaces are needed, but they are not an 'end objective' per se

- Common standards & validated interfaces (TC, TM, mid-rate Science data, discrete, Power) lead:
  - to reduce integration risk, time, cost => avoid the 'plug and pray'
  - to improve competitiveness => focus on the instrument

Industrial Challenge (not just a matter of mass / power):

–Large number of units in the spacecraft (all terminals must have it)

–developed by different industrial partners

but also new I/F needs
(to made common / standardised)

Higher data rate instruments (e.g. with higher resolution, higher swath, higher accuracy, etc.)

require **higher data rate interfaces**:

- space-to-ground (in Earth Observation @ multi Gb/s):
- Optical InterSatellite to EDRS (European Data Relay Satellite) @ multi Gb/s
- 26 GHz-band data downlink => 4 times more Bw than X-band, and better coding & modulation (e.g. from QPSK to 64-APSK) – limit is around 10 Gb/s with two polarizations.
- On-board Data Interfaces to match instrument and space-to ground I/F (also @ Gb/s)

More functionality (higher protocol)

- to increase reliability
- facilitate redundancy schemes (easier with serial links than going parallel)

NASA’s Common Instrument Interface (CII)

- 2011: NASA’s Earth Science (equivalent to the Earth Observation Programme, EOP in ESA), initiated CII with the objective to facilitate the integration of ‘hosted payloads’ in missions of opportunity like NASA’s Venture Class
  - one of them was EE8: FLEX or CarbonSat, from ESA
  - ESA (EOP Future Missions, and TEC Data and Power Divisions) collaborated
- Basic requirements of Secondary (hosted, opportunity, CFI) Payload of Risk Class C/D (NPR 8705.4)

http://science.nasa.gov/about-us/smd-programs/earth-system-science-pathfinder/common-instrument-interface-workshop/cii-reference-documents/

Parameter	Requirements for LEO	Requirements for GEO (added in 2012)
Mass	< 100 kg	< 150 kg
Power	< 100 W on 28 $\pm$ 6 V unregulated bus	< 300 W on 28 $\pm$ 3 V unregulated bus
Data rate	< 10 Mb/s (average) < 100 Mb/s (bursts) (assumed own storage in S/C)	60 Mb/s to transponder

- ESA collaborated for some interfaces: Data, Power, EMC aspects.
- Other aspects only covered by NASA CII (e.g. mechanical, thermal): considered mission specific.

ESA's CII Power assumptions for CII

- The power interface shall be defined/adaptable to **mission** & **system specific** needs
  - e.g. 1.5 hours LEO orbit ; Bus power 500W-1kW (no pulse LIDAR or RADAR)
  - Architecture (**Battery sizing**) assumptions needed (7/8 Li-Ion cells in series)
    - Leading to **Unregulated => 28 V range (agreement ESA-NASA)**

- **Voltage range** (a bit wider than NASA's CII)
  - **Max** 4.2V * 8 cells = **33.6V**
  - **Min (operative*) TYP** 2.8V * 7 cells = **19.6V @ 30% DOD, EOL**
- **Capacity range** (assumed 1 full orbit survival with no SA support, max 30% DOD)
  - **Max** 1000W*1.5hours/30% = 5kWh (corresponding to about 5KWh/7cells/3.7V/cell = **193 Ah**)
  - **Min** 500W*1.5hours/30% = 2.5 KWh (corresponding to about 2.5KWh/8cells/3.7V/cell = **84 Ah**)
- **Derived Impedance at low frequencies (@ 0degC, EOL, 10Hz to 1 KHz)**
  - **Max 41 mOhm** (84 Ah, 7 cells in series),
    Min 15 mOhm (193 Ah, 8 cells in series)

  (assuming small cells of 1.5 Ah each)

* Instrument keeps performance
** Instrument is not operative

DOD = Depth of Discharge

- **NASA-ESA approach very similar**, but detailed parameters to be iterated for e.g. power feeds characteristics (normal, abnormal, transients, over and undervoltage conditions, etc)

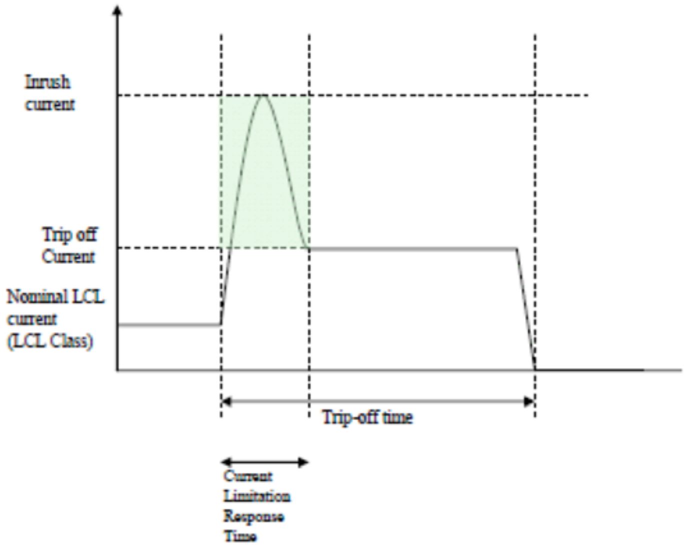
Power I/F requirements

Similar, but two main differences:

