Government Office for Science

Foresight

Foresight Report: Exploiting the Electromagnetic Spectrum

Mid-Term Review

Foresight, Government Office for Science

Contents

Executive summary

The Foresight Project on Exploiting the Electromagnetic Spectrum (the Project), published in 2004, had two main aims. The first was to identify key areas of rapidly moving science that offered significant potential future commercial opportunity for the UK. The second was to agree a plan of action to ensure that the UK could capture a share of those emerging markets.

On the first aim, the Project was broadly effective in identifying areas that continue to be relevant five years later. This is reflected in sustained commercial interest and high levels of Research Council funding in the areas identified by the Project, particularly in optical data handling, photonics and electromagnetics.

The second aim of ensuring the UK benefit commercially from these emerging technologies - is more difficult to measure after five years. In many areas there have been continuing government and research council initiatives to encourage development, including some direct funding, since the Project's launch. The MoD, for instance, agreed to monitor and consider opportunities for funding research on metamaterials. The EPSRC has provided 48 grants, with a total value of over £41 million, on topics relating to systems on a chip, and 72 grants worth £55 million relating to optoelectric devices. In 2008, a £50 million fund supported the development of cancer intrusive techniques. A Photonics Strategy Group was established in 2005 and knowledge transfer networks set up in this area.

However, it is difficult to separate the impact of the Project from other, often more significant, reasons for the development of certain technologies. The opinion of several experts involved in the Project was that, while it encouraged greater attention of the areas it selected (which may have encouraged some focus in research) much of the work following the Project would have happened without the Project. In addition, there are few references to the Project findings in either government or academic literature.

In some areas identified in the project there has been less progress overall. Although research is continuing, some experts claim there are still few clear applications of the technology relating to electromagnetics in the near field. A Project aim to establish a network in coherent x-rays did not gain momentum following the Project's launch.

By comparison to many Foresight Projects, it would be fair to say that EEMS has had relatively little clear or measurable impact.

1. Introduction

This Review outlines the outcomes of Foresight's Exploiting the Electromagnetic Spectrum (EEMS) Project over a five year period since the launch of its findings. The Review provides an overview of the Project and main findings and draws links between the Project's outputs and the impact it has had. It considers how relevant its findings still are, how effective it was at informing research and development, and its impact in establishing links between business, investors and researchers and strengthening communities of interests.

Achieving and recording impact is an important aspect of all Foresight's major Projects. To this end, Foresight routinely undertakes a mid-term review around three to five years after the Project publication, of which this is one. This Review includes contributions from those involved in the Project as well as investigation into the areas the Project focused on and wished to influence, such as investment and research council funding.

This review was conducted by Foresight through a series of interviews with key stakeholders and experts involved with the Project.

2. Project overview

The Project had two main areas of focus. The first was to identify key areas of rapidly moving science that presented significant future commercial opportunity for the UK. This was completed in April 2004.

The second was to agree a plan of action to ensure that the UK captured a share of those emerging markets. It identified four areas to concentrate on, based on specific criteria: that areas should represent major economic activity 10-20 years hence and be innovative; be economically significant; be available for the UK to exploit; and provide a balanced portfolio of topics. The four selected were:

- Switching to light: all-optical data handling
- Manufacturing with light: photonics at the molecular level
- Inside the wavelength: electromagnetics in the near field
- Picturing people: non-intrusive imaging.

Each area had it own action group to develop plans for action based on their technical challenges and business opportunities. Members of the action groups were drawn from business, academia, user communities, government and other agencies.

The Project outputs included:

- A report containing the findings and analysis of the Project https://www.gov.uk/government/publications/exploiting-the-electromagnetic-spectrum
- State of Science Reviews http://webarchive.nationalarchives.gov.uk/20140108140803/http://www.bis.gov.uk/foresight/our-work/projects/published-projects/exploiting-the-electromagentic-spectrum/reports-and-publications
- ‘Tales from the Future’, a set of narrative stories designed to bring to life aspects of the developments in technology identified in the Project https://www.gov.uk/government/publications/exploiting-the-electromagnetic-spectrum
- A ‘Real Options Calculator’ developed to help assess potential investments in research and development, based on real options methods. http://webarchive.nationalarchives.gov.uk/20140108140803/http://www.bis.gov.uk/foresight/our-work/projects/published-projects/exploiting-the-electromagentic-spectrum/reports-and-publications

