# Centre for EO Instrumentation

## Annual Report

## 31st March 2010

**Produced by the CEOI Leadership Team**

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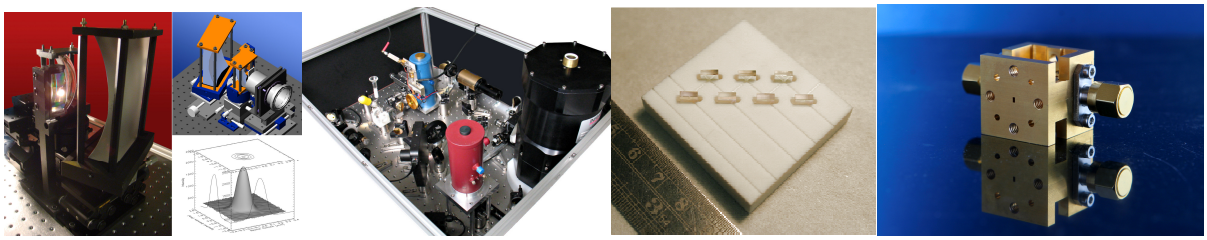
# EXECUTIVE SUMMARY

## Objectives of the Centre for EO Instrumentation

The recent UN Copenhagen climate conference highlighted the ways in which man's industrial and other activities are modifying our environment, by changing the composition of the atmosphere through emissions of carbon dioxide and other greenhouse gases. Satellite instruments are essential tools to improve our understanding of the processes driving the climate, to monitor the changes and provide a health check on the environment in which we live.

With a vision to develop and strengthen UK expertise and capabilities in EO instruments, the Centre for EO Instrumentation is helping to position the UK to win leading roles in future international space programmes. The CEOI was created in 2007 as a result of joint support from the Natural Environment Research Council (NERC), the Technology Strategy Board (TSB) and industry. It is funded through the UK Space Agency with the aim to develop key capabilities through the teaming of scientists and industrialists. The CEOI is set-up as a partnership led by Astrium together with the University of Leicester, STFC/Rutherford Appleton Laboratory and QinetiQ.



This Executive Summary of the CEOI Annual Report covers the period from April 2009 to March 2010 and summarises the main achievements of the CEOI over that period. During the year the CEOI has continued development of key instrument technologies that will be required by major future EO missions, for ESA and other agencies. This includes technologies for the candidate ESA Earth Explorer missions, future meteorological missions and the GMES Sentinel missions.

> "There is clearly a case for greater investment in the Centre for Earth Observation Instrumentation to prepare for opportunities in Living Planet and GMES"

*Space Innovation and Growth Strategy Report, February 2010*

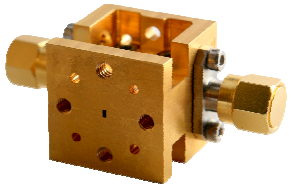
Key to the success of the CEOI is to bring together the strengths of UK industry and academia. The Centre actively encourages the participation of the full EO community, both academic and industrial, to ensure maximum benefit can be taken from all capability in the UK.

The CEOI is a catalyst for the development of advanced technologies for environmental and security monitoring from space. Through a collaborative national network of top research universities and high-tech industry, the CEOI aims to be a driving force and centre for innovation in the UK. Leading scientists are actively engaged in the development of the science drivers and critical instrument technology areas, ensuring that technology development is aligned with scientific need. The main technologies advanced by the CEOI during the last year are described in the following pages, with more detail in the main Annual Report.

# CEOI Achievements in 2009/10

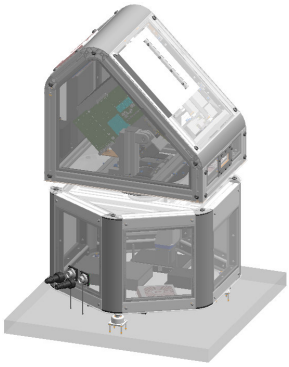
## Development of Technologies for future EO missions

### Passive microwave developments (STFC-RAL with Astrium)

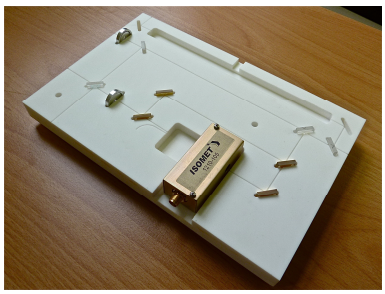


Future missions such as Premier and Post-EPS for atmospheric composition measurement using the millimetre wave are necessary to understand the climate and in weather forecasting. Key technologies under development include a novel single sideband separating sub-millimetre mixer, local oscillator (LO) source technology and a novel substrate-less optical filter. In addition, a new optical methodology for designing microwave instruments was investigated and scientific support provided to the STEAM-R Phase 0 Explorer study. Excellent success has been achieved. Shown in the picture is the 320-360 GHz Sub-Harmonic Image-Rejection Mixer (SHIRM) developed for STEAM-R. The STEAM-R instrument is part of the PREMIER mission.

### CompAQS UVN compact spectrometer (University of Leicester with SSTL)



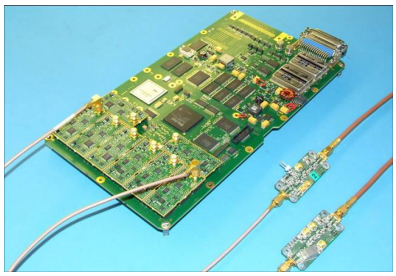
A breadboard demonstrator of a novel and compact UV/VIS spectrometer to measure air quality has been developed. Using designs from Surrey Satellite Technology Ltd (SSTL) a demonstrator was constructed and tested at the University of Leicester's Space Research Centre. This spectrometer provides an exceptionally compact instrument for differential optical absorption spectroscopy (DOAS) applications from LEO, GEO, HAP or ground-based platforms. Further funding has led to the development of the CityScan concept, consisting of two fully operational ground-based CompAQS spectrometer systems for the retrieval of nitrogen dioxide and aerosol concentrations (420 to 590 nm). The rooftop instruments (concept shown right) will provide 3D gas concentration measurements and aerosol information across urban areas every 10 minutes.



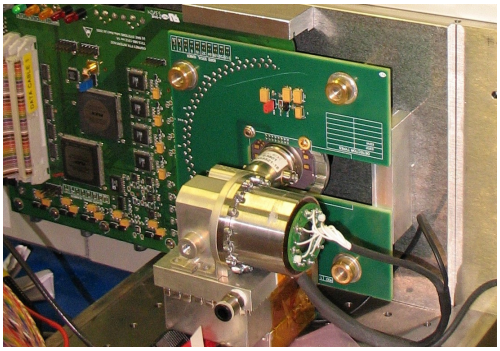
### Hollow Wave Guides for Laser Heterodyne Radiometer (STFC-RAL with QinetiQ)

QinetiQ has developed an approach to optical and laser systems manufacture which is the optical equivalent of the electronic printed circuit board. The technology provides a fundamentally new way of manufacturing compact, low mass, low cost optical systems which can maintain optical alignment in harsh vibration and thermal environments. The project to apply the technology to the Laser Heterodyne Radiometer has revealed great potential to reduce the size of the instrument by an order of magnitude. It is estimated that the instrument can be realised in an approximate volume of 20x10x10 cm.

### GNSS-RSI development with a number of flight opportunities (SSTL with NOC, Universities of Surrey and Bath)



This project is developing a flexible multi-channel receiver of reflected GNSS signals for surface sea-state measurements. Signals from GPS/GNSS navigation satellites reflected from land, ice and ocean can be analysed with an instrument flying on a separate small satellite to derive important scientific data on the nature of the reflecting surface and the atmosphere, such as the sea-surface roughness or soil moisture content. Measurements of ocean roughness are important for operational ocean and weather forecasting.



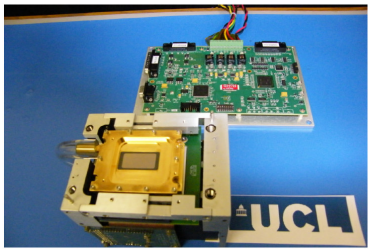
### Thermal IR Detectors and On-Board Processing (Astrium with Selex Galileo, STFC-RAL and Uni of Leicester)

TIDAS is a concept demonstrator of a 2D thermal infrared detector array system and its associated signal processing unit for Fourier Transform Spectroscopy (FTS). Experimental tests at NERC's Molecular Spectroscopy Facility are being conducted to investigate the design and operational issues in using 2D detector arrays to improve the spatial resolution and coverage of FTS instruments.

Future spaceborne instruments will require high performance on-board digital signal processing to handle the large volume of data generated by modern high resolution sensors. The latest FPGA (Field Programmable Gate Array) technology offers the required processing capacity and speed within tight mass, power and volume constraints, with the ability to reconfigure the processor in flight to accommodate multiple operational modes.