- NASA proposes **fuses** – ESA proposes **Latching Current Interface (LCL)**
  - many classes of LCL (A to F)
  - Affecting definition of specific parameters (e.g. in rush current, trip-off time)

- ESA applies ECSS Standards:

- ECSS-E-ST-20C: Electrical and electronic
- ECSS-E-ST-20-07C: Electromagnetic compatibility



See specific presentation (by F. Tonicello)

for more Power I/F details at 14:45

Data I/F requirements: NASA's CII in 2011

SpaceWire (SpW) used for everything (5 types):

-Science data

-TC / HK TM (status, ack, …)

-and even for synchronisation with platform

but, lack of specification in NASA's CII for:

- accuracy / determinism requirement

  (SpW is asynchronous, and SpW routers increase time-uncertainty)

- higher level protocols to support it

  (e.g. to ensure prioritisation in the SpW network,

  and that critical TC & HK TM arrive at destination within a time-limit)

CII SpaceWire Packet							
SpW Logical Address	Cargo						ExP
	Protocol ID (0x02)	CCSDS					
		Reserved (0x00)	Type Code	Header	Data	CRC	
1 byte	1 byte	1 byte	1 byte	15 bytes	0–236 bytes	1 byte	4 bits
	19–255 bytes						

Specification Legend

- SpaceWire (ECSS-E-ST-50-12C)
- SpaceWire Protocol Identification (ECSS-E-ST-50-51C)
- SpaceWire – CCSDS Packet Transfer Protocol (ECSS-E-ST-50-53C)
- GOES-R Reliable Data Delivery Protocol (417-R-RPT-0050; uses CRC only)
- Packet specific data (e.g. time, position, commands, telemetry, science data)

Figure 16-1: CII SpaceWire Packet

Table 16-1: CII Message Types

Type Code	Message Type	Data Path
0x02	Spacecraft Status Message	Spacecraft to Instrument
0x04	Command	Spacecraft to Instrument
0x08	Command Acknowledgement	Instrument to Spacecraft
0x10	Instrument Telemetry	Instrument to Spacecraft
0x20	Instrument Science Data	Instrument to Spacecraft

ESA CII group (data part)

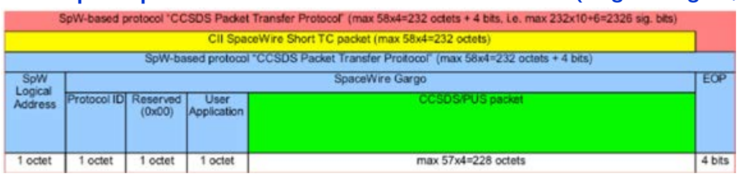
ESA CII accepted partially NASA's approach with SpW, but:

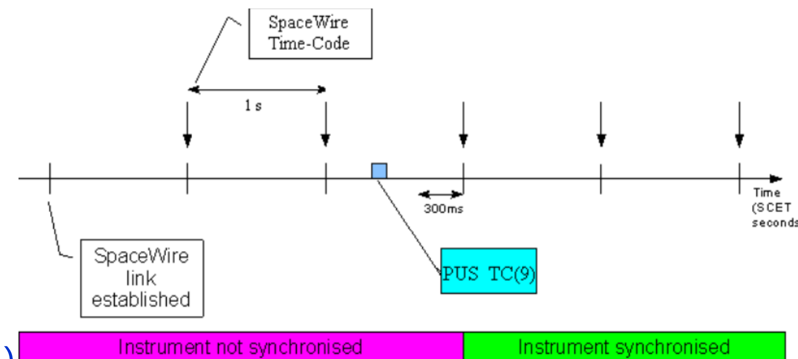
-proposed additional synchronisation protocol:

- based on PUS TC messages + Time Code to ensure low (e.g. n x 1 μs) determinism.
- BepiColombo approach was taken (in the absence of a solid SpW-D Std, - D for determinism)

-Packet Utilisation Service (PUS, **ECSS-E-70-41A**) applicable

-Extended SpW packet definition with PUS (e.g. length, ACK missing)



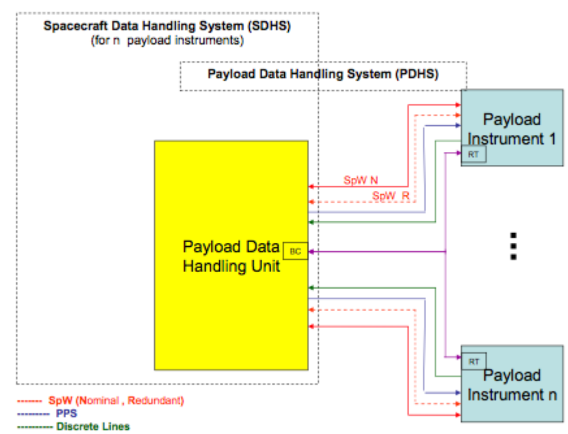


Additional guidelines (keep **SpaceWire for Science Data**) **and allow**:

