Airborne Synthetic Aperture Radar technologies and product generation – Relevance to Spaceborne Systems

CEOI-ST Space Technology Showcase, 13th November 2014

Geoff Burbidge – Airbus Defence and Space, Portsmouth

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Airborne and spaceborne radar instrument / equipment technology developments targeting low cost payload products

- Airborne SAR architecture and technology developments
- Progression to spaceborne design and implementation
- Commonality of design features with key technology enablers
- Generic low-cost SAR sensor product line for airborne and spaceborne applications
- Wide range of operating performance resulting in complementary image products

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AirSAR is a collaborative project between:

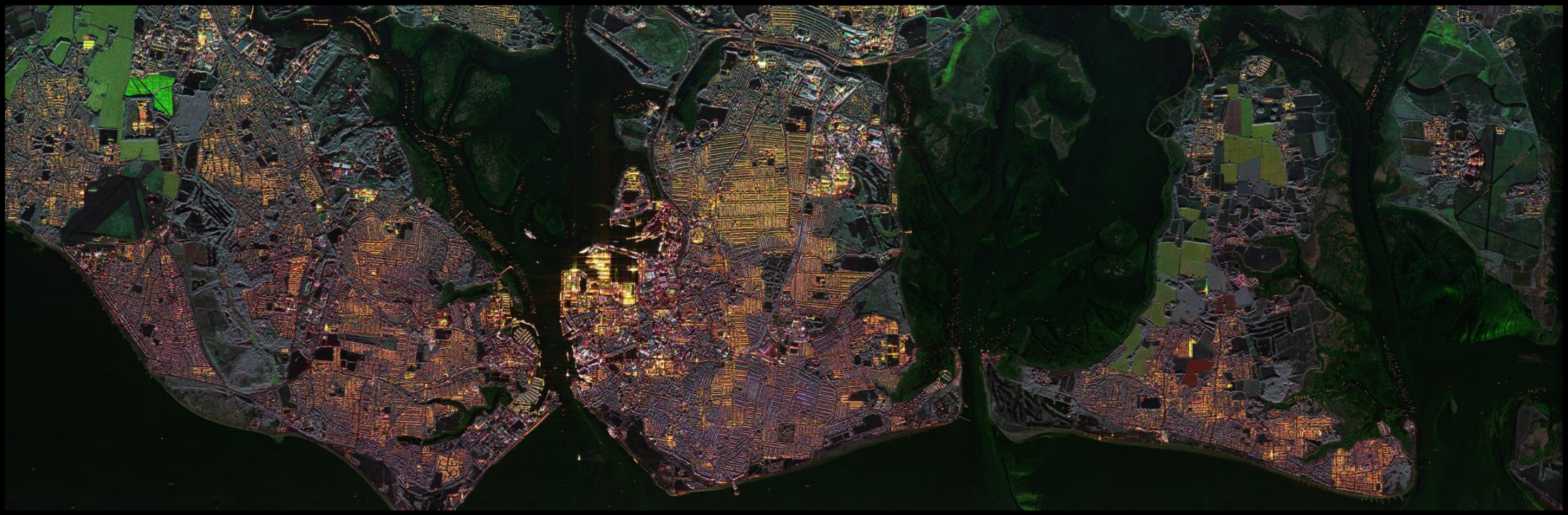
Satellite Applications Catapult

Airbus Defence and Space

Natural Environment Research Council

to establish an **Airborne Synthetic Aperture Radar Demonstrator Facility**

NERC BAS Twin Otter

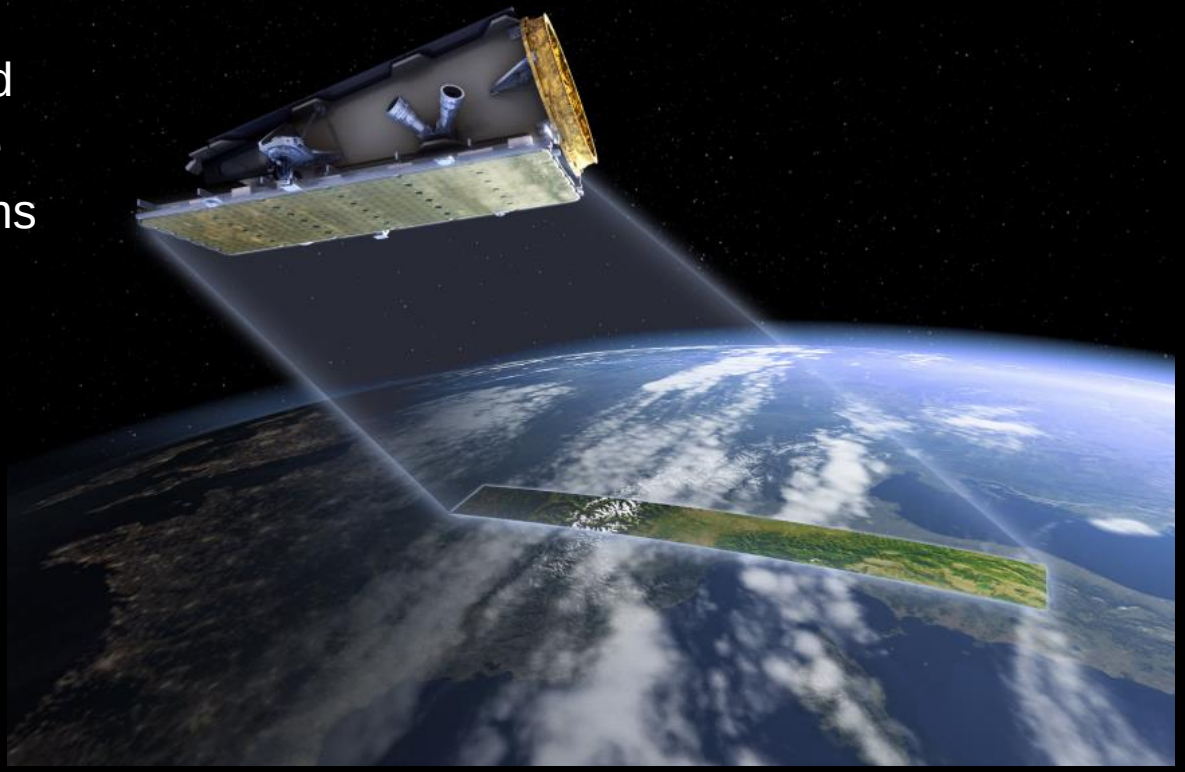


Fareham – Gosport – Portsmouth – Hayling Island
S-band, 7km x 22km swath

The **NovaSAR-S** payload is a low cost S-band Synthetic Aperture Radar providing mid-range performance and offering attractive applications

Key enabling technology is exploited in an innovative design to disrupt the normal performance-to-cost ratio

Mission is a partnership between SSTL and Airbus Defence and Space, funded by the UK Government via the UK Space Agency



