AGGA-4:
core device for GNSS space receiver of this decade

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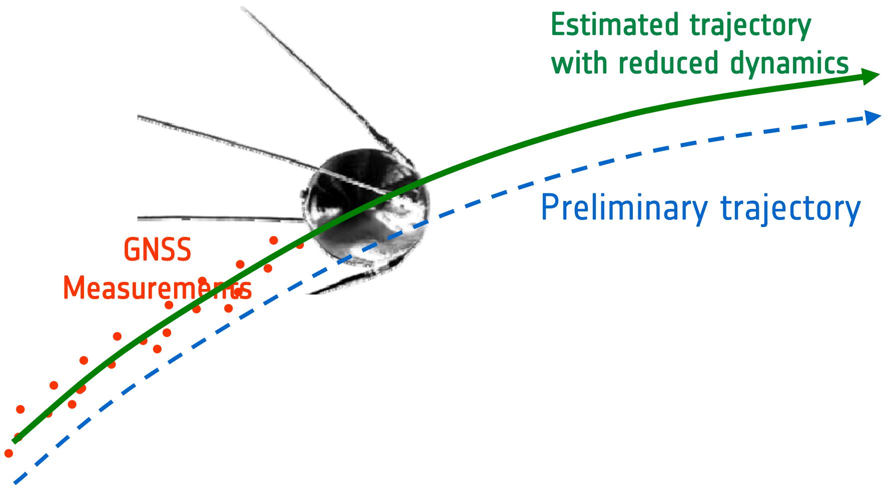
Precise Orbit Determination (POD)



<u>Continuous high accuracy Navigation O/B by combining:</u>

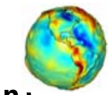
- Orbit knowledge
- GNSS measurements

<u>Better if done with post-processing on-ground</u>

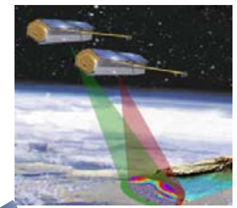
- Longer orbit segments
- available GNSS Tx clocks from ground (IGS)

SUPPORT TO OTHER APPLICATIONS

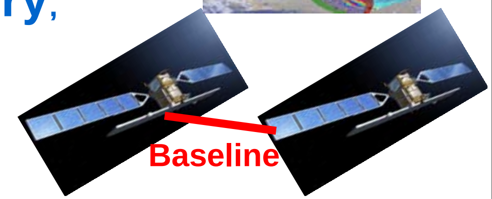
- **Altimetry** (e.g. Sentinel-3)
- **Solid Earth**
  - **Gravity missions** (e.g. GOCE mission)
  - **Earth Magnetic Field** (e.g. Swarm)



- **Relative positioning**
  - (e.g. Tandem-X, TerraSAR-X)



- **SAR interferometry**,
  - e.g. for Sentinel-1



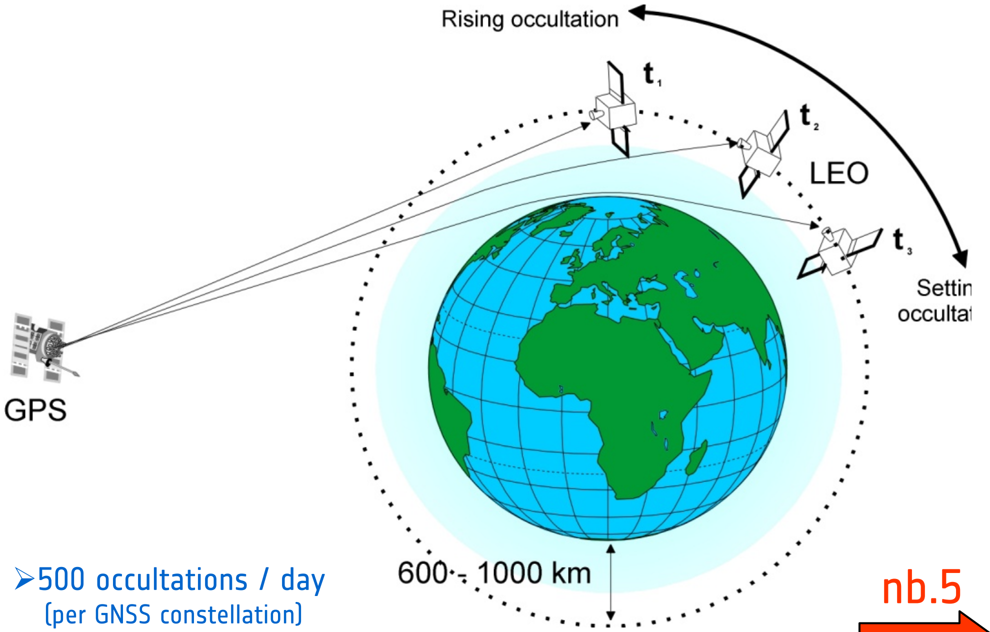
- **Earth Science applications**
  - **Radio Occultation** (e.g. METOP GRAS)
  - **GNSS-R**

Requirements in POD

Key issues impose different GNSS receiver architectures and operational approach
- data timeliness (real-time OB and / or post-processing OG)
- robustness : high number of observations
- accuracy