-SpW or others (Mil-1553, RS422) for communic. with OBC (TC * HK TM)

- CarbonSat/Flex baseline is 1553
- 1553 still Baseline for the OBC by most Primes
- PPS: simple and much better accuracy (< 100 ns)

-Discrete lines (**ECSS-E-ST-50-14C**): e.g. HPC, ASM, TSM, BSM



Also added guidelines to **consider Redundancy / FDIR**

(e.g. TimeCode, buffers, restart, master/slave vs OBC)

NASA CII (2013)

Main effort on new GEO scenario: could not find Opportunity hosting S/C in LEO

- also Flex/CarbonSat will not host an international secondary P/L
- collaboration more likely in convoys (i.e. separate S/C in formation), tandem (see SAOCOM-CS later) or constellations

NASA CII realized (also with the American industry) similar issues pointed out by ESA CII:

- SpaceWire packet definition removed from the 2013 CII document
- TC and HK TM: open to other standards than SpW
- also open to discrete lines

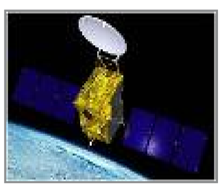
ESA's Earth Observation Missions

Earth Explorer
Research driven

Core Missions

GOCE
March 17th 2009

ADM-Aeolus



EarthCARE

Earth Explorer 7

Biomass

Opportunity Missions

CryoSat-2
April 8th 2010

SMOS
Nov. 2nd 2009

Swarm

Earth Explorer 8

FLEX
or
CabonSat

Initial Missions

ERS-1/2

Envisat

Earth Watch
Operational Service driven

Operational Meteorology
- Meteosat
- MSG
- EPS (MetOp)
- MTG
- MetOp SG

Copernicus (GMES)
- Sentinel 1 (a,b, c,d)
- Sentinel 2 (a,b, c,d)
- Sentinel 3 (a,b, c,d)
- Sentinel 4 (MTG)
- **Sentinel 5 precursor**
- Sentinel 5 (MetOp-SG)
- Sentinel 6 (Jason-CS)

EarthCare, S5p, MTG: presented this morning

All LEO, except Meteosats in GEO

S1/2/3 (c,d) very likely as (a,b)
=> no data rate increase

EOP satellites: Project by project, but many commonalities

Unregulated Power in LEO satellites

-Mostly: 28 V , but also 50 V (MetOp-SG, Sentinel-1)

Instrument Data I/F:

-TC & HK TM:

- via Mil-1553 (On-Board Computer legacy at Prime's)
- but **MetOp-SG** (launch in 2021) **will be the first one to use SpaceWire** (legacy BepiColombo)

-Science data up to ~ 100 Mb/s: SpaceWire (Solid State Memories well equipped with SpW routers)

-Science data > 200 Mb/s: WizardLink (e.g. Sentinel-1, SAOCOM-CS)

-PPS line for synchronisation protocols

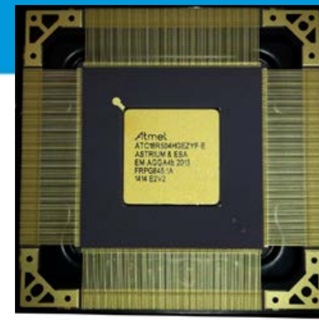
-Discrete lines (ECSS-E-ST-50-14C): e.g. High Power Command, Analogue, Temperature, etc.

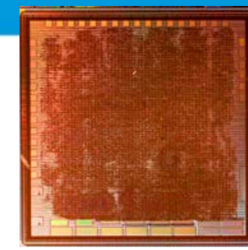
-PUS (ECSS-E-70-41A)

Very similar (e.g. Biomass, Flex, CarbonSat) to what described for ESA CII.

Advanced GPS-Galileo ASIC (AGGA-4)