Artist's impression of NovaSAR-S satellite in-orbit

Representative S-band NovaSAR-S image product

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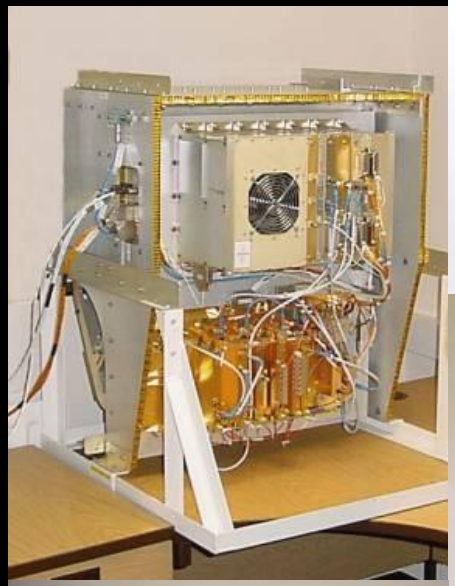
Enabling SAR Technologies

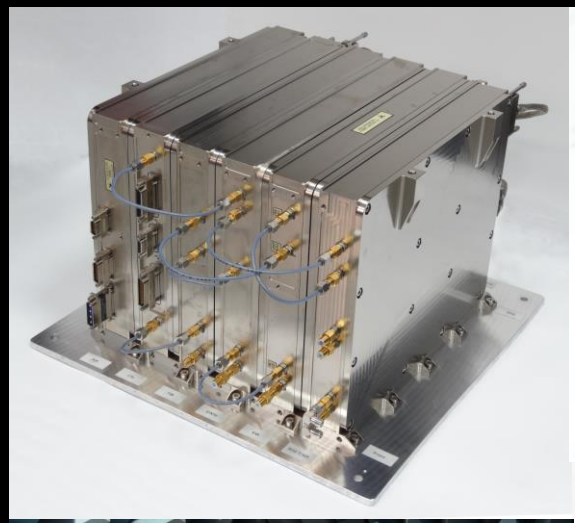
Airborne SAR equipments

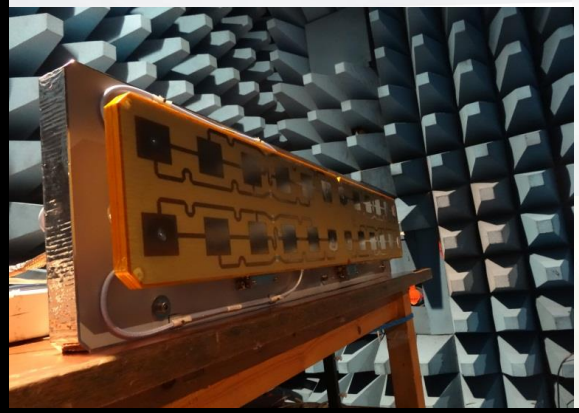


Airborne Demonstrator Central Electronics 215MHz configuration
X band wideband Front End

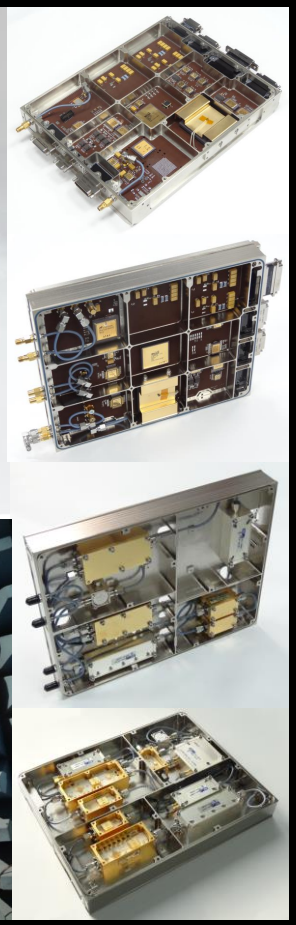
Airborne Demonstrator Back End Electronics
X-band / S-band Front End Electronics
X+S-band Antenna/Gimbal Assembly

NIA / NovaSAR-S equipments





NIA EQM Back End for NovaSAR-S
NovaSAR-S S-band Antenna Subarray



EQM CTG Module
EQM Digitiser Module
EQM RF Modules

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SAR Viewing Direction

Flight Direction

Harwell, 23 June 2014
X-band quad-polar 20cm spatial resolution

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Technology, product and project stakeholders

Airborne SAR Demonstrator

- Airbus DS Space Systems –
  SAR technology and product development

NIA (New Instrument Architecture)

- Airbus DS Space Systems –
  SAR technology and product development

AirSAR

- Airbus DS Space Systems –
  AirSAR project lead, SAR Inst. provider
- UK SMEs (various) –
  Payload equipments, modules, parts
- Satellite Applications Catapult –
  AirSAR project sponsor and facilitator
- NERC –
  AirSAR survey aircraft provider
- Airbus DS CIS –
  AirSAR data cataloguing and assessment

NovaSAR-S

- Airbus DS Space Systems –
  NovaSAR-S Payload and Processor provider
- UK SMEs (various) –
  Payload equipments, modules, parts
- SSTL –
  NovaSAR-S Mission/Satellite prime
- Satellite Applications Catapult –
  NovaSAR-S application development
- Airbus DS CIS –
  NovaSAR-S downstream exploitation
- UK Space Agency / TSB –
  NovaSAR-S customer / technology funder

Airborne SAR Demonstrator / AirSAR Technologies, Capabilities and Imagery

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Airborne SAR Instrument

Technologies and Design

Back End Electronics (X+S)

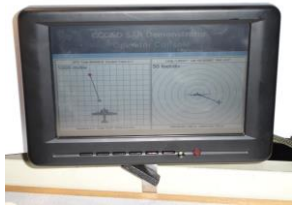
Front End Electronics (X)

Antenna (X+S) / Gimbal Assembly

Enabling technologies

- Back End – multi-frequency wideband Tx signal generation and Rx processing
- Front End – X & S-band signal amplification, switching, CAL network
- Antenna – X & S-band wideband, multi-polar, low loss signal transmission

Chirp and Timing Generator



Cockpit Navigation Aid

Operator Console

Key features of the design:

- software-definable radar electronics
- current implementation comprises up to 3 simultaneous frequencies
- X-band (9.5-10.7GHz); S-band (3.1-3.3GHz); option: Low band (100-1300MHz)
- X+S-band antenna assembly on pan/tilt gimbal for motion compensation
- one antenna phase centre – mechanical steering to boresight
- 100W peak RF power

Flexible mode / swath definition and imaging parameters:

- programmable transmit pulse bandwidth within licensing constraints
- programmable frequency nulling
- flexibility to trade-off imaging parameters, exercise new modes

Typical cabin fit

Rapid iteration and design evolution on airborne test bed

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Airborne SAR Instrument

Imaging performance

Nominal performance parameters:

- Incidence Angle: fully flexible (10-85 degrees)
- Swath Width: from 500m up to 10km *
- Polarimetry: quad polar, dual polar, single polar
  (any combination of HH, VV, VH HV and VH)
- Spatial Resolution: X-band – finest resolution 18cm *
  S-band – typically 1m (far) to 2.2m (near) *
- Ambiguity Ratio: typically <<-20dB for range and azimuth
- Sensitivity (NEσ0): typically <<-20dB

** scope exists to increase coverage and adapt resolution*

All parameters flexible / tailorable to meet user requirements

- Opportunity to create bespoke mode definitions for image acquisitions
- Range of options available within SAR image processing