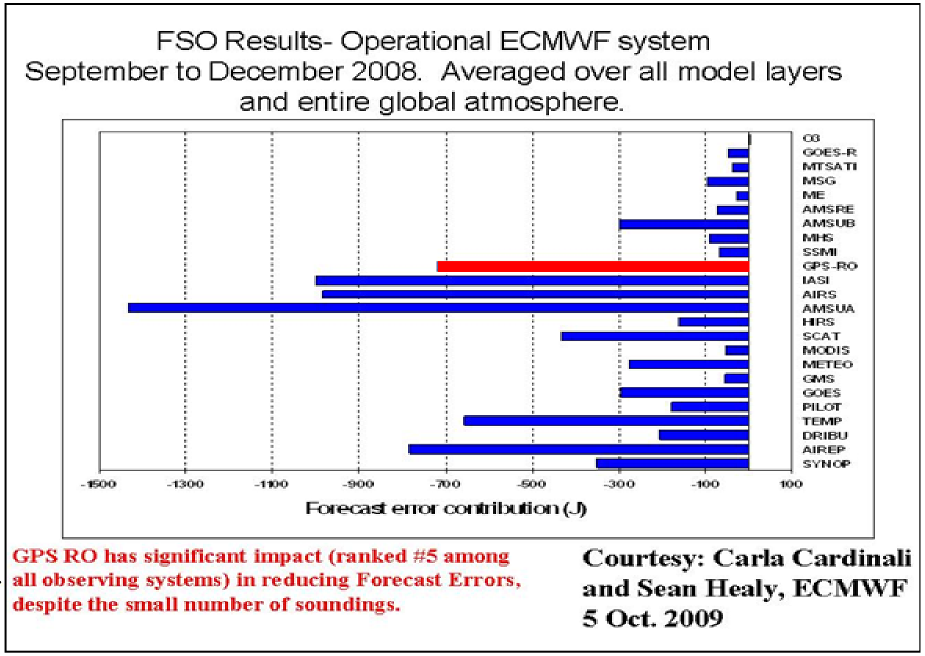
Mission	Real Time (RT)	Non RT (1-3h)	Slow Time Critical STC, (1-2 days)	Non Time Critical (1 month)
GOCE (launch: March 2009)		< 50 cm rms (requirement)	< 10 cm rms (ACHIEVED ~ 4 cm)	< 2cm rms (ACHIEVED)
Swarm		< 10 cm rms		
Sentinel-1 (SAR interferometry)	10 m. 3σ xyz	5 cm rms xyz		
Sentinel-3 (Altimetry)	3 m. rms (radial)	8 cm rms (radial)	3 cm rms (radial)	2 cm rms (radial)
MetOp-GRAS (Occultations) (launch: 2006)		0.1 mm/s (velocity. along) **ACHIEVED**		

Radio Occultation (RO)



➢500 occultations / day
(per GNSS constellation)

nb.5



While a GNSS satellite 'sets' or 'rises' behind the horizon:

➢ Additional bending of the GNSS signal's ray path due to <u>refraction</u> in the atmosphere

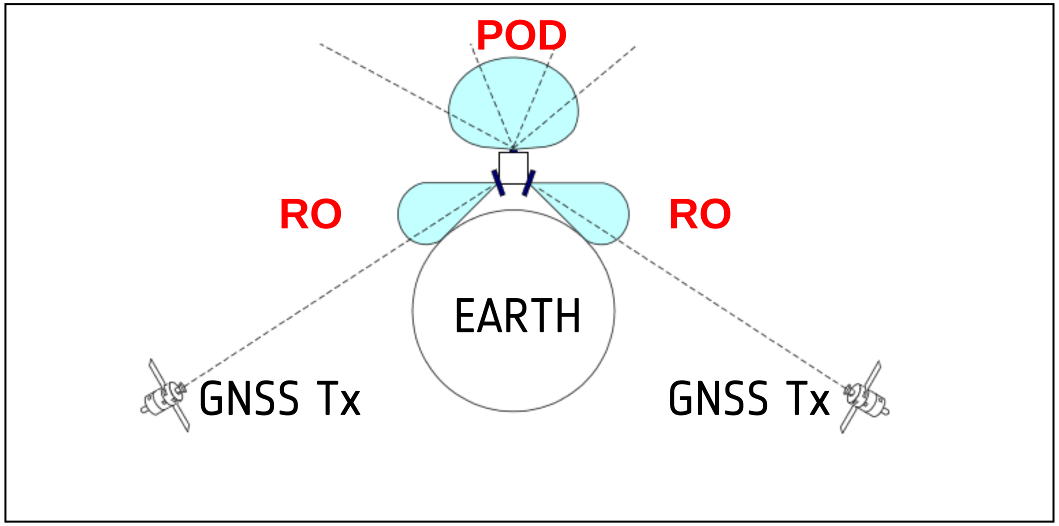
➢ The GNSS receiver measures the excess Doppler shift