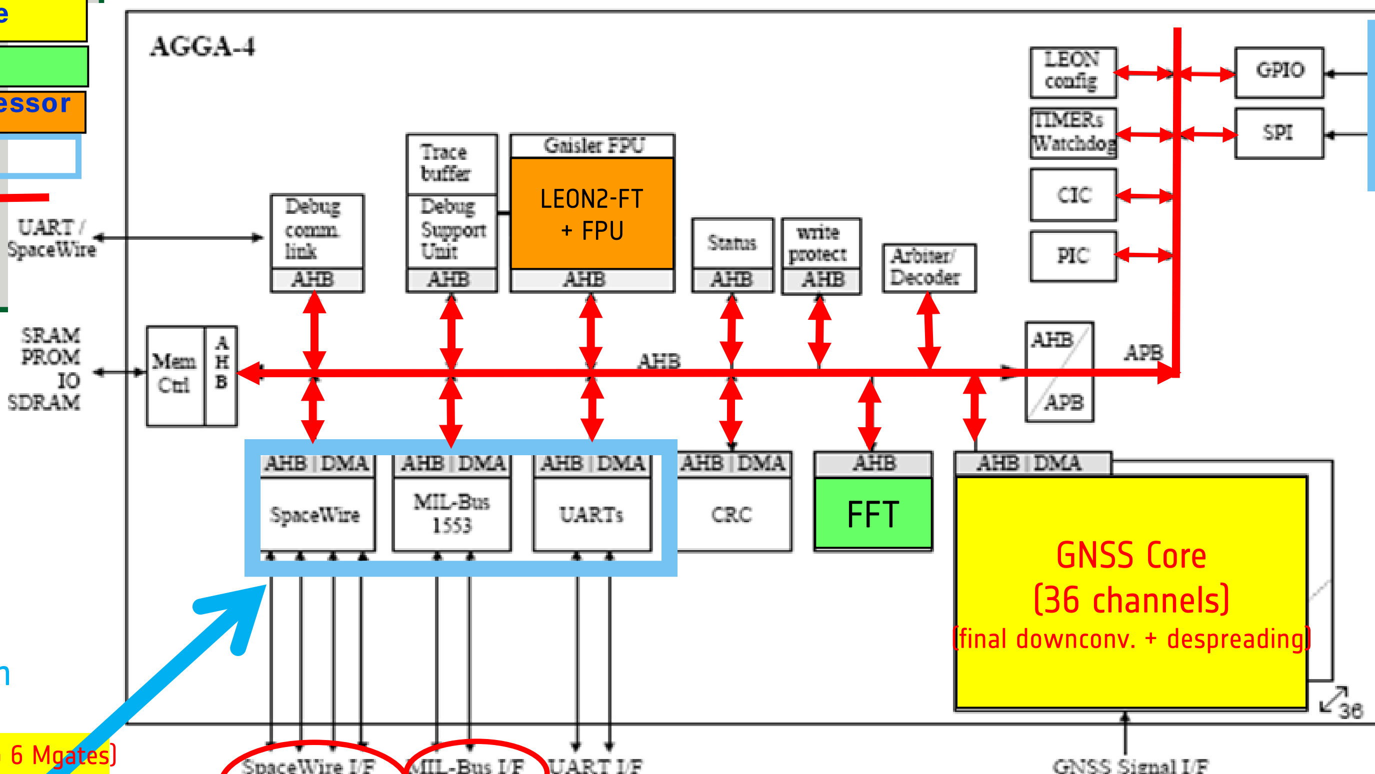
Designed by Astrium GmbH under ESA Contract
Manufactured by ATMEL under UMC 0.18 micron in 2Q-2014
Available to all European parties under equal conditions





LEGEND

- GNSS module
- FFT module
- LEON µ-processor
- external I/F
- AMBA I/F
- DMA I/F

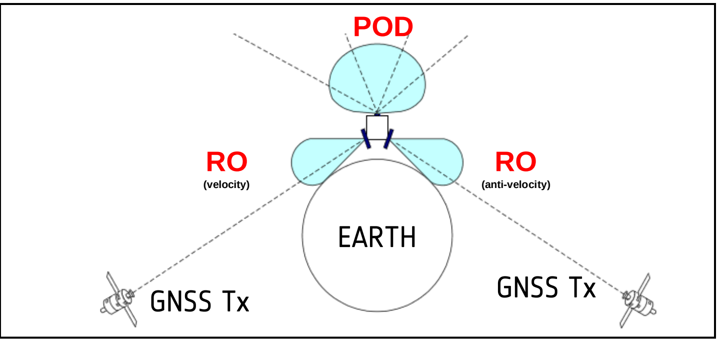


Modules with
4 SpaceWire
(< 2% of the chip 6 Mgates)

IP cores were used
Important to be small / simple

AGGA-4 used in Digital Module
of GNSS Receiver (see next slide)