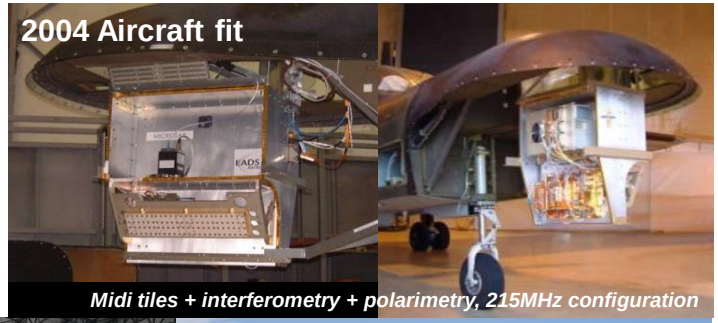
Radiometric Calibration

- Corner reflectors used as reference radiometric targets
- Calibration constant derived to relate image amplitude to radar cross section

Calibration run at Staverton using corner reflector reference target

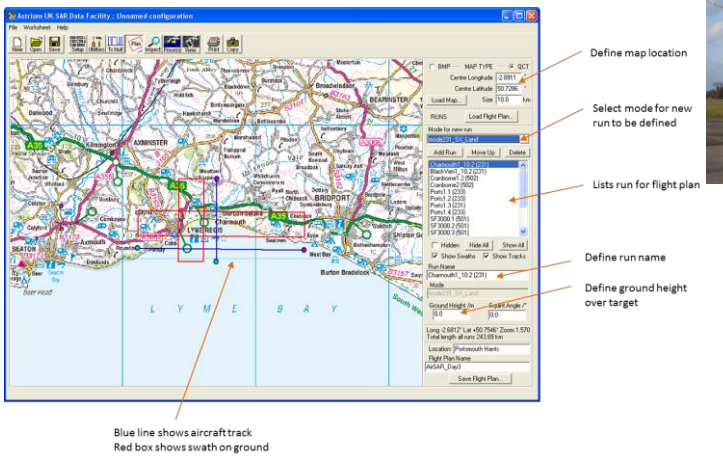
Airborne SAR Instrument

Airbus DS Airborne Radar Heritage



Airbus DS Airborne Radar Demonstrators

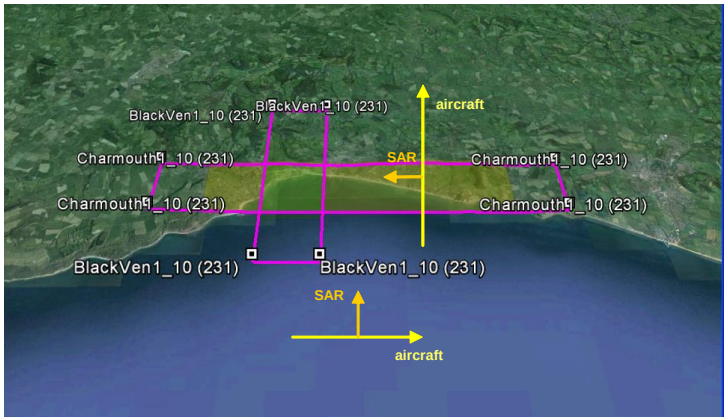
- flight proven and robust system
- 3rd generation instrument equipments
- heritage on 4 different aircraft platforms
- more that 15 airborne trials conducted
- data sets gathered over a 10 year period



Black Ven, Dorset
S-band (left), X-band (right)

AirSAR project flight trials

- in response to AirSAR AO/Call 23 project Expressions of Interest received
- 10 primary projects selected
- May and June 2014 – acquired 167 swaths over 19 locations during 5 days flying
- 11 SAR application areas addressed
- validated operations on NERC platform



AirSAR flight trials

May/June 2014 on NERC BAS Twin Otter (VP-FAZ)

SAR Viewing Direction

Flight Direction

Milton Keynes, 26 June 2014
X-band quad-polar 20cm spatial resolution

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Portsmouth, 25 June 2014
S-band quad-polar 3m spatial resolution

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Flight Direction

SAR Viewing Direction

Connington nr Peterborough, 14 May 2014
S-band quad-polar 4m spatial resolution

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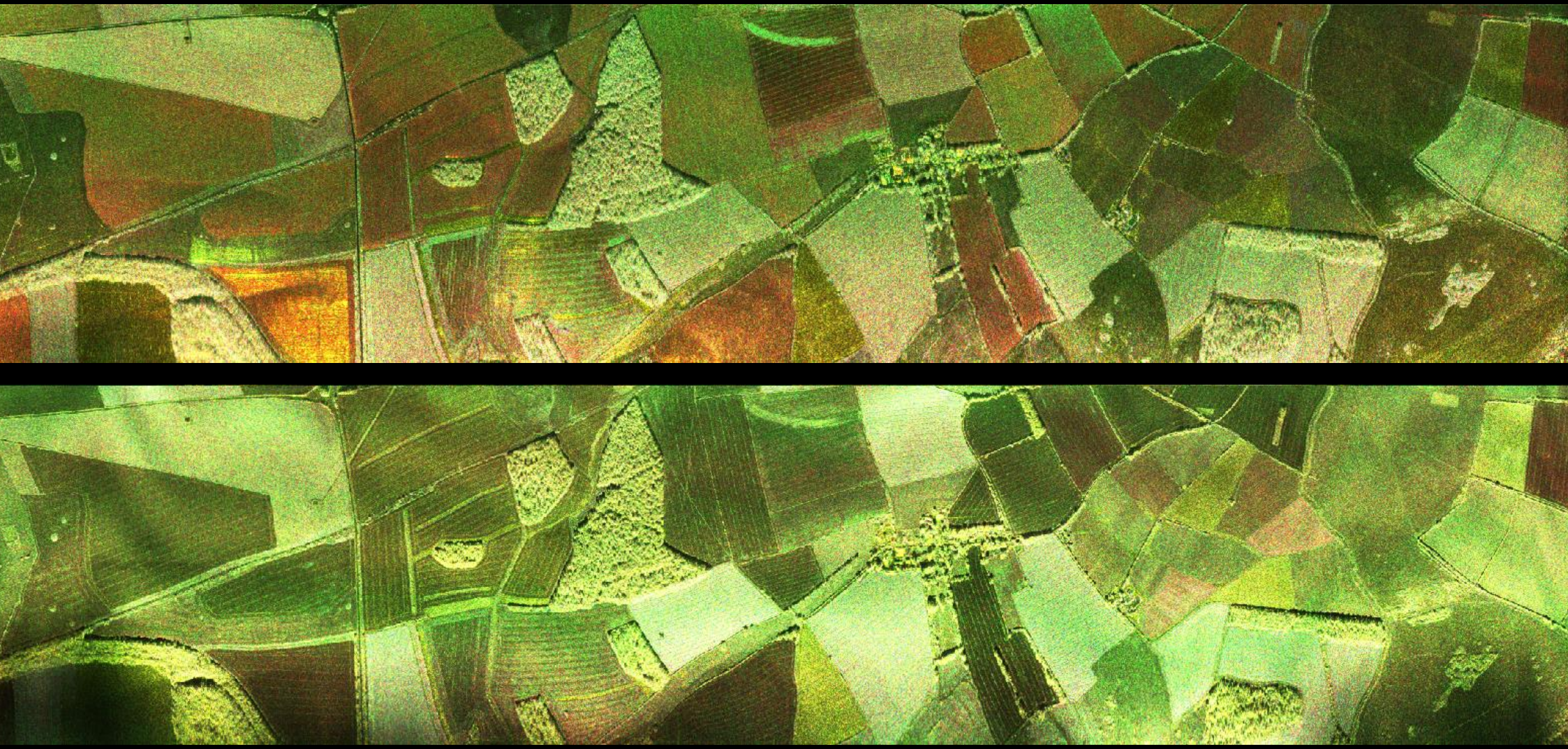