## Seedcorn projects

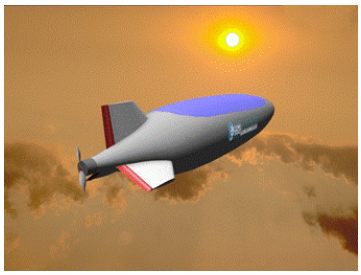
Seedcorn projects are smaller, more speculative projects which may have strong enabling potential for future Earth observation applications. Those funded in the 2nd CEOI Open Call are completing or have completed:



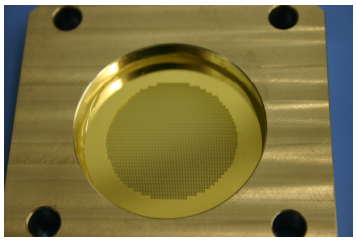

**Multiangular IR Stereo Radiometer (MISRlite) – UCL/MSSL**

This study is examining simplified instrument options for cloud-top height and wind measurement from space. This CEOI project is exploring a concept known as MISRlite which is based on the MISR (Multi-Angle Imaging Spectro-Radiometer) instrument on the NASA Terra satellite measuring winds with a single set of optics and no in-flight calibration. A simple laboratory demonstrator set up has been produced to demonstrate the instrument and elementary processing principles. The MISRLite mission is being proposed into the ESA Earth Explorer 8 Call.

**Air quality monitoring from High Altitude Platforms (Astrium with University of Leicester, Lindstrand Technologies)**



High Altitude Platforms present an intermediate step to space for air quality measurements, and could enable early high-priority science to be obtained, as well as offering an unrivalled observation platform for regional science and monitoring. The study has examined the development of sensor and platform technology for HAPs (primarily large airship style dirigibles), investigated Lidars and spectrometers in UV/VIS/NIR/SWIR and built system budgets for the HAP platform. It also looked at the regulatory aspects of deployment of HAPS in unregulated airspace.



**Frequency Selective Surface (FSS) Filters (Queen's University Belfast)**

Space-borne measurements from passive instrumentation provide key contributions to Earth science. Very low loss quasi-optical FSS filters will facilitate the detection and analysis of polarised radiation in multi-spectral passive remote sensing instruments operating up to 700 GHz. The development of this key technology exploits state of the art advances in computational electromagnetics, precision micro-machining technology and millimetre wave metrology.

## 3rd Open Call

Three mainstream and five seedcorn projects were selected for funding by an independent review panel from the nineteen bids submitted into the 3rd CEOI Open Call. The three mainstream projects are to continue development of the TIDAS laboratory demonstrator of an FTIR infra-red detector and on-board-processing system (Astrium led team); to continue development of the GNSS Reflectometry work (SSTL led team); and a new project to develop the concept for a 3D Interferometric SAR.

The five selected seedcorn projects are as follows:

- Fibre optic/HWG coupling (QinetiQ): a major technology step of optimally integrating fibre optics into hollow waveguide optical circuits.
- Wavemill SAR On-Board Signal Processing (Astrium lead) : on-board processing for an ocean topography synthetic aperture radar.
- Microslice: 'Integral Field Spectroscopy' (University of Durham lead) to provide multiple spectra of a sub-divided focal plane with a micro-lens array, a technique developed for astronomy, to improve coverage of hyperspectral land/water missions.
- IFU Spectrometers (STFC-ATC): exploiting another astronomy spectroscopy technique for EO, to divide an optical focal plane using an image-slicing mirror. This will operate in the SWIR to improve the monitoring efficiency of $CO_2$ and other trace gases.
- Methane Bubbles (University of Cranfield): examining the radar signature from 4 - 19 GHz of methane bubbles in Arctic lake ice.

All these projects will commence in the first 4 months of 2010.

## ESA Earth Explorer 8 proposals

The CEOI has supported UK teams in developing concepts for the current ESA Earth Explorer 8 rounds, funding technology activities and providing a firm basis for the technology underpinning their mission proposals. It held a joint town meeting with BNSC to allow UK PIs to present their initial ideas and network with potential UK partners in November 2009 in the early stages of the proposal process and during the CEOI Conference in April 2010 the UK community was updated with the latest information on intended proposals.

# Investing in the Future

## Horizon Scanning

The CEOI has continued horizon scanning to identify the UK's highest priority future EO missions through the Challenge Workshops. During 2009/10 three workshops were held, each attracting between 30 and 50 attendees. These workshops covered surface/atmosphere interactions, technologies for future Lidar missions and operational EO missions. In addition the Annual CEOI Conference was held in April 2009 at Warwick University Conference Centre, with over 70 participants.

> "Overall conference provided a very good opportunity for networking and a good overview of ongoing CEOI activities"
> "Very full schedule! Very good time-keeping too, but almost overwhelming amounts of new information"

*Feedback from the 2009 Annual Conference*

## Business Development

The CEOI carries out a comprehensive knowledge exchange programme focussed on identifying potential non-space applications for the technologies under development by CEOI project teams. The CEOI Knowledge Exchange partner, Qi3, carries out technology mining and brokering activities to identify Intellectual Property position, technology maturity and potential for additional funding. In total around £2.7M in additional funding has been secured over the period April 2007 to December 2009 i.e. around £1M pa.

## Learning and Development

A long-term CEOI objective is to develop the highly skilled workforce and leadership necessary to maintain the UK at the forefront of the world-wide EO community. The CEOI training and development programme addresses the needs of the academic and industrial community at all stages, from early stage training through to leadership development. CEOI funded projects are encouraged to use the development activities as a training opportunity for younger staff. In March 2010 the CEOI ran a workshop on 'Designing an EO Instrument Concept' in London, which provided valuable insight into the design process to more than 45 participants from academia and industry.

> "It is good to understand & interact with people who have vastly different experiences of knowledge e.g. scientist vs. engineer/developer - it is important to continue this."

*Feedback from the CEOI Training Workshop*

The CEOI also supports studentships on novel EO instrumentation. In January 2010, the Centre awarded new PhD studentships in EO instrumentation to the Universities of Edinburgh, Durham and Surrey to commence in October 2010: in total ten CEOI supported studentships have been allocated.

## Publicity

The CEOI publicises its technologies and achievements to a wide audience through articles and presentations of its activities at conferences and seminars. Articles have been published in NERC and STFC Newsletters and in a variety of technical journals including the IET Journal, SPIE Newsletter and publications from the KTNs. The CEOI project teams have published more than 15 technical papers and 2 patents resulting from CEOI technology developments have been applied for. Useful contacts from other industries interested in the CEOI developed technologies have resulted from this publicity.
There was significant recognition of the CEOI activities in the recently published Space Innovation and Growth Strategy reports and CEOI is making important contributions to the technology strategy of the UK Space Agency.

> "The Centre for Earth Observation Instrumentation is an excellent and very successful example [of a virtual centre of excellence] which merges the capabilities of industry and academia to develop the next generation of Earth Observation Instrumentation."

*Space Innovation and Growth Strategy Report, February 2010*

## Further Information

More information about the CEOI is available at www.ceoi.ac.uk, or contact the CEOI Director:

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# Contents

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# 1 INTRODUCTION

## Outline

This 2009/10 Annual Report for the Centre for EO Instrumentation summarises the progress of the CEOI in the past year, including progress towards the strategic objectives, updates on the technology projects and open call, and describes the horizon scanning and knowledge exchange activities. An outline of the work to be undertaken in 2010/11 is also presented.

In addition Annex 1 identifies progress towards meeting the CEOI overall objectives.

## What is the CEOI?

The CEOI was created in 2007 as a result of joint support from the Natural Environment Research Council (NERC), the Technology Strategy Board (TSB) and industry. It is funded through the UK Space Agency with the key aim to develop capabilities in future space instrumentation for Earth Observation through the teaming of scientists and industrialists. With a vision to develop and strengthen UK expertise and capabilities, the CEOI will help to position the UK to win leading roles in future international programmes. The CEOI is funded until March 2011. It is led by Astrium in partnership with STFC/RAL, QinetiQ and University of Leicester. The CEOI leadership team consists of the CEOI Director, Mick Johnson (Astrium) working with Co-Directors Paul Monks (University of Leicester), Chris Mutlow (STFC/RAL) and Rob Scott (QinetiQ).

Further information about the CEOI can be obtained on the CEOI website at www.ceoi.ac.uk.

## Governance

The CEOI Management Board has been set up in accordance with NERC guidelines and is responsible for overall governance of the CEOI. It is chaired by the CEOI Director, with membership consisting of Dr Bill Eason (NERC), Mr Michael Lawrence (TSB) as representatives of the funding bodies, Professor Alan O'Neill (NCEO) and Mr Ben Olivier (Systems Engineering & Assessments Ltd [SEA]) to represent the user community (non-executive members) and the CEOI Leadership Team (executive members). The Board meets approximately 6-monthly and reviews the CEOI progress, considers and approves future plans and advises the Director on strategy.

## Outline of the CEOI objectives and programme

The overall CEOI objective is to develop UK space instrument capability, leading to a mission funded by a national, bi-lateral or ESA programme which implements the mission concepts and technologies developed through the Centre's programme. The strategy to deliver this objective centres on development of innovative ideas through combined academic/industrial teams, with horizon scanning linked to the NERC science priorities. The addition of technology transfer by spin-in non-space technologies and spin-out the developed technologies to non-space applications is used to ensure maximum economic benefit.