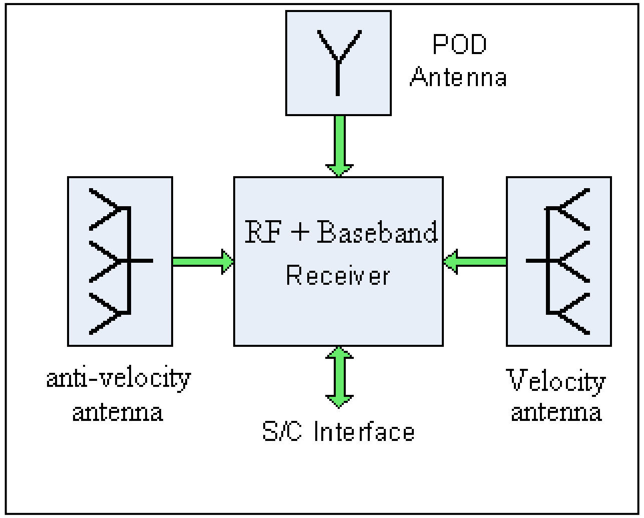
⇒ key measurement is **<u>CARRIER PHASE</u>**

➢ derive vertical profiles (Temperature, Pressure, Humidty)

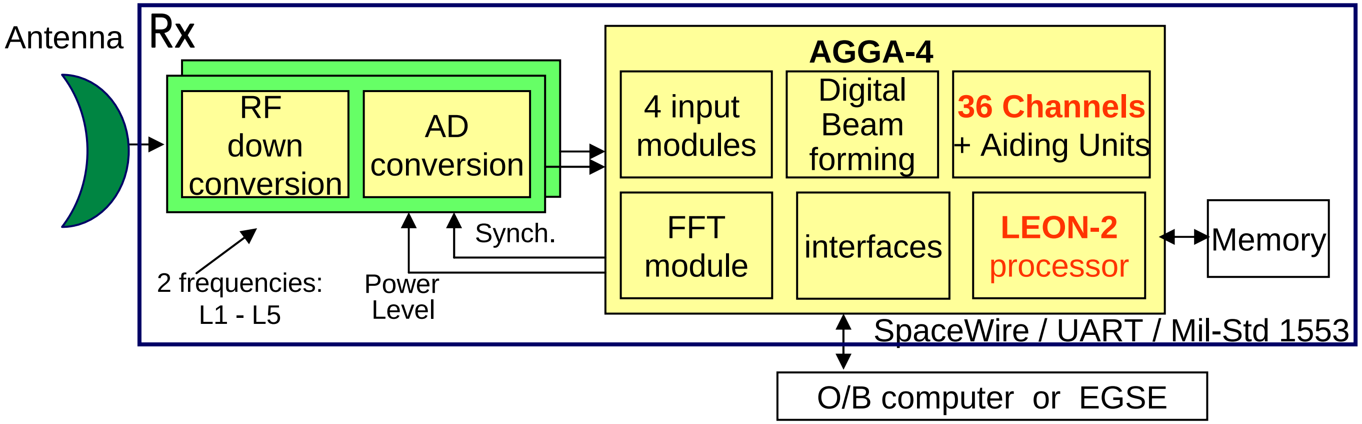
Performance is driven by very good clocks, open loop processing, high antenna gain

Future GNSS receiver architecture





‘n’ antennas
and ‘n’ Rx



Attempt to make it as modular as possible (reproducibility & re-use)
Difference POD and RO could be software and antenna

Baseband GNSS processor developed under ESA guidance and contracts

esa

AGGA = Advanced GPS / Galileo ASIC

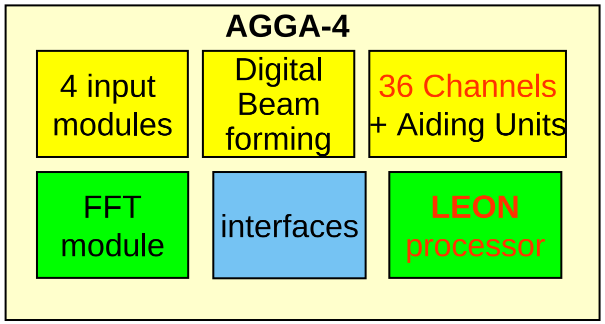
AGGA-2: [T7905E component] manufactured by Atmel in the year 2000

- Targeted for EO applications: POD, Radio Occultation (RO), attitude determination.
- Used in many missions:
  - ESA: e.g. MetOp-Gras a/b/c for RO, GOCE, Sentinels 1/2/3, Swarm, EarthCARE, etc.
  - Non-ESA: e.g. ROSA in Oceansat Radarsat-2, Cosmo-Skymed, …

Reasons to go for a new generation of devices

- new scientific requirements & experience from current instruments like MetOp GRAS
- new enhanced GNSS signals (GPS / Galileo / Compass / Glonass)
- Advances in space ASIC technology allowing more on-chip integration