SAR Viewing Direction

Flight Direction

Cranborne Chase, 24 June 2014
(top) S-band quad-polar 3m spatial resolution
(bottom) X-band quad-polar 3m spatial resolution

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NIA and NovaSAR-S
Generic SAR Technologies and Products

Development relationship between Airborne SAR and NovaSAR-S instruments / equipments

Commonality of design features / technology

- shared use of Xilinx Virtex FPGA within Chirp and Timing Generator (CTG)
- common CTG architecture
- common mode design/definition architecture and SAR instrument configuration/operation protocols
- operation with 100W S-band amplifier phase centre
- common S-band radiating subarray design
- identical P1/P2/P3 instrument calibration scheme
- shared airborne and spaceborne SAR image processing algorithms

Complementarity of AirSAR and NovaSAR-S

•gathering of S-band products as precursor to NovaSAR-S

•simulation of products representative of NovaSAR-S performance

•comparison of S-band imagery with co-temporally acquired X-band data

•research and simulation of NovaSAR-S maritime mode

•provision of input data sets for validation of NovaSAR-S Image Formation Processor

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NIA and NovaSAR-S

Developing a Low Cost SAR Payload

Drivers

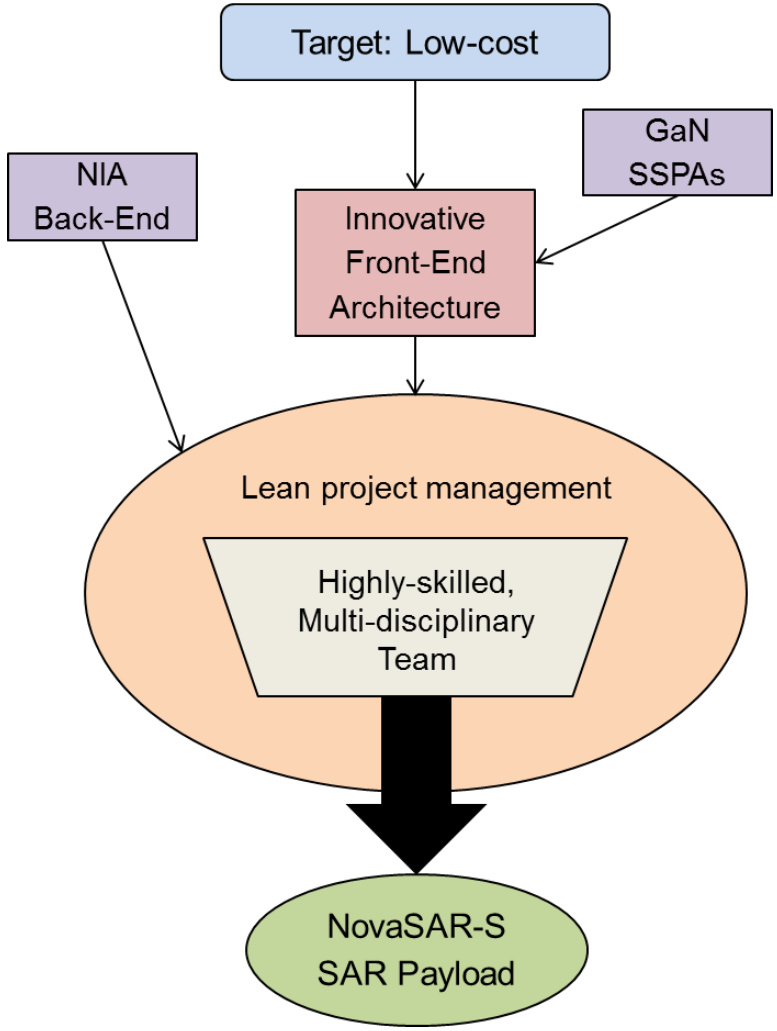
- Total mission cost of £50M in-orbit (including NRE)
- Capable instrument
- Small enough to fit in low-cost launcher fairing – 3x1 m

Enablers

- Innovative Front-End Architecture (Low phase centre count)
- Reduction of instrument complexity (No CPU / software)
- Low-cost, high-flexibility Back-End
- Intelligent parts selection and screening philosophy
- Reduced number of subcontractors
- Lean project management and a compact, highly skilled, multi-disciplinary team

Airbus DS has undertaken a development programme from 2010-2014 with the objective of designing a generic, flexible radar central electronics product to address these needs

First customer for NIA is SSTL, for the NovaSAR-S mission



NovaSAR-S Front-End

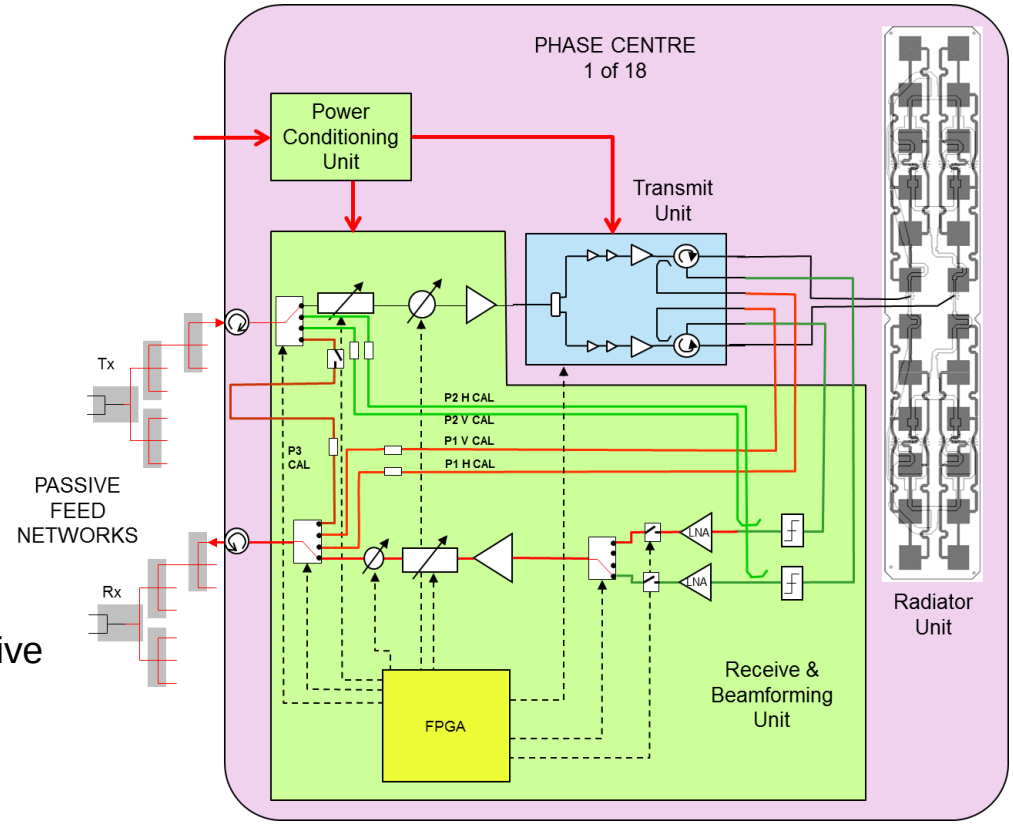
The result is a 18 phase-centre antenna, with 100 Watts of peak power delivered per phase centre, in a 3 columns/6 rows configuration, all accommodated in a 3 x 1m panel