3. Key findings

The following table sets out the initial investment and best-guess predictions of the UK's market share of five of the EEMS subject areas. The table can be found in the Findings and Analysis document. https://www.gov.uk/government/publications/exploiting-the-electromagnetic-spectrum

EEMS topic area	Phase 1: Initial investment (duration)	Total investment cost (total duration)	Value of UK share of market
Optical switches	$15 million (5 years)	$215 million (8.5 years)	$0.5 billion
Diagnostic lab on a chip	$15 million (3 years)	$570 million (9 years)	$5.0 billion
Low cost security imaging	$50 million (2 years)	$145 million (6 years)	$0.4 billion
Laser machining	$100 million (4 years)	$580 million (12 years)	$2.0 billion
Smart contrast agents	$160 million (5 years)	$1,500 million (16 years)	$6.0 billion

4. Impact

This Review considers the Project's impact in each of the four areas it selected as emerging markets. These are based on the continuing relevance of the areas, whether the Project informed research and development and the Project's role in establishing links between business, investors and researchers and strengthening communities of interests.

4.1 Continuing relevance

Overview

One of the aims of the EEMS Project was to identify the key areas of long-term opportunity across the electromagnetic spectrum. The continuing wide ranging interest in these areas gives a good indication that it selected the right topics to focus on. More detailed consideration of the Project's relevance in each of its four priority areas is outlined below.

Switching to light: all optical data handling

One of the factors that the Project claimed would aid the development of a market for optical data handling is the increase in the home market for high-rate broadband. The development of high rate (100mb/s) broadband to the home/user is still a major issue, especially with the increasing use of online entertainment, such as the BBC's popular iPlayer. Domestic fibre optic broadband is now available, although in a very limited number of areas.

Francesco Caio's report for the Department for Business, Enterprise and Regulatory Reform in 2008 on a review of barriers to investment in next generation access suggested that:

> *'In the mid- to long term, Broadband/NGA (next generation access) will become a critical digital utility, essential to the competitiveness of any country and to the quality of life of its citizens. The UK will be no exception and, if anything, it will be even more dependent on this infrastructure than other economies. Here, high-quality broadband will be essential for the continued development of sectors that in recent years have elevated the UK to a position of global leadership, such as the creative industries, financial services, software and gaming. Equally importantly, broadband will be central to critical processes of information and innovation in education and health services.'*

Internet connectivity is an issue still relevant to government: the Digital Britain report in June 2009 aspired to universal access to 2Mbps broadband in the UK by 2012. In 2009, the Government also made public funds available to encourage next generation digital networks, including optical networks, which they believed would be desirable for the majority of the country. The increasing desire for high-speed broadband makes optical data handling at least as relevant as when the findings were published.

Manufacturing with light: photonics at the molecular level

There is still much research going in this area and several commercial possibilities for the technology are being developed. The Photonics Strategy Group, part of the action plan following publication of the Project, published a report in 2006 which predicted very significant growth in several markets for photonics products.

In 2006, Lord Sainsbury gave a speech in which he explained that "very significant growth is expected in several markets for photonic products over the next ten years- they include Lab-on-Chip, Security, Fibre to the Premises (FTTx) and Next Generation Broadband, Displays, and High Brightness LEDs."

Inside the wavelength: electromagnetics in the near field

Although research is continuing, some experts claim there are still few clear applications of the technology. The Ministry of Defence remains interested in the potential for defence applications.

Picturing people: non intrusive imaging

Non-intrusive imaging remains especially relevant in the two areas identified in the EEMS Project: healthcare and security.

In healthcare, the range of options for non invasive medical imaging is increasing with the discovery of new technologies, from laser scans rather than biopsies to 3D CT images. As new computing technology becomes available, growth in this area is likely to follow. It has also been claimed that a greater desire by consumers to monitor their health is likely to increase the market for medical imaging.

The desire for security is greater than ever, and that requires more effective imaging of people, for example as they enter buildings or prior to boarding an aircraft. Development of scanners must respond to new security threats, while also not dramatically affecting the length of time taken to screen for problematic items.