The main activities of the Centre are a technology development programme, including programmes initiated by the Centre and projects selected through a series of Open Calls. This is supported by substantive horizon scanning, knowledge exchange and training/development programmes. Full participation of the UK EO and technology communities from academia and industry is encouraged through these activities to ensure exploitation of existing UK capability. The CEOI Leadership Team ensures that the programme is delivered cost effectively and has a high impact on UK EO capability and international standing.

## 2 MAIN ACHIEVEMENTS IN 2009/10

### Technology development

The four CEOI high priority initial technology projects have been completed:

- The CompAQS benchtop demonstrator of a compact UV/visible spectrometer for monitoring air quality (University of Leicester lead) is complete. The development continues as the CityScan project, lead by University of Leicester, under East Midlands Development Agency (EMDA) and NERC Follow-On Funding. Based on the optical design of CompAQS, the project will develop ground-based air quality monitors.
- The millimetre wave limb sounder project (RAL lead) is complete. The project has analysed the critical issues and improved the design of the STEAM-R instrument for observation of tropospheric and stratospheric exchange processes. The team has built and tested a 320-360 GHz Sub-Harmonic Image Rejection Mixer (SHIRM) mixer.
- The project to improve the space Technology Readiness Level (TRL) of the hollow waveguide (HWG) technology for future $CO_2$ lidar missions (QinetiQ lead) is complete. The study of ruggedisation techniques for HWG optical systems has been carried out and representative HWG optical circuits have been constructed.
- Surrey Satellite Technologies Limited (SSTL) has completed the follow-on work on Grism designs for future missions including for a short-wave infrared (SWIR) spectrometer for the Global Monitoring and Environmental Security (GMES) Sentinel-5 Precursor mission. The SWIR instrument will provide accurate assessment of key atmospheric variables such as methane and carbon monoxide.

### Technology projects from the 2nd CEOI Open Call are mostly complete or nearing completion:

- Astrium in partnership with Selex Galileo, STFC-RAL and University of Leicester are leading the Thermal Infra-red Detector Array System (TIDAS) study to develop a demonstration breadboard of a 2 dimensional IR detector system and associated on-board signal processing unit, to provide significant amounts of on-board data compression.
- SSTL with National Oceanographic Centre and the Universities of Bath and Surrey are undertaking a project to develop a multi-channel receiver prototype for a Global Navigation Satellite System (GNSS) Remote Sensing Instrument (GNSS-RSI) to demonstrate use of reflected GNSS signals for EO applications, such as measurement of the sea-surface state from which surface wind speed can be derived.
- Mullard Space Science Laboratory (MSSL) are examining simplified instrument options for the Multi-angular IR Stereo Radiometer (MISRlite) mission for the remote-sensing of cloud-top height and wind, in scope for an Earth Explorer 8 proposal.
- STFC-RAL in partnership with QinetiQ have studied the use of hollow waveguide technology to provide an optically integrated and miniaturised laser heterodyne radiometer (LHR), a high spatial and spectral resolution passive infra-red spectrometer to study atmospheric chemistry.
- Astrium completed a project with Lindstrand and University of Leicester to investigate the use of High Altitude Platforms (HAPs) – vary large inflatable airships - for monitoring regional or local air quality.

- Queens University Belfast has completed the project to design and manufacture low-loss Frequency Selective Surface (FSS) filters operating a 664 GHz. These filters can enable important design advantages for the next generation of advanced passive microwave instruments for use in meteorological and other atmospheric instruments.
- STFC-RAL with Astrium are continuing with development of key millimetre wave technologies for the STEAM-R instrument, synchronised with the ESA Earth Explorer 7 PREMIER mission candidate Phase A study. STEAM-R will measure atmospheric composition in the upper troposphere and lower stratosphere, an area important to scientific climate studies.

Eight new projects from the 3rd CEOI Open Call have been selected and contracts have been provided to the winning teams.

## Potential Mission Opportunities

The objective for CEOI developments is to take the instrument technologies through to a flight opportunity and therefore potential future missions are identified and tracked by the teams. Opportunities being pursued include the GMES Sentinels 4, 5 and 5 Precursor, the ESA PREMIER Earth Explorer candidate mission, the Post-EPS humidity sounder, the UK technology demonstration TechDemoSat mission and the Earth Explorer 8 mission.

- The Grism development work undertaken by SSTL under CEOI funding is highly relevant to the SWIR instrument for the GMES Sentinel 5 Precursor mission and has allowed SSTL to engage with potential partners in Europe.
- The PREMIER mission candidate for the next ESA Earth Explorer mission has been down-selected by ESA's Earth Science Advisory Committee (ESAC) and Earth Observation Programme Board (PBEO), along with BIOMASS and CORE-$H_2O$ candidates. The next stage will be competitive Phase A mission study. In parallel the Swedish team are carrying out a Phase A study on the proposed nationally funded STEAM-R instrument, for flight on the PREMIER mission. The UK team led by RAL are working on passive millimetre wave technologies which are critical to the performance of this instrument, making the UK ideally placed to participate through a national contribution to the mission. Furthermore, studies on passive millimetre wave technologies are targeted to the Post-EPS humidity sounder.
- SSTL had announced an opportunity to gain space flight heritage for UK technologies through a Technology Demonstration Mission. CEOI teams have submitted proposals to provide an EO instrument or related technologies and two projects have been down-selected as candidate payloads. The TSB are currently undertaking a detailed commercial and engineering assessment of the mission concept. Subject to approval, the final payload selection process will take place later this year.
- A number of CEOI Teams are involved in bids into the Earth Explorer 8 call.

## Events

The CEOI Annual Conference was held on 29th and 30th April 2009 at the University of Warwick Conference Centre, with 75 attendees. The conference addressed future EO missions and instrumentation, emerging instrumentation technologies and CEOI projects.

Three Challenge Workshops were also held during the year:

- The 4th CEOI Challenge Workshop was held on 7th July 2009 at the Centre for Ecology and Hydrology (CEH) Wallingford. The workshop investigated potential future missions to observe surface-atmosphere interactions (snow-atmosphere, biosphere-atmosphere and ocean-atmosphere).
- The 5th CEOI Challenge Workshop, held on 21st September 2009 in Abingdon, focused on the technology for future space-based Lidar missions, including a review of the science drivers, the range of Lidar missions being considered, the driving technology requirements and the current UK technology capability. It investigated the technology opportunities presented by future space missions and how we can better co-ordinate development of UK Lidar capabilities for application to the critical missions of the future.
- The 6th Challenge Workshop (13th November 2009, Leamington Spa) to investigate operational Earth observation missions and instrumentation and to identify potential opportunities matched to the capabilities of UK academia and industry.

A joint BNSC & CEOI Town Meeting was held in London on 5th November 2009 to discuss the ESA Earth Explorer 8 Opportunity Missions, with the objective to bring together UK interests from academia and industry, to inform the UK EO community about the opportunity and to initiate potential collaborations.

## Training

The CEOI held its second one-day training workshop on "Designing and Delivering an EO Instrument Concept" on Monday March 15th 2010 in London. The workshop built on the highly successful first CEOI training workshop and was particularly timely given the call for Earth Explorer 8 missions.

The CEOI allocated three fully funded NERC PhD studentships in EO instrumentation to the Universities of Durham, Edinburgh and Surrey, following a second call for studentship proposals issued on 1st December 2009.

## Technology Transfer

Technology exchange is an important part of the CEOI programme, looking at both spin-in of non-space technologies and spin-out of CEOI developed technologies into non-space applications. The Knowledge Exchange programme is carried out on behalf of CEOI by Qi3 and the activities have continued with evaluations of five of the CEOI projects to identify potential for spin-out into other applications.

# 3 TECHNOLOGY ACTIVITIES

The four initial instrument technology projects selected for further development on the basis of their science priority and relevance for future missions being considered by ESA and other institutions are complete. They are described briefly at the start of Section 2 but for further details please refer to the CEOI website (www.ceoi.ac.uk) and to the 2007/08 CEOI Annual Report.

The seven instrumentation projects from the Second CEOI Open Call are almost all completed. Three mainstream and 4 seedcorn activities were selected for funding and are described in the following sections.

**The third CEOI Open Call** with a nominal budget of £600k was held in autumn 2009 and attracted interest from new participants in CEOI. In total 19 bids were received, which were evaluated by an independent assessment panel, supported by the CEOI Technology Director and advised by NERC and TSB. Three mainstream and five seedcorn activities were selected for funding as listed in the table below.

| Title | Type | Lead organisation |
|---|---|---|
| TIDAS/SPU Follow-on | Main | Astrium |
| GNSS Remote Sensing Instrument (GNSS-RSI) | Main | SSTL Ltd |
| Interferometric SAR | Main | University of Leeds |
| Fibre/hollow waveguide coupling | Seedcorn | QinetiQ |
| Wavemill | Seedcorn | Astrium |
| Microslice | Seedcorn | University of Durham |
| IFU spectrometers | Seedcorn | UK-ATC |
| Radar signature of methane bubbles | Seedcorn | Cranfield University |

**Table 3-1. Projects selected in the third CEOI open call.**

The progress with all these projects is described in the following pages.

