Centre for EO Instrumentation & Space Technology

Report on the Activities of the Centre for EO Instrumentation and Space Technology

1st November 2013 to 31st October 2015

Produced by the CEOI-ST Leadership Team

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UK SPACE AGENCY

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1 Introduction

This report summarises the activities of the CEOI-ST in the period 1st November 2013 to 31st October 2015.

The CEOI was set up in 2007 by NERC and DTI (now BIS) as an initiative 'to boost UK capability and remain at the forefront of EO technology for space'. Responsibility for CEOI was taken over by the UK Space Agency when it was formed in 2011. In November 2013 the contract was competed once more by the UK Space Agency, resulting in the current arrangements with the existing industrial/academic partnership forming the Centre for EO Instrumentation and Space Technology (CEOI-ST).

The CEOI-ST follows on from the activities of the CEOI. In addition to EO activities, the CEOI-ST is managing Space Technology (ST) projects in the UK National Space Technology Programme (NSTP). The initial CEOI-ST contract completed on 31st October 2015 and has recently been extended to 31st March 2016.

The CEOI-ST programme is based around a series of themes to combine the activities in EO and space technology to address the key drivers of the UK Civil Space Strategy. The Centre has selected 5 themes over the 3 year programme, with activities supporting each theme as shown in the following table

Theme	Rationale	Supporting Activities to Add Value
1. Innovation in EO and Space Technology	Driving theme under-pinning all the Centre activities. Through funding innovative developments of EO instruments and ST, it will position UK teams in national and international competitions and in winning commercial opportunities	Challenge Workshops: - Emerging technologies - Opportunities for SMEs Knowledge exchange – Technology showcase - Annual CEOI Conference
2. Technologies for services and growth	Future growth in space identified in the IGS is dominated by downstream applications, but these will be enabled by developing new and innovative developments in EO instruments and space technologies	Challenge Workshop - Developing services Knowledge exchange – user community workshops Interaction with Catapult
3. Leveraging UK investment in Europe	The UK makes significant investment into the ESA programme for EO and ST. The theme targets maximising the return on that investment within the ESA and wider EU programmes	Training for PIs Horizon scanning Mission advisory panel International opportunities
4. Achieving higher TRL through demonstration	By taking key technologies through the development 'valleys of death', we will ensure that they move as quickly as possible to implementation and exploitation	Challenge Workshop - Making demonstrators a reality; Training – barriers to higher TRL
5. Developing low-mass cost-effective instrumentation	Key for affordable future EO and ST missions, for both institutional and commercial markets	Challenge Workshops Technology workshops

Table 1.1 Centre Themes for EO and ST

A major programme focus is on the development of technologies to beyond TRL4, including where beneficial, development for airborne and in-orbit demonstrators.

In addition the CEOI-ST has a programme of challenge workshops and horizon scanning conferences to promote and develop UK capability. The Centre engages with ESA to highlight and promote the achievements of UK developed technology and provides support to UKSA when requested to provide technical advice for their meetings and other interactions with international and national Agencies.

With a new approach to Knowledge Exchange, the CEOI-ST promotes UK capability in space technology to non-space markets, increasing the impact of the technology investment. The activities include a series on small but focussed industrial consultation workshops and approximately every 2 years a technology showcase to advertise the technologies developed under CEOI-ST funding to the non-space remote sensing industry.

The CEOI-ST is also working to identify missions and technologies with high potential commercial benefit, working with the Satellite Applications and other Catapults.

The CEOI-ST partnership is led by Airbus DS, with contracts between Airbus DS and the other CEOI-ST Partners (QinetiQ, University of Leicester and STFC/Rutherford Appleton Laboratory), who together run the CEOI-ST.

2 Main Events in 2014-2015

The Centre has held a number of events over the last 2 years, listed below. For further information on each event please refer to Section 4 and 5.

Date	Event	Venue	Objective
30/04/14	Emerging Technologies 2014	College Court, Leicester	Two day residential workshop to show case current and emerging EO instrument technologies
16/10/14	Affordable Space	Bristol	
31 Mar 15	Challenge Workshop: Future Science for EO - Needs and Missions	Leicester	To identify technology needs for ESA Earth Explorer 9 and other science-driven EO missions
21/22 Apr 15	CEOI Technology Conference	Cosener's House	2 day residential conference to show case current and emerging EO instrument technologies, and the needs of future EO missions
07 May 15	Industrial Consultation Workshop	London	By invitation. A networking opportunity to investigate microwave / millimetre wave & terahertz instrumentation.
03 Sep 15	Training Workshop - What makes a good proposal for an EO space mission?	Sheffield	Aimed at potential Principal Investigators and teams for next ESA Earth Explorer Call
08-11 Sep 15	National EO Conference	Southampton	Joint national EO conference with RSPSoc and NCEO, title 'Earth Observation in the Sentinel Era'
07 Oct 15	Challenge Workshop - Airborne Demonstrators	Edinburgh	To investigate the potential offered by airborne demonstrators as a step to space qualification and to learn from the practical experience of others
15 Oct 2015	Industrial Consultation Workshop	London	By invitation. Industrial networking workshop focussing on optical/visible wavelength technologies
24 Nov 2015	SME Event	Cardiff	Joint workshop with Welsh Government to promote space instrumentation opportunities to space industry and academia

The Centre is planning a programme of additional events and workshops in the coming months:

Title	Timescale	Objective
Regional SME Workshop (Wales)	24 Nov 2015	Joint with Welsh Government and the Wales Aerospace Partnership. The workshop will help SMEs and other non-space businesses understand the barriers and opportunities of space business.
NSTP-2 Pathfinder Project Review	27 or 28 Jan 2016	A Review of NSTP-2 Pathfinder projects from the 2014/15 round. UKSA booking venue
EO7 and EO8 Project Review	Feb/Mar 2016	A Review of completed and ongoing EO7/8 projects
Advanced manufacturing technologies for EO instrumentation and satellites	Feb/Mar 2016	Joint workshop with Sat Apps/HVM Catapults
Industrial Consultation Workshop	Early March 2016	Small focused discussion workshop with 12-16 non-space industrialists. Technology focus tbd.
Science Challenge workshop	Spring 2016	To follow up appropriate issues from the Nov 2015 strategy workshop
Training Workshop	Spring 2016	eg GBER and State Aid (half day). Dependent on progress with UKSA notified State Aid scheme

3 Technology Activities

The Centre offers grants awarded through competitions for projects for EO and ST at the funding levels defined in the NSTP strategy:

- Small Grants - up to £10K (ST only)
- "Pathfinder" projects – typically up to £50K
- "Fast-track" projects - typically up to £200K
- "Flagship" projects - typically up to £1,000K

The projects require a level of industrial PV in accordance with their size and closeness to market, thus enhancing the project value and impact.

The CEOI-ST has held two Open Calls for projects to advance EO instrument technologies – the EO7 and EO8 Calls.

The CEOI-ST EO9 Call for proposals to prepare for the expected ESA Earth Explorer 9 Announcement of Opportunity closed on 31st October 2015. The selection of projects to be funded is in progress.

In addition to the EO Calls, the CEOI-ST has issued a number of Calls for Proposals under the UK Space Agency National Space Technology Programme. Details of the outcome of the NSTP Calls are available on the CEOI website.

The Calls issued by CEOI-ST are listed in the following table:

Call	Grant Value	ITT Release	Closing Date	Status/Comments
7th EO Call	£2.2M	Nov 2013	Dec 2013	18 Fast Track/Pathfinder projects.
8th EO Call	£3.2M	Jul 2014	Sep 2014	4 Flagship EO projects and one Feasibility study
9th EO Call: EE9 Mission and Technology Preparation	£1M	17 Jul 15	30 Oct 15	To prepare UK team's response to the ESA Earth Explorer 9 Call for Ideas Call closed, proposals being evaluated
NSTP2 GEI Calls	£200K	Rolling programme	Every 4 months	Next GEI Call closes on 2nd Feb 2015 23 mini-studies in first 4 rounds,
1st NSTP2 Fast Track and Pathfinders	£3.2M	Jul 2014	Oct 2014	22 Fast Track and 11 Pathfinder projects
1st NSTP2 Flagship	£2M	26 Mar 15	9 Jun 15	2 projects selected for funding
2nd NSTP2 Pathfinder	£800K	28 Jul 15	15 Sep 15	15 projects selected for funding
2nd NSTP2 Fast Track	£2M	3 Sep 15	14 Oct 15	Call closed, proposals being evaluated

7th Open Call

The 7th Open Call closed on 4th February 2014. In total 36 proposals were received, 13 for Fast Track projects and 23 for Pathfinder projects. The over-subscription level is greater than a factor of 2.

An independent review panel met in early March 2014 and recommended the projects to be funded.

A summary of these projects is given below and their status is described in the next section.

Title	Category	Lead Organisation	Partners
LOCUS Critical Payload Development for Future In Orbit Demonstration	Fast Track	University of Leeds	STFC RAL, STAR-Dundee
Exploring SAR Interferometer Calibration Solutions for Ocean Surface Current Errors for the Wavemill Space Mission	Fast Track	National Oceanographic Centre	Starlab Ltd Airbus DS
MISRlite - Multi-angle IR Stereo Radiometer using Uncooled Microbolometer Arrays for Global Winds	Fast Track	MSSL-UCL	TAS UK Ltd
Global Satellite Observations of Winds, Rain and Clouds	Fast Track	University of Reading	University of Leicester
Mechanised Precision Bonding of Composite Assemblies	Fast Track	University of Glasgow	Gooch & Housego
TRUTHS: Traceable Radiometry Underpinning Terrestrial and Helio Studies	Fast Track	NPL Management Ltd	SSTL
Demonstration of a CO2 Laser Heterodyne Radiometer	Pathfinder	STFC RAL	
UK Support for the ALiSS Mission Study	Pathfinder	STFC RAL	
High Frequency Doppler Radars #2 (HIDRA 2)	Pathfinder	STFC RAL	University of Leicester
Hyperspectral Imaging for Air Quality: Application of a Hyperspectral Imaging Suite for 3D Retrievals	Pathfinder	University of Leicester	
183 GHz Frequency Selective Surface (FSS)	Pathfinder	Queens University Belfast	
ICEMuSIC – Instrument Optimisation Study and Mission Definition	Pathfinder	University of Cardiff	Met Office Uni of Hamburg
COnformal Retro Reflectors for Earth Observation (CORREO)	Pathfinder	University of Cranfield	University of Nottingham
Characterisation of Ferrite Material in Remanent State for use in New High Peak Power Applications	Pathfinder	COM DEV International Systems Ltd	

Table 3-1 Projects Selected in the 7th CEOI-ST Open Call

8th Open Call

The 8th Open Call closed on September 2014. In total 10 proposals were received for EO Flagship projects. The over-subscription level is greater than a factor of 2.

An independent review panel met in early October 2014 and recommended the projects to be funded.

A summary of these projects is given below and their status is described in the next section.

Title	Category	Lead Organisation	Partners
Compact Air Quality Spectrometer	Flagship	University of Leicester	SSTL
Critical Technology Advancement of the LOCUS Mission	Flagship	University College London	STAR-Dundee Ltd, Leeds University, Glyndwr University, JCR Systems Ltd
Industrial Research for Next-generation Radar Electronics	Flagship	Airbus Defence and Space	None
TRUTHS: Traceable Radiometry Underpinning Terrestrial and Helio Studies	Flagship	NPL Management Ltd	Airbus DS Ltd
Compact Infrared Imager and Radiometer	Feasibility Study	University of Oxford	RALSpace Clyde Space Ltd Satellite Applications Catapult

Table 3-2: Projects Selected in the 8th CEOI-ST Open Call

Strategic EO Projects

In addition to the projects funded as a result of the EO7 and EO8 Calls, the UK Space Agency funded a number of strategic projects, selected to advance UK capabilities in areas of importance.

Title	Category	Lead Organisation	Partners
Radiation Testing of Selex ES CMOS ROICs for Earth Observation IR Sensors	Fast Track	Selex ES, UK	None
Contactless Power & Data Transfer for Conical Scanning Instruments	Fast Track	TAS UK Ltd	ESR Technology Ltd
UKSA-CNES Bilateral Carbon Mission: Support Study	Flag Ship	University of Leicester	UK ATC, SSTL, Airbus DS, Selex ES, Space Connexions

Table 3-3: Strategic EO Projects

3.1 Flagship Projects

3.1.1 Compact Air Quality Spectrometer

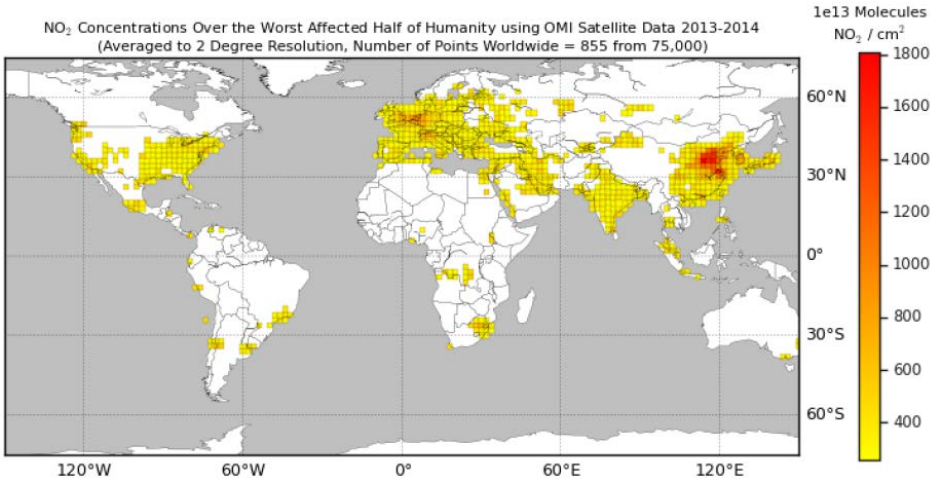
Status: In progress, KO in January 2015, Completion October 2016

Team: University of Leicester with SSTL

Project Objective

The main goal of the CompAQS demonstrator mission is to provide a relatively inexpensive and small instrument which can provide better performance in terms of NO_2 sensing than other more expensive LEO instruments (OMI, TROPOMI) by using a concentric optical design based on an Offner relay spectrometer[1], offering superior spectral and spatial performance at a fraction of the cost.

Obtaining a sub-urban spatial resolution not seen before will allow for a more detailed understanding of daily changes in concentrations of trace pollutants and lessen the chance of cloudy pixels, increasing the reliability of such measurements.



The Science target regions cover 50% of the world's population with the "worst" exposure to pollution, covers just 8% of the Earth's surface. It allows optimised retrieval over small areas and constrains the data volume.