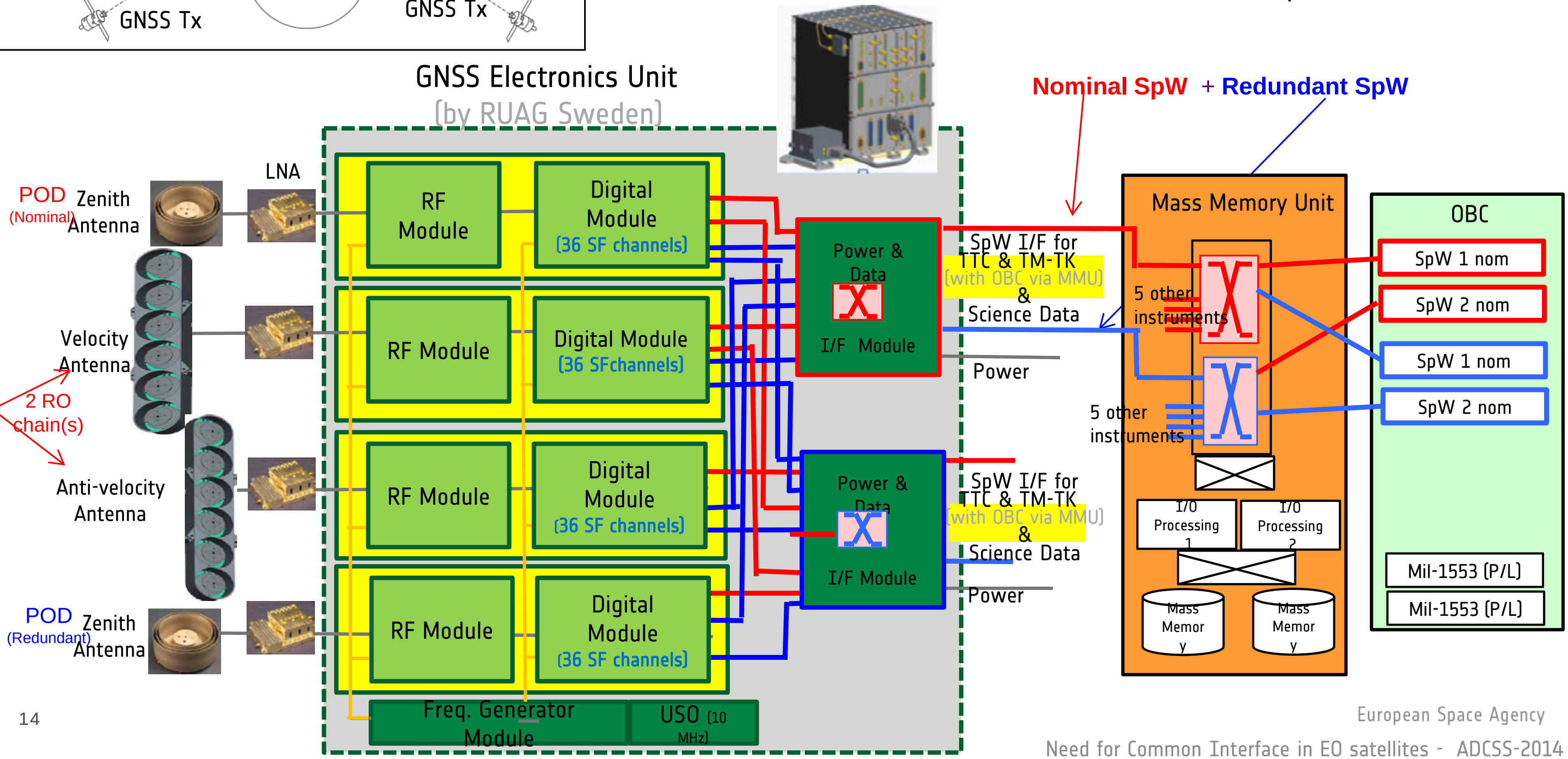
Radio Occultation Instrument in MetOp-SG (TC/ HK TM via SpaceWire)



First EO satellite using SpaceWire for TC / HK TM

4 SpaceWire links per AGGA-4 device
- Router ensures interconnectivity/redundcancy with MMU
- RO instrument data rate < 5 Mb/s

All instruments with data rate < 100 Mb/s => SpaceWire at MMU



Radio Occultation Instrument in Jason-CS (Sentinel-6)
(TC/ HK TM via Mil-Bus 1553)

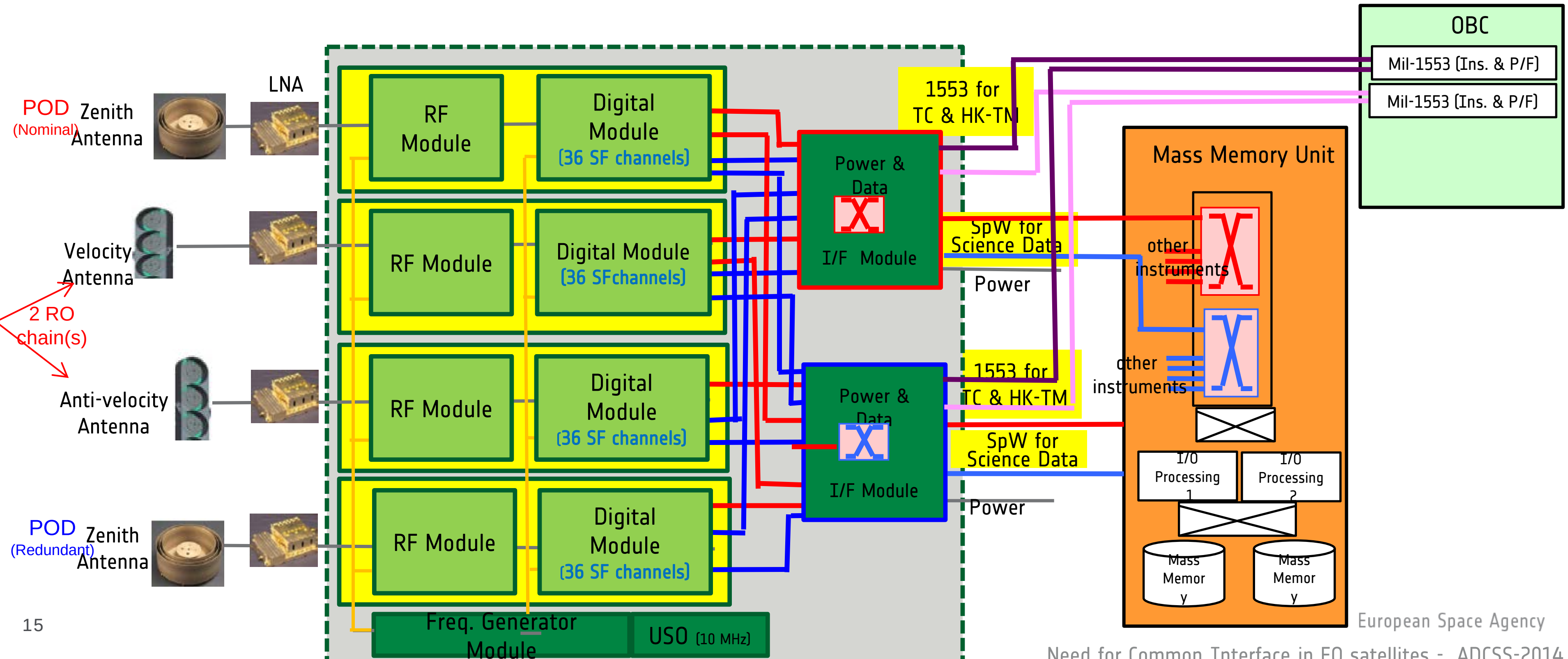
Same RO instrument as for MetOp-SG, except for:
- smaller antennas
- **TC & TM, Power** interfaces