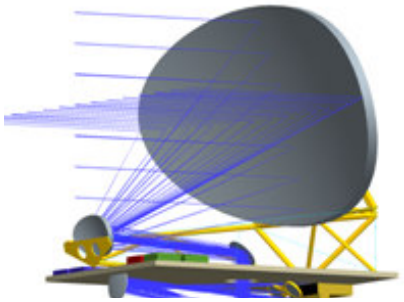
## 3.1 High priority initial CEOI technology projects

### 3.1.1 STEAM-R (Passive Microwave)

**Objectives**

STEAM-R is a passive, millimetre-wave limb-sounding radiometer proposed by Sweden as a nationally-funded contribution to the candidate ESA Earth Explorer core mission PREMIER. The primary aim of PREMIER is to explore processes controlling the composition of the mid/upper troposphere and lower stratosphere. This will be achieved by resolving 3-D structure in this atmospheric region, using limb imaging, on finer scales than has previously been possible from space. Earlier CEOI work led by RAL, has provided vital inputs into the instrument concept and this, with other work, has resulted in the selection of the PREMIER mission for Phase A study, for a flight opportunity in 2016.

The concept for STEAM-R includes novel single-channel, sideband-separating receivers following the design developed at RAL, focused on a single optimal frequency band (313-356 GHz); and the focal plane incorporates a receiver array that obviates the need for a mechanical scanning main antenna.

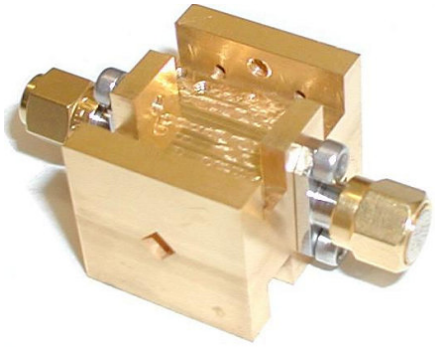


STEAM-R (courtesy SSC)

**Achievements**

Key technologies chosen for development include a new sideband separating sub-millimetre mixer, local oscillator (LO) source technology and a novel substrate-less optical filter. In addition, a new optical methodology for designing microwave instruments was investigated and scientific support has been provided to the STEAM-R Phase 0 Explorer study. Excellent success has been achieved. The highlights include:

- Radiative transfer and retrieval simulations have underpinned the STEAM-R instrument baseline design.
- Novel image separation mixer technology (SHIRM), based on UK Schottky diodes, has been demonstrated by Astrium and RAL. The UK is well positioned to supply critical technology (mixers, optical filters) and other hardware for STEAM-R.
- Astrium has developed an optical design methodology that accurately predicts antenna patterns for sub-millimetre radiometer instruments
- Novel, generic, filter technology has been developed by Queen's University Belfast and Astrium and demonstrates state-of-the art low loss performance.
- Two studies, precursors of a possible airborne cirrus instrument have been started. UK involvement in STEAM-R through continued work under CEOI in preparation for the PREMIER Explorer Phase 0 study will consolidate UK excellence in THz radiometry.



320-360 GHz SHIRM

Work led by Dr Dave Matheson of STFC-RAL with Astrium and Queens University Belfast.

**Contact point for further information:**

Dr David Matheson, STFC-RAL, david.matheson@stfc.ac.uk

### 3.1.2 CompAQS spectrometer

**Objectives**

A breadboard demonstrator of a novel UV/VIS spectrometer has been developed. Using designs from Surrey Satellite Technology Ltd (SSTL) a demonstrator was constructed and tested at the University of Leicester's Space Research Centre. This spectrometer provides an exceptionally compact instrument for differential optical absorption spectroscopy (DOAS) applications from LEO, GEO, HAP or ground-based platforms.

**Achievements**

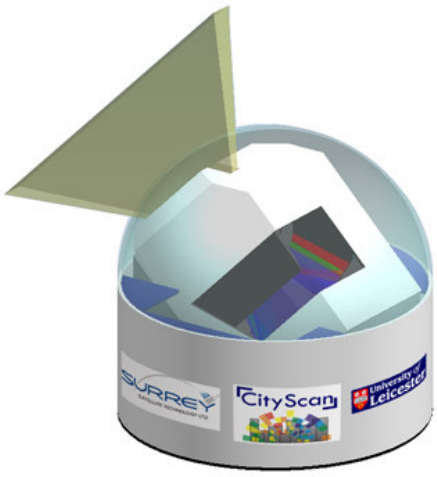
Following specification, design, procurement, and build phases, the instrument was characterised at the University of Leicester. The key conclusions are that the required gratings for concentric spectrometers can be manufactured effectively, with exceptionally good stray light characteristics; that the target spectral resolution can be achieved and that adequate spatial resolution can be provided over the length of the entrance slit.

An atmospheric spectrum has been measured which demonstrates the potential of this spectrometer for DOAS applications when coupled with appropriate entrance optics.

The CompAQS project has brought together a very successful academic and industrial team, strengthening the UK capability in UV/Visible spectroscopy. A complex and novel optical system has been designed, built and tested to budget and within timescales. This operational breadboard demonstrator significantly enhances the maturity of this approach for future space missions and for potential terrestrial applications.

Resulting from the CEOI project, University of Leicester has received NERC Follow-on funding to develop the CityScan concept, which will result in construction of two fully-operational ground-based CompAQS spectrometer systems for the retrieval of nitrogen dioxide and aerosol concentrations (410 to 590 nm). This project will proceed in parallel with the CEOI project until June 2010 to ensure maximum cross-benefits are obtained.

The work is led by Dr Roland Leigh, University of Leicester with SSTL and Astrium




The CityScan concept for a ground-based scanning spectrometer for monitoring urban air quality

**Contact point for further information:**

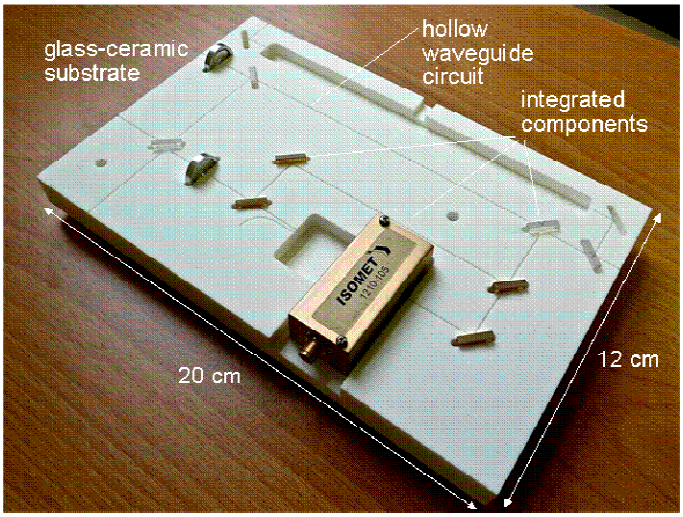
Dr Roland Leigh, University of Leicester

Email: rl40@leicester.ac.uk

http://www.leos.le.ac.uk/research/CEOI/index.htm

### 3.1.3 Hollow Waveguide Optical Circuit Board Technology

## Objectives




Hollow waveguide (HWG) optical circuit board technology is a novel approach to producing compact rugged optical instrumentation. In the approach hollow waveguides formed in the surface of a dielectric substrate are used to guide light through a circuit of optical components, each of which is mounted in a precision alignment slot also formed in the substrate. The upper wall of the hollow waveguides takes the form of a lid mounted on the substrate. Alignment of the optical components is achieved by precision manufacture of the alignment slots. As each component is physically constrained within an alignment slot, the optical system is immune to misalignment due to mechanical shock, vibration and thermal effects. The photograph shows an example of the approach applied to a compact rugged differential absorption lidar (DIAL) system for monitoring of atmospheric $CO_2$.

## Achievements

As an example of the coherent detection capabilities of the hollow waveguide DIAL circuit shown above, in conjunction with a 1.55 µm laser source, the system was used to measure the Doppler line-of-sight velocity of a rotating target in a laboratory environment. In a further facet of work aimed at addressing space flight hardening issues, a hollow waveguide (HWG) Michelson interferometer circuit has been designed, manufactured and assessed in a set of environmental tests consistent with the thermal, vibration and shock conditions encountered in space vehicle launch and operation. Following the environmental test procedures the measured optical performance of the Michelson interferometer circuit has, in all cases, been excellent with a measured homodyne detection efficiency ~90% of the theoretical maximum. More recently hollow waveguide circuit board technology has been used to address the miniaturisation of a laser heterodyne radiometer (LHR) system developed by RAL (STFC) – this is described in more detail in a separate report. The hollow waveguide LHR system operates at 9.0 µm highlighting the flexibility provided by the broad waveband, low loss, transmission characteristics of hollow waveguide circuits. From the latter perspective, in separate measurements, the practical attenuation coefficients within hollow waveguide circuits have been confirmed to be close to the low theoretically predicted values of 0.0005 $cm^{-1}$.

