Institution: Queen's University Belfast

Unit of Assessment: 13

Title of case study: Advanced Radiometer Instrumentation for Earth Observation

1. Summary of the impact

Research on Frequency Selective Surface (FSS) structures has led to major advances in the design and manufacture of the world's most advanced payload instrumentation for use in Earth observation satellites. This technology has provided the core element of the radiometer instrumentation needed for more accurate global weather forecasts and better understanding of climate change. The advances described have made it possible to combine all of the different functions of the MetOP-SG radiometer into one instrument, thereby halving the footprint of the satellite payload resulting in a (text removed for publication) cost saving.

2. Underpinning research

Key researchers involved *Robert Cahill (Reader) 2000-, Vincent Fusco (Professor) 2000-, Neil Mitchell (Senior Lecturer) 2008-, Harold Gamble (Professor, now retired) 2000-2010, Alex Schuchinsky (Reader) 2005, and Raymond Dickie (PhD student then RA/Engineer) 2003-.*

Time period, *2000-2013*

Space borne radiometers enable the retrieval of a wide range of geophysical parameters on a global scale. Between 1996 and 2005, 220,000 people were killed by weather related disasters, down from 2.6m in the period 1956 to 1965. This reduction is due, in part, to increasingly accurate early weather warnings. Improved understanding of climatic processes requires satellite instruments to monitor the changes and provide a health check on the environment. European mandatory programmes have been initiated to provide, for the first time, detailed observations for climate monitoring. The core sensing instrument deployed for this purpose is the radiometer.

Within the radiometer it is necessary to separate naturally occurring electromagnetic molecular emissions in the sub-millimetre range, 250GHz-850GHz, by frequency. This frequency range encompasses many of the natural resonances associated with green house gases. These emissions are extremely weak thus high receiver sensitivity is required. The key to the success of these Earth observation missions is predicated on frequency selective surface (FSS) filters which exhibit ultra-low insertion loss. In 2000 when missions for 2020 and beyond were being planned it was recognised by the European Space Agency, ESA, that all relevant existing filter technologies could not achieve the system level insertion loss requirement. Therefore there was an urgent requirement to address this gap in technology.

QUB were invited by ESA to undertake research to minimise mission risk through the creation of new advanced FSS technologies. Since 2000 to 2013 supported by EPSRC, ESA, RAL, Centre for Earth Observation Instrumentation, new modelling, microelectronics fabrication and metrology techniques were developed in order to produce a new class of substrateless FSS which resulting in the core research [1-3] underpinning this case study. The span of the work ranged from, technology concept formulated (2003), to system prototype demonstration in an operational environment (2012), to actual system, (2013).

The core underlying research necessary for this progression was as follows. In [1] we described an advanced micromachining technique that was used to create a multilayer freestanding FSS for single sideband filtering in a space borne radiometer. The work demonstrated that the structure exhibited significantly lower insertion and reflection losses than a conventional dielectric backed FSS, and, moreover, is structurally more robust hence better able to survive the forces of a launch vehicle. In [2] we described the electromagnetic design, fabrication and measurement of the *first ever* ultra-low loss space qualified frequency selective filter. This gave instrument designers, for the first time, the ability to detect vertical and horizontally polarised sub-mm wavelength signals simultaneously, thereby opening the possibility for radically simplified radiometer architecture development. These FSS were fabricated in the UoA13 Advanced Microsystems Centre, using specially developed precision micromachining techniques as described in [3], and have been successfully passed rigorous mechanical and thermal analysis, testing by the space industry as well as being approved for patent grant, [4].

3. References to the research

Four publications covering/underpinning this research are listed below. These have undergone rigorous peer review and the research funded through the externally peer-reviewed external grants shown. The three highlighted papers* are considered indicative of the quality underpinning the research.

IEEE Transactions on Antennas and Propagation *is one of the most cited peer reviewed electrical and electronic communication engineering journals (Impact Factor 2.151) specifically aimed at theoretical and experimental advances in antenna research, design and development.*

IEEE Transactions on Terahertz Science and Technology *is a recently published bimonthly peer-reviewed scientific journal covering terahertz science, technology, instruments, and applications.*

*[1] Dickie R, Cahill R, Gamble HS, Fusco V F, Schuchinsky, A, and Grant N : 'Spatial Demultiplexing in the sub-mm wave band using multlayer free-standing frequency selective surfaces', *Proc IEEE Antennas and Propagation*, 53, (6), 2005, pp. 1903-1911, doi 10.1109/TAP.2005.848668. *Cited by 22 Scopus.*

*[2] Dickie R, Cahill R, Gamble HS, Fusco VF, Henry M, Oldfield ML, Huggard PG, Howard P, Grant N, Munro Y, and de Maagt P: 'Submillimetre Wave Frequency Selective Surface with Polarisation Independent Spectral Responses', *Proc IEEE Antennas and Propagation*, 57, (7), 2009, pp. 1985 – 1994, doi 10.1109/TAP. 2009.2021933. *Cited by 15 Scopus.*

*[3] Dickie R, Cahill R, Gamble H S, Fusco VF, and Mitchell N: 'THz Frequency Selective Surface Filters for Earth Observation Remote Sensing Instruments', Proc IEEE Terahertz Science and Technology, 1, (2), 2011, pp. 450 – 461, doi 10.1109/TTHZ.2011.2129470.