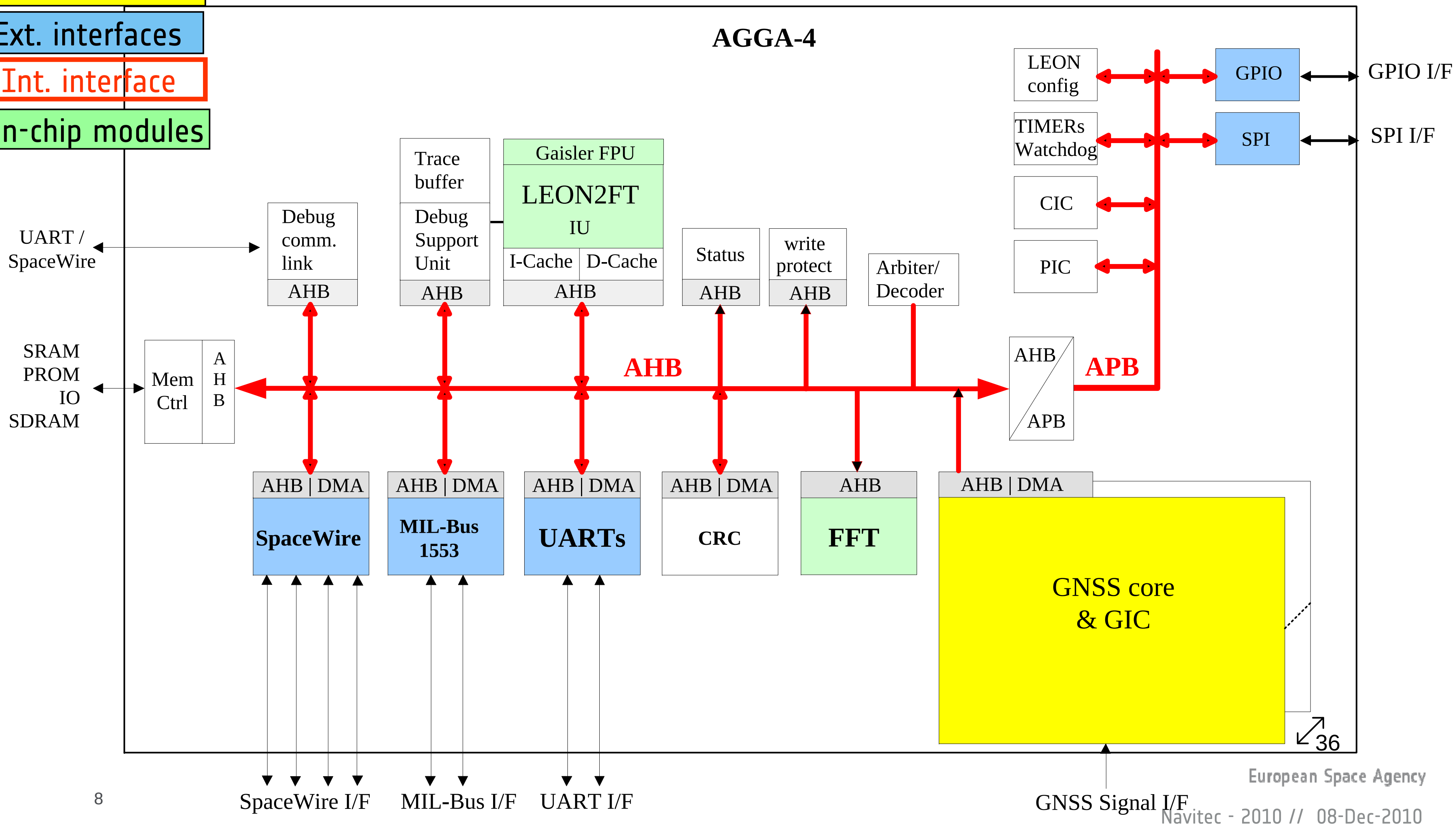
AGGA-4 : Next generation with more functionality