CompAQS aims to deliver a 1×1km resolution map covering the worst polluted 50% of the world's population, locating major emission sources within the world's biggest megacities and providing coarser resolution around these locations with a higher sensitivity to track lesser concentrations around residential areas. CompAQS also aims to fill the gap left between the end of OMI's lifetime and the launch of the Sentinel-5 in 2020, with a demonstration launch possible in 2016.

The mission objectives and requirements that make CompAQS unique are:

- Small and cheap enough to manufacture and launch a fleet for near real-tome measurements
- Higher spatial resolution and good spectral performance and reliability with significantly reduced instrument optical 'smile' distortion

The main goal of the CEOI-ST Flagship project is to advance the design and overall TRL of the instrument, in particular the high risk items, against a nominal small-satellite implementation. This project will therefore address the structural and thermal design, focal plane design and associated alignment issues of the instrument, as well as some of the electronics development. It does not include a space-flight standard build for the full electronics as this is perceived as comparatively low risk.

The integrated "flight" system will be put through laboratory testing and environmental testing, the latter to show survival of orbit like temperature excursions and vibration consistent with those expected of (e.g.) an ESA spacecraft launch. Laboratory testing will fully characterise the instrument prior to and post environment testing. Additionally an airborne demonstration of the instrument will be used to show instrument performance "in the field".

[1] Lobb, 1994

Current Status

Overall Progress to Date

A review of the CompAQS instrument science and technical requirements documents has been held; the conclusion is that the essential science requirements are understood and quantified; the wider requirements are understood and largely numerically defined; some (secondary) requirements will fall out of the next (System Design) phase of the project such as data rates and the requirements of the data processing electronics. Work has also been carried out to identify the alignment requirements and individual element sensitivities to position errors and on positioning and alignment techniques.

SSTL has supplied a design for the fore-optics (telescope) which is in-line with the instrument's compact nature; further work has been done to develop the thermal model of the instrument.

University of Leicester has identified a compatible CCD (CCD47-20). These activities have shown that ground sampling distances (GSD) of around 1-2 km are possible.

System Design:

The system design continues to evolve and now incorporates the fore optics design. The incorporation of the polarisation scrambler remains an issue with available space still to be solved. Similarly, combining the main and calibration light has an impact on space before the spectrometer. A review of the calibration requirements is underway and the option of bringing a solar reference into the telescope is being considered.

The test plan is being progressed to include a build plan to look at verifying the alignment requirements and for the instrument and engineering teams to develop a common approach.

Optics Design:

The sensitivity of the alignment of the various optics elements has been assessed. Initial indications are that within the spectrometer, adjustments to the position of the spectrometer mirror are able to accommodate alignment errors in the slit and lens. The analysis is being fed into the mechanical engineering designs and the strategy for alignment and a secure fixation once the instrument is aligned. A new design of the fore optics has been produced. Design drawings of these elements have been produced and are being prepared to be sent for quotation. The team are currently investigating if the fore optics can be rotated through a fold mirror, which would have the benefit of providing more space for the calibration optics in a location that will not impact the main optical design.

A review of spectrometer optics has been completed which has enabled the grating procurement to progress. It has also resulted in minor design changes for the lens and mirror. Drawings for these items have been revised and are currently being reviewed by manufacturer (ICOS).

Mechanical and Thermal Design:

Work continues to develop the thermal model to understand the main sources of heat (loss). The system will be divided thermally into two: optics & spectrometer with the focal plane (to be temperature controlled) and the backend electronics treated separately. The mechanical design has started: currently the material for the optical bench is being considered and the use of a CFRP baseplate examined. Tolerance analysis work in Zemax has enabled the major contributors to spectrometer misalignment to be understood. This has shown that the mirror requires adjustment in the most degrees of freedom to ensure alignment. The team are currently working on a mechanical design that enables this to be possible whilst also meeting flight requirements. The benefit for this is that less adjustment degrees of freedom are needed for the grating and lens, where there is significantly less available space.

Contact Point for Further Information

Dr Roland Leigh, University of Leicester

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3.1.2 Critical Technology Advancement of the LOCUS Mission

Status: In progress, KO in , Completion October 2016

Team: University College London with STFC RAL, MSSL, Glwyndr University, JRC Systems, STAR-Dundee Ltd

Project Objective

The LOCUS mission will primarily focus on observations of the Earth's Mesosphere and Lower Thermosphere (~50-180 km) through the application of passive THz radiometry. Ultimately, the purpose of the technology demonstration and validation performed in the mission is to enable new instrumentation and missions for future science. Under-pinning the technology demonstration aspects of LOCUS are several scientific themes that will be explored by the mission. These are:

1. Correlation between "direct" THz and IR measurements of O, O_3 and OH and O_2 and probing the energy balance in the MLT region.
2. Investigations into the chemistry and formation mechanisms of Noctilucent Clouds (NLC).
3. Observations of chemical processes and energetic particle precipitation in the MLT during and following auroral forcing events, e.g. Coronal Mass Ejection (CME).

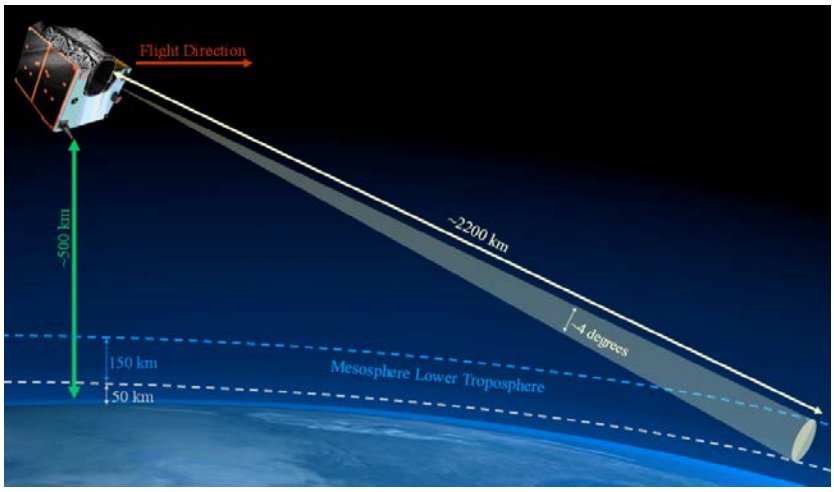


Illustration of the LOCUS limb-sounding radiometer in operation.

The main objectives of the CEOI-ST Flagship project are to verify payload system performance, reduce the payload power consumption, and demonstrate its compatibility with the environment within which the satellite will operate. This, in turn, will demonstrate the instrument concept, and further enhance the mission and UK position with respect to a future ESA competitive opportunity for an in-orbit demonstration. To achieve this objective, our programme of work incorporates the design, construction, and test in a representative thermal environment of an "elegant breadboard" of the LOCUS payload optics and support infrastructure. The optical system is particularly challenging due to the wide wavelength range over which it has to perform (2-375 μm) and the compact nature of the antenna needed to fit into the small satellite concept.

Additionally, the team are developing a new low-power digital wide band spectrometer (WBS) with power consumption compliant with small satellite deployment. As a final step, we are integrating the breadboard optics and WBS with THz and IR receiver components in order to characterise the full end-to-end performance of the LOCUS payload. Once complete and tested the LOCUS breadboard will be capable of deployment on a balloon or high altitude aircraft to further demonstrate the performance and ground breaking design of the instrument.

Current Status

Overall Progress to Date

The project commenced in February 2015 with a 22 month duration.

Antenna Design

A trade-off analysis and redesign was performed in light of all the constraints (some opposing):

- scientific requirements on beam size; (implications on focal plane scale)
- excessive overspill on secondary;
- size within platform requirements;
- difficulty in secondary null-testing; (measurability)
- focal plane scale limited by engineering constraints on mixer split block;
- In addition, the latest design was tweaked to allow clearance for the current cryostat housing the receiver on the breadboard in order to avoid primary beam obstruction; (9.5cm as requested by MSSL)

The latest iteration is believed to allow all requirements (within 10%), when a more efficient (Potter) horn is used (outside scope of this project). The current diagonal horn performance is much worse, but is at least measurable.

Although this is on the critical path, it is hoped that some time can be caught up in mirror manufacture. It is likely that the project will still be delayed at least two months, though. Telecons are being held each week to finalise optical design.

Optical Bench Design (MSSL)

Progress is limited by completion of the optical design. The current optical design fits with main parameters of original layout, with an ncreased M2 size. The diameter of M1 is now fixed which allows mass estimate of the mirror for FE to be held at 7.5kg. Once the optical design is complete, the FE model is ready to allow the optimisation of the Optical Bench.

Mounting methods for mirrors have been investigated. A system of bonded stud fixings to secure the mirror to a kinematic mount on an optical sub-bench is the most likely design solution for the breadboard.

An optical sub-bench provides most secure and stable support, but is not optimal with regard to launch mass. Strut mountings are however significantly compromised by volume and field of view constraints.

Receivers (RAL)

The 1.15THz mixer is being assembled, with Schottky diodes fabricated using photolithography. The multiplier is being assembled, and the Cryostat has been tested and demonstrated to provide the required heat lift. The digital spectrometer has been supplied and integrated to the system, which is now ready to accept the mixer and multiplier. The production of the E-beam diodes is progressing.

The 4.7THz Receiver ESA GSTP supra-THz activity is due to commence on 1st October 2015. The QCL manufactured by University of Leeds has been added to the new block with integrated feed. First test results from this new block are good and very promising.

Wideband Digital Spectrometer (WBS) - STAR-Dundee

The spectrometer architecture has been developed to explore the optimal redundancy approach, resulting in the reference clock generator (10 MHz) on the Processor board, whilst each Fast Fourier Transform board will have its own 1.2 GHz clock generator. Hence no separate clock generator board is required. The reference clock and SpaceWire to FFT boards are distributed over backplane, utilising KVPX backplane connectors. The next step is to finalise the specification of the WBS V FFT board, complete the schematic design and complete PCB layout.

Contact Point for Further Information

Project lead by UCL/MSSL:

- Michael Emes (Project Manager)
- Giorgio Savini (Principal Investigator)

3.1.3 Industrial Research for Next Generation Radar Electronics

Status: In progress, KO in March 2015 and has a planned duration of 18 month

Team: Airbus DS Ltd

Project Objective

The CEOI-ST Flagship project will make important enhancements to existing Radar Electronics products, developed by Airbus Defence and Space in Portsmouth, to enable them to support a broader range of future missions than currently possible.

The research and critical developments being undertaken includes the evolution and demonstration of hardware modules applicable to the Integrated Central Electronics (ICE), originally developed for Sentinel-1, and to the New Instrument Architecture (NIA), based on the product developed for NovaSAR-S. The requirements of the BIOMASS and the SAOCOM-CS missions (to the extent that they are currently known) will be used to guide the bread-boarding and demonstration activities.

The proposed work is broken down into three areas for which TRL will be raised towards 5/6:

1. ICE Receive Module modification & bread-boarding for low frequency operation and enhanced science data interface flexibility
2. Qualification of the Virtex-5 FPGA in agreement with ESA parts experts
3. Development of an embedded computer option for the NIA product to broaden its applicability to a range of future ESA missions.

Current Status

1.ICE Receive Module Development

This work is split into 4 principle activities:

a) P-Band Filter development and breadboard test

b) P-Band Downconverter development and breadboard test

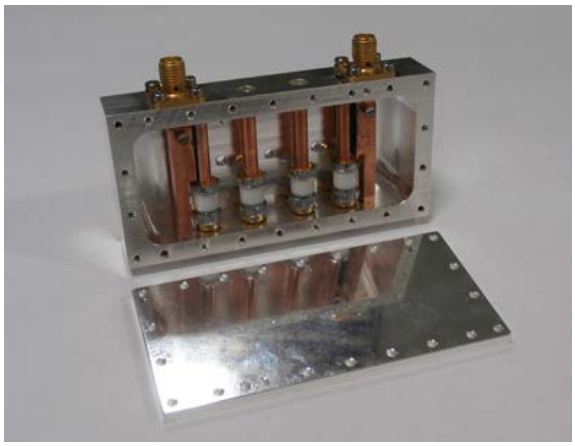
c) Control & Interface FPGA (CIF) Enhancement

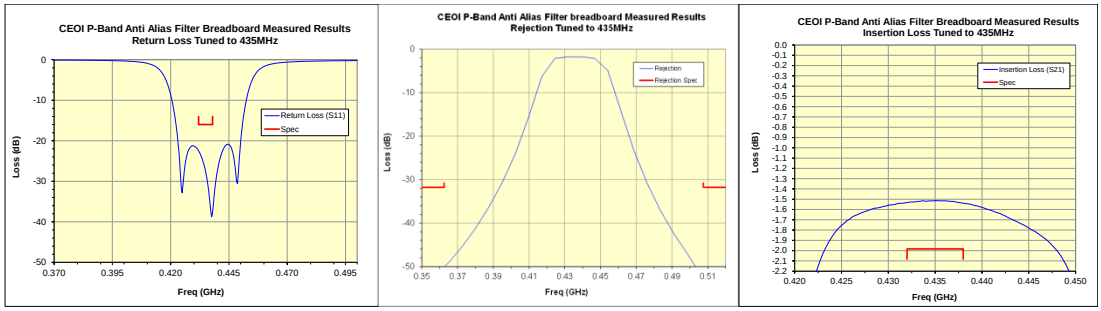
d) RxM PCB modification, RxM build and test

These are described in the following

a) P-Band Filter

The P-Band Filter has been successfully designed manufactured and tested, meeting all its performance and design requirements in order to fit in the RxM. This work is now complete and the filter is ready to be integrated in the RxM breadboard.





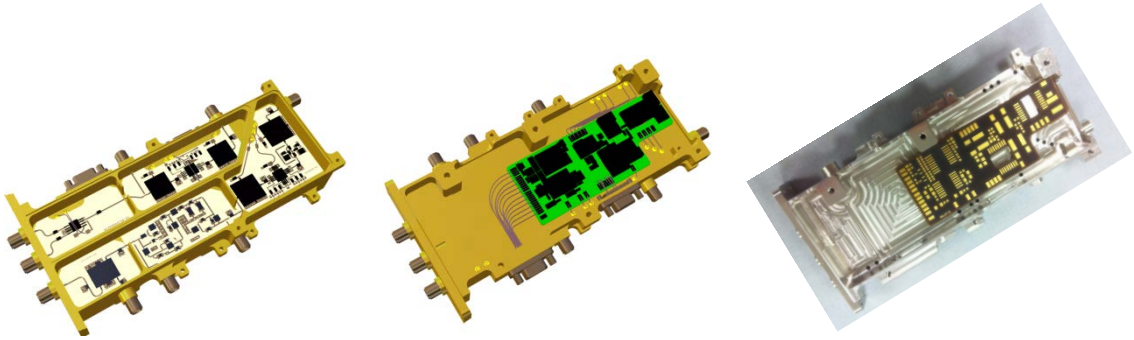
P-Band Breadboard Filter & Performance

b) P-Band Downconverter

A trade-off has been carried-out at ICE system level to determine if direct sampling of the RF or downconversion to IF is preferable. Downconversion has been selected as it provides a frequency plan which is aligned better to the RxM digital processing chain, e.g. clock rates for the ASICs.