An antenna area 3m^2 presents its limitations but, in conjunction with careful tuning, delivers very attractive performance:

- 125 km access width for 20-31° incidence
- 165 km access with incidence down to 16°
- 6m resolution with 15-20 km swath width
- 20-30m resolution ScanSAR with 100-140 km swath width

Key features of the NovaSAR-S Front-End:

- Low cost
- Phased Array Antenna – flexible operating modes
- Graceful degradation
- Up to 200 MHz of available Bandwidth (ITU regulations)
- P1, P2, P3 Calibration Scheme
- Polarimetric Capability – H or V polarised transmit, H or V receive
- Fully scalable



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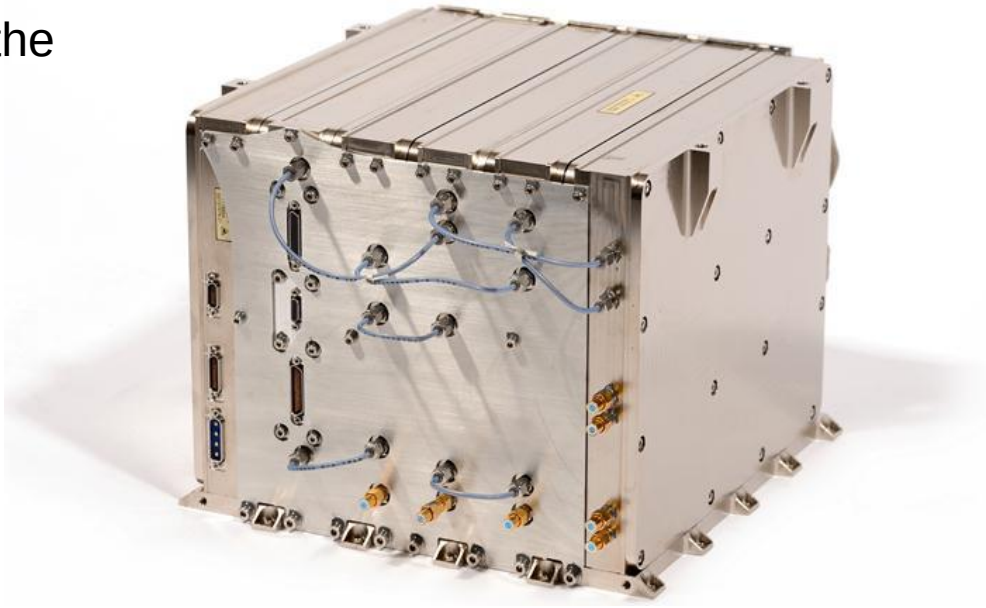
NIA Back End / Central Electronics Product

NovaSAR-S Payload uses Airbus DS NIA Generic Central Electronics for it's Back End, leveraging NIA's simplicity, flexibility, low mass, low power consumption and compact size

The NIA Generic Central Electronics exploits the power and flexibility of Space-Grade Xilinx Virtex 5 FPGAs, in tandem with high-speed data converters (ADC & DAC), providing a generic and modular solution for space radar payloads (SAR, Altimeters, etc..) that requires no CPU and is reprogrammable in-orbit

NIA gives NovaSAR-S the flexibility needed to control the Front End efficiently and allows the implementation of complex and novel operation modes



Key features of the NovaSAR-S Back-End:

- Simple - No Payload Software or CPU
- Flexible and reprogrammable
- Low-power: 46W
- Low-mass: 10.9 Kg
- Small size: approx. 209mm H x 265mm W x 272 mm D

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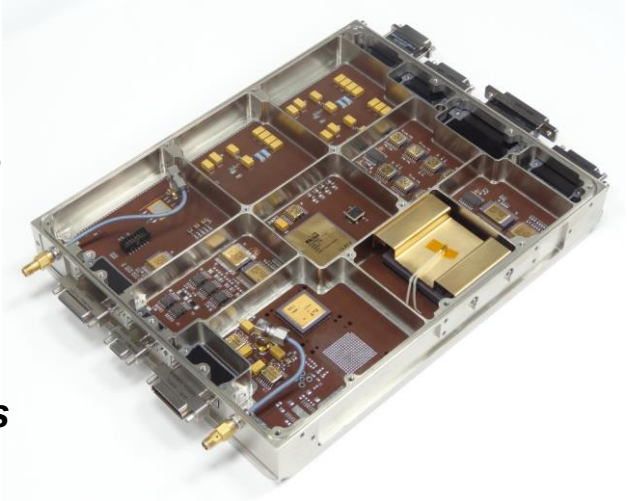
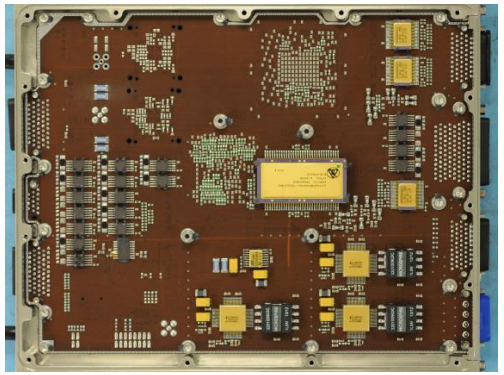
Chirp & Timing Generator Module (CTG)