The success of the HWG DIAL, Michelson interferometer and LHR demonstrators has highlighted the potential of the technology to enable the manufacture of compact, rugged, low mass, high performance systems for a wide range of space instrumentation applications.

The work is led by QinetiQ with University of Leicester, UCL, CTCD and STFC-RAL.

## Contact points for further information:

Prof R Mike Jenkins, QinetiQ Ltd, rmjenkins@qinetiq.com,

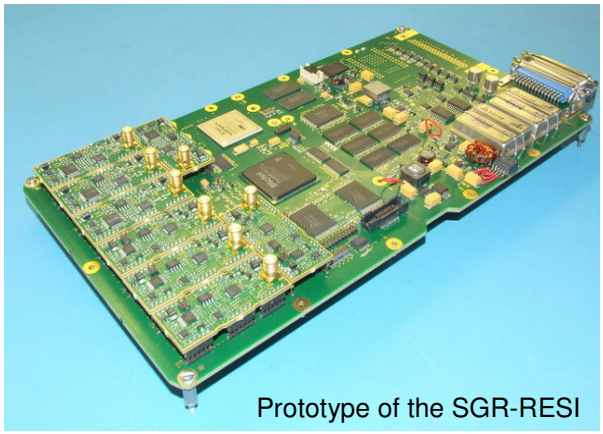
Dr Brian J Perrett, QinetiQ Ltd, bjperrett@qinetiq.com

## 3.2 CEOI Projects selected in the 2nd Open Call

At the end of 2008, bids into the 2nd CEOI Open Call were assessed by an independent panel against defined criteria, resulting in funding for seven instrumentation projects to be carried out by teams from UK industry and academia. The projects were won in open competition and are advancing technological capability in line with UK Earth observation science priorities. The funded projects are described in the following paragraphs.

### 3.2.1 Use of reflected GPS signals to measure the ocean surface state

**Project Objective** Signals from GPS/GNSS navigation satellites reflected from land, ice and ocean can be analysed with an instrument flying on a separate small satellite and important scientific data on the nature of the reflecting surface and the atmosphere, such as the sea-surface roughness or soil moisture content can be derived. Measurements of ocean roughness are important for operational ocean and weather forecasting. The project is developing a flexible multi-channel receiver of reflected GNSS signals for surface sea-state measurements. It is led by SSTL working with Universities of Surrey and Bath and the National Oceanographic Centre.



Prototype of the SGR-RESI

**Current status** Design work continues and despite delays with procurement and the complexity of the main (20-layer) electronics board, the project is expected to deliver a working prototype in April 2010 and achieve the main goals of the development. Indeed in the last week of March 2010, the last goal – sampled data was logged that was shown to contain the L2C signals.

The prototype has performed a navigation fix using L1 signals from a rooftop antenna, logging data from a MAX2112 front-end and writing and reading a test pattern in DDR2.

Surrey Space Centre have tested their dual-frequency antenna array for the nadir reflectometry antenna. However results show a mixed performance with gain at L1 and L2C not quite meeting the simulated levels. It is anticipated that further work on the antenna array will be required in order to meet requirements. The results for the single dual-frequency patch element for use on the zenith face or for atmospheric sounding meet specification.

For ocean and atmospheric applications there is a need for more data for global coverage and gap-filling in current scatterometry products, and work by NOC and University of Bath details the science objectives for a Reflectometry instrument.

With successful demonstration of the data logging capability of the SGR-ReSI and completion of the dual-frequency antenna array, the major goals of the development work are achieved. A few minor issues and tests remain, but SSTL have exploited programme delays, to produce a robust design, which has enabled a very efficient integration phase.

**Contact point for further information:**

Dr Martin Unwin, SSTL, m.unwin@sstl.co.uk

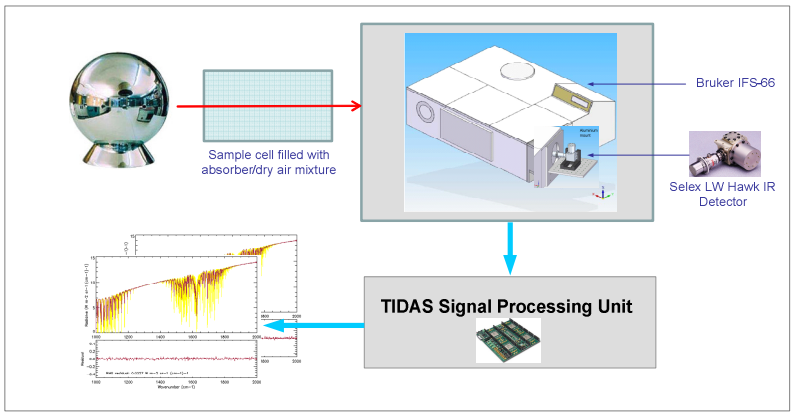
### 3.2.2 TIDAS – Thermal Infra-Red Detector Array System

**Project Objective** Spectrometry is one of the most important assets of passive remote sensing systems since it is the ability to observe spectra of top of the atmosphere radiance which provides the most detailed information on atmosphere composition. Infra-red nadir and limb sounders can provide fundamental observations of the anthropogenic and natural greenhouse gases, as well as many related species. These systems are excellent for measuring height-resolved profiles of water vapour, ozone, methane and CFC-related species.

This project addresses the deployment of detector array technology to meet the challenge of building thermal infra-red Fourier transform spectrometers (FTS) for future EO missions. A test demonstration concept of a two-dimensional thermal infra-red detector array system and on-board signal processing unit has been developed using mainly COTS equipments to minimise costs. The setup has been optimised to test the performance appropriate to limb sounding missions such as PREMIER, but the findings will also be relevant to nadir sounding missions. A key application of this technology is the provision of long-term data sets for these gas concentrations for use in climate and climate-feedback studies. The team is led by Astrium with Selex Galileo for detectors, University of Leicester as the science lead and STFC-RAL to provide a laboratory high spectral resolution Fourier transform spectrometer (FTS/IFS).

**Current Status** The detector and interface electronics have been successfully integrated with the Bruker IFS at NERC's Molecular Spectroscopy Facility at RAL. NERC has allocated four weeks of Bruker instrument time to this study. The signal processing unit (SPU) has been tested stand-alone using sample interferograms and has been interfaced to the Selex Hawk detector electronics.

The use of COTS equipments has resulted in numerous interface issues which constrain the performance of the demonstration system; however the identification of the underlying system design issues has lead to a greater understanding being developed towards how to specify a future bespoke system for space flight. The performance of the system integrated with the Bruker IFS is due to be demonstrated in April 2010.




TIDAS architecture

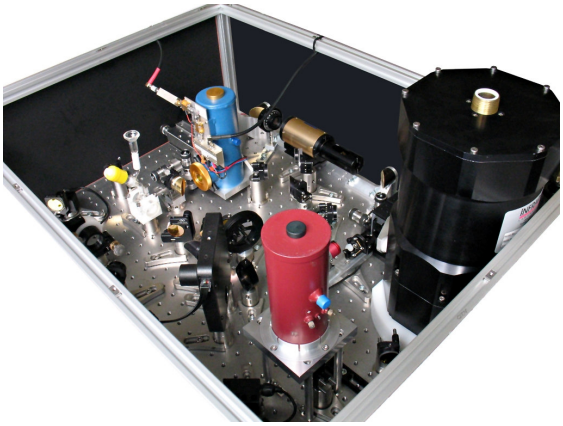
**Contact point for further information:**

Dr Alex Wishart, Astrium, alex.wishart@astrium.eads.net

### 3.2.3 Hollow waveguide technology for high resolution spectroscopy

**Project Objective** Monitoring of air quality and emissions is a vital goal for human health and for our understanding of climate change. A major step forward would be provided by sub-city scale observation from space or from high altitude platforms. This project aims to miniaturise optical aspects of a very high resolution spectroscopy, by applying hollow waveguide (HWG) technology to a Laser Heterodyne Radiometer (LHR). This is a passive radiometer which uses a low-power, highly-stable quantum cascade laser to modulate the incoming optical beam. QinetiQ have developed an approach to optical and laser systems manufacture which is the optical equivalent of the electronic printed circuit board. The technology provides a fundamentally new way of manufacturing compact, low mass, low cost optical systems which can maintain optical alignment in harsh vibrational and thermal environments. The team is led by STFC RAL working with QinetiQ Ltd.

**Current Status** . This seedcorn project is complete - its final review was held in March 2010. The project studied the development of a hollow waveguide board for heterodyne mixing, the assessment of mixing performance using quantum cascade lasers and the implementation of demonstration of a full laser heterodyne spectro-radiometer based on a hollow waveguide board. The notable technical highlights are:



Breadboard of the LHR

- The ability of the hollow waveguide to purify the mode structure of the coherent laser radiation and to virtually eliminate optical feedback to the laser.
- The implementation of the hollow waveguide core to the instrument has demonstrated that the approach virtually eliminates alignment problems. This is an important characteristic which enables several applications of the optical heterodyne technique, including terrestrial imaging Lidar. Heterodyne Lidar is notorious for difficulties with optical path alignment, and HWG techniques overcome this issue very effectively.
- The successful demonstration of heterodyne detection of gaseous absorption and emission using the hollow waveguide mixer.
- The first ever heterodyne measurements using the combination of a room-temperature laser and photomixer.