The P-band downconverter has been designed and all parts are on order. The mechanical chassis has been received along with the PCB, which are shown in the photograph below. Alongside the photograph are the CAD representations of the unit.

The next stage is to assemble and test the unit after all parts have been received.



P-Band Downconverter CAD and Photo (PCB side only)

c) Control & Interface FPGA (CIF) Enhancement

The occupancy assessment for the Sentinel-1 CIF FPGA plus an integrated Science Data SpaceWire codec has been revisited and the conclusion reached that the RTAX2000S is compatible with good margin, around 20%. This is acceptable for design growth so a change of target FPGA to RTA4000S is unnecessary.

The feasibility of using a modified ESA Spacewire Codec IP with an external Spacewire transceiver device (Aeroflex UT200SpWPHY01) to provide a Science Data interface at up to 100Mbps has been established and Initial work has shown that it will run at more than twice the required rate

d) RxM PCB modification, RxM build and test

Update to the Sentinel-1 RxM Schematic and PCB layout is advancing well to accommodate the changes in physical interface to Spacewire. The RxM bill of materials has been established by the manufacturing department in readiness for stock transfer or procurement as necessary.

Next steps are completion of the PCB layouts and procurement, updates to mechanical design for the new interface connectors and transfer / purchase of stock prior to manufacture.

2.Virtex-5 FPGA Qualification

The qualification plan has been prepared and gone through a review cycle with ESA. Further information about Xilinx qualification process has been supplied to ESA. A meeting will be held very soon to finalise agreement on the process.

The qualification PCB has been designed and is being ordered. All other parts are already on order and the Xilinx V5 units themselves have been received.

Next step is to confirm the qualification plan, assemble the qualification board, and carry-out the environmental testing.

3.NIA Computer Breadboard

An implementation Trade-off has been completed and the Leon-3 processor has been selected. An a Aeroflex-Gaisler GR712RC development board has been chosen for the breadboarding. For the Flight Module it is expected to be the CPUGEN from EREMS, which has the added benefit of an FPGA which can be used to customise the interface to NIA. The Development Model Processor Module has been received and is under test in the lab (see figure below).

An Eclipse cross compiler software development environment has been established, allowing GR712RC target software to be built. Initial integration is underway; the first standalone test executable is successfully running on the received GR712RC board. This is a preliminary initial step to allow prototyping of the interface software.

An interface module to convert 8-bit to 9-bit UART has been built. This will provide the connection between GR712RC and CTG.

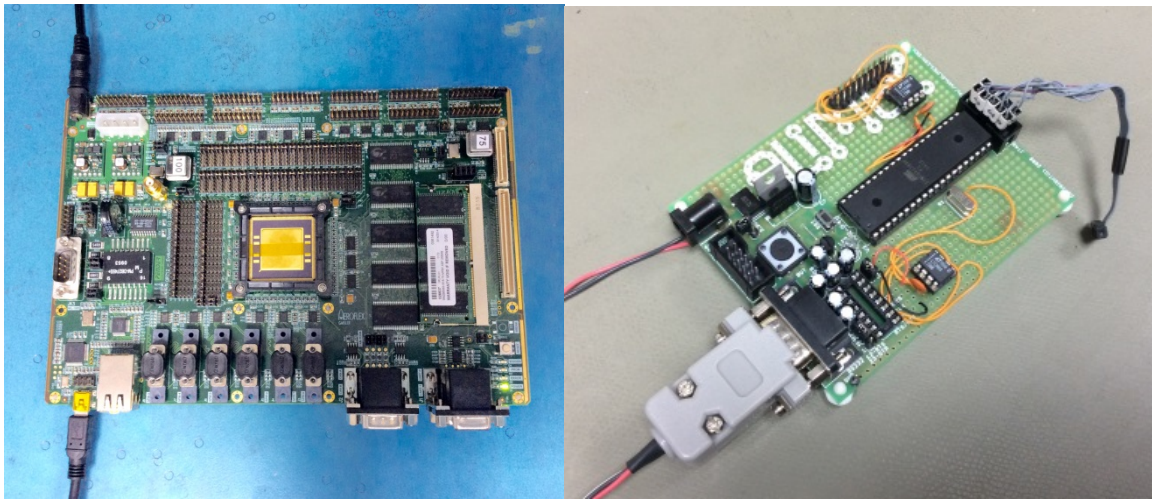


Figure 2 GR712RC Board & UART Interface Module under Test

Contact Point for Further Information

Project Lead: Mike Gibbons, Airbus DS Ltd

Email: mike.gibbons@airbus.com

3.1.4 TRUTHS: Traceable Radiometry Underpinning Terrestrial and Helio Studies

Status: In progress, KO in February 2015 and has a planned duration of 20 months

Team: NPL Management Ltd with Airbus DS Ltd

Project Objective

To enable CSAR to provide the radiometric calibration of the Earth & Sun viewing imaging spectrometer, a novel calibration procedure utilising monochromatic radiation has been devised, mimicking that used terrestrially at National Metrology Institutes such as NPL. This full calibration system will be designed and built to space consistent constraints: scales, materials, mechanism types etc and fully tested in vacuum with the new HPSC cooled CSAR. This calibration system will look to demonstrate calibration uncertainties of <0.3% for spectral radiance and irradiance over the Visible to SWIR spectral range, greater than a factor ten better than has been achieved for any previous EO mission (although downgraded from that achievable using optimised terrestrial technologies (0.02%)) resulting in a TRL of 5/6.

The conclusion of this project will mean that all key technologies and concepts needed for TRUTHS will be at TRL 5/6 with little risk to implementation remaining. In addition key sub-systems like the HPSC and VANTA black coatings will have a wider range of applications in the space sector, Earth Observation and space science leading to economic return to the UK. The HPSC, will be able to continue and expand the market lead of its predecessor the 50-80K cooler, emphasising its strengths over competing technologies such as pulse tubes from elsewhere in Europe.

Current Status

Overall Progress to Date

The project commenced in March 2015 and is planned to complete in October 2016.

HPSC EM Compressor Improvement (Airbus):

The manufacture of new parts for compressors is near completion and the strip down of HPSC compressors is underway.

CSAR Instrument Cryostat Design & Breadboard Manufacture (Airbus):

The preliminary design of the cryostat is complete and preliminary detail drawings are complete. Initial stress and thermal analysis is being carried out. Communication with the cryostat manufacturer is in progress, with preliminary drawings complete.

CSAR instrument and cavity design and test (NPL):

The first measurements of the VANTA black coating (Vertically Aligned carbon Nano Tube coating on Aluminium substrate) have been performed, and the results are being analysed. The engineering drawings for the Cryogenic Solar Absolute Radiometer (CSAR) have been finalised.

Spectrally resolved in-flight calibration system of TRUTHS (NPL):

Physical layout for satellite calibration system has been determined. This layout will be mirrored as closely as possible in the demonstration setup

Contact Point for Further Information

Dr Nigel Fox, NPL

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3.1.5 UKSA-CNES Bilateral Carbon Mission: Support Study

Status: Project complete

Team: University of Leicester with UK ATC, SSTL, Airbus DS Ltd, Selex ES Ltd and Space Connexions Ltd

Project Description and Outcome

The aim of this study is the development of a potential UK contribution to a UK-French bilateral greenhouse gas (GHG) satellite mission, using as a starting point the existing CNES MicroCarb mission concept. MicroCarb is designed to map sources and sinks of CO_2 and CH_4 by absorption spectroscopy in the near and shortwave infrared. It aims to infer the total column of CO_2 and CH_4 to the very high precision necessary to quantify surface fluxes at regional scales. The mission is currently in the definition phase in France with a potential launch date of 2020.

There are a number of scientific, economic, and technological objectives that underpin the importance of a UK contribution to this mission. The UK can contribute substantially to almost every aspect of a GHG mission, including instrument development, platform design, ground-based operations and science exploitation. This study focussed on contributions to the payload and platform engineering, supported by a mission design study that analysed the efficacy of estimating carbon fluxes from the resulting space-borne concept. It also assessed the ability for existing UK technology and science sectors to deliver a UK-led GHG satellite mission concept.

The work programme consisted of a series of concurrent activities in the UK in cooperation with CNES in three key areas:

1) Development of UK contributions to a bilateral mission
    a. Platform options (SSTL)
    b. Detector options (Selex ES)
    c. Pointing and steerability options (Airbus DS)
2) Demonstration of new UK technology with an airborne demonstrator
    a. Deployment of GHOST on the ARSF aircraft (University of Leicester)
    b. Aircraft campaigns (University of Leicester)
    c. Assessment of GHOST as a space-borne instrument (STFC ATC)
3) Assessment and consolidation of top-level mission objectives and investigation of potential enhancements of the mission
    a. Review of MicroCarb mission requirements (University of Leicester)
    b. Orbit and sampling strategy (University of Edinburgh)
    c. Collocated CO2 and CO observations (University of Edinburgh)
    d. Space-based carbon monitoring concepts (Airbus DS)

The project goals have been achieved. The study identified and assessed potential UK contributions to the MicroCarb mission against defined requirements and demonstrated UK instrument technology by flying the GHOST instrument on the ARSF aircraft. Furthermore, the overall mission concept was evaluated in the areas of pointing, non-CO_2 gases and, constellation concepts. In addition, a good working relationship with the CNES MIcroCarb team has been established.

Presentations summarizing the project were given at the CEOI-ST Technology conference and the RSPSoc/NCEO/CEOI 2015 conference. All TNs will be available for public use.

The project has led to extensive knowledge exchange between the BCM and CNES teams.

Future steps and roadmaps are addressed in the business plan. UKSA and CNES are currently discussing the potential for a UK contribution to the MicroCarb mission, building on the work of the BCM study.

Contact Point for Further Information

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3.2 Fast Track Projects

3.2.1 LOCUS Critical Payload Development for Future In Orbit Demonstration

Status: In progress, Kick-off May 2014, completion due in December 2015

Team: University of Leeds with STFC Rutherford Appleton Laboratory and STAR-Dundee Ltd

Project Objective

Advances in satellite remote-sensing measurements of the constituents of the atmosphere have substantially increased our knowledge of atmospheric composition over the last decade. For instance, relatively localized studies of the mesosphere and lower thermosphere (MLT) region of the Earth's atmosphere have shown such measurements to be an important indicator of global climate change.

Nonetheless, global measurements of key atmospheric species in the MLT have not been made directly by previous satellite missions. To address this limitation, UK scientists and technologists have developed the concept of a novel and breakthrough limb sounding, multi-channel radiometer operating in the terahertz (THz) spectral range (0.8 – 5 THz) and deployed in low Earth orbit. The radiometer payload will be carried aboard a small UK developed satellite and will allow global high spectral resolution measurements of important MLT atmospheric species, particularly atomic oxygen and the hydroxyl radical.

As a direct outcome of previous CEOI-ST support, the UK team has proposed a Low Cost Upper atmosphere Sounder (LOCUS) mission to the European Space Agency (ESA) for study as a candidate in-orbit demonstrator. The mission concept has key objectives of demonstrating breakthrough THz science and technology, and has been accepted for further study by ESA.

With the possibly of a space flight demonstration before the end of the current decade, this Fast Track project supports the advancement of the LOCUS mission concept by addressing key aspects of the payload detector and infrastructure technology. The project is raising the instrumentation technical maturity to a level compliant with the in-orbit-demonstration opportunity, and will place the UK in a position of scientific and technical leadership with respect to MLT climate studies.

The specific technical goal is to advance and demonstrate UK THz radiometer and high-speed signal processing technology used in conjunction with a UK developed miniature spaceborne cryogenic system. Four areas of the payload concept are targeted for development in this project, improving the TRL of critical technologies in all four radiometer bands (0.8 THz, 1.1 THz, 3.7 THz, 4.7 THz) for space use. A small science activity provides scientific end-user guidance.

The proposed programme will deliver additional return through future application in a wider range of diverse disciplines including planetary science, astronomy, spectroscopy, security and telecommunications.

Project Status and Achievements

1.1 THz Band 3 Technology Development

The objective is to construct and test Band 3 technology in a laboratory environment, in conjunction with a digital spectrometer (WBS) and space cooler. Specifically the team are developing a 1.1 THz sub-harmonic mixer of the required sensitivity together with a 0.57 THz source of harmonically generated LO power (note that the Quantum Cascade Lasers (QCLs) to be used in higher frequency channels are not suitable below ~ 2 THz).

Two mixer blocks have been assembled with appropriate diodes and are ready for testing. Multiplier blocks are also ready for assembly, but the diodes have been found to exhibit a relatively high, and undesirable, series resistance. A trial assembly of the multiplier is taking place, but it is not expected to perform well. A new diode fabrication run is now underway that is expected to provide more suitable diodes. The mixer cannot be tested until the latter is completed, an approximate two week timescale, as there is no source of LO power. The WBS has been integrated with the receiver and the system is ready for mixer and multiplier integration and test. The overall LOCUS system is ready to accept the mixer and multiplier devices once both are available. A system test will then be performed.

4.7 THz and 3.5 THz Bands Technology Development

Quantum Cascade Laser (QCL) devices will be developed as the Local Oscillators at the targeted frequencies of 4.7 THz and 3.7 THz, initially mounting them directly on the RAL space cooler to determine the continuous-wave output power that can be achieved for different cool end temperatures/heat loads. The stability of the QCL spectral profile is to be evaluated using mixer techniques (with comparison to measurements in the 2.0–2.9 THz spectral range at Leeds, using commercial coolers). This will enable demonstration that the required LO power, emission frequency and stability can be achieved in these bands for LOCUS without external locking technology.

Two new QCL source blocks containing integrated diagonal feedhorns have been fabricated at RAL and tested at Leeds. The peak, pulsed, output power at temperatures <80 K has increased from <0.3 mW to ~ 8 mW. The continuous-wave output had increased from ~0.03 mW to 8 mW at low temperatures, with >1 mW being available up to a heat-sink temperature of ~70 K. The QCL devices are now seen to be capable of meeting the requirements for LOCUS.