Platform legacy from **Cryosat-2**

OBC only has **Mil-1553**=> **TC & TM**
Only Mass Memory has SpaceWire links => Science data

Programmatics:
- study proved feasibility for embarking in J-CS the same RO instrument in MetOp-SG
- Finally a non-European RO was selected due to non-technical reasons

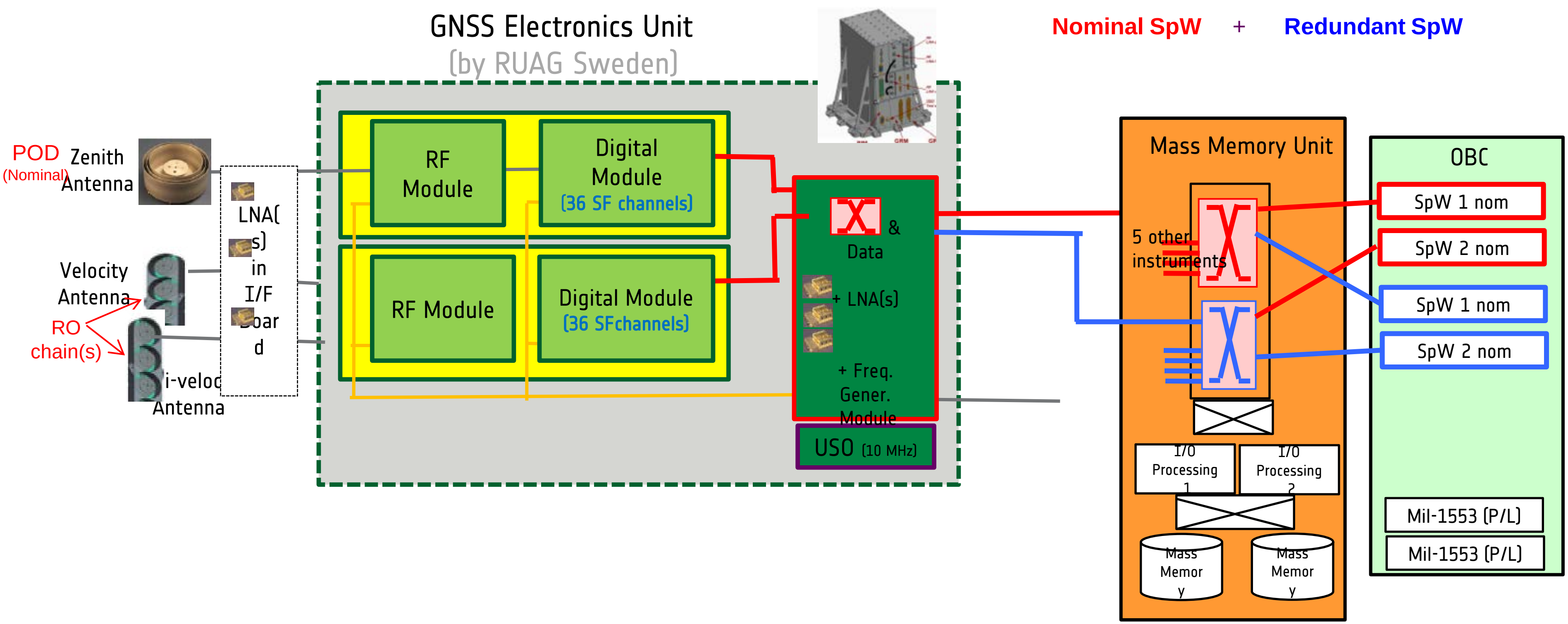
Nominal SpW + **Redundant SpW**



Radio Occultation Instrument
GOPALS optimsation

R&D in GOPALS ESA study with RUAG-Sweden shows additional miniaturisation (from 7 to three boards) with less redundancy and very reduced impact on scientific data output

