BR-212
November 2003

TECHNOLOGY PROGRAMMES

STARTIGER

TECHNOLOGY PROGRAMMES

The success of a space mission is always linked to the performance of technology. To have a technology ready when a satellite flies, research and development must start years in advance. This is the objective of the Technology Programmes of the European Space Agency: to ensure effective preparation for European space activities.

StarTiger is a good example of space technology. It is a technology breakthrough achieved in a very short time by a motivated European team.

I hope this brochure will let you share the enthusiasm of the engineers who made it happen. Above all, I hope it will help you to appreciate the efforts of all those European engineers who work behind the scenes on space projects, not only for this project, but also in many other fields. Without their hard work, Europe's success in space would not have been possible.

Niels E. Jensen
Head of the Technology Programmes Department

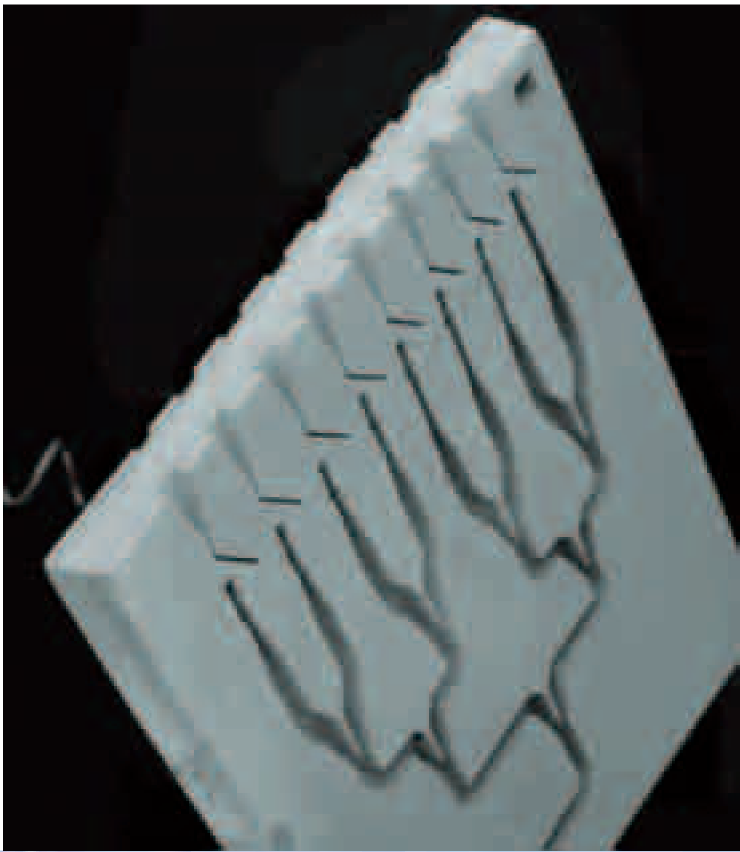
STARTIGER

A Fresh Look at Innovation

As exciting as it was challenging, the StarTiger project had a twofold objective: to develop a new and promising technology, and to conduct leading-edge R&D in a novel and innovative manner. It has proved to be very successful on both counts, illustrating ESA's innovation policy as well as reflecting its overall policy of striving to serve European citizens.