Wide Band Spectrometer (WBS) Enhancement

Digital spectrometers are increasingly the instrument of choice for heterodyne spectroscopy. A prototype wide band spectrometer (WBS) with >2 GHz instantaneous bandwidth has been designed and successfully demonstrated by STAR-Dundee. This important UK development was in part funded by the CEOI and is undergoing trials for future integration with ground-based and airborne EO instruments. However, the present instrument power consumption is non-compliant with the limited power resource available from a small satellite and the project aims to enhance the WBS design concept through implementation of new and lower power consuming circuit topology that will reduce power consumption, and simultaneously optimise instrument form-factor and mass.

All work is now complete, with the exception of testing the minor corrections to the updated WBS IV FFT board.

Space Cooler Integration

The RAL Cryogenic Cooler with a higher efficiency units have been developed, better suited to small satellite platforms such as LOCUS, and a prototype cold head is available with representative cryogenic characteristics including a heat list capacity ~3 W at 50 K and a typical thermal stability of ±50 mK. The unit will be used to cool the QCL and THz receivers. Work includes design and installation of the necessary cooler vacuum shroud and cold plate assembly.

The cryostat is complete, vacuum integrity checked, and systems cleans and helium gas added; Appropriate support infrastructure for the cryocooler has been relocated from Cryogenics Group to the LOCUS laboratory.

Contact Point for Further Information

Project Lead: Prof Edmund Linfield, University of Leeds

Email: E.H.Linfield@leeds.ac.uk

3.2.2 Exploring SAR Interferometer Calibration Solutions for Ocean Surface Current Errors for the Wavemill Space Mission

Status: In progress, Kick-off May 2014, completion due in December 2015

Team: National Oceanographic Centre with Starlab Ltd and Airbus D&S Ltd

Project Objective

The Wavemill concept for measuring ocean surface currents globally, at unprecedented spatial resolution using a novel SAR approach, makes it a potential Earth Explorer 9 Call candidate mission. It is also a CEOI-ST indicative mission. The potential of this approach has been shown using the Wavemill airborne demonstrator, but that work pointed up the need for accurate calibration of the interferometic phase from which the ocean surface current measurements are obtained. This project aims to investigate the calibration problem theoretically and explores a solution that can be implemented technologically both for a future Wavemill space mission and for the existing airborne demonstrator. As part of the study new antenna hardware is being developed that can be used with the Wavemill airborne demonstrator to enable dual-sided viewing and therefore emulate the calibration approach of the flight instrument. This study on the calibration aspects of the Wavemill instrument represents a new and ground-breaking area of work: namely, the calibration of squinted interferometric SAR systems.

Project Status and Achievements

This CEOI-ST Fast Track project developed system and instrument phase calibration solutions for Wavemill. Its measurement principle relies on single-pass squinted along-track SAR interferometry to deliver high-resolution maps of total ocean surface current vectors with collocated wind vector and spectral wave data. The stringent 5 cm/s science requirement on current accuracy demands rigorous assessment of the contribution of phase calibration errors to the geophysical error budget. The project led to significant advances in estimating unwanted wave-induced velocities and ocean surface velocity accuracy and the impact of errors in platform attitude and interferometric baseline knowledge. It provided clear recommendations for the system and mission definition, including the fact that dual-sided viewing is not an absolute requisite to achieve the necessary phase calibration accuracy.

Major benefits:

- New world-leading scientific capability at NOC to analyse and interpret airborne Wavemill data, to model and correct airborne and spaceborne ATI SAR and SAR data for unwanted wave-induced velocities, to support the design of future systems and plan future airborne campaigns.
- Refined instrument and mission concept for the Wavemill mission, particularly regarding the calibration elements, resulting in a more mature concept.
- Improved understanding of the calibration requirements and identification of the parameters that impact calibration for an along-track interferometric instrument. New implementations and techniques to ensure performance remains within required levels. Several results are applicable to both along-track and across-track interferometry and are therefore transferable.
- Improved software tools for performance analysis and Wavemill data simulation.
- Roadmap for Wavemill to identify critical priorities, including hardware and software developments, validation of the geophysical inversion and new airborne campaigns.

Key outputs and achievements

- Scientific presentations and publications
- Documented interferometric phase calibration strategies and instrument and system definition.
- These were of mutual benefit to the ESA Ocean Surface Current Mission study.
- Wavemill technical and scientific roadmap

Improved positioning for future opportunities

- High-visibility within ESA of existing UK technological and scientific capability for the development of the Wavemill mission, leading to increased leveraging of ESA funding from later competitive ESA Invitations To Tender e.g. ESA OSCAR airborne demonstrator.

- The Wavemill Along-Track Interferometric mission design has been matured through this CEOI study; tackling the key question of calibration. This positions the consortium well should such a mission be required.
- Consolidated UK presence at international science meetings (remote sensing, oceanography and operational forecasting) to present the capability and high level of maturity of the Wavemill concept and therefore increase the credibility of the mission as a candidate to EE9.
- High-visibility within the science community to consolidate the science objectives and requirements, to gather international support for the mission and improve its chances of selection in EE9.

Contact Point for Further Information

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National Oceanography Centre, Southampton
UNIVERSITY OF SOUTHAMPTON AND NATURAL ENVIRONMENT RESEARCH COUNCIL

3.2.3 MISRlite - Multi-angle IR Stereo Radiometer using Uncooled Microbolometer Arrays for Global Winds

Status: In progress, Kick-off July 2014, completion due in November 2015

Team: Mullard Space Science Laboratory (MSSL), UCL with Thales Alenia Space UK Ltd

Project Objective

Atmospheric winds are a vital input parameter to Numerical Weather Predictions. The NASA Multi-angle Imaging SpectroRadiometer (MISR) instrument on the Terra platform obtains along-track stereo from moderately high-resolution imagery (275m) at nine view angles from nadir to ±70.5º, in four (3 visible, 1 near-infrared) spectral bands. It uses stereoscopic parallax, time lapse among the nine views, and the variation of radiance with angle and wavelength to enable retrieval of geometric cloud and aerosol plume heights, height-resolved cloud-tracked winds, and aerosol optical depth and particle property information.

The Multi-angle IR Stereo Radiometer (MISRlite) is a proposed low mass and power IR instrument which provides the required subset of the functionality of MISR to measure cloud-top height and winds. It will provide a 1500km swath-width and capable of day/night operation, to produce CMVs at 900m resolution. MISRlite is based on proven microbolometer technology exploiting Time Delay Integration and fast electronics to generate high quality thermal IR images. MISRlite will address the proposed geometric gCMV concept selected by ESA to meet the needs of a tandem mission with the EPS 2nd Generation MetOp operational satellite due for launch in the early 2020s.

This Fast-Track project has developed a prototype instrument which has been mounted on a gimbal and flown in a light aircraft. The instrument was demonstrated on a series of flights in Australia where a coincident Lidar altimeter recorded the cloud-top heights.

The industrial partner, Thales Alenia Space UK Ltd, is studying the flight implementation of the MISRlite concept, to derive system design and baseline resource budgets. They are also investigating the data processing required to handle the data from multi-element focal plane required for the flight implementation.

Project Status and Achievements

In the CEOI funded programme a gimbal mounted TIR imaging system was built and flown to demonstrate multi-angle TDI based using COTS units. The airborne platform was provided by the Airborne Remote Sensing (ARS) centre of Flinders University in Australia. Australian regulations allowed a small instrument to be developed with minimal official regulation. The aim was to demonstrate stereo imaging of ground/cloud scenes in the thermal infra-red to the required signal to noise.

Main benefits

The main benefit of the programme is to demonstrate the core sensor technology for MISRlite in a representative environment. This is a key element of establishing a case for MISRlite as an ESA Earth Explorer programme or other flight opportunity.

Key outputs and achievements

The current key outputs are

- demonstration that IR imaging of clouds (from above) can achieve the required signal to noise
- that it is possible to fly small payloads of this type, at low cost, at ARA. By the end of the programme it is intended to show
- that stereo imaging of clouds can be achieved
- complete a study of implementation of MISRlite on a small satellite.

Contact Point for Further Information

PI: Professor Jan Peter Muller, MSSL/UCL

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3.2.4 Radiation Testing of Selex ES CMOS ROICs for Earth Observation IR Sensors

Status: Project complete

Team: Selex ES Ltd

Project Objective

Selex ES Ltd carried out a Fast Track project to position the UK for imminent international flight programmes and future bi-lateral opportunities through exploitation of leading edge infrared detector technological capability.

Building upon earlier work carried out successfully with NSTP funding to demonstrate the environmental performance of MCT avalanche photodiode arrays, the project undertook heavy ion testing of the latest large format ROIC technology for MCT infrared detectors. This will support detector proposals for Earth observation missions including those where low flux conditions would take advantage of the in-pixel avalanche gain already exploited in other high performance applications such as wave-front sensors supplied for ground based astronomy. This work will advance existing EO technology developments towards a higher TRL, which will de-risk the flight programmes indicated.

Project Outcome

The heavy ion testing was carried out on the ME930 (LFNIR) 2D infrared detector array ROIC during November 2014. This work is necessary for Selex to access future ESA missions such as Microcarb.

This work has demonstrated that the LFNIR ROIC and array has a high level of radiation hardness by design, which is a significant step towards achieving TRL 5. As a result, the chances of success in competing for the next phase of ESA funding for this development have been increased, the selection of this device for future space missions has been de-risked. It has also provided a valuable learning experience for a number of members of the technical team, which will allow them to retain knowledge within their organisation and therefore have a positive impact on their other programmes.

Results from this heavy ion radiation test campaign demonstrate that the ROIC designs are immune to latch-up up to a LET of 67MeVcm2/mg. Frame readout operability at cryogenic temperatures is 60% up to a LET of 67MeVcm2/mg.

Testing of the devices was done using the Heavy Ion Irradiation Facility at the Centre de Ressources du Cyclotron, Université Catholique de Louvain, Louvain-la-Neuve, Belgium.

Selex have completed the project. The next step is to complete the full suite of radiation testing by carrying out campaigns on Gamma and Proton testing.

Contact Point for Further Information

Project Manager: Keith Barnes, Selex ES Ltd

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3.2.5 Global Satellite Observations of Winds, Rain and Clouds

Status: In progress, Kick-off May 2014, completion due in 2015

Team: University of Reading with University of Leicester

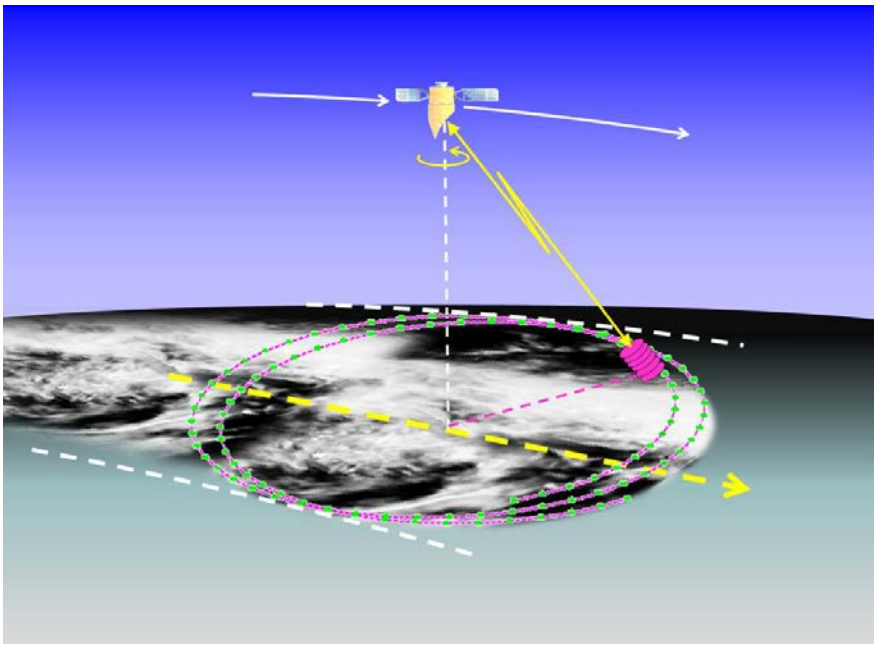
Project Objective

Building on recent ESA and CEOI studies, we project investigated aspects of a conically scanning spaceborne broad-swath Dopplerised 94GHz radar to provide global measurements of winds, rainfall and cloud ice water content using the radar returns from cloud and precipitation particles. The observations will have 50km horizontal and 1km vertical resolution with several visits every day at European latitudes.

Windstorms in Europe caused £18.5B of damage in Europe in 1999, £1.5B in 2009 and £1.3B in 2010. High losses also result from flooding. The loss of life in tropical cyclones is decreasing due to improved forecasts and better warnings: compare the 138,000 deaths in Myanmar due to cyclone Nargis in 2008 with the 43 deaths from the more powerful Indian super-cyclone, Phailin, in October 2013. Better observations would lead to more accurate forecasts with improved timing and location so that mitigation activities can be better focussed. The in-cloud winds from this project would complement the clear air winds from the ESA explorer ADM/AEOLUS when it is launched in late 2014.

The 94GHz (3mm) radar has a very narrow beam and so even with a slant path can achieve 1km vertical resolution. The satellite will have the same 94GHz transmitter that has operated flawlessly for Cloudsat since its launch in 2006. The 2.9 by 1.8m elliptical antenna rotates once every seven seconds sweeping out a broad swath on the ground. The Doppler shift and rainfall rates will be derived using the returns from twin pulse pairs alternately polarised in the horizontal and vertical.

Following a successful ground based demonstration of the technique the concept will be proposed to ESA for the next Earth Explorer call which is expected in 2015. If this is successful, the next stage would be to test the technique using an airborne 94GHZ radar.



The 'WIVERN'- WInd VElocity Radar Nephoscope - concept from a recent ESA study by Astrium, Starlab and the U of Reading.

Current Status

This Fast Track project aims to validate the polarisation diversity technique with observations from with the recently upgraded 94GHz radar at Chilbolton, Hampshire.

The project team is experiencing some technical issues and has been examining the range dependent artifacts in the velocity that arise when irregular pulse sequences are produced from the EIK tube. It produces twin pulses with a separation of 60usecs every 160usecs.

Interference is evident when irregularly spaced pulses are produced, which does not vary with polarization state. It is suspected that the interference might be caused by the triggering of the second pulse, because the DC-DC converter used to produce this pulse was adjacent to the receiver electronics, but reconfiguring the electronics so the converter was more remote lead to no improvement.

Most recently the team has analysed the changes in the I-Q received from each pulse pair at each range gate, and the result change in the angle. Initially it was believed that the range dependent velocity offset might be caused by a shifting of the mean DC level of the signals in the I,Q detection circuitry or which was occurring in phase with the basic 160usec pulse sequence. This way Doppler from pulses separated by 160usec would be unchanged, but those with 60usec pulse separations would have a range dependent offset.