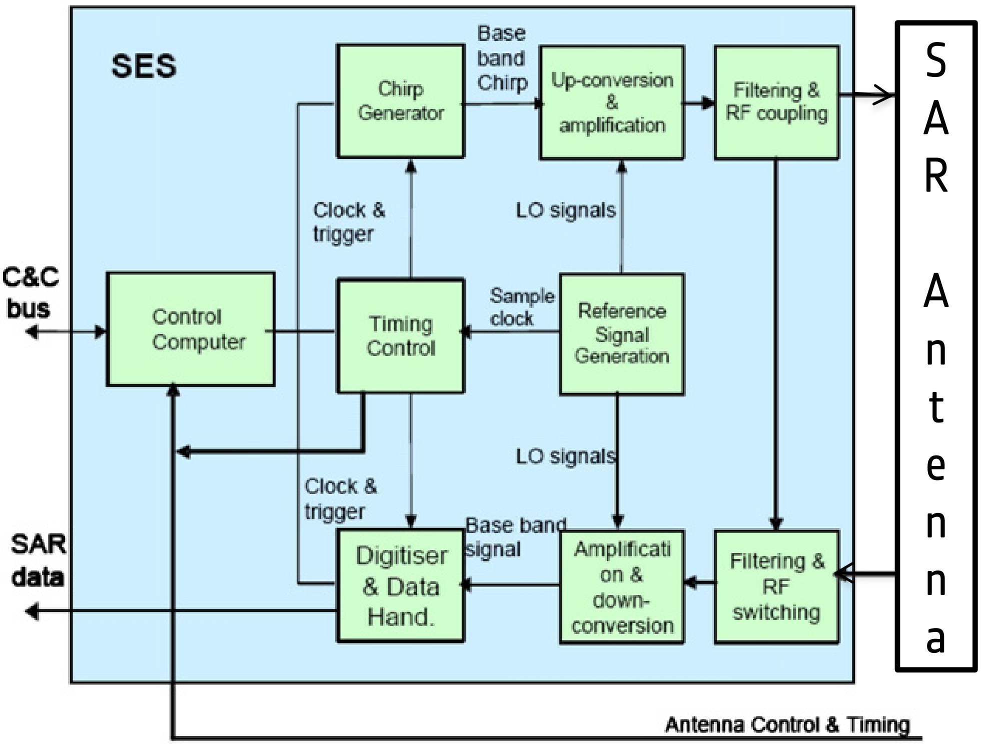
Power & Data Interface board is:
- key for the connectivity (ideally with SpaceWire only)
- often adapted to the needs of the mission



Sentinel-1

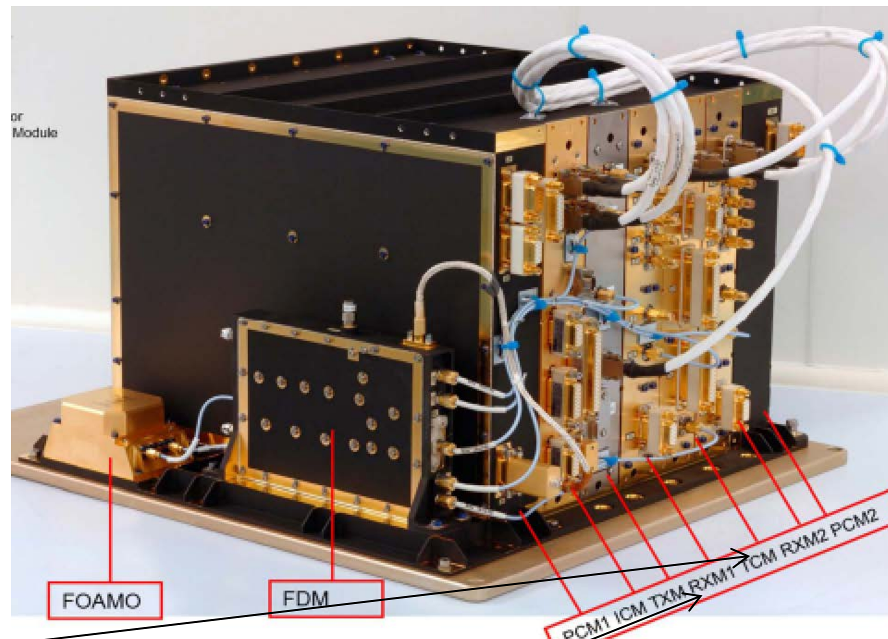
Antenna

Electronics System



50 V Unregulated power lines

ICE (Instrument Ctrl Electronics)