In yellow the GNSS core

AGGA-4 overall architecture

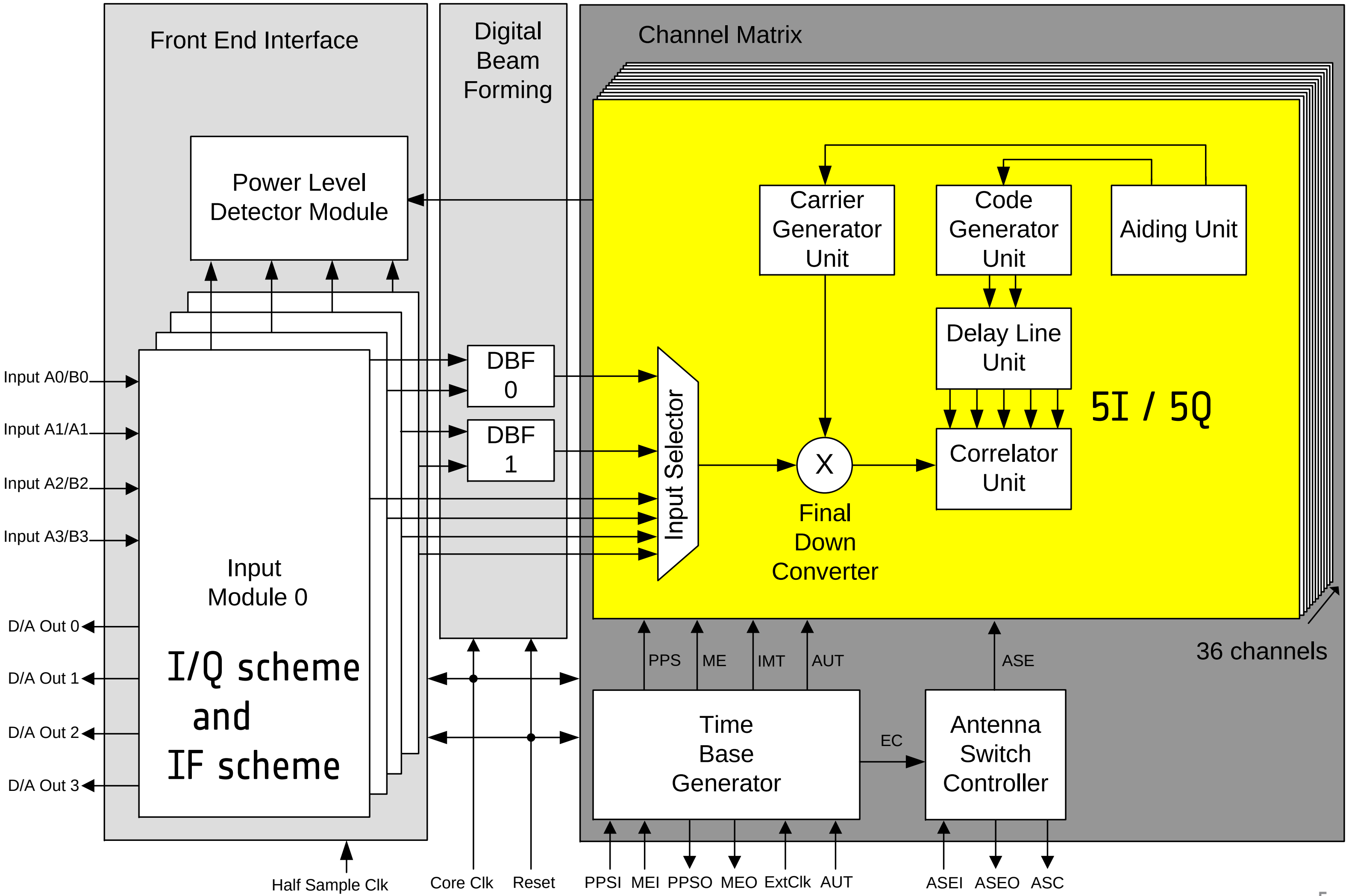
Legend
- GNSS core
- Ext. interfaces
- Int. interface
- On-chip modules



AGGA-4 vs AGGA-2

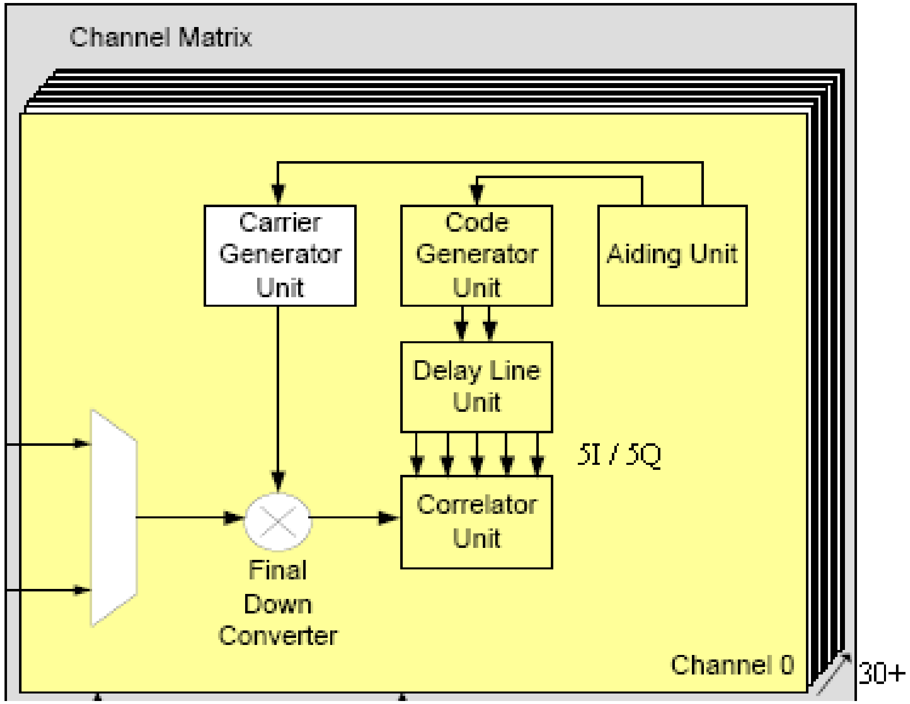
	Feature	AGGA-4	AGGA-2
GNSS CHANNELS	# of channels	**36** Single Freq. or 18 Dual Freq (target)	**12** SF or 4 DF
	Compatible signals	**Galileo Open Service**: E1bc, E5a, E5b Modernized GPS: L1 C/A, L1C, L2C, L5 Existing FDMA Glonass Potentially: Beidou, modernized Glonass	GPS L1 C/A **Codeless** L1/L2 Existing FDMA Glonass
	Code Generators	(2 code generators per channel for Pilot and Data) Primary: LFSR and **memory based** **Secondary codes** and **BOC(m,n)** subcarriers	1 code generator per channel Fixed LFSR for certain primary codes only No secondary code and no BOC.
	Correlators per channel	**5** complex (I/Q) with **EE**, E, P, L, **LL** (E=Early ; P=Punctual) and autonomous NAV data bit collection in HW	**3** complex (I/Q), with E, P, L (L=Late) NAV data bit collection requires software interaction
	Codeless P(Y) code	No	**Yes** (4 P-code units) – ESA patent
	Channel Slaving	Hardware and software slaving	Hardware slaving
	Aiding Unit per channel	Yes: **Code and Carrier aiding**	No. Done in software
	Observables	16 Integration Epoch (IE) observables - DMA capable 5 Measurement Epochs (ME) observables – DMA capable	6 IE observables (no DMA – interrupt based) 2 ME observables (no DMA – interrupt based)
	Common to all channels	Antenna Switch Controller (ASC) Time Base Generator (TBG)	ASC TBG
	MICRO-PROCESSOR	**LEON-2 FT on-chip** with IEEE-754 compl. GRFPU Float.Point)	**Off-chip** (typically ERC-32, ADSP 21020)
	INPUT FORMAT	**3 bit** (0.17 dB losses) (I/Q, real sampling and **interface for IF. ~ 250 MHz**)	**2 bit (0.55 dB losses)** (I/Q and real sampling)
	CRC MODULE	Check Redundancy Code in **hardware On-chip**	No
	FFT MODULE	**FFT in hardware** on-chip	No
	INTERFACES	Two DMA capable UART, **Mil-Std-1553, 4 SpaceWire** SE, SPI I/F, DSU, S-GPO, 32 GPIO, SRAM I/F	Microprocessor I/F, Interrupt controller and I/O ports
	BEAMFORMING	Yes (2 **Digital Beam Forming**)	No
	TECHNOLOGY	**0.18 Micron** from ATMEL, 352 pins GNSS clock up to 50 MHz (target) – LEON clock target 80 MHz	0.5 micron from ATMEL, 160 pins GNSS clock up to 30 MHz