The investigations are continuing.

Contact Point for Further Information

Project PI: Anthony Illingworth, University of Reading

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3.2.6 Contactless Power & Data Transfer for Conical Scanning Instruments

Status: Project complete

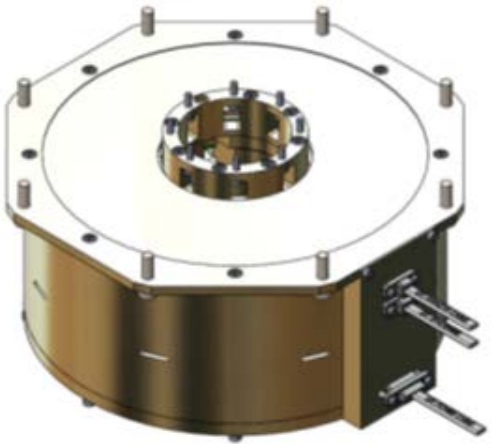
Team: Thales Alenia Space UK Ltd with ESR Technology Ltd

Project Objective

The transmission of power and data though rotating mechanisms in space currently relies on contacting technologies, such as slip and roll rings, which have a limited lifetime due to mechanical wear.

A new system using contactless data and power transfer technology that eliminates contact wear has been advanced by Thales Alenia Space UK Ltd (TAS-UK) and its partner ESR Technology with the aim of eliminating lifetime issues associated with power transfer across tribological contacts in rotating mechanisms for space applications. The technology is targeted at applications requiring reliable operation for hundreds of millions of revolutions and hundreds of thousands of stop/start/reverse cycles.

The system is suitable for space uses including conical scanning instruments, inter-satellite links, antenna scan mechanisms and also for terrestrial harsh environments (e.g. civil nuclear, sensor turrets for aircraft and sample handling for particle accelerators).



Contactless Data and Power Transfer Mechanism

The objectives of the CEOI-ST funded project were to expand on earlier, ESA funded, technology developments by taking an existing prototype, designed for integration within a particular scan mechanism breadboard, and adapting it for wider use as a module on Metop-SG or other missions.

Current Status

The 13 month CEOI-ST project has been successfully completed, achieving the following outcomes:

- Widened the range of input voltages supported and improve the power transfer efficiency at low voltages
- Added the ability to directly transfer thermistor and analogue signals
- Increased the speed of the serial data channel and converted to using SpaceWire
- Reduced the mass and modularised the housing to make the system a direct swap-out replacement for slip and roll rings

The project has enabled TAS-UK and ESR Technology to better position themselves to offer this new design as a direct replacement for slip and roll rings on space missions that have rotating elements. The team have also identified new opportunities and applications that this technology could be well suited to.

The next steps towards development for flight are:

- De-risking activities including prototyping of the new FPGA-based data transfer architecture and representative thermal, vibration and shock testing of the mounted transformer
- Development of an Engineering Qualification Model including a representative thermal vacuum accelerated life test to prove reliability (>100 million revolutions)
- Qualification to flight status

Contact Point for Further Information

Project Manager: Andrew Bacon, Thales Alenia Space UK Ltd

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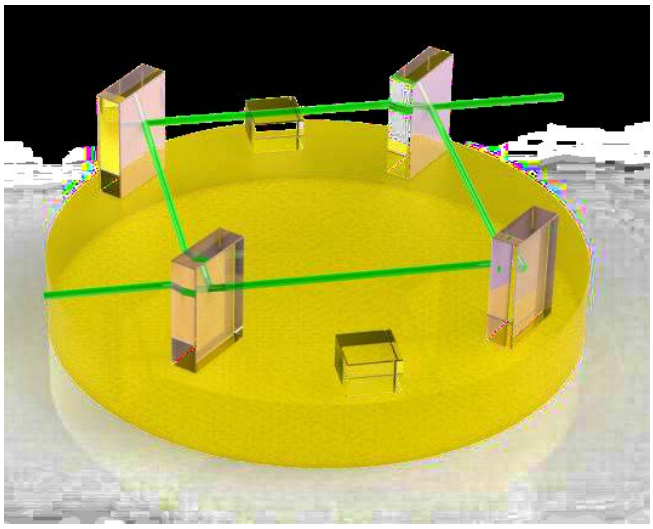
3.2.7 Mechanised Precision Bonding of Composite Assemblies

Status: Project complete

Team: University of Glasgow with Gooch & Housego Ltd

Project Objective

The ability to design and construct complex optical assemblies is crucial to many experiments that use light to carry information. As requirements on missions become more demanding, so the precision of the sensing apparatus must improve. An advanced technology – hydroxide catalysis bonding – used to join parts together at the molecular level has been adapted at the University of Glasgow to make space flight hardware for the LISA Pathfinder mission. The bonding technology has many advantages over traditional methods like epoxy and optical contacting, and components have been aligned with submicron accuracy. The aim of the proposed project is to secure the UK lead on this enabling technology by demonstrating alternate methods to realise bonded optical assemblies using novel procedures such as mechanised component alignment and bonding, and ground surface active alignment prior to bonding. These advances will result in the technology becoming more mature and at the same time requiring less infrastructure to perform, opening the technology up to become a simpler and therefore more widely used method of making precision sensing hardware, and one that is more suitable to the operating methods of industrial manufacturers of precision optics such as Gooch and Housego.



The UK currently has world-leading technical capability in the design and construction of precision-aligned ultra-stable optical assemblies for space flight. This is largely due to heritage from the European Space Agency LISA Pathfinder mission. The techniques developed for the LISA Pathfinder Optical Bench Interferometer resulted in multiple centimetre-scale optical components being permanently attached to a substrate with submicrometre level absolute accuracy, and beams reflected from the components being within a few micrometres and few tens of microradians of nominal. This technology is an evolved version of the hydroxide catalysis bonding process.

It was realised that to benefit more fully from this capability further advances to the technique would be necessary. Currently the capability resides within a small, skilled team at the University of Glasgow and involves complex and lengthy operations that require significant support equipment. The technique also relies heavily on the know-how and experience of the operating team. The aim of this project was to mechanise parts of the process and in doing so widen the applicability and use of the technique. There was also potential to further increase the level of control with which components can be located, and considerably reduce the overall assembly time.

A further strand of this project was to investigate bonding using ‘ground’ surfaces, i.e. not optically polished, which has the potential to remove many of the constraints that make the current state-of-the-art procedure so specialised, and potentially open the technology to new markets.

Project Achievements

The project has resulted in the development of a new method of aligning prior to bonding, and crucially, the parts of the process that were previously the most specialised and required manual intervention have been rendered trivial. Gooch and Housego (UK) Ltd were a partner in the project in order to provide expertise, but also with a view to embedding the capability of precision ultra-stable optical assembly construction from UK academia into UK industry.

Two optical assemblies were built and environmentally tested: an assembly with polished bonding surfaces using interferometric alignment of surfaces prior to joining, and an assembly with polished-ground bonding. The control of beam alignment during construction for both assemblies resulted in a beam alignment precision of <10 µm and 30 µrad – meaning that this prototype work is already as precise as the current state-of-the-art.

A successful demonstration of optical contacting was conducted using the alignment prior to joining technique, showing the versatility of the technology. This work would benefit from further effort, but already there is potential for new areas to benefit from this technology. The University of Glasgow has commissioned an independent market study for the technology, and will consider patenting an aspect of the work depending on the findings.

Considerable knowledge has been generated through this work, both for the academic and industrial partners, and this will provide valuable leverage when pursuing new opportunities to generate impact using this technology.

Contact Point for Further Information

Project PI: Christian Killow, University of Glasgow

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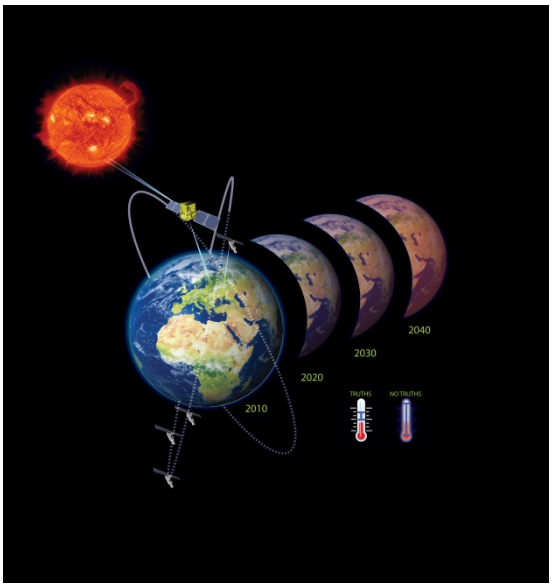
3.2.8 TRUTHS: A climate benchmark mission - National Physical Laboratory with Surrey Satellite Technologies Ltd (SSTL)

Status: Project complete, awaiting final report

Team: NPL Management Ltd with SSTL Ltd

Project Objective



The establishment of an observational climate benchmark data set of sufficient accuracy to enable the unequivocal detection of climate change with the ability to constrain and test climate forecast models on a decadal time scale is one of the key challenges laid down by the international climate science community. The UK led TRUTHS (Traceable Radiometry Underpinning Terrestrial- and Helio- Studies) and its US sister, CLARREO (Climate Absolute Reflectance and Refractivity Observatory) are mission concepts proposed to address this exacting issue. TRUTHS' primary goal is to provide benchmark measurements of both incoming (solar) and outgoing (reflected solar) radiation with sufficient spectral resolution and accuracy to detect the subtle changes in as short a timescale as possible (~12 yrs) - limited by natural variability of the climate system. In summary, measuring global spectrally resolved (10 nm) Earth radiances, continuously sampled (spectrally and spatially) with GIFOV of ~<100 m from 340 to 2340 nm and the corresponding solar spectral irradiances both with uncertainties to SI units of <0.3%.

Although not selected in the ESA EE8 call, TRUTHS received a strong recommendation of support and encouragement that an early implementation should be explored as part of a wider international collaborative effort. In support of that goal this project will look towards developing optimised baseline designs for the missions core elements: Imaging spectrometer (Earth and Sun view) and the on-board calibration system together with key aspects of the satellite bus impacting the observational requirements, with the aim to establish a set of baseline building blocks with outline designs to facilitate the establishment of international partnerships for early implementation of TRUTHS

Current Status

The design study has traded-off complexity, risk and cost against the science drivers, to ensure that the core objective of providing a climate benchmark is achieved whilst maximising the opportunity for secondary objectives.

An optical design for the spectrometer and calibration system has been developed.

The implementation options for the calibration transfer system have been considered and an optimal configuration with minimum number of mechanisms designed.

The study has also evaluated the performance advantages achievable from using TRUTHS as a reference calibration satellite for sensors with Sentinel 2 & 3 like characteristics and also as a 'calibration mother ship' for low cost constellations.

The main benefits from the study are:

- A fully analysed and prioritised science to Mission technical requirements document and an optimisation based on technical readiness
- A design for a hyperspectral imager of high but achievable performance with analysis of radiometric and stray light performance
- An updated mission design achievable in space with a reduction in complexity from 5 to 2 instruments and seven to three movements.
- A costed, implementable mission (all elements) in readiness for an opportunity.

- A broad-based UK science and industry team promoting the mission as a desired opportunity together with support from international bodies and government departments
- Evidence to prove the viability and performance of both the on-board calibration system and also the ability of TRUTHS to upgrade other sensors .e.g Sentinel 2 from 3 to 0.5%.
- A UK led mission with sufficient credibility and uniqueness to facilitate the establishment of a bi/multi-national mission on UK defined terms
- Raised profile has put mission into key international strategy documents including as two recommended actions new GCOS implementation plan.

Contact Point for Further Information

Project PI: Nigel Fox, NPL Management Ltd

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3.3 Pathfinder Projects

3.3.1 Demonstration of a CO2 Laser Heterodyne Radiometer

Status: In progress, completion due in November 2015

Team: STFC Rutherford Appleton Laboratory

Project Objective

This project focuses on the demonstration and assessment of thermal infrared laser heterodyne spectro-radiometry for the remote sensing of carbon dioxide. Theoretical concept studies based on modelling have indicated Laser Heterodyne Radiometers (LHRs) can contribute to improving remote sensing of carbon dioxide in the thermal infrared, on-board a variety of platform from ground-based to space-based. During the project, ground-based measurements will be carried out and compare against theoretical modelling in order to fully assess the instrument technology and devise forward steps toward low cost, miniature autonomous carbon dioxide remote sensors. As one of the most important greenhouse gas, improved carbon dioxide measurements are needed to address both science questions related to the carbon cycle and to develop emission measurements services.

Project Outcome and Achievements

CO_2-LHR focused on the demonstration and assessment of thermal infrared laser heterodyne spectro-radiometry for the remote sensing of carbon dioxide total atmospheric column amounts and height-resolved vertical distributions. To that end, a semi-operational benchtop system has been assembled in the laboratory, and a passive solar tracker has been developed, installed on the roof and coupled to the instrument. The CO_2 LHR system has been demonstrated to operate extremely well, very close to the ideal performance limit, and data have been recorded continuously since May 2015. In addition to the hardware development, considerable efforts have been made to evolve the raw data processing towards an operational use. An algorithm that automatically screens, calibrates, and conditions the data for atmospheric retrieval has been developed. The retrieval of both atmospheric CO_2 and H_2O has been demonstrated. In particular, preliminary results show that measurements of the lower troposphere CO_2 mixing ratio with an instrument precision <0.3% are feasible.

Overall, the project was highly successful. Data and evidence were produced that advocate the deployment of LHR for CO_2 sounding in the thermal infrared. Whilst the project has strengthened the case for LHR in orbit demonstration, it has also opened a wide range of potential exploitation activities in the field of ground-based calibration and validation of spaceborne atmospheric composition measurements. Miniature and autonomous LHR systems have the potential to enable cost-effective dense ground networks for validation, hence disrupting the current status quo in this area.

Lastly, through the excellent data collected during the project demonstrating LHR relevance, collaboration with Australia has been established towards a micro-satellite in orbit demonstration mission of LHR technology. This is a unique cost-effective opportunity to raise the LHR to space mission readiness as part of a UK/Australia CubeSat bilateral mission. A phase A study has been proposed to gather support from the UKSA towards this timely opportunity.