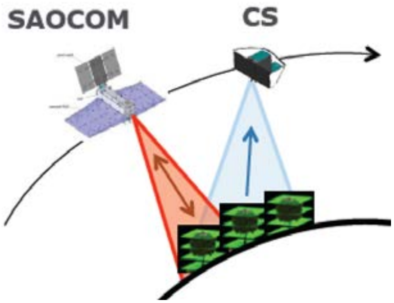
Timing Control Module (TCM):
- Mil-1553 I/F for TC/TM
- SpaceWire for Instrument Control (no SpW I/F to Platform)

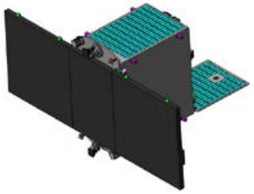
Receiver Modules (RXM): with WizardLink (up to 1.6 Gb/s)

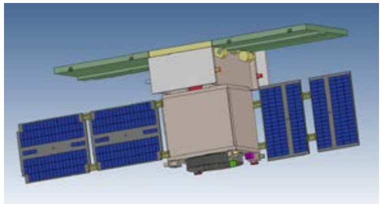
SAOCOM-CS (or TangoSat)

(almost a case of hosted payload)

- Studies for a Companion Satellite (CS) for SAOCOM (CONAE)
  - demonstrate L-band bi-static (tandem) SAR
  - 2 parallel Ph.A studies: one with QinetiQ + one with SSTL
    - Small satellite providers for platform (400 kg, 290 W peak)
  - Advanced status: decisions for CS implementation in EO-PB Feb.2015
  - launch opportunity in 2018 (together with SAOCOM-B)







- Feasibility studies of Central Electronics Payload with Astrium and Thales show very similar patterns from the instrument side:
  - Req. High speed data I/F (800 Mb/s): WizardLink
  - TC & TM HK: RS-422+UART
  - Power LCL types under discussion

Very high speed links

Used in high data rate (high-end) instruments (e.g. 1.6 Gb/s in Sentinel-1, S-2)

Currently Wizard Link is baseline (e.g. S-1, S-2, SAOCOM-CS, …), but:

-Non-European

-Not complete: higher protocols (similar to SpW for point to point) are helpful (e.g. easier integration, FDIR)

SpaceFibre can provide the Wizard Link data rates and overcome its limitations, BUT

-needs to be simple and fast (multi Gb/s)

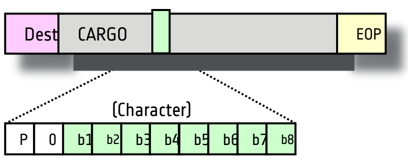
- Implementable with FPGAs (limited # gates)
- also for point-to-point versions as Wizard Link
- allow redundancy
- priority for science data

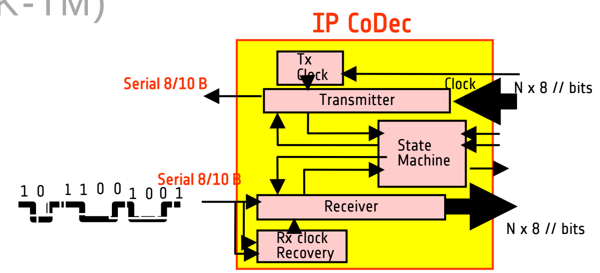
(does NOT need to have the full protocol as for TC & HK-TM,

high-end instruments can afford additional I/F for TC & HK-TM)

-needs to be quickly **available to all parties in the project**

- at high TRL components
- as IP core (example of SpW in AGGA-4)





Need for full products, IP cores, and standards

Products:

- CoDec IP cores => to ensure miniaturisation and quick adoption by everyone
- components (non proprietary and non-ITAR sensitive)
  - Analogue (also cables, connectors, drivers, etc.) very critical, specially @ Gb/s
  - Digital part (with codec IP core + additional functionality)

Supporting Standards

- for analogue part (not just description, also what needs to be verified: e.g. LVDS case)
- for CoderDecoder (serial to parallel nx8 bits)
- Upper layer protocols &. Services (e.g. a solid SpaceWire-Deterministic Std)
  - MetOp-SG opens the door for SpW as TC & HK-TM

Timely for project & Scaleable : applicable to CoDec, components, Stds

- start simple (for first projects, e.g. solid point-to-point)
- build up gradually (e.g. network)

Conclusions

- CII and ESA EOP projects show common usage (although decided mission by mission)
  - TC & HK TM: via Mil-1553 (driven by OBC), but **MetOp-SG** will use SpaceWire (new trend)
  - Science data up to ~ 100 Mb/s: SpaceWire
  - Science data > 200 Mb/s: WizardLink (e.g. Sentinel-1, SAOCOM-CS), but **SpaceFiber** could take over
  - PPS for synchronisation, Discrete lines (ECSS-E-ST-50-14C),
  - Packet Utilisation (PUS) used
  - LCL Power

- Technology Products need to be available to projects (SpaceWire successful experience):
  - High TRL components
  - IP cores for quick adoption by everyone

- Supporting Standards needed
  - For each I/F: Physical Layers, **verification** points (or test cases) required
  - Higher level protocols & services (e.g. synchronisation)
    - to avoid changes for each project / company
    - to ensure that TC & HK TM arrive timely and reliably
    - Also verification points