Following the successful demonstration of the hollow waveguide mixing block the next step would be to develop a fully integrated LHR system to reach the goal of a 10 fold reduction in instrument dimensions.

**Contact point for further information:**

Dr Damien Weidmann, STFC/RAL, d.weidmann@rl.ac.uk

### 3.2.4 MISRlite - Multiangular IR Stereo Radiometer

**Project Objective** This project aims to explore a concept known as MISRlite, based on the MISR (Multi-Angle Imaging Spectro-Radiometer) instrument on the NASA Terra satellite, but using thermal infrared, a single set of optics and no in-flight calibration. It will explore the optical and sensor design issues associated with building an instrument of very low mass incorporating linear pushbroom technology, preferentially using an uncooled thermal IR microbolometer system. It will permit cloud-top stereo motion vectors with accurate height measurements to be made during both day and night. Such instruments carried on a constellation of some 3 micro-satellites will provide daily coverage and with 12 micro-satellites will provide synoptic 6-hourly coverage. This project is being undertaken by a team at the Mullard Space Science Laboratory at University College London.

**Current Status** Optical design of the system was undertaken by the Astronomy Technology Centre in Edinburgh, but manufacture could not be afforded within the current funding. The work therefore proceeded with COTS optics, and fore optics from other in-house TIR sensors. An end-to-end demonstration of the imaging system (viewing the cal target) was successfully achieved at a Mid Term Review in October 2009. However hardware problems in the microbolometer pushbroom packaging have delayed delivery of the detector until early February 2010. This seedcorn project is expected to complete in May 2010.


Laboratory demonstrator for MISRlite

**Contact point for further information:**

Prof. Jan-Peter Muller, UCL/MSSL, jpm@mssl.ucl.ac.uk

### 3.2.5 Air Quality Monitoring from High Altitude Platforms

The aim of this project is to provide an assessment and roadmap for the development of sensor and platform technology for High Altitude Platforms (HAPs). HAPs present an intermediate step to space for air quality measurements and could enable early high-priority science to be obtained relating to such space missions. They offer an unrivalled observation platform for regional science and monitoring in their own right. The study is led by Astrium Ltd, with University of Leicester and Lindstrand Technologies Ltd. By maintaining a roughly stationary position with respect to the ground, HAPs provide an observing platform for both the surface (e.g. cities) and the atmosphere (e.g. pollution). In comparison with traditional remote sensing HAPs can provide near-continuous observations, excellent spatial resolution, low operating costs, and long mission life, giving the prospect of dedicated platforms covering environmental "hotspots". The ability to recover payloads easily from HAPs also offers a test-bed for the development of EO space-borne instrumentation.

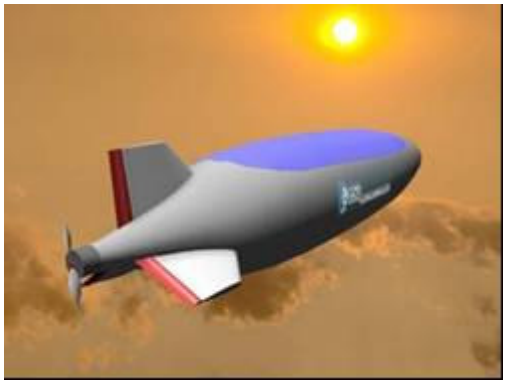


Illustration of a High Altitude Platform
(courtesy of Lindstrand Technologies Ltd)

As well as rapid deployment, HAPs can provide benefits of close range (hence high resolution), high

data capacity, and flexible configuration. HAPs could fill a distinct niche as a low cost technology between global-monitoring EO satellites and in-situ terrestrial systems.

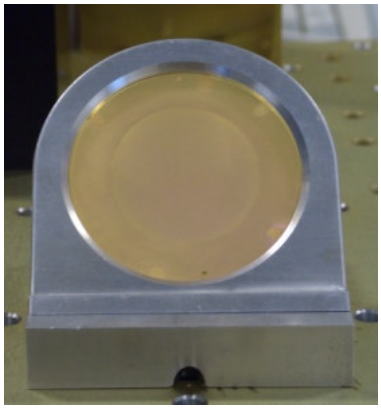
**Current Status** This seed-corn study is complete with a final review held in December 2009. The study has examined the development of sensor and platform technology for HAPs (primarily large airship style dirigibles). A UV-VIS-NIR-SWIR spectrometer and a High Spectral Resolution Lidar have been identified as candidate payload, but the mass and power budgets are driven by the platform itself and additional payload could be accommodated. The system budget aspects of the platform will need more development as the designs mature. The study has attracted interest from Defra for coastal and marine environment remote-sensing.

**Contact point for further information:**

Nicolas Leveque, Astrium Ltd, nicolas.leveque@astrium.eads.net

### 3.2.6 Frequency Selective Surface (FSS) Filter Technology

Spaceborne measurements from passive instrumentation, operating from microwave to sub-millimetre wavelengths, provide key contributions to Earth science. Information retrieved from this type of measurement is integral to operational meteorology and the study of atmospheric chemistry. These multi-spectral instruments usually operate over extremely wide bandwidths and can employ FSS filters to demultiplex the scene radiation into separate spectral channels prior to down-conversion and detection. For more than 20 years the UK has played a leading role in the development of this key technology by exploiting state of the art advances in computational electromagnetics, precision micromachining technology and millimetre wave metrology.



FSS filter

The project is developing low loss quasi-optical sub-mm wave filter technology, operating at up to 700 GHz, for channel separation on the Microwave Imager (MWI) instrument, which is part of the Post-EPS mission currently undergoing Pre-phase A study. The technology is also critical for other planned cloud monitoring and atmospheric sounding missions, for example CIWSIR and GOMAS.

**Current Status**. This seed-corn study completed in March 2010 has demonstrated the UK's capability; in FSS design, fabrication, and spectral measurement techniques up to 700 GHz.

The work completed has designed and manufactured a dual linearly polarised sub-mm wavelength FSS to provide a passband centred at 664 GHz. Precision micromachining and multilayer plating processes have been developed to fabricate the structures achieving manufacturing tolerances of ± 2μm. The measured transmission and reflection spectral response plots are in very good agreement with the electromagnetic computer model and the loss measurements demonstrate that the filter performance exceeds the specifications.

This work strengthens UK expertise and capabilities in MWI instrumentation and will help to position QUB together with UK industrial partners Astrium and RAL, to win leading roles in future European space programmes. QUB believe that the CEOI funding has successfully positioned them for ESA and other funding.

**Contact point for further information:**

Dr Robert Cahill, Queen's University Belfast (QUB), r.cahill@ee.qub.ac.uk

### 3.2.7 Support to STEAM-R Phase A Study

This project continues the work to develop enabling technologies for the STEAM-R instrument on the Premier mission (see Section 3.1.1 for further information) and will allow further work on the significant technology developments carried out in the first 24 months of the CEOI.

The image separation single sideband receivers are new technology, and further performance and resource optimisation is necessary. In addition, STEAM-R will be the first millimetre wave atmospheric limb sounder to use a 'staring' receiver array rather than mechanical antenna scanning. As a consequence, it is especially important that receiver array elements and instrument performance is fully understood and well characterised. Development work will be undertaken in three critical areas, in order to confirm details of the design of the instrument, to optimise its performance and to minimise instrument risk:

- Retrieval simulations that estimate the effects of instrumental design features, calibration, uncertainties and errors on STEAM-R's target products, and refinement of specifications accordingly. Calibration of the array receiver is critical.
- Enhancement and further development of the mixer array, focusing on best possible performance, both in terms of sensitivity and, in the case of the lower altitude limb views, sideband separation. There are also key trade-offs regarding the detailed design of the array that need resolving; these include, for example, the level of receiver integration and LO generation.
- Coordination of a proposal to DIUS/NERC for wider UK involvement in Phases B/C/D.

**Current Status** The project was kicked off, following a delay of some months in order to synchronise with the ESA Phase A study for the Premier. The first step of the project is for RAL and Astrium to hold alignment meetings with the Swedish Space Corporation. The current activity is expected to consolidate the UK position in the instrument, and if selected following Phase A, will consolidate a UK role in the PREMIER mission.

Most attention remains focussed on the sideband separation mixer development, since further demonstration of this technology is needed before the STEAM instrument baseline design can be confirmed. Design and simulations of SHIRMv3.0 are under way, and retest of SHIRM v2 is expected shortly.

**Contact point for further information:**

Dr David Matheson, STFC-RAL, d.n.matheson@rl.ac.uk

### 3.3 CEOI Projects selected in the 3rd Open Call

The Third Call was released in autumn 2009; the nineteen bids received were evaluated by an independent assessment panel in December 2009, which examined both the scientific environmental objectives and technological aspects of the proposals. In line with UK EO science priorities, the funding has been approved for eight instrumentation projects. The majority of these projects started in 1st quarter 2010, with the two follow-on projects awaiting successful completion of the previous phase before being initiated.