Contact Point for Further Information

Project PI: Damien Weidmann, STFC Rutherford Appleton Laboratory

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3.3.2 UK Support for the ALiSS Mission Study

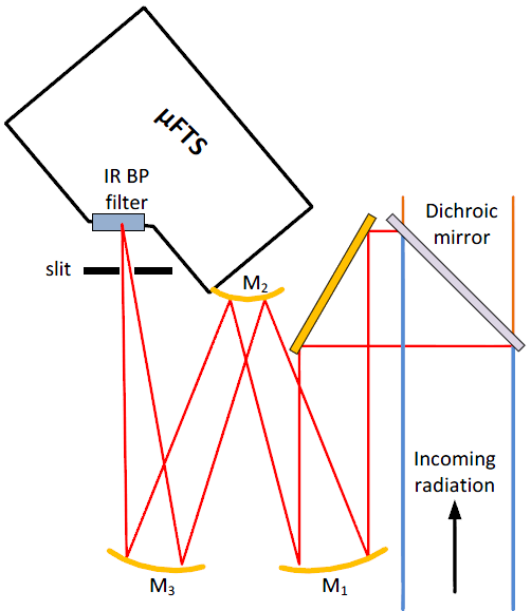
Status: Project complete

Team: STFC Rutherford Appleton Laboratory

Project Objective

ALiSS, the Atmospheric Limb Sounding Satellite, is a Canadian-Swedish concept for a Space Mission to provide a limb-sounding satellite to measure the chemistry and composition of the Upper Troposphere – Lower Stratosphere (UTLS). The UK has a long-standing technology stake in the submillimetre-wave radiometer STEAM-R which is one of two prime instruments of the ALiSS mission payload. A new generation of sideband-separating heterodyne receivers for submillimetre-wave remote sensing has been developed at RAL and Airbus Defence and Space with previous CEOI funding. These receivers have been designed specifically for a UTLS instrument like STEAMR, where the benefits of the spectral separation of wide pressure-broadened molecular emission lines are most apparent.

The CEOI-ST funded project was initially conceived to address further technology development for STEAM-R. However, during the course of the activity a second, potentially attractive, opportunity was identified for the UK to provide a small infrared instrument, providing synergy with the millimetre wave instrument. Therefore, the remaining part of the study was re-directed to assess the feasibility of developing a micro-Fourier Transform Spectrometer (µFTS) within the timeframe of the ALiSS mission and to quantify the expected scientific impact.



Micro-Fourier Transform Spectrometer Optics Arrangement

Project Outcome and Achievements

The CEOI-ST Pathfinder project has concluded with the following outcomes:

- The technical characteristics of the µFTS, its mass and power requirements, as well as an estimate of its measurement performance has been derived from lab measurements.
- The retrieval performance of the µFTS in atmospheric limb-sounding mode has been estimated based upon lab measurement performance. The retrieval simulations show, that for a choice selection of scientific observables the low resolution of the µFTS is no obstacle to good scientific performance.

In addition, the option of deploying the µFTS within the MARSCHALS instrument frame from the stratospheric research aircraft M55 Geophysica has been assessed both in terms of the engineering feasibility and the measurement performance from an airborne platform.

The overall conclusion is that a space-borne limb-sounding infrared µFTS is technically feasible and scientifically relevant. It would provide an important contribution to the ALiSS mission, complementing the mm-wave STEAM-R limb sounder.

Contact Point for Further Information

Project PI: Brian Moyna, STFC Rutherford Appleton Laboratory

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3.3.3 Compact Infrared Imager and Radiometer

Status: Feasibility Study - Complete

Team: University of Oxford with Clydespace, STFC RAL and Satellite Applications Catapult

Project Objective

The purpose of the feasibility study is to investigate the capabilities of a 6U CubeSat-type spacecraft and instrument, the Compact Infrared Imager and Radiometer (CIIR). CubeSats are modular systems of standard 10 x 10 x 10 cm cubes and launch adapter. This allows them to be included as additional payloads if the primary customer for a launch vehicle leaves spare capacity, providing access to space at significantly lower cost than traditional Earth Observation satellites.

The science goals chosen for study are: the effects of aerosols, clouds and the behaviour of stratospheric water vapour on the Earth's radiation budget that are key to understanding our current climate and its subsequent evolution. The CIIR concept is a new approach to infrared sensing of the Earth from space that can provide calibrated data on timescales of hours as well as years.

The spacecraft/instrument is designed for both nadir viewing and scanning of the Earth's limb, preferably from a Sun synchronous orbit. The infrared filter bandpasses are targeted to support investigations of the properties of clouds and aerosols and to monitor concentrations of stratospheric water vapour.

The CIIR concept (Figure 1) builds on the design heritage of the Compact Modular Sounder (CMS) instrument currently flying on TechDemoSat-1 and adapts it to work on a CubeSat. CIIR includes two components to ensure it returns data that can reliably complement and enhance existing Earth observation data sets. Firstly, it includes a traceable radiometric calibration target to guarantee accuracy of <0.2K. Secondly it incorporates an intermediate focus between the input telescope and detector array; this allows a large (>10) number of discrete spectral channels to be used.

Finally, the instrument uses an uncooled microbolometer array to combine medium resolution imaging with atmospheric sounding.

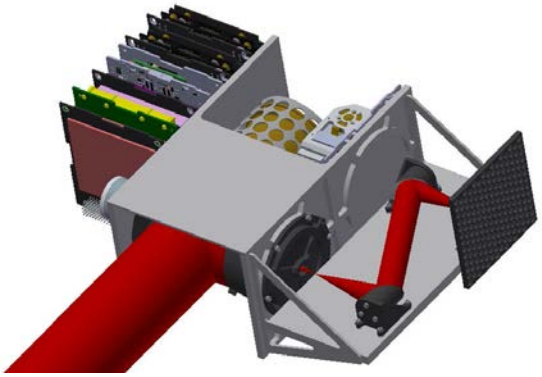

Figure 1: The CIIR instrument integrated into a 6U CubeSat envelope

Current Status

The feasibility study is complete and the team are actively pursuing options for the funding of the full CubeSat mission. The main results from the study are:

- Scientifically useful data on stratospheric aerosol are achievable with the baseline design.
- Trace gas abundances such as water vapour and ozone are more challenging using existing infrared filter designs, but further optimisation is possible.
- A significant additional source of error in limb sounding is the pointing performance of the platform, this is limiting the ability to retrieve trace gas abundances but technology development is rapid and we expect this project to result in improvements in this area.
- Nadir viewing at moderate spatial resolution (~150 m) is achievable in the thermal-IR.
- The integrated CubeSat/instrument concept is viable for low cost Earth system science where global coverage is a requirement.

Contact Point for Further Information

Neil Bowles (PI) / Simon Calcutt (Instrument Manager)

Department of Physics / University of Oxford

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3.3.4 High Frequency Doppler Radars #2 (HIDRA 2)

Status: Completed; Final Report in review

Team: STFC Rutherford Appleton Laboratory with University of Leicester

Project Objective

Despite the well-recognized role played by clouds and precipitation in affecting our climate, gaps in the remote sensing capabilities of their vertically resolved microphysics significantly hamper progress in understanding the physical processes within them, whose parameterizations underpin numerical weather and climate models. A previous CEOI-funded seedcorn study (HIDRA4PPM) has established the potential of G-band Doppler radars (i.e. frequency between 110 and 300 GHz), in combination with Ka and W-band millimetre wave radars, to improve current profiling capabilities in precipitating snow (see Figure 1). This is achieved by partially overcoming the snow microphysical deadlock, i.e. the dependence of the snow rate on the snow microphysical characteristics: particle habit, fall velocity and size distribution.

This Pathfinder project has further developed a mission concept based on a dual frequency, 35 and 240 GHz, Doppler radar with radiometric mode for the detection and quantification of mid and high latitude precipitation. STFC-RAL has developed a prototype of 240 GHz frequency multiplier with the challenging high output power level required to drive the radar transmitter's output stage. The University of Leicester has analysed the potential of the system to improve further the retrievals of microphysical properties in precipitating snow and also in stratocumulus, cirrus and mid-level ice clouds.

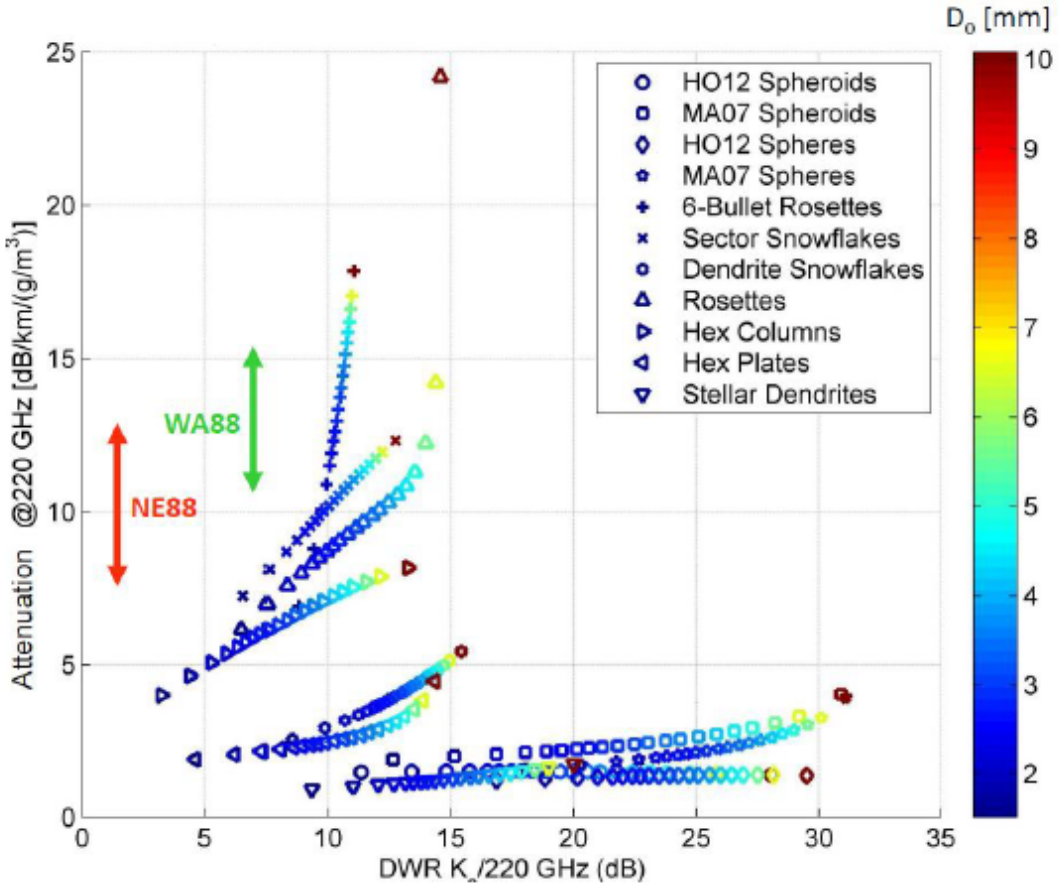

Figure 1: Snow attenuation per unit mass at 220 GHz for different snow particle habits and particle size distribution (the colour indicates the mean volume diameter of the particle size distribution), plotted against Ka–220 GHz dual wavelength ratio (DWR). A 35-220 GHz radar measurement has great potential for identifying the dominant particle habit and the mean particle size. See Battaglia et al., 2014 for details.

Project Outcome and Achievements

RF prototype hardware development

- A 240 GHz Schottky diode frequency tripler has been designed and optimized, including EM simulation and thermal simulation
- A bespoke multiple anode GaAs Schottky diode structure been created and fabricated.
- Four blocks have been assembled and tested successfully, with demonstrated high input power handling, up to 325 mW.
- Maximum power conversion efficiency is nearly 6%, and maximum output power is 15 mW.

35-240 GHz potential for space-borne mission

- An optimal-estimation-based retrieval technique for profiling snow clouds has been developed.
- Quantify multiple scattering effects for the G-band radar in presence of thick ice clouds.
- Study about the dual wavelength reflectivity ratio behaviour in presence of multiple scattering.

Issues and problems encountered

The multiplier performance deviates slightly from predictions: efficiency is lower than expected, and the optimal output frequency is shifted to a value about 15 % higher that the design value, 250 GHz. The main reason is attributed to a lower than expected diode breakdown voltages: 5.5 V as opposed to the anticipated 8 to 9 V. Cleanroom process improvements are underway to address this problem.

Technology development roadmap

Our roadmap towards an ESA TRL of 4 for is based upon the conclusions above report and current MMT work in producing space qualified devices Schottky for MetOp SG. This work encompasses the design, test and qualification of frequency multiplier and mixers using passivated Schottky diodes.

The main obstacle in achieving a useful tripler component with a TRL of 4 is providing diodes with the anticipated reverse breakdown voltage than can handle the relatively high powers. The state of multiplier development is such that we cannot yet determine the maximum realisable efficiency, and therefore if power combining will eventually be required. However, the current design performs over a wider bandwidth than is required, and a redesign should concentrate on narrowing the region of best performance and ensuring that this coincides with the desired operating frequency.

A revised tripler design is required with performance optimised in a narrow band around 240 GHz, with little sensitivity to changes in temperature of a few tens of degrees. This would need the highest efficiency and lowest drive powers: both will enhance the device lifetime and place least demands on the driving amplifiers. This will also facilitate increasing the output power if/when the E1K tube gain decreases during its lifetime.

Contact Point for Further Information

Project PI: Peter Huggard, STFC Rutherford Appleton Laboratory

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3.3.5 Hyperspectral Imaging for Air Quality: Application of a Hyperspectral Imaging Suite for 3D Retrievals

Status: In progress, Kick-off May 2014, completion due in 2015

Team: University of Leicester

Project Objective

This Pathfinder project had the objective to enhance the future flight potential of UK hyperspectral imagers such as CompAQS, through instrument optimisation and demonstration of key application areas for data. The project builds on an earlier successful CEOI project which demonstrated an airborne hyperspectral instrument, CompAQS. In the current project, the TRL of CompAQS has been improved through an intense six-month programme of work. The work has included instrument optimisation, an additional flight with ground-based CompAQS instruments in operation and improved retrieval algorithms.

Improvements in retrieval algorithms have led to the development and demonstration of a 3D retrieval process for NO_2 concentrations over a city scale using two ground-based CompAQS instruments and one airborne CompAQS instrument. The understanding of air quality has demonstrated the value of enhanced hyperspectral imaging, and the applications which could be delivered as a result. These findings will feed into both future payload proposals, and future application developments.

Current Status

The CompAQS instrument has been significantly upgraded and is currently being assessed for airborne certification prior to flight. Additional finance has been secured to enable full aircraft certification, leading to a significant number of piggy-bank flight opportunities in 2016 as the instrument is operated during standard flights of the relevant aircraft.

A new entrance slit has improved the resolution and instrument line shape of the spectrometer, and new readout electronics have upgraded the detector readout speed, permitting a 20x20m ground pixel for all future flights. The ground-based systems have also been upgraded with new entrance slits, and pseudo frame transfer readout, enabling more precise and reliable NO_2 imaging.