AGGA-4 GNSS Core



AGGA-4 Channel matrix

* **36 single-frequency double-code**



* Very flexible primary **code generator** units:
  – a LFSR to generate very long codes
    (e.g. 767,250 chips in L2CL)
  – memory-based codes
    (e.g. for Galileo E1b and E1c).

* Support of Binary Offset Carrier – **BOC(m,n)** and **secondary codes** required in modernized GPS and new Galileo signals.
* **5 complex (I/Q) code correlators**, to allow the EE, E, Punctual, L, LL required for the processing of BOC signals.
* **hardware Aiding Unit**, allowing autonomous CODE and CARRIER aiding in order to compensate for the 'predictable' Doppler rate (Hz/s) caused by high orbit dynamics

Signals processed with AGGA-4

- Relying on Public signals (no PRS, SoL, …)
- The double code generator allows to process the two component signals in one channel
- High flexibility => also compatible with GLONASS and Beidou (as known today)

Band	Freq. (MHz)	Compo nent	Code Rate (Mcps)	Primary code length (chips)	Secondary code length (chips)	Symbol/ Data Rate (sps / (bps)	Replicas in AGGA-4	LFSR/ Memory (config. AGGA4)	AGGA4 Nb. Channels
E1	1575.42	E1 B	1.023	4,092	No	250/125	BOC(1,1)	Memory	**1 SF** (Sing. Freq.)
		E1 C	1.023	4,092	25	Pilot	BOC(1,1)	Memory	
E5a	1176.45	E5a-I (E5b-I)	10.23 (idem)	10,230 (idem)	20 (4)	50/25 (250/125)	BPSK(10) (idem)	LFSR (idem)	**1 SF**
(E5b)	(1207.14)	E5a-Q (E5b-Q)	10.23 (idem)	10,230 (idem)	100 (idem)	Pilot	BPSK(10) (idem)	Memory (idem)	**(idem)**
L1c	1575.42	L1Cd	1.023	**10,230**	No	100/50	BOC(1,1)	**Memory**	**1 SF**
		L1Cp	1.023	**10,230**	1800	Pilot	BOC(1,1)	**Memory**	**1 SF**
L1	1575.42	L1 C/A	1.023	1,023	No	50	BPSK(1)	LFSR	**1 SF**
L2C	1227.6	L2CM	10.23	10,230	No	50/25	BPSK(0.5)	Memory	**1 SF**
		L2CL	10.23	767,250	No	Pilot	BPSK(0.5)	LFSR	
L5	1176.45	L5-I	10.23	10,230	10	100/50	BPSK(10)	LFSR	**1 SF**
		L5-Q	10.23	10,230	20	Pilot	BPSK(10)	Memory	