Can be fitted with one or two E2V 12-bit 3Gsps DACs

Multiple I/O interfaces

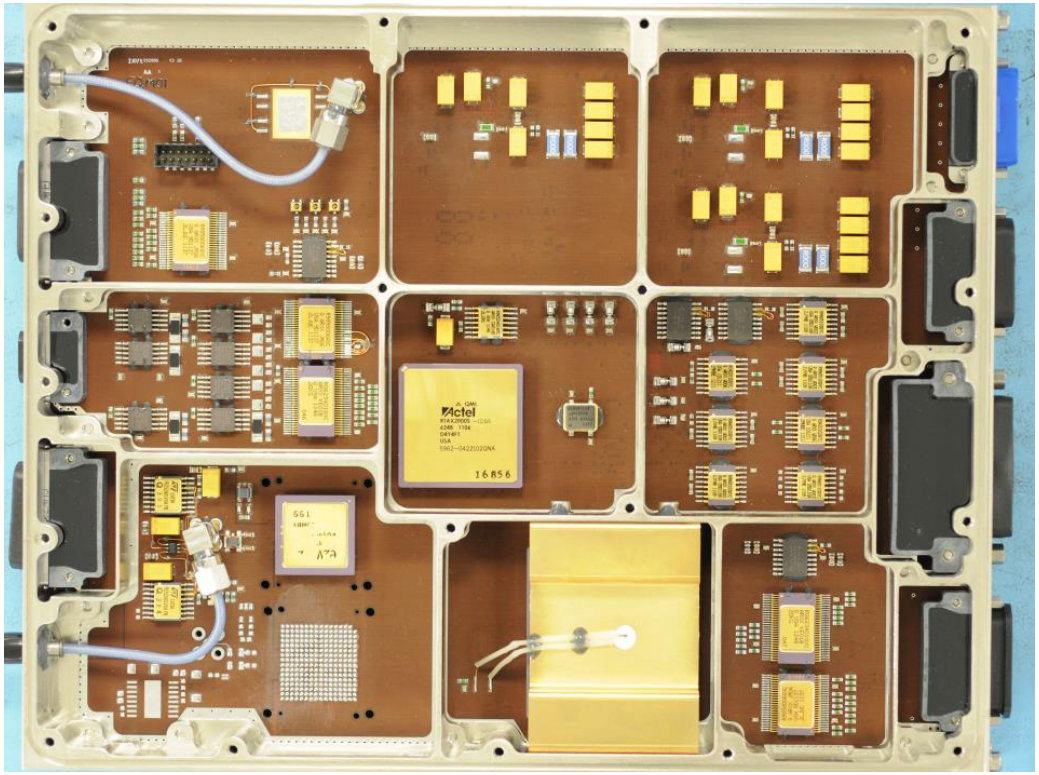
Single highly capable FPGA or ASIC for

- Timing & Control Engine (control of Tx Enable, Sample Trigger, RF/IF Atten etc...)
- Digital Chirp Generation with frequency mapped amplitude & phase pre-distortion
- Control of instrument front-end (flexible interface & protocol)
- Other telemetry / housekeeping functions

Can be the Xilinx Virtex 5 or the Aeroflex ASIC in the same package

Actel RTAX2000 Arbiter FPGA

- Primary Command/Ctrl Interface
- Supply rail monitoring



Mass : 1.3kg
Size : 25 x 20(H) x 4cm

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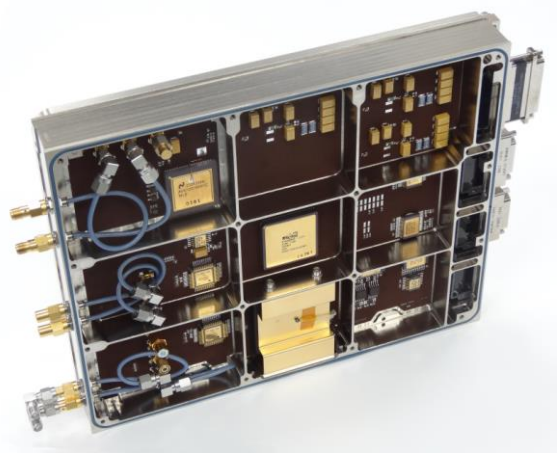
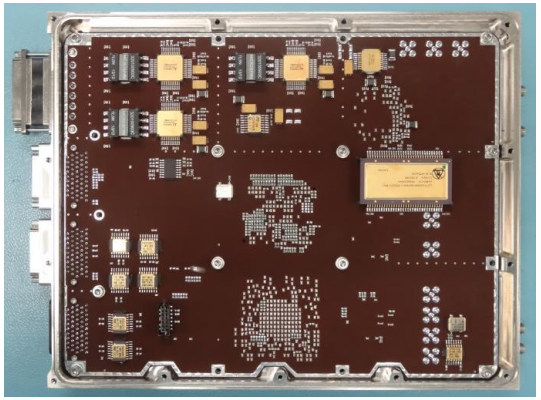
Digitiser Module





12-bit National Semiconductor 3.2Gsps ADC

Flexible I/O interfaces for control / handshaking

Single Highly capable FPGA or ASIC for

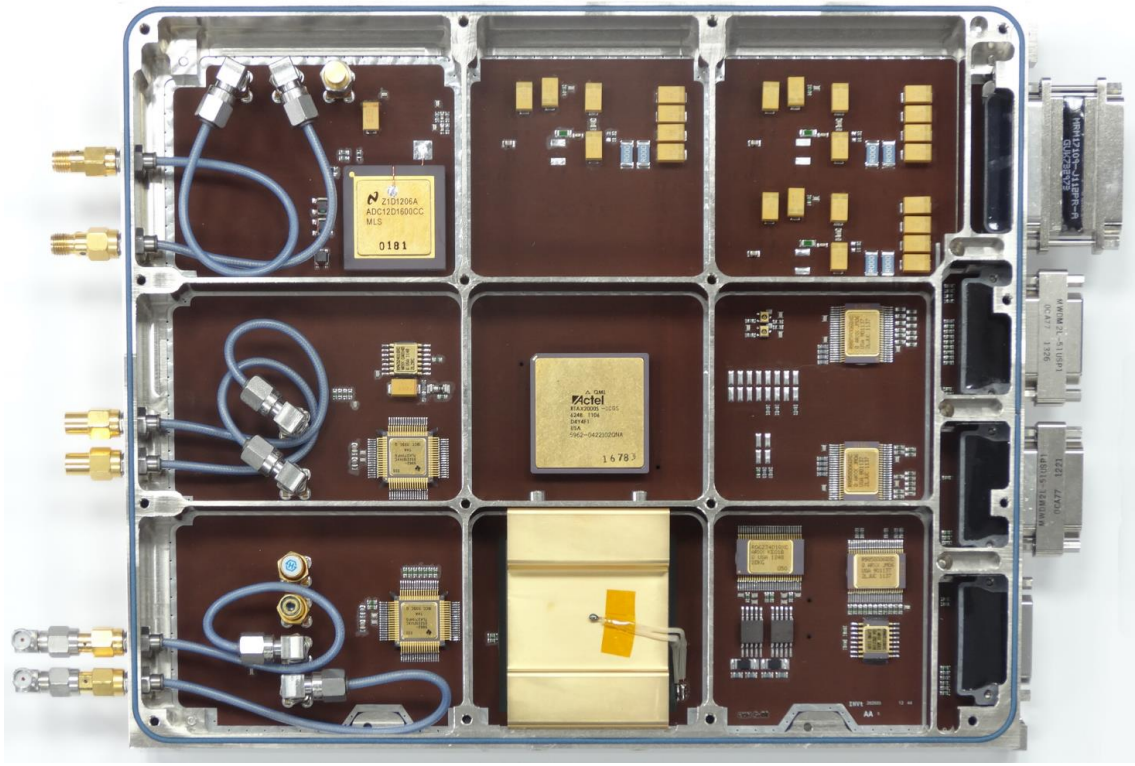
- 12-bit A/D Conversion (single or dual at half rate)
- Digital Down-conversion to baseband
- Digital frequency shift and/or de-ramp
- Programmable L/M Decimation Filter
- Vector-encoded BAQ modes enable compression with selectable bit rate (2,2½,3,3½ etc...)
- Special CAL compression mode
- CCSDS compliant packetiser
- Buffering and output to high rate data interfaces