**TIDAS Follow-on** (Astrium with STFC-RAL, Selex-Galileo and Uni. of Leicester)

The TIDAS/SPU follow-on project will continue the development of the thermal IR detector system, to provide a laboratory demonstrator for FTS measurements of the atmosphere. The project is aimed at on-board processing of data from the spectrometers on PREMIER, and the post EPS missions.

**SGR-ReSI** (SSTL with NOC, Polar Imaging and Universities of Surrey and Bath)

The SGR-ReSI project (Space GNSS Receiver – Remote Sensing Instrument) will extend the capabilities of the GNSS-RSI receiver to the point where it can be adapted for spaceflight. This places the technology in a good position for a flight on TechDemosat or another small satellite mission. The instrument will use GNSS signals of opportunity to probe the atmosphere and provide data on surface state e.g. to derive wind speed from sea-surface roughness.

**Interferometric SAR** (University of Leeds with Astrium)

A study of an interferometric SAR mission for monitoring Earth surface deformation, including detection of ice motion in 3-dimensions. The novel feature is dual azimuth configuration which overcomes the limitation of conventional InSAR which sees only 1 component of displacement. The project will support a strong bid into the Earth Explorer 8 Call.

**Fibre/HWG coupling** (QinetiQ)

This seedcorn project addresses a major technology step of optimally integrating fibre optics into hollow waveguide optical circuits. If successful it will greatly increase the utility and flexibility of this integrated optics approach, which will implementation of smaller and physically robust optical systems, including implementation of Lidar instruments.

**Wavemill SAR On-Board Signal Processing** (Astrium with NOC)

Building on complementary areas of expertise, this seedcorn project will address the on-board processing for an ocean topography synthetic aperture radar. Significant quantities of data are expected from this multiple aperture SAR mission, so on-board data reduction will be vital.

**Microslice** (University of Durham)

This seedcorn project seeks to exploit 'Integral Field Spectroscopy' to provide multiple spectra of a sub-divided focal plane. The method uses an array of micro-lenses to improve the spectroscopic efficiency of the instrument, a technique from the astronomy domain. The science driver for this comes from environmental monitoring of inland water.

**IFU Spectrometers** (UK-ATC)

The team proposes to exploit an astronomy spectroscopy technique for EO, by using an image slicing mirror or integral field unit (IFU) to reformat the image field for greater overall efficiency. The design study, based on science goals for monitoring $CO_2$ and other climate-

relevant chemical species, will investigate this technique in short-wave infra-red (SWIR) spectroscopy to provide enabling technology for future EO missions.

This seedcorn project will complement the Microslice investigation, and the CEOI will be able to evaluate advantages and disadvantages of these approaches for EO.

**Methane Bubbles** (Cranfield University)

This seedcorn project will examine the radar signature of methane bubbles in Arctic lake ice from 4 - 19 GHz. The release of methane from tundra/permafrost could cause very serious additional greenhouse warming if significant thawing occurs. This project lays the foundation for an EO mission to survey the methane threat. Once a new laboratory is commissioned at Shrivenham, progress on the project is expected to be rapid.

## 4 HORIZON SCANNING

The aim of the CEOI horizon scanning program is to assess science and policy needs, together with the potentially disruptive technologies that can be pulled through into EO. This includes adapting and adopting technologies being developed elsewhere and from applications other than EO. Out of this process of scoping the science, policy and technology drivers there is a requirement to identify and prioritise UK interests in current and future EO missions through a range of implementation (flight) options.

- The first CEOI Annual Conference was held at the University of Warwick Conference Centre on 29/30 April 2009. The Conference, 'Future EO instrumentation in the UK', was based on the driving UK science priorities for future EO missions and instruments. More than 75 experts drawn from academia and industry attended.
- The second CEOI Annual Conference is to be held at the University of Warwick Conference Centre on 22/23 April 2010. The subject of the Conference is 'Technologies for Future EO Missions' and will cover some of the ideas being prepared for the current ESA Earth Explorer call, look at emerging technologies of relevance to EO and review the current activities and future plans of the CEOI.

The Challenge Workshop to investigate Surface/Atmosphere interactions was held at the Centre for Ecology and Hydrology (CEH), Wallingford. About 40 experts attended the workshop and major new insights were gained into future missions requiring a cross-disciplinary approach (e.g. ocean-atmosphere).

The Challenge Workshop to investigate 'Enabling Technologies for future lidar missions' was held on 21st September at The Cosener's House, Abingdon. More than 40 experts in lidar technologies, science and applications attended. This was a very useful event for all attendees, both in terms of identifying UK strengths, in bringing together a rather scattered community of laser expertise and in networking more generally. Resulting from the workshop, good contacts have been made with the Lidar SIG of the Sensors and Instrumentation KTN and joint activities have been discussed.

The final Challenge Workshop of 2009 was held on 13th November in Leamington Spa. The aim of this meeting was to investigate the instrumentation needs for operational missions, map the capability of UK academia and industry in operational Earth observation missions and instrumentation and explore potential opportunities.

A joint BNSC & CEOI Town Meeting was held in London on 5th November with the objective to bring together UK interests from academia and industry, to inform the UK EO community about the opportunity and to initiate potential collaborations.

# 5 KNOWLEDGE EXCHANGE

CEOI technology projects are built on knowledge exchange through their academic-industrial partnerships, resulting in many practical benefits that are directly attributable as KE. In addition CEOI have engaged Qi3 Ltd as their Knowledge Exchange partner to carry out a dedicated range of activities on behalf of CEOI.

The knowledge exchange (KE) activities are targeted at maximising the benefit of the CEOI programme by identifying the full range of applications for the technologies under development. It includes the exchange of expertise and skilled people between the science base, industry and the EO user communities and aims to contribute to the economic competitiveness of the UK, effectiveness of public services and policy and quality of life.

The main activities are as follows:

## (1) Technology mining

Qi3 Ltd work with the CEOI project teams to identify existing technologies from outside the EO space community which are potentially applicable (spin-in) and/or technologies from the CEOI project which can be applied in other areas (spin-out). This process is recognised as a long-term activity and spin-in/out benefits from the initial CEOI projects are still arising. The outputs from the activity are in the form of Technology Mining Evaluations (TMEs). During the last 12 months the following TMEs have been carried out: CompAQS; Microwave Millimetre and Sub-millimetre Radiometer and MISRlite.

Work has commenced in 2010 on a TME for miniaturisation of the LHR and for the TIDAS project.

## (2) Publicity and dissemination

This activity has the objective to make the activities of the CEOI better known to a broad range of potentially interested parties. The work includes the preparation and publication of technical articles, targeted at audiences in related fields, including through the Sensors and Instrumentation KTN and presentations of the CEOI technologies at conferences and seminars. Articles have been published on the Laser Heterodyne Radiometer (LHR), Lidar for Space, the Lidar Technologies Challenge Workshop, the PhD Studentship Call and the 2009 CEOI Annual Conference. Publicity has been through the KITE newsletter, the STFC Innovations Newsletter, NERC News, the Aerospace and Defence KTN and other publications.

## (3) Brokering Prospects

This activity is targeting opportunities in other application areas, identified as potential users of CEOI developed technologies. Qi3 make initial contact with candidate organisations on behalf of the CEOI, with a view to putting the parties in direct contact when justified by the potential.

The SI-KTN undertook visits on behalf of the CEOI, including Edinburgh, Surrey, Imperial, Selex Galileo and Optic Technium, to investigate the non-space commercial potential for a number of the CEOI developed technologies.

Qi3 has provided assistance to four CEOI project teams to prepare bids into sources of additional funding. They have also raised awareness and provided some initial guidance to a number of teams intending to bid into the CEOI Open Call.

CEOI funding opportunities were discussed with ZiNIR and Surrey Space Centre. Brokering prospects are still being pursued for CompAQS, Hyperspectral Lidar, Multispectral Lidar and the FSS Filters.

# 6 TRAINING

The long term objectives of the CEOI training and development programme are (1) to develop a highly skilled workforce capable of meeting the needs of academia and industry in EO instrumentation and (2) to provide a leadership pool able to deliver world-class EO missions and instrumentation.

The training programme addresses the needs of the academic and industrial community at all stages of their development, from early stage training, for those in industry and academia immediately following their first degree, through to skills and leadership development for those with more experience.

## Training Workshop

The 2nd CEOI Training Workshop on 'Designing and delivering an instrument concept' was held in London in March 2010 with 45 attendees. The workshop looked at the fundamentals of EO instrumentation techniques and included two workshop sessions which allowed participants to develop a better understanding of the inter-relationship between the science requirements, the instrument design and the mission parameters. Excellent feedback was received from participants who found it a very worthwhile workshop.