The full spectrometer system has been radiometrically calibrated under this programme, enabling more robust retrieval of aerosol properties. This in turn improves NO2 retrievals through improved modelling of photon scattering. The instrument spectral response and field of view have also been characterised more robustly.

Figure 1 Upgraded CompAQS airborne demonstrator (in CAD, with outer casing removed).

Data from the first flight of the CompAQS airborne demonstrator has recently been accepted for publication in Atmospheric Measurement Techniques, and is currently available in draft form here (http://www.atmos-meas-tech-discuss.net/8/5677/2015/amtd-8-5677-2015.html)

Contact Point for Further Information

Project PI: Roland Leigh, University of Leicester

Email: rl40@le.ac.uk

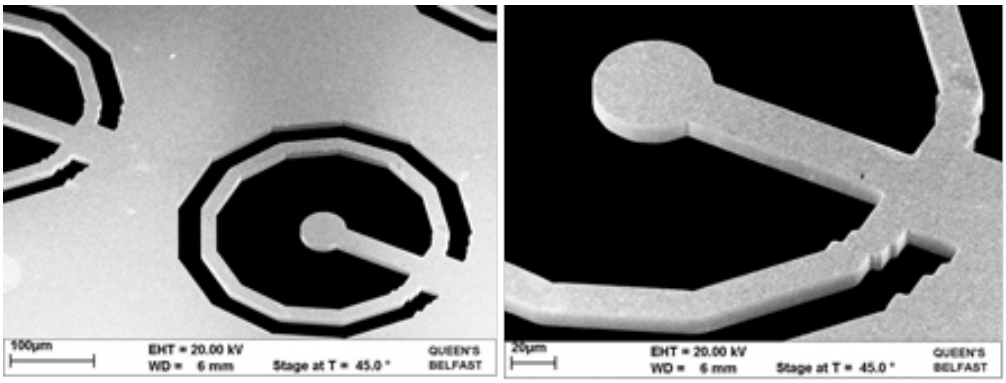
3.3.6 183 GHz Frequency Selective Surface (FSS)

Status: Project complete

Team: Queens University Belfast

Project Objective

The purpose of this project is to develop an FSS to separate the 183 GHz channel from the 166 GHz channel in the MetOp-SG Microwave Sounder. At these frequencies the instrument provides global temperature and water vapour profiles for numerical weather predictions. They are closely spaced with an edge-of-band ratio of only 1.05, requiring state-of-the-art filter performance to separate. Current MWS instrument technology shows higher NEDT than required, and this project aims to demonstrate improved performance from ultra-low loss FSS.



The project set out the design of a Frequency Selective Surface (FSS) which simultaneously allows transmission of 175.3 – 191.3 GHz radiation and rejection of 164 - 167 GHz for TE waves, polarized at 45 incidence. The primary application for the FSS is in the microwave sounder (MWS) radiometer instrument on the MetOp second generation mission. This 24 channel instrument has a spectral span of 23 - 230 GHz, and provides measurements of temperature and water vapour profiles which are key data requirements for numerical weather prediction models. The aim of this work is to improve the sensitivity of the instrument by developing an ultra-low-loss FSS.

Project Outcome and Achievements

This project exploits computational electromagnetic modelling and advanced micromachining manufacturing capability that has been developed at QUB and established the feasibility of an FSS which can separate the 183 GHz and 165.5 GHz bands in the quasi-optical feed train of the MWS instrument. The FSS consists of three air spaced perforated screens with unit cells that are composed of nested resonant slots. Maximum transmission loss in the 183 GHz band is predicted to be < 0.45 dB and in the 165 GHz channel the reflection loss is <0.40 dB. For comparison, a waveguide diplexer currently used to separate the 183/165 GHz bands has a measured loss of 0.8 dB. Given the requirements for low insertion losses in the instrument, this study demonstrates performance improvements from the freestanding FSS design.

The measured results were combined with the predictions. Good agreement is observed, and the measured passband loss is shown to vary between 0.2 dB and 0.5 dB. In the reflection band the minimum and maximum measured losses are 0.2 dB and 0.75 dB. Generally the losses are very good across both the bands.

The FSS structure was fabricated using precision micromachining techniques. Silicon on Insulator (SOI) was used as the substrate material and Deep Reactive Ion Etching (DRIE) employed to pattern the top layer of the substrate with slots, and also remove the silicon under the slots. The structure was then coated with a high conductivity metallisation process.

In the course of this project, the team at QUB developed a low-loss FSS meeting the demanding requirements of the MetOp-SG MWS radiometer. A detailed numerical study established the optimum geometry, and the developed three-screen structure is shown to give a maximum insertion loss of 0.5 dB. FSS test results have demonstrated good agreement with predictions and the performance is in line with the specification across the passband, and across 80% of the reflection band. These results are significant as

instrument designers now have proven hardware options at their disposal to cover a range of spectral filtering requirements. This work coincides with the bread boarding phase of the MWS QO network which is due to conclude in March 2015. The UK consortium consists of QUB, RAL Space, Airbus and QMUL.

Contact Point for Further Information

Project Lead: Raymond Dickie, Queens University Belfast

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3.3.7 ICEMuSIC – Instrument Optimisation Study and Mission Definition

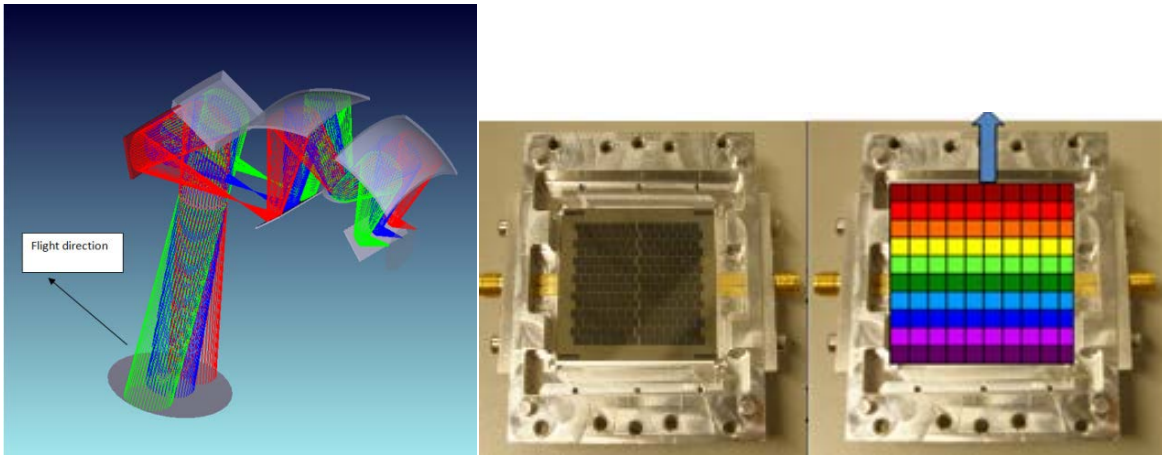
Status: Project complete

Team: University of Cardiff with UK Met Office and University of Hamburg

Project Objective

CEOI-ST Pathfinder funding was awarded to develop a novel instrument concept for observation of ice clouds. These observations will constrain essential climate variables in global circulation models. The same instrument will also be useful for temperature & humidity monitoring of the atmosphere. The original instrument concept was based around large two-dimensional arrays of sub-mm detectors, the enabling technology (kinetic inductance detectors). The goals of the CEOI-ST funded project were:

- Review of science requirements for climatology and meteorological applications in the frequency range 100 GHz – 1.5 THz
- Derivation of observational and instrument requirements from the science requirements
- Proposal of instrument concepts to address these requirements
- Trade-off concepts to identify optimal instrument configuration – maximum impact for moderate cost
- Development of selected instrument concept to instrument proposal



Left: Wide FOV fore-optics coupled to detector array via re-imaging optic and reflective cold stop.

Right: Indication of multispectral/hyperspectral imaging configuration. Flight direction is indicated by the arrow. Across-track direction is spatial domain, along-track direction is spectral domain.

Project Outcome and Achievements

During the course of the project, the team were able to ascertain that the simple 2-D multispectral array based system would perform better than the ICI instrument for MetOp-SG, but that the performance enhancement would not be strong enough to justify the need for cooling the array.

The optimal instrument identified is one that makes use of on-chip spectroscopy, using kinetic inductance detectors in a different configuration. Such an instrument should have a very large impact in operational meteorology. Initial simulations show greatly enhanced resolution and accuracy for temperature & humidity

retrievals. And at the same time, such an instrument would fulfil (exceed) all observational requirements for ice cloud observations for climatology applications.

The on-chip spectroscopy has been demonstrated in the lab, and currently has a TRL of 4.

This instrument concept has the full backing of the Met Office. It has also been presented at the European Centre for Medium Range Weather Forecasts, who strongly support it. The concept was also mentioned in a recent ESA GSP study report on hyperspectral imaging concepts. Full retrieval simulations are currently in progress, in preparation for a paper to be published in January 2016.

As a result of the CEOI-ST funding, the team has developed a very promising instrument concept, and a strong team. This forms the basis of a Horizon 2020 proposal that is now in preparation and will propose to build and fly an airborne demonstrator.

Contact Point for Further Information

Project PI: Peter Hargrave, University of Cardiff

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3.3.8 COnformal Retro Reflectors for Earth Observation (CORREO)

Status: In progress, awaiting Final Report

Team: Cranfield University with University of Nottingham

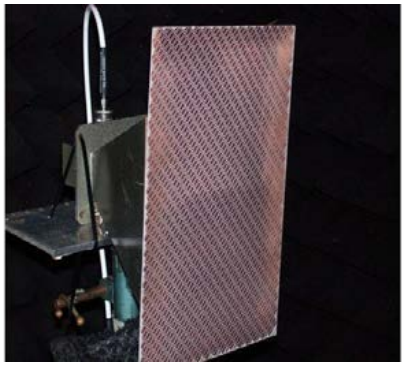
Project Objective

Ground-segment calibration and validation activities in support of a satellite mission are a vital and continuous component of the mission, and ultimately upon which successful exploitation of the data depends. Time has seen increasing sophistication in SAR functionality and the emergence of new application areas with a clear trend towards higher resolution and increased radiometric and geometric performance. In addition, future systems, featuring digital beam forming techniques based on multi-channel architectures, will require further sophistication of calibration techniques and procedures. In contrast to these advances, the use of trihedral retro reflectors in calibration strategies has remained largely static. Trihedrals are an effective but blunt tool;- they have fixed, broad beam patterns and operate across wide bandwidths.

The dimensions of a corner reflectors are chosen to give a large signal-to-noise (SNR) to allow them be seen and located precisely amongst background clutter in a radar image. Unfortunately, this usually results in the corner reflector being large and cumbersome which can;

- make it difficult transporting the reflector to and around the site
- make the reflector difficult to secure to a structure such as a bridge or side of a building
- cause problems with stability in the presence of high winds and extreme weather conditions
- become an eyesore in an urban environment, meaning planning applications may be resisted
- require regular maintenance as reflectors often fill with flotsam and jetsam borne by the wind, in addition to water and snow
- make them likely to be the subject of theft and vandalism.

To address these issues, the team is developing a new form of passive retro-reflector. A meta-reflector (M-R) is conformal, thin, lightweight, easily attached, and possesses a highly stable reflection phase property.



Electromagnetic Band Gap (EBG) polarisation transformer

Current Status

Following initial build and laboratory testing of the meta-targets, laboratory measurements and field trials were undertaken.

In very high-resolution, near-field laboratory imaging the meta-surfaces did not act like a point targets, unlike the conventional target. Significant differences were seen in the performance of the meta-target with polarisation which is absent for the dihedral. The lower resolution field imaging produced much better results.

Laboratory SAR imaging data was collected and analysed. The performances of the meta-surfaces were assessed against a variety of metal reference targets of equal size, namely: a) conventional 90-degree flared dihedral b) ‘bent’ conventional dihedral opened out to the same 135 degree flare as the meta-surface c) flat plate. This was explored against polarisation, resolution, and imaging geometry. Apparent anomalous

behaviour is now understood as operation outside its specified operating parameters. The bandwidth is identified as ~150MHz, rather than 300MHz as previously.

The team has constructed target mounts for field deployment for each of the three retro-targets, which have been delivered to Nottingham University. The two meta-materials dihedrals were deployed, together with a bent conventional dihedral.retro-targets for high-resolution spotlight TerraSAR-X spotlight image acquisition, which occurred during the late summer.

The remaining step is for full analysis of the imagery for critical appraisal of retro-target performance.

Contact Point for Further Information

Project PI: Keith Morrison, Cranfield University

Email: k.morrison@cranfield.ac.uk

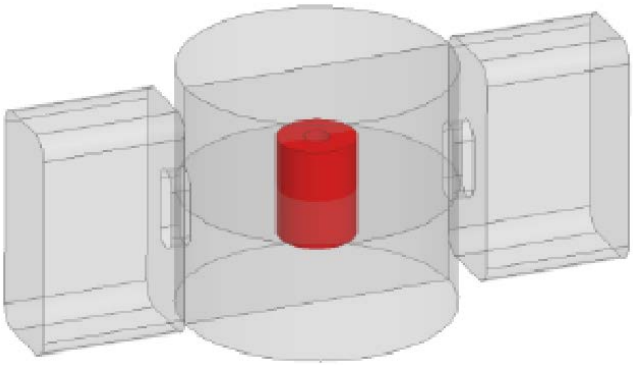
3.3.9 Characterisation of Ferrite Material in Remanent State for use in New High Peak Power Applications

Status: Project complete

Team: COM DEV International Systems Ltd

Project Objective

The next generation of radar missions cover a wide range of frequencies from C-band to Ka-band. A common feature of all these missions is the dramatic increase in the peak power requirement of the system. Previous instruments operated at typical peak powers of 100 W, whilst newer instruments have requirements for peak powers in excess of 3 kW, presenting new challenges to power amplifier, radar feeds, antenna, and switching element providers.



Dielectric Ring Resonator

Ferrite switches are the technology of choice for radar switching elements since they provide a very high number of switching actions over the instrument lifetime, low insertion loss, high reliability, fast switching time, and high peak and average power handling. A key issue for the design of ferrite switches capable of handling high peak power is the selection of the ferrite material, and being able to predict the power threshold at which the switch will start to behave in a non-linear manner. Typically, the manufacturer's published material properties for the ferrite material have very wide tolerances on the key parameters and are only measured at in a single frequency and in saturated condition.