Can be the Xilinx Virtex 5 or the Aeroflex ASIC in the same package

Actel RTAX2000 Arbiter FPGA

- As per CTG

Dual WizardLink Interfaces



Mass : 1.7kg
Size : 25 x 20(H) x 4cm

NovaSAR-S Central Electronics Qualification Status

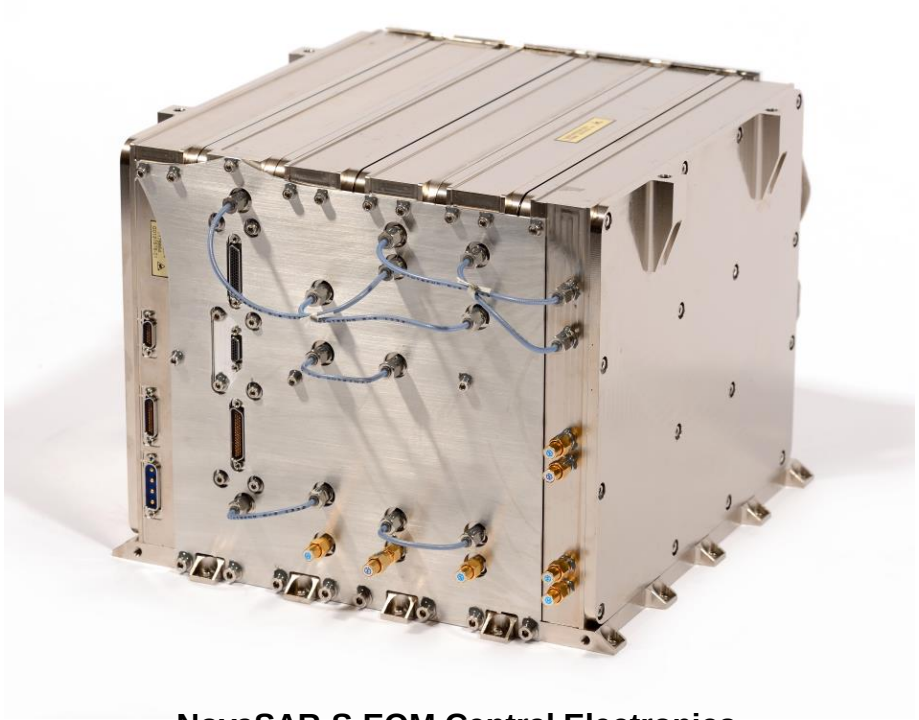
EQM design, built and ambient functional testing complete

All functional and performance metrics within spec

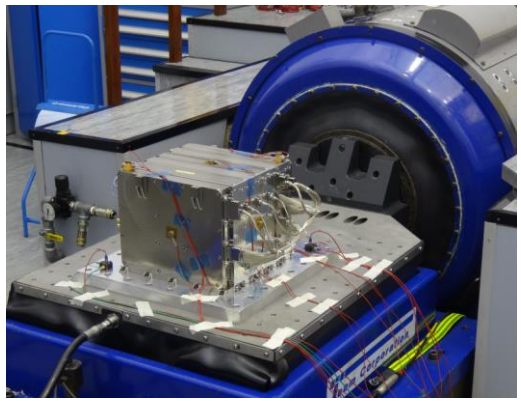
Vibration testing successfully completed to ECSS levels
(February 2014)

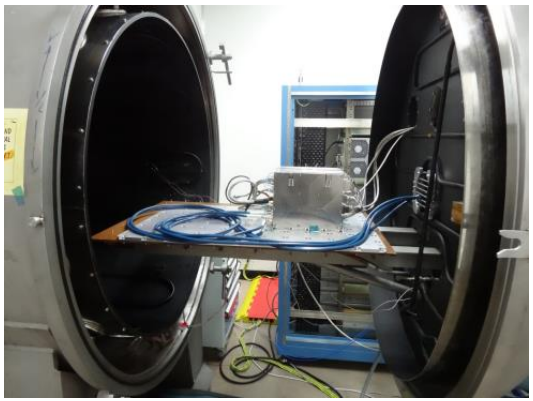
Thermal Vacuum Testing successfully completed (8 cycles)
-20 to +50°C operating temperature range
(March 2014)

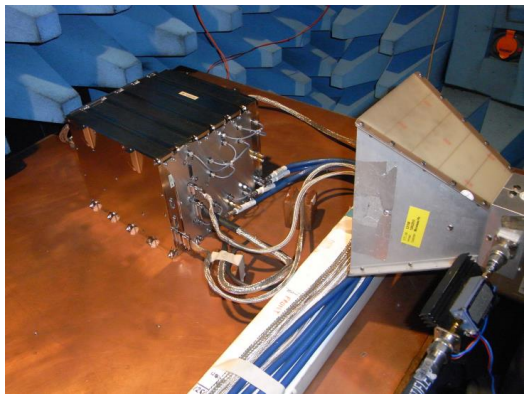
EMC testing completed successfully
(June 2014)



NovaSAR-S EQM Central Electronics







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Airborne SAR / AirSAR Way Forward

Airborne SAR Capability

An AirSAR asset supporting NovaSAR-S

Flexible, tailorable SAR data acquisitions to support applications development for current and future space-based SAR systems

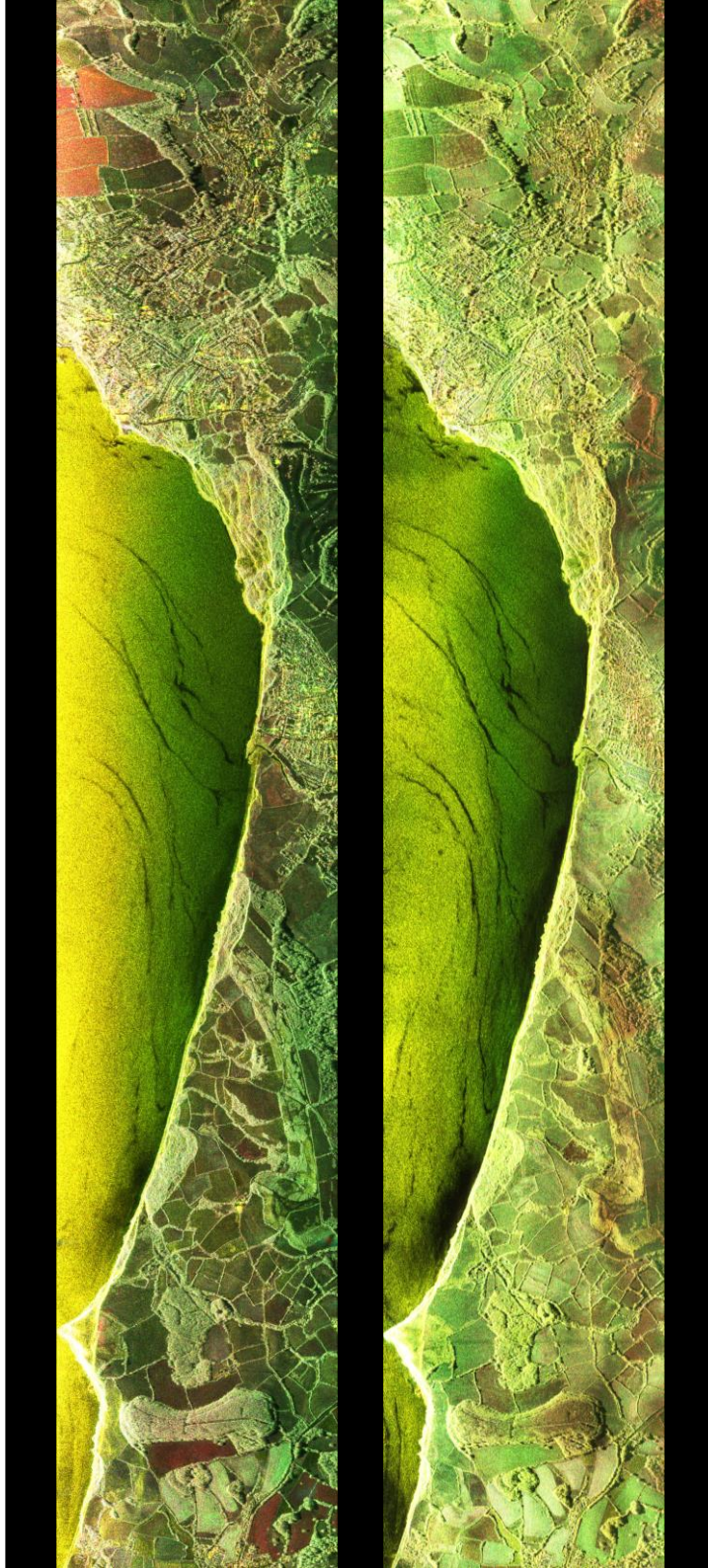
Acquisition of contemporaneous X and S-band data