4.2 Informing research and development

Overview

It is unclear how far research and development can be traced to the Project's impact. It is increasingly tenuous to draw links between the project outputs and the effects it may have had, since there are likely to have been many factors, such as consumer demand and market conditions, which have influenced investment decisions Experts involved in the Project have reported that the ideas of the EEMS Project are still at the front of the Research Councils agenda, but an explicit link back to the Project is difficult to make. The author of a state-of-science paper written for the Project considered that the Project has been relevant but summarised the difficulty of evaluating its impact:

> *"The direct impact of the EEMS process is naturally a difficult and hard thing to gauge after this time: certainly (ad hoc) many people in the industrial sector I know in the UK are aware of this and have found its outcomes of relevance and very informative for their company strategy."*

Instead, this Review highlights those areas of research and development most closely associated to the work of the Project.

Three of the four Engineering and Physical Sciences Research Council (EPSRC) -led 'mission' programmes in 2008/9 for instance, have obvious links to the Project's areas: The digital economy; nanotechnology, through engineering to application, and 'Towards next generation' healthcare. With similar objectives to the EEMS Project, these missions include the aim to maximise exploitation by business. A representative from EPSRC considers that, although the Project did not play a major part in shaping their policies, the fact that they circulated the Project report and findings to academics led to it playing a part in shaping the proposals which they received.

Switching to light: all optical data handling

There is still much research being carried out in this area, and this is reflected in the grants provided by the research councils. In 2008/9, EPSRC funded 21 proposals, with a total value of £46.2 million, though its Digital Economy 'mission'. At the time of writing there were 41 grants, with a total value of over £26 million, in the area of optical communications, which included areas such as advanced optical modems and ultra-fast photo-detectors.

One of the Technology Strategy Board's November 2008 competition subjects was 'Photonics – next generation optical internet access', where £1 million of funding is available. One of the areas for proposals is optical switching devices, which the Project highlighted as being an area that needs improvement and more widespread use in order to satisfy future internet demand.

According to an expert involved in the Project, the interest in photonic crystals is now more focused on the area of specialised sensors, particularly in biophysics, than in telecommunications.

Manufacturing with light: photonics at the molecular level

Lab-on-a-chip, highlighted in the report, continues to be a major research area. An author of one of the Project's state-of-the-art science reviews stated that *"… the themes and directions indicated by EEMS are still very much alive and moving forward even in these turbulent times. Certainly the review was accurate in predicting where say novel photonics might help in healthcare and lab-on-a-chip devices for example which continues to be a major area".*

EPSRC funds 18 Industrial Doctorate Centres, which award industrial doctorates that enable graduates to move into industry. One of the new centres is the Optics and Photonics Technologies Centre, a collaboration between Heriot-Watt, St Andrews and Strathclyde universities, which aims to research and knowledge transfer between the participating universities and UK industry across a wide range of related technologies.

At the time of writing, EPSRC had 48 grants, with a total value of over £41 million on topics relating to systems on a chip, and 72 grants, with a total value of over £55 million, relating to optoelectronic devices and circuits. Defra awarded Central Science Lab near York £1.5 million in funding to carry out research on lab-on-a-chip, although this is likely to have been more directly influenced by the Foresight Project on Infectious Diseases.

The last 3 years has seen success for many photonics companies. Mesophotonics, a spin-out company from the University of Southampton, which develops photonic crystal technology for optical devices, was recently bought by another spin-out company, from Strathclyde University. In the years up to their take-over, Mesophotonics won substantial

funding from investment companies, which made commercialisation of their product more possible.

Inside the wavelength: electromagnetics in the near field

The EPSRC's 2008/9 Annual Report included an interesting association of two of the EEMS Project's subjects. Professor Nikolay Zheludev, of the Optoelectronics Research centre at the University of Southampton claimed that "the next photonic revolution will be fuelled by the development of photonic Metamaterials"

Following the Project launch, the MoD agreed it would now monitor the metamaterials area and consider opportunities to fund research in metamaterials under the Joint Grant Scheme. The MOD also raised meta-materials as an area of interest in its 2006 Defence Technology Strategy. The Defence Technology Plan states a desired outcome that the *"MOD gains military advantage through early adoption of Metamaterials, Micro and Nano Technologies in defense equipment"*, with a timescale of activity to the end of 2010.

Terahertz technology is also highlighted in the Defense Technology Plan as an area which could have provide opportunities for sensor equipment, with a research objective in this area until early 2013. EPSRC has also funded research into portable terahertz technology which would make the technology more desirable for military use.

Picturing people: non intrusive imaging

The Project report identified two applications of non-intrusive imaging where there was opportunity for the UK to make commercial benefits: healthcare and security.