## PhD studentships

CEOI sponsored NERC PhD studentships are selected by an independent panel. A call for proposals for an additional 3 NERC CEOI PhD Studentships was issued at the end of 2009. Monitoring of these studentships is via an annual student report and student presentations/posters at suitable CEOI events. The CEOI has now approved and is supporting ten NERC PhD Studentships in a number of Universities in the UK:

| Title | Institution | Status |
|---|---|---|
| Potential for LiDAR to measure $CO_2$ sources and sinks from space. | Univ. of Leicester | Student in 3rd year |
| Development of sub-mm heterodyne technology | Univ. of Leeds | Student in 3rd year |
| Electronically Scanned Rotman Lens Antenna with Liquid Crystal Phase Shifters. | QUB (CASE with Astrium) | Commenced in October 2009 |
| Development of a Fabry-Perot Etalon Spectrometers for High-resln. NIR/SWIR obsvtn | Univ. of Leicester | Recruiting student |
| Quantifying the impact of a spaceborne multispectral lidar | Univ of Edinburgh (+ Selex-Galileo) | Recruiting student |
| LiDAR Measurement of Forest | UCL (CASE tbd) | Recruiting student |
| Study of a Far Infra Red Spectrometer for Climate Studies | Imperial College (CASE: Astrium) | Commenced in October 2009 |
| Multi-spectral imaging for EO | Univ of Edinburgh | Awarded Jan 2010 |
| Advanced Technologies Hyperspectral Imaging | Univ. of Durham | Awarded Jan 2010 |
| Remote Sensing using GNSS Reflectometry | Univ. of Surrey | Awarded Jan 2010 |

## ANNEX 1 PROGRESS TOWARDS STRATEGIC GOALS

The following table identifies the progress of the CEOI in achieving its strategic goals. The short/medium term goals identified are defined in the CEOI Work-plan (Ref: Appendix A to Extension to NERC Contract R8-H12-50, 25th June 2008). Progress is in line with expectations.

| Strategic Objective | Short/Medium-term Goal[1] (2-5 years) | Current Status |
|---|---|---|
| Vision | Maintain vision, strategy and roadmap in line with UK science priorities and industrial capability | The over-riding vision for the CEOI is to place UK technology on high priority EO science missions. Opportunities being pursued are (1) the Sentinel 5 pre-cursor mission, building on grism-based optical designs produced by SSTL (2) the PREMIER Earth Explorer mission candidate, using millimetre wave technologies from RAL, Astrium and QUB and (3) opportunities on the proposal to SEEDA/TSB for a UK Technology Demonstration Mission. |
| Instrument Development | Create and develop UK instrumentation addressing NERC science goals to access known near-term mission opportunities | CEOI instrument projects continue to develop technologies in readiness for potential future ESA EO missions, matching high priority NERC science goals |
| Technological Capability | Exploit known technologies in UK academia and industry to develop world class space EO instrumentation | The CEOI projects are actively exploiting existing UK competencies in optics, Lidars and passive millimetre wave technologies. Seven new projects resulting from the 2nd Open Call are underway. Eight new projects commenced in 2010, resulting from the 3rd Open Call. CEOI projects involve over 10 academic institutions at present. |
| International links | Identify and develop relationships with international partners in academia, industry and agencies to develop instrumentation and technology programmes of mutual benefit | Contact with ESA staff through face-to-face meetings and other communications. At the project level many partners are involved in the Earth Explorer and Sentinel programmes, and are collaborating internationally.<br>Good contacts are developing with Eumetsat through the UK Met Office, particularly in relation to Post EPS instruments. |
| Scientific Drivers | Map NERC strategic goals onto mission and technology options | The Challenge Workshop report on Future EO Missions identifies potential missions with high science priority for the UK. A programme of further challenge workshops on cross-cutting themes is underway. |

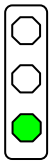
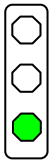
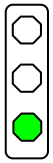
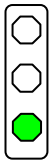
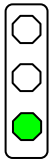
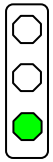
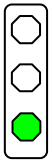
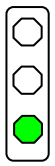
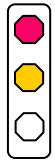
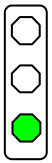
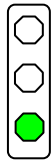
| Strategic Objective | Short/Medium-term Goal[1] (2-5 years) | Current Status |
|---|---|---|
| Training and Development | Establish CEOI studentship programme; Provide training and development programme for PhD/early stage people | Training Workshop on 'Developing and Delivering an Instrument Concept' held.<br>The two initial CEOI studentships are in their 3rd year; two studentships from Phase 2 have successfully recruited. A further 3 studentships are approved and seeking to recruit suitable students. |
| Horizon Scanning | Identify critical areas where an EO mission can give large scientific capital | The science Challenge Workshops series has identified a range of EO missions of high relevance to the UK science community.<br>Further work on identification of critical areas is taking place through CEOI events, the Sensors and Instrumentation KTN and other events. |
| Partnerships | Obtain funding from additional partners of £1M p.a. and initiate 6 additional technology partnerships within CEOI | Four additional technology partnerships have resulted through the CEOI 2nd Open Call, with industrial co-funding of £206K and academic co-funding of £51k. CEOI project partners have won contracts of >£1M p.a. from ESA and other sources, resulting from the CEOI work. |
| Technology pull-through | Identify critical technologies that can make a significant impact on the delivery of a key science missions and establish a development programme to pull through their benefits. | A summary of critical UK capability is maintained in the 'CEOI Opportunities Status Document' which was reviewed and revised in September 2009. |
| Missions | Identify potential UK national or bi-lateral missions<br>Prepare winning PI proposal for ESA EOEP mission | The Challenge Workshop series has identified potential national, bi-lateral and international EO missions. A number of UK-led proposals are under preparation for the current ESA EE8 mission, including CEOI teams. |
| Knowledge Exchange | Identify KE opportunities arising from the CEOI technology programme | CEOI projects have bid for and won funding for non-space applications of the technology. Qi3 are carrying out Technology Mining Activities into the CEOI technology projects to identify opportunities. |
| Industrial capability | Exploit known capability in space and non-space industry and make available to the Centre's instrumentation activities | Seven projects have been funded from the 2nd CEOI Open Call and eight projects from the 3rd CEOI Open Call. |

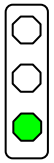
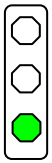
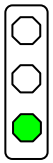
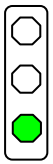
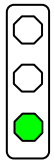
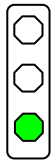
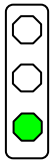
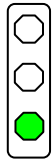
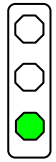
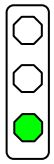
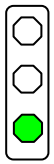
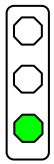
**Table 1. Short and long-term goals for the CEOI**

[1] Note: The long term goals (5-10 year time horizon) are described in the CEOI Workplan.

## ANNEX 2 CEOI METRICS

The CEOI Metrics were agreed between the CEOI, NERC and TSB in July 2008 as a means of identifying the successful outcomes from the CEOI programme. The status at the end of 2009/10 is as follows:

| ID | Target/Milestone Description | Owner | Start Date | End Date | 31-Dec-09 | 31-Mar-10 | Projection for next Quarter | Comments |
|---|---|---|---|---|---|---|---|---|
| 1 | **Three EO instruments incorporating CEOI developed technologies** | **CEOI Director** | **01-07-08** | **31-03-11** |  |  |  | Opportunities being pursued include Sentinels 4, 5 and 5 P-C; Premier, the Post-EPS humidity sounder and the proposed TechDemoSat. |
| 2 | **£1M Leveraged funding for technology development per year** | **CEOI Director** | **01-07-08** | **31-03-11** |  |  |  | In excess of £2.7M won in period 01-Apr-07 to 30-Dec-09. |
| 3 | **One/two new funding Partners engaged with the Centre** | **CEOI Director** | **01-07-08** | **31-03-11** |  |  |  | Good fit to proposed UK Space Agency National Space Technology Programme expected.<br>TSB are new funding partner for CEOI from April 2009.<br>EMDA are co-funding the CompAQS/ CityScan project. |
| 4 | **Four/five new project Partners engaged with the Centre** | **CEOI Director** | **01-07-08** | **31-03-11** |  |  |  | Four new partners through 2nd Open Call and an additional three through 3rd Open Call. |

| ID | Target/Milestone Description | Owner | Start Date | End Date | 31-Dec-09 | 31-Mar-10 | Projection for next Quarter | Comments |
|---|---|---|---|---|---|---|---|---|
| | | | | | | | | |
| 5 | **>75% of planned technology milestones achieved per quarter vs. plan** | **CEOI Technology Director** | **01-07-08** | **31-03-11** |  |  |  | Three of the four Phase 1 continuation projects completed on time.<br>The Phase 2 projects are coming to completion and on target. STEAM-R has delayed its start to align with the ESA Premier Phase A study. |
| 6 | **Five patents, publications and conference presentations per year** | **CEOI Director** | **01-07-08** | **31-03-11** |  |  |  | List of publications and conference presentations available |
| 7 | **Three Science and Technology Challenge Workshops per year** | **CEOI Science Co-Directors** | **01-07-08** | **31-03-11** |  |  |  | Three workshops held in 2009/10:<br>1. Surface/Atmosphere Interactions<br>2. Lidar Technologies<br>3. Operational EO Missions |
| 8 | **Four spin-in and spin-out opportunities identified per year** | **CEOI KE Programme Director** | **01-07-08** | **31-03-11** |  |  |  | Potential application areas identified for CompAQS, the LHR and Hollow Wave Guides through Technology Mining Activity in KE programme. |