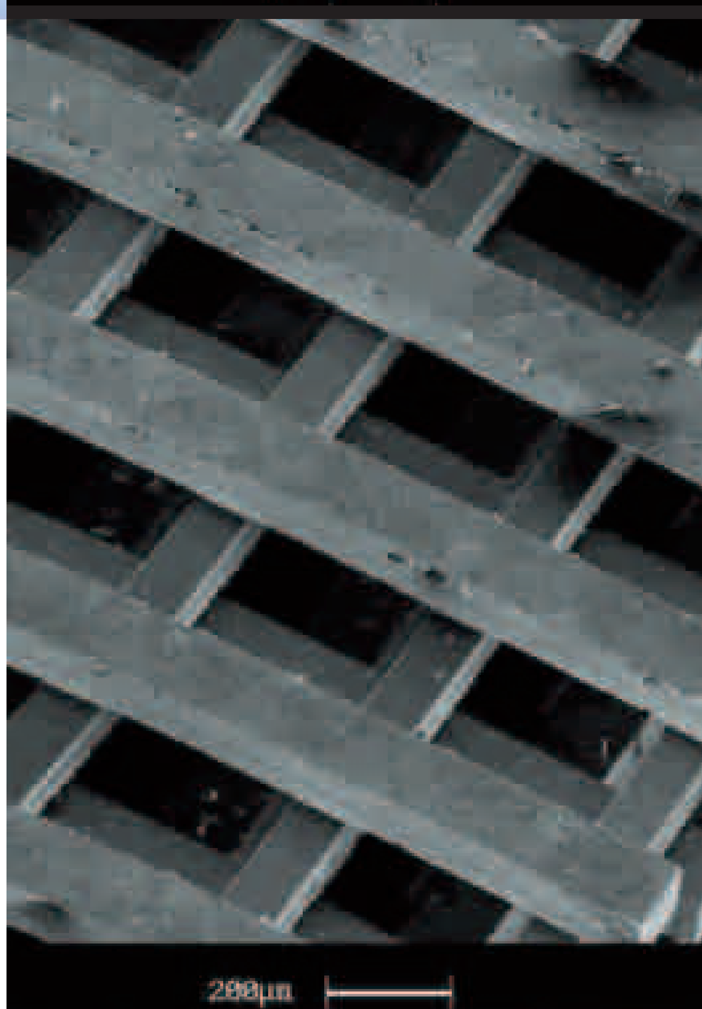
INTRODUCTION

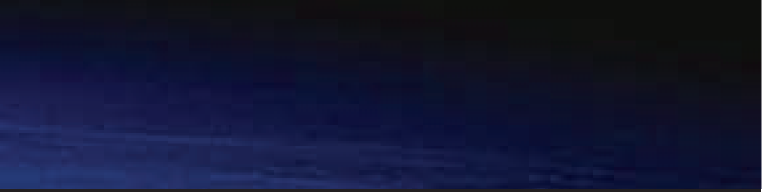
Bring together a small group of highly motivated researchers, grant them full access to laboratory and production facilities, remove all administrative distractions, and let them work intensively four to six months. That's what 'StarTiger' was all about! It is a new approach to conducting R&D that aims to demonstrate the feasibility of a new and promising technology within a very short time scale. In line with the recent initiative within the Agency's Basic Technology Research Programme (TRP) to facilitate innovative and breakthrough research, StarTiger has also provided a fresh look at innovation, specifically addressing the way in which space-related R&D is conducted and implemented.



The StarTiger concept - Space Technology Advancements by Resourceful, Targeted and Innovative Groups of Experts and Researchers - can be applied to all innovative technological research. The field of antennas was chosen for the pilot project and the goal was to develop a compact submillimetre-wave imager using state-of-the-art micro-electromechanical technology. Such an imager would overcome a number of barriers currently limiting progress both in space-application fields and in terrestrial systems.

The pilot project started at CCLRC Rutherford Appleton Laboratory (RAL) in June 2002 and was scheduled to last for four months. RAL was chosen as the most suitable location because of its advanced laboratories and technical support facilities. The team would be granted full access to the resources of the Central Microstructure Facility and the



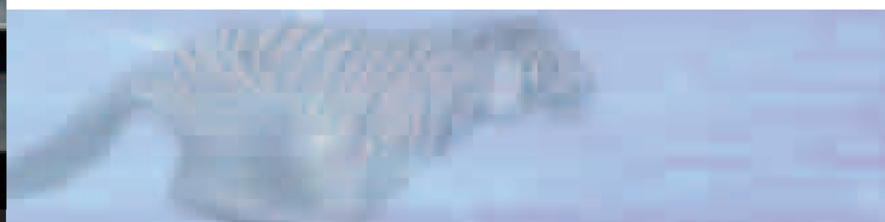


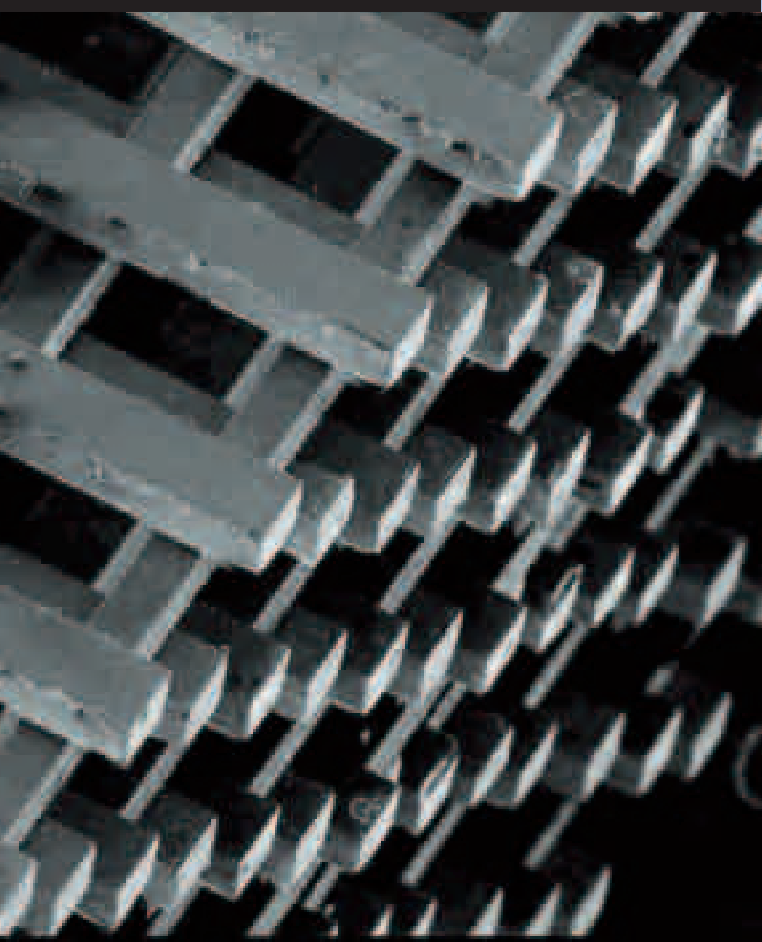
Millimetre-Wave Technology Group, and would be supported by the laboratories' engineers and scientists. This would ensure that emerging ideas could immediately be applied and confronted with reality.