Healthcare is a particularly difficult area to make a causal link between research and its motives. There will always be many reasons other than the purely financial to investigate means by which we can diagnose illness and treat it effectively. In 2008, a £50 million fund, made up of grants from research organisations including EPSRC and the Medical Research Council, was set up to support the development and introduction of the latest cancer imaging techniques, including non intrusive methods such as MRI. This strategic investment has the potential to help the UK become a world leader in cancer imaging research.

Security is also a particularly difficult area in which to link the findings of the Project to informing research and development, as technology development responds to changing security needs. An example of this is the recent intensifying of research into detecting liquid explosives in a non-intrusive manner following their use in attempts to carry out terrorist attacks on aeroplanes. EPSRC, for example, is funding DISTINGUISH, a project at Liverpool University which aims to research, design and build a system to enable efficient screening of goods in transit, both domestic baggage and international cargo.

4.3 Establishing links between business, investors and researchers and strengthening communities of interests

Switching to light: all optical data handling

The Technology Strategy Board (TSB), along with industry and academia, funds 25 Knowledge Transfer Networks (KTNs), which aim to promote the exchange of knowledge and the stimulation of innovation in communities with a shared interest in emerging technologies. Optical communications is one of the priority areas for the Photonics and Plastic Electronics KTN, identified as one with maximum potential for wealth creation. Exploiting the Electromagnetic Spectrum is included on their website.

Manufacturing with light: photonics at the molecular level

In 2005, the Photonics Strategy Group was set up, with the aim of ensuring a coherent and co-ordinated national strategy for developing and applying the technology. In 2006, they published 'Painting a Bright Future. Photonics: A UK Strategy for Success', which considered Information & Communication technologies and Consumer Photonics; Life Sciences and Healthcare; Defence and Security; Lighting and Energy and Industrial Photonics.

The Photonics Knowledge Transfer Network (KTN) was set up in July 2006, to run for 3 years, to support the photonics community through knowledge, enhanced skills and collaborative partnerships. In 2009, this KTN was merged with another to create the Photonics & Plastic Electronics KTN.

One of the new Industrial Doctorate Centres, funded by the EPSRC, is the Optics and Photonics Technologies Centre. A collaboration between Heriot-Watt, St Andrews and Strathclyde universities, it aims to research and transfer knowledge between the participating universities and UK industry across a wide range of related technologies.

Inside the wavelength: electromagnetics in the near field

In the Project report, one of the measures given that would support the industry growth in the area is 'facilitating and encouraging industry collaboration, in particular establishing clear Intellectual Property (IP) exchange/protection rules'.

NPL hosted a conference on Precision Electromagnetic Measurements inLondon from 27 June - 2 July 2004, with over 500 international delegates, at which the EEMS findings were reported. This encouraged the formation of a Project on attosecond laser technology at NPL as part of the 2004-07 Quantum Programme.

However, experts claim that there are still few clear links between the research and applications that would be useful for business.

Picturing people: non intrusive imaging

Following the publication of the report, NPL, Department of Health, EPSRC, BBSRC and Medical Research Councils all strongly supported the creation of a medical imaging network. DTI was initially taking this forward through the Faraday Partnerships. In 2006 the Health Technologies Knowledge Transfer Network was been established, which includes the area of medical imaging. This provides an opportunity to network between business, academia and the clinical base through events, meetings and special interest groups.

4.4 Factors limiting impact

Some planned activities in the Project did not come to fruition. For instance, one of the activities set out at the Project launch was for the National Physical Laboratory (NPL) to help develop and support a network in Coherent x-rays (one of the non-selected topics from the EEMS shortlist) and run workshops. However, lack of funding meant that the network was not created and there were no further events in this area after a 2 June 2004 seminar at NPL.

This chapter has been developed directly from the contributions from stakeholder organisations.

5. Conclusions

Foresight's Exploiting the Electromagnetic Spectrum Project was largely successful in identifying areas of science and technology that would be important areas of commercial interest, and these areas are still relevant after five years. This is evident from the subject of Research Council grants and from Government funding and publications, probably most notably the report Digital Britain, highlighting the desire for high speed broadband across the UK.

The project may have influenced research by raising the profile of certain areas, although there is little continuing reference to the Project's findings on either Government or academic websites and literature. This is likely to be because the areas selected, because of their continuing relevance, are those which have many factors behind their development. Many of the actions following the Project, such as the setting-up of Knowledge Transfer Networks or events bringing together communities of interest, have encouraged discussion of the importance of these areas, although the implications of this are difficult to quantify.

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