AGGA-4 schedule

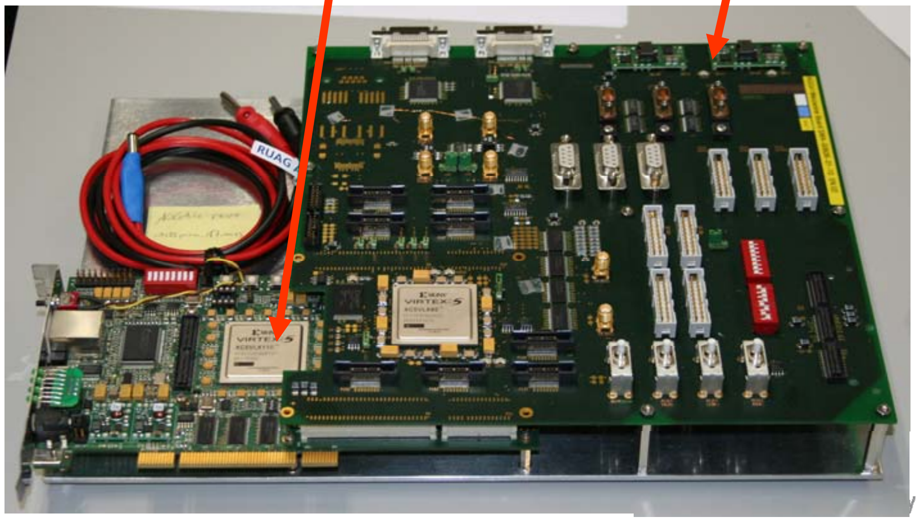
- AGGA-4 is under development by **Astrium GmbH** under ESA guidance and Contracts.
- Extensive validation (acquisition & tracking) with:
  - FPGA version (same as ASIC but with only 4 GNSS channels)
  - Block testing and use of E2E testing with Spirent simulator at ESTEC

  by **Ruag Space Austria** in August 2010
- **Deimos Engenharia** also contributing to FPGA validation

- ASIC components by Atmel in ATC18RHA **0.18** μm process (MQFP package with 352 pins).
  - available for the whole European space industry (equal basis).
  - ASIC prototypes by 4Q-2011.

Mezzanine Multi-interface testing board

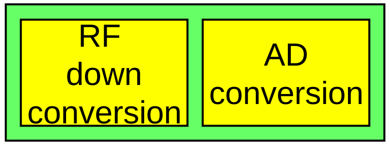
AGGA-4 FPGA



AGGA-4 FPGA testing at ESTEC in Aug. 2010 with Spirent simulator

Programmable RF ASICs

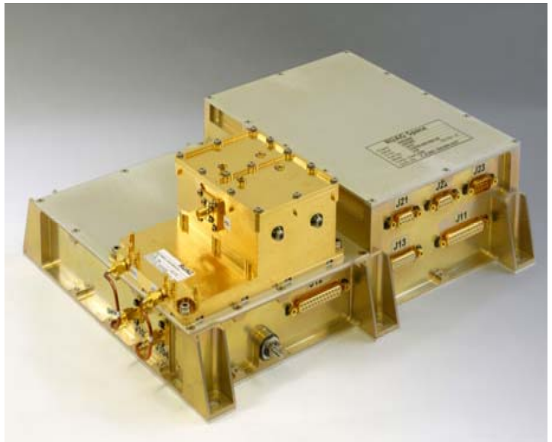
- Saphyrion (former Nemerix) RF ASIC chipset developed under ESA R&D programmes and used for POD applications in Swarm, EarthCare and Sentinel 1a/b, 2a/b, 3a/b.



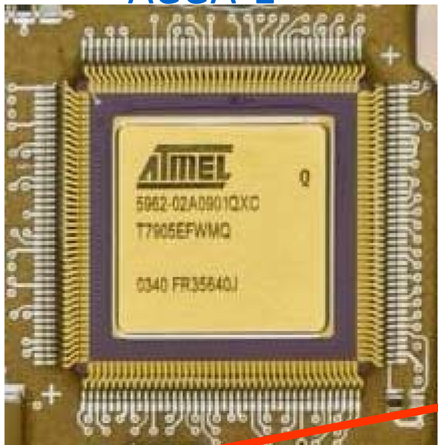
- RF performance is even more important for Radio Occultation (carrier phase measurements)
  - Good filtering against interference (Search & Rescue payloads)
  - Good frequency plan (e.g. integer values between all clocks in the receiver)
  - Clock coherency between bands
  - Low phase noise at 1 Hz & short term stability

- ESA is preparing the next generation of RF ASICs:
  - For POD, Radio Occultation and GNSS-R receivers
    - good RF performance and miniaturisation is important
  - Compatible with AGGA-4 (including 3-bit Intermediate Frequency sampling)