[4] Cahill, R., Dickie, R., Fusco, V, Gamble, H, Improvements in or Relating to Frequency Selective Surfaces, European Patent EP1 861 896 B1, 2007, and Frequency Selective Surfaces, US 7,982 686 B2, 2011.

Key Grants:

R. Cahill, R. Dickie, V. Fusco and N Mitchell; "Quasi-Optical Network for Microwave Sounder**",** ***European Space Agency***, 4000/12/NL/BJ, - January 2013, 500K€ .

R.Cahill, R. Dickie, V. Fusco and H. Gamble; "Quasi-Optical Filter for Post-EPS Mission**",** ***European Space Agency***, 22938/09/NL/JA, - November 2009 - Feb 2012, 355K€.

R.Cahill, R. Dickie, V. Fusco and H. Gamble; "Frequency Selective Surface Filter Technology for Submillimetre Wave Radiometers", ***UK Centre for Earth Observation Instrumentation (CEOI***), Feb 2007 – Feb 2010, £84K.

R.Cahill, R. Dickie, V. Fusco and H. Gamble; "Innovative Low Loss Frequency Selective Surface Structures", ***European Space Agency*** - 19854/06/NL/JA, May 2006 - Feb 2009, 265K€.

R.Cahill, V. Fusco and H. Gamble; "Multilayer Mesh Filters for Quasi Optical Beamsplitting

Applications", ***EPSRC,*** GR/S13828/01, July 2003 – November 2005, £171K.

4. Details of the impact

The space industry is a UK Government priority[a] high growth sector with growing market in climate monitoring. QUB has made a significant and recognised contribution to this growth by developing new technologies and IP which have contributed directly to the UK space industry (not defined here – but below) securing a (text removed for publication) contract for advanced instrument development which is guaranteed to use QUB technology.

The UoA has been responsible for significant technology transfer to the UK and EU space industry. The main stakeholders, ESA, Astrium, RAL Space, the UK Space Agency and the UK Centre for Earth Observation Instrumentation (CEOI - www.ceoi.ac.uk) fund programmes which bring together academia and industry to identify and advance critical instrument technologies.
In 2008 a consortium comprising these organisations and the UoA was formed[1] with the express purpose to put the UK in an extremely strong bidding position for known future millimetre wave radiometry programmes through engagement with a series of carefully selected projects. These projects were chosen to reflect UK priorities, by identifying gaps in short- and mid-term radiometer instrumentation enabling technology requirements, where UK developed technology would have the largest impact.

FSS technology is a key enabler for improved sensitivity of remote environmental monitoring instrumentation. Since 2008 we have developed a variety of world leading patented FSS devices, European Patent EP1 861 896 B1, 2010, US patent US 7982 686 B2, 2011, based on advanced micromachined fabrication techniques. Consequently the UoA is the current main supplier of FSS to ESA. Working in partnership with RAL Space (2003-2008), QUB has supplied prototype micromachined frequency selective filters: quartz based FSS (2003); and improved air-spaced FSS (2008).

Several of these FSS have been used in PREMIER-Ex (Kiruna, Sweden 2010) and ESSenCe (Kiruna, Sweden 2011) scientific space instrumentation programmes resulting in two-to three-fold improvements in sensitivity in all observing channels. The higher-quality spectra obtained in these Swedish campaigns has resulted in more accurate retrieval of atmospheric constituent profiles. Another mission currently employing patented technology is the MARSCHALS radiometer. MARSCHALS is an airborne testbed for a new class of millimetre wave limb sounder and is the first such instrument to be explicitly designed and built for the purpose of Upper Troposphere and Lower Stratosphere composition sounding. By 2011 MARSCHALS represented approximately (text removed for publication) worth of business to RAL[2].

A major mission deploying QUB FSS technology is the Microwave Sounder Instrument (MWS), part of the MetOP-SG mission. When launched in 2020 this will be the world's most advanced meteorological data acquisition system. In 2008 the UoA started work on developing the different FSS structures for the MWS breadboard instrument. In (2012) ESA awarded QUB mandatory tender status for this mission-critical FSS work[3]. One of these structures - delivered in Feb 2013 - makes it possible to combine all of the scientific functions of the mission into one instrument thus saving more than (text removed for publication)[3] and halving the footprint of the payload on the satellite platform.

In Feb 2013 ESA preselected Astrium UK as the prime contractor to supply the advanced radiometer instrument for the MetOP mission. The QUB contribution to the proposal was critical to the success of the UK's bid to supply the instrument and QUB are guaranteed as the FSS prime for the instrument[4]. The value of the contract to Astrium is (text removed for publication) and the project will provide an estimated (text removed for publication) jobs in the UK resulting directly and indirectly from MWS[4,b].

5. Sources to corroborate the impact

CEOI[1]:
Director of the UK Centre for Earth Observation Instrumentation

RAL Space[2]:
Head of Millimetre Technology Group
Science & Technology Facilities Council
Rutherford Appleton Laboratory

ESA[3]:
Head of Antenna and Submillimetre Wave Section
Electromagnetics & Space Environments Division
European Space Agency

Astrium[4]:
Head of Future Programmes Astrium Ltd.

[a]http://news.bis.gov.uk/Press-Releases/Minister-gives-space-industry-added-boost-67cc1.aspx

[b]http://www.bbc.co.uk/news/science-environment-23313153