- Improving understanding of NovaSAR-S data as a source of future products
- Enabling direct comparison and assessment of SAR frequencies

Filling an important UK national capability gap

Demonstrating the potential that exists for offering an airborne SAR data gathering in concert with a NovaSAR-S asset

- supporting a variety of user applications:
  - maritime monitoring
  - flood monitoring
  - soil moisture / water security
  - ocean surface current measurement
  - oil on water detection
  - heathland burn assessment
  - forestry management
  - biomass measurement
  - crop identification
  - slope stability
  - archaeology
  - land cover mapping



Lyme Regis / Charmouth
S-band (left), X-band (right)

Airborne SAR Capability

AirSAR: Airborne SAR remote sensing with complementary sensors

Future AirSAR operating capability will targeted on exploitation of NERC Dornier 228 (G-ENVR)
Platform offers a significant remote sensing asset for the UK community for operations both locally and globally
Airbus DS and NERC planning AirSAR installation/certification on G-ENVR for summer 2015

NERC Dornier 228 (G-ENVR)

Aircraft features –

- Unpressurised twin-turboprop
- External hard-points and under-wing pylons/PMS pods
- Operating ceiling: 25 000ft
- Data collection typically at 135 knots (70m/s)
- Transit speed is approximately 200 knots (7 hrs endurance at 10 000ft)
- Range >1800 nautical miles

Core instruments –

- Leica ALS50-II LiDAR
- Leica RCD105 (39 megapixel digital camera)
- AISA Fenix (VNIR & SWIR) imaging spectrometer
- AISA Owl (LWIR) imaging spectrometer
- Atmospheric Suite (GRIM OPC, AIMMS-20+)

Summary and Conclusions

Significant commonality of development and end-product between Airbus DS Airborne Radar Demonstrators and NIA / NovaSAR-S

Strong synergy of SAR instrument technologies resulting in a very powerful and competitive generic product

Airborne SAR heritage and capability provides opportunity for further technology demonstrations

- flight-proven instrument available for gathering of SAR data to support development of SAR applications
- mature SAR demonstrator equipments exist – important to define development roadmap to next generation

A range of options are being exploredfor future exploitation of the AirSAR asset

NIA offers prospect of generic low cost solution for a range of missions and applications

- NovaSAR-S payload will be first instantiation of NIA in a spaceborne mission
- further NIA further development evolutions necessary to maximise it's potential for ESA missions (V5 qualification, ICM functionality) for which CEOI-ST support is being sought

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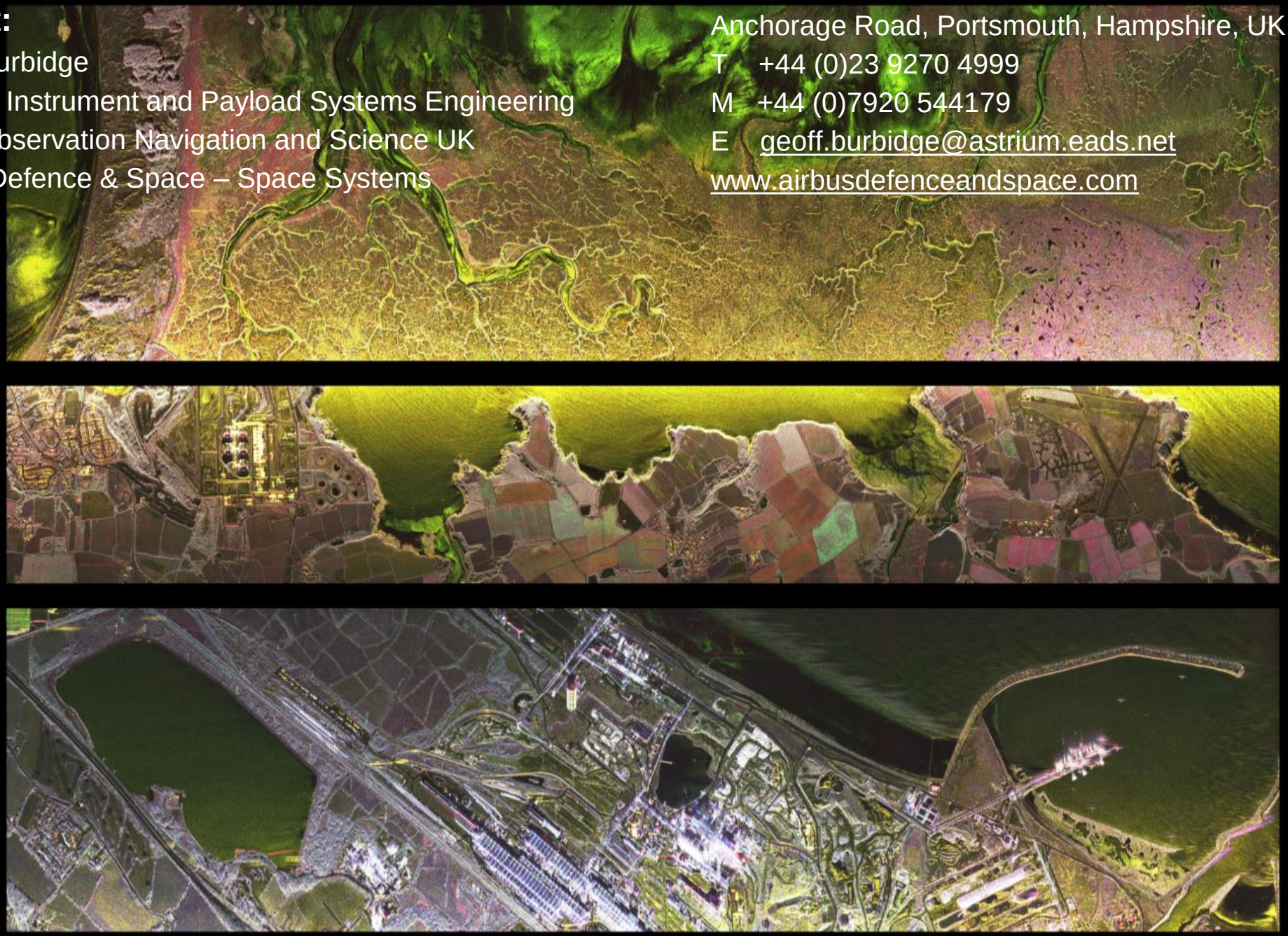

Polarimetric Airborne SAR Imagery of South Wales
Acquired by Astrium UK Airborne SAR Demonstrator
on July 28th 2010 from 10,000ft through total cloud cover.

Locations : Llanrhidian Sands (Gower), Milford Haven and Port Talbot

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