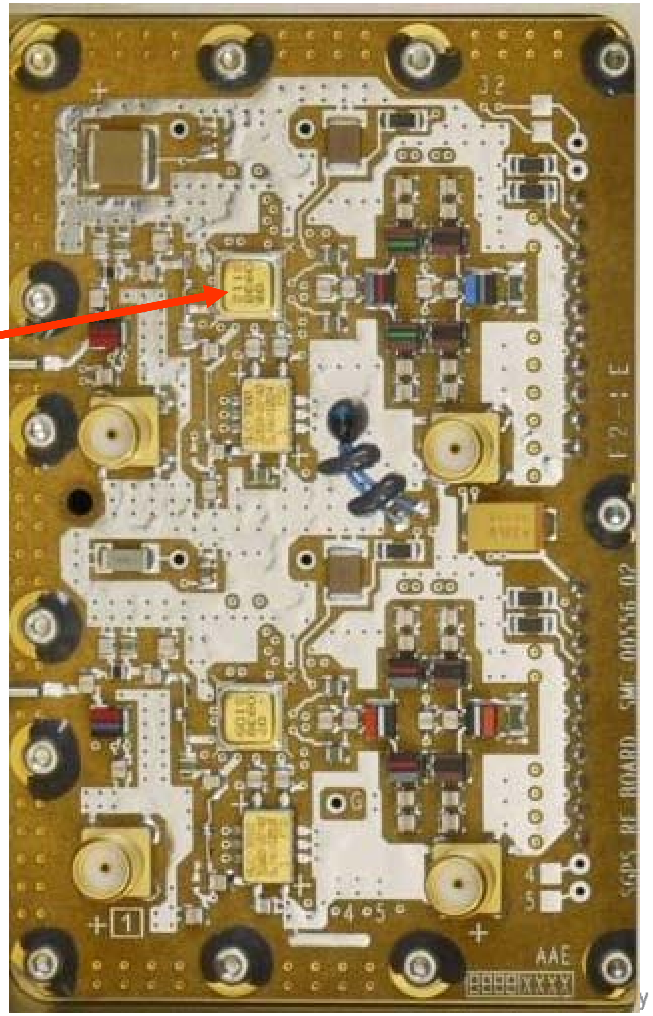
EQM model (example with AGGA-2)

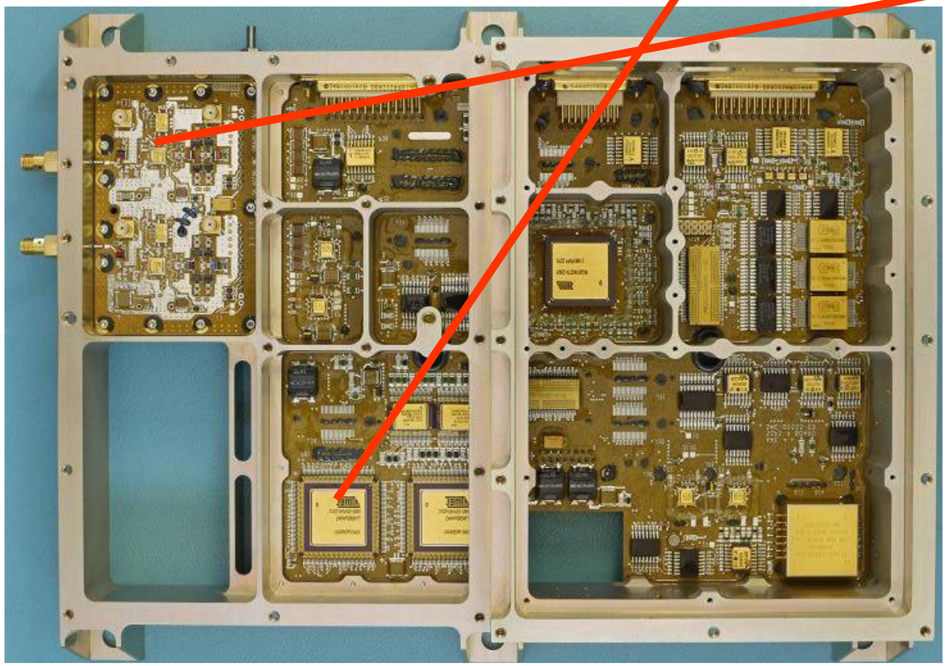


AGGA-2



RF Front End





New GNSS signals and constellations (Galileo, modernized GPS, others)

More **robustness** thanks to:

- More signals in Open Service => (error detection / correction)
- no semi-codeless: dual frequency available also with low SNR
- Pilot components (no bit wiping) => very good for EO needing carrier measurements.
- secondary codes: ‘lengthen’ the spreading code, better autocorrelations while fast acquisition

Small improvement in accuracy (signals with better codes, but similar carrier)

- Similar signal power levels
- higher code bandwidths (e.g. 10 MHz), BOC modulations
- but similar carrier measurements (driver in EO applications)

The new GNSS signals imply:

- **Components more flexible** and **with more digital processing**
  - more channels to improve robustness and RO measurements
  - more digital functions (e.g. digital down conversion, carrier & code aiding, etc).
  - Flexibility (e.g. LFSR & memory-based code generators, more frequency plans)
- Different software: no codeless processing or bit wiping, but more available signals

ESA preparing the AGGA-4, RF ASICs and antenna **components** compatible with new GNSS.
We can **start** developing the **receivers** (ASIC final pin layout known soon)

Conclusion

Applications:

- cm accuracy in Precise Orbit Determination demonstrated (GOCE)
- Radio Occultation: excellent performance of MetOp GRAS

AGGA-2 baseband processors: widely used in ESA and non-ESA missions

ESA preparing the next generation of key GNSS receiver components that can be used for both POD and RO

- **AGGA-4** : compatible with Galileo, modernized GPS, Glonass, Beidou.

  Higher number of channels. Expected ASIC samples: 4Q-2011 for all European space industry under equal basis.
- RF ASIC also important in performance and miniaturisation

We start developing the receivers compatible with future signals:

- more robustness (e.g. higher number of Open Signals, pilot components),
- little accuracy improvements