The objective of the CEOI-ST activity is to develop a generic, low cost method of measuring the spinwave linewidths of ferrite materials in their remanent state (partially magnetised), in order to characterise the linearity and peak power threshold of these material prior to entering a lengthy and expensive breadboarding cycle. This characterisation is key in the design of an efficient ferrite switch – if incorrectly specified it can result in either a ferrite switch that becomes non-linear below the specified peak power level or a ferrite switch that has a high power threshold significantly in excess of that required but with the penalty of unnecessary additional insertion loss, which will adversely affect instrument performance.

Project Outcome and Achievements

A test methodology was successfully developed to measure the spinwave linewidths as a result of the CEOI-ST activity, which is now complete. Using this methodology the linewidths of three different materials were measured in both the saturated and remanent state, at three different frequency bands (C, X, and Ku) and at various angles of orientation of magnetic field with respect to the incident RF field. The key results of the test

- At the standard measurement frequency and in the standard saturated condition a good correlation was found between the measured and published data
- Substantial differences were found between the published data and measurements at different frequencies and/or in a remanent state

The results give great confidence that the measurement technique is sound and that this approach should be used on future high power programmes to allow the optimum selection of the ferrite material. This will enable the design of ferrite switches that provides the best trade-off between linearity and insertion loss.

Further work is required to extend the developed technique to Ka-band frequency range

Contact Point for Further Information

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4 Horizon Scanning

The principal tool used by CEOI-ST to discover new requirements and new technologies is the Challenge Workshop. In these meetings we invite scientists and instrument developers to identify future needs, and we invite technology and instrument developers to consider and if possible propose solutions and approaches to meet the needs. These workshops are attended by national delegates from industry and academia, but also attract attendees from the European Space Agency, NASA PIs and instrumentalists from international laboratories. The meetings are usually held at space centres of excellence around the country, and meetings have been held in Scotland, Wales, the north of England, the Midlands as well as the South, London and the Harwell cluster. Typically 3 or 4 workshops are held per year in addition to other CEOI-ST events.

- Science Challenge Workshops: These focus on the primary science domains of Earth Observation such as Atmosphere, Land, Ocean, Solid Earth, Cryosphere. They are used to identify science priorities, match to UK technology capabilities and develop domain interfaces. They are refreshed every few years as the science landscape changes.
- Emerging Technologies: These meetings are held every ~2 years, and are normally held over 2 days. They act as a showcase for CEOI instrument developments, and explore new techniques which are applicable to EO instrumentation. Miniaturisation and mass saving is also a key driver. Speakers from outside the space domain and in the forefront of physics are also invited, so that the potential of more exotic techniques can be assessed, which may become of great importance in the decades to come.
- Theme Workshops: Workshops are held periodically to address technology issues of current interest. We have held workshops on Lidar, SAR, mmWave, airborne platforms, UAVs, and also application specific workshops (water, offshore industries, polar exploitation etc.) . We have also held workshops to review and enhance the CEOI-ST technology roadmaps.

RAL Space and the University of Leicester share responsibility for organising Challenge Workshops, while all CEOI-ST partners participate strongly in the meetings.

The following Challenge Workshops have been held (November 2013 to October 2015):

Date	Workshop Title	Location
30/04/14	Emerging Technologies 2014	College Court, Leicester
16/10/14	Affordable Space	Bristol
31/03/15	Future Science for EO - Needs and Missions	College Court, Leicester
21/04/15	Emerging Technologies 2015	Cosener's House, Abingdon
07/10/15	Airborne Demonstrator Opportunities	ATC, Edinburgh

Benefits from Workshops and Conferences:

The workshops provide fertile ground for new collaborations to form:

- Following a talk by Robert Thomson of Heriot-Watt on his laser inscription technique for realising waveguides and other optical structures, a collaboration is now under way with RAL space in the context of his Laser Heterodyne Radiometer and related instrumentation.
- Following the 2014 Emerging Technologies workshop, SELEX (Southampton) and RAL Space are collaborating on high speed photodetectors
- Following the same 2014 emerging technologies workshop, RAL Space and NPL are exploring the capabilities of Vantablack carbon nanotube materials as a high emissivity coating for black bodies and other calibration sources. Similarly RAL Space's range of miniature sterling cycle coolers generated significant interest among instrument builders.
- Collaboration between the Met Office and RAL Space was initiated following a Calibration Workshop held in RAL, regarding the potential of LHR techniques to numerical weather forecasting.

- A new solid state spectroscopy technique from Zinir was showcased at the 2014 Emerging Technology conference which promises a 'spectrometer on a chip'. This works by creating tiny resonant cavities in silicon which resonate at the wavelengths of interest. A dialog began between Zinir and Imperial College regarding the application of recent advances in plasmonics, which appear applicable to the interaction of radiation at these small distances.

Information Exchange and Awareness Raising:

- At the recent Airborne Demonstrator workshop in Edinburgh, a dialogue began between various national providers and users of airborne platforms. It became clear that the stakeholders were not fully aware of all opportunities and facilities.
- At the Polar EO Challenge Workshop held at Harwell, the SA Catapult was made aware of existing polar services such as Polar View which support operations and science at high latitudes. The meeting also served to promote understanding of problems and the economics of operating in high latitudes. This included broadening the understanding of capability of EO at high latitudes, and problems with GPS accuracy, and comms coverage above ±80?.
- The technology conferences have raised awareness of facilities accessible by all, including miniature engineering workshops, foundries, calibration facilities, and techniques.
- The technology workshops provide a discussion forum and showcase for techniques and progress in miniaturisation. Miniaturisation will remain a primary interest for CEOI-ST in all technology domains.
- The workshops provide good opportunities to improve understanding of ESA's thinking in an informal setting e.g. at the Airborne Demonstrator workshop ESA indicated that new EO instruments will normally require proving flights on aircraft.
- The Challenge Workshops provide a shop window to promote UK capabilities to ESA, and we normally attract one or more of Pierluigi Silvestrin, Amanda Regan, Joerg Callies, Bruno Leone, Andy Barnes, and Dirk Schuttermeyer. The workshops also provide an opportunity for UK groups to understand and align with European initiatives.

Emerging Technologies Challenge Workshop 2014

The 3rd Emerging Technologies Challenge Workshop was held over the 2 day period 30th April to 1st May 2014 at College Court, Leicester (www.collegecourt.co.uk). Presentations from the Workshop and the workshop report are available on the CEOI website for download.

The workshop explored scientific and commercial EO measurement challenges, and presented new sensor and instrumentation technology to the community to stimulate novel measurement concepts. The audience consisted of EO scientists, commercial applications engineers and entrepreneurs, and technologists from academia and industry and examined all EO measurement domains.

CEOI Technology Conference 2015

The CEOI-ST held a 2-day Technology Conference at Cosener[1]s House in Abingdon on 21st and 22nd April 2015. This conference brought together personnel from recent CEOI projects to showcase and discuss their work and its context of science need, commercial need and mission opportunities. Presentations from the Conference are available for download from the CEOI website.

Challenge Workshop on Future Science for EO - Needs and Missions

CEOI-ST held a challenge workshop to look at Future Science for EO - Needs and Missions on the 31st March 2015 at College Court, in Leicester.

The workshop looked at future science needs for Earth Observation, the technology needs for ESA Earth Explorer 9 and other Science-driven Missions and developed an understanding of how CEOI-ST can further support science-driven EO missions.

The workshop was aimed at scientists and industrialists interested in future science EO missions and their science drivers. There were open sessions for people to present new ideas and science as part of the workshop.

The agenda was:

- Introduction and aims (Paul Monks)
- Science directions for EO – an NCEO perspective – Prof. John Remedios
- New ESA strategy what does it mean for EO? – Prof. Chris Merchant
- The UKSA view on future EO directions – Maria Adams
- What has CEOI-ST supported to date? – Paul Monks/Mick Johnson

The presentations from the workshop are available on the CEOI website.

Airborne Demonstrator Opportunities

The CEOI-ST held a Challenge Workshop on "Airborne Demonstrator Opportunities", at the Astronomy Technology Centre at the Royal Observatory, Edinburgh, on 7th October 2015. The meeting explored current platforms and opportunities, and current users shared their experience of flying a variety of payloads.

Airborne demonstration, in all its forms, provides a pragmatic and affordable methodology to establish viability and credibility for most new instrument concepts, and is seen as acceptable proof of concept by international agencies, both commercial and institutional. In addition, airborne deployments can give early science data, which are both valuable in themselves, and allow mission refinement and configuration planning. This is particularly important given ESA's introduction of Science Readiness Levels (SRLs) into its mission planning criteria.

This workshop explored the opportunities available to fly new instrumentation in a variety of high and low altitude airborne scenarios. It explored the likely costs and regulatory issues that must be embraced, and teams already engaged in airborne campaigns have shared their experiences.

The invited speakers include operators of scientific aircraft, and those engaged in modification and fitting-out to accommodate scientific payloads. Experts in aircraft and payload certification were asked to outline the hurdles that must be overcome and the processes that must be followed in order to be cleared to fly. Science users were asked to relate their experience, both good and bad, so that new entrants know what to expect.

The workshop was also a forum for interaction between new users of airborne demonstrators and the various stakeholders, and the breakout sessions at the end allowed free interchange of information. This allowed CEOI to capture the needs and outcomes, which should be valuable in the future.

The workshop was attended by around 40 delegates and speakers, representing: industry; academia; national and international agencies, attended the conference.

CEOI-ST Annual Conferences

CEOI-ST have held 2 Annual Conferences. The objectives are:

- To showcase technologies developed under CEOI funding, both within the UK community and more broadly to ESA and other international agencies
- To investigate potential future EO missions of interest to the UK community (national, European and international) and to describe the technologies and studies underway in preparation
- To support networking between EO instrument technologists, EO academics and others from the space and non-space communities

In 2014 we held a conference jointly with NCEO (circa 150 attendees). Following discussions at EOAC, in 2015 for the first time, we held a joint national EO conference with NCEO and RSPSoc which was attended by more than 300 people.

5 Knowledge Exchange

Objective

The CEOI-ST Knowledge Exchange programme has two key objectives:

- To engage the non-space industry in spin-out / spin-along / spin-in activities to ensure the widest commercial exploitation of the technologies supported by CEOI-ST
- To understand future non-space industrial requirements and how these may impact on EO instrument design requirements.

To address the first objective, the programme of promotional activities, including publications, mailshots, showcases and publicity was continued and strengthened with the addition of a social media campaign.

The second objective has proved more difficult to achieve, due to the dispersed nature of the potential community, but CEOI-ST has developed a highly successful programme of Industry Consultation Workshops, supported by EO technology applications articles. This has allowed direct engagement with a wide range of relevant companies to understand their needs and opportunities.

In turn, this has led to a better and deeper understanding of how companies engage with and potentially adopt new technologies from sectors such as space, which continues to inform and guide the evolution of the Knowledge Exchange programme.

The CEOI-ST programme has now been running long enough for the first hard KE outcomes to be achieved. Companies working on CEOI-ST projects are now deploying the technologies in industrial products, instruments are being deployed in industrial services and the first spin-out companies are being formed. Details are given below.

Promotional Activities

A good knowledge exchange programme starts with awareness building and the CEOI-ST continued the successful activities initiated in previous Phases. Activities include:

- Publicity
- Articles
- Technology Showcases

To supplement and strengthen this programme a review was undertaken of social media channels to determine which would be the most effective in building awareness in relevant industrial markets:

- **Linkedin** is highly relevant to many individuals in the target markets and a programme of regular postings was implemented
- **Twitter** has a mixed usage. Individuals in most industry sectors do not follow Twitter, although there are a few enthusiasts. While no activity has been undertaken through this channel, it is an option if ways can be found to exploit it effectively
- **Facebook** is not used by the target audiences to acquire information and has not been used.

The outcome has been a wider awareness of the CEOI-ST programme and a broader interest from the non-space industry in following its activities. Attendance at the 2014 Technology Showcase included over 40 organisations who had not attended the previous Showcases in 2010 and 2013.

In addition, it became apparent during the engagement programme for the Technology Showcase that a wide range of companies were aware of the CEOI-ST programme, although they had not taken that awareness further to active engagement. This finding provided an additional incentive / objective to the Direct Industry Engagement part of the programme.

The effectiveness of the promotional activities is assessed through the metrics given in the section below.

Direct Industry Engagement

The programme of direct engagement with the non-space Industry is built around the Industry Consultation Workshops, supported by a series of articles which describe the potential applications of EO technologies in industrial, environmental and other terrestrial activities. The articles are used to build deeper awareness of the non-space applications, and the workshops provide the next step in the engagement process.

The approach used by CEOI-ST closely matches the process used by industry to look outside of their organisations for sources of innovation and technology solutions.

- Company technology and product development programmes are mapped out in detail over 3 – 5 year time periods.
- The first steps in engagement are to create awareness of the technologies under development by CEOI-ST
- We then help companies understand how EO technologies may fit in to their own development plans.

Feedback from delegates indicates that the Workshops are being very successful in achieving this.

So far, over 100 companies have been directly engaged through the workshops, telephone conferences and e-mail discussions. Of these 61 companies, including large corporations such as Arup, BP, Cobham, GE, Lockheed Martin, Meggitt and Rolls Royce as well as SMEs have attended the workshops. Metrics on this engagement are given below. Further evidence of interest in industry comes from the number of companies who are circulating the workshop invitations to Directors and Senior Technology Managers across a wide range of business units and subsidiary companies with their organisations. Examples include United Technologies, Oxford Instruments, MBDA, E.ON, and Chemring.

The next stage is to deepen that engagement process and the CEOI-ST programme is evaluating additional, pragmatic activities to achieve this.

Broadcast Promotional Metrics

The KPIs targets and achievement are given below:

KPI	Delivered	Target
Publicity Items	41	40
Social Media Items	104	36
Workshops	3	3
Technology Showcase	1	1
Application Articles	8	0
One to One Engagements	142	0

6 Training

Training Workshop: What makes a good proposal for a space mission?

The CEOI-ST held a Training Workshop in Sheffield on 3rd September 2015. The workshop introduced the participants to experienced mission leaders in the EO community (science, technology and project) as well as providing a briefing on the ESA Earth Explorer 9 (EE9) Call and an opportunity to discuss potential mission proposals.

The objectives of this training workshop were:

- To introduce the participants to experienced mission leaders in the EO community (science, technology and project)
- To provide training in the techniques (hard and soft) required for proposing, winning and delivering successful space-based EO missions.
- To bring together experienced and trainee EO scientists and technologists to form UK networks for the future.
- To provide a briefing on the ESA Earth Explorer 9 Call and an opportunity to discuss potential mission proposals

Audience

- Potential PIs, technologist and instrumentalists as leaders of future UK EO mission/instrument teams.
- PDRAs and PhDs in Earth Observation
- Recent graduates entries (degree +up to 4 years) into space industry