A team of eleven scientists from seven European countries were handpicked in April 2002 for their expertise and their ability to work together, to push present state-of-the-art technology to its limit. Highly motivated, they also possessed as a team all of the know-how needed to make the project a success within the tight schedule. The project was officially inaugurated on 24 June by Lord Sainsbury, the UK Minister for Science and Innovation.

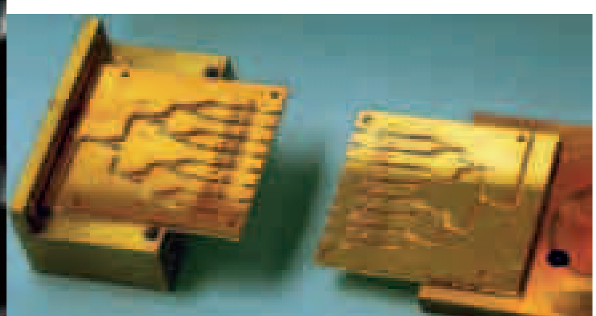
THE BIRTH OF A NEW R&D CONCEPT

The concept for StarTiger was born out of research into photonic band-gap technology led by ESA's



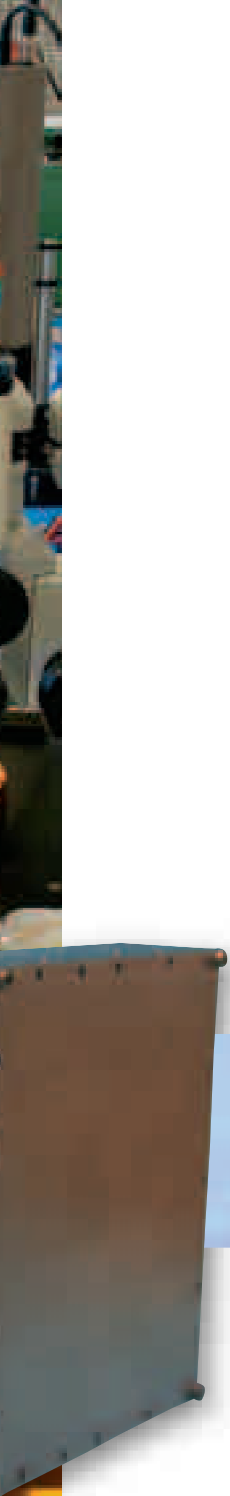


European Space Research and Technology Centre (ESTEC) in Noordwijk (NL) in the late 1990s. By the end of the decade, this had resulted in the development of one of the first photonic-bandgap antennas able to operate at sub-millimetre wavelengths. At the same time, several other researchers were working at ESTEC on similar topics and the potential synergy did not go unnoticed.



‘We noted that the total result would be larger than the sum of the individual parts. This eventually led to the idea of providing a more solid framework for collaboration,’ says ESA’s Peter De Maagt, one of the originators of the StarTiger idea.

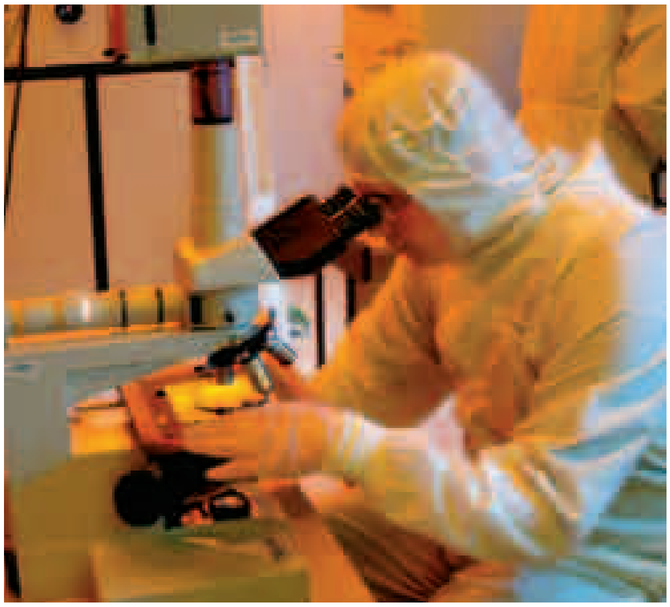
Elsewhere, a suitable programmatic framework for the project was falling into place. The first version of the ESA Technology Master Plan had been issued in 2000 and among the directives set was one to allocate 50% of the Technology Research Programme (TRP) budget to ‘innovative/prospective technologies’. To serve this innovation policy properly, a whole new set of approaches was being proposed and implemented. Not only compliant on the technology side – because it was to demonstrate a unique and highly promising technology – the StarTiger project was also appropriate because of what it offered in terms of a potential new way of performing technology R&D. The project was therefore presented at the Space Technology Innovation Workshop held on 6-7 September 2001 in Copenhagen, Denmark. The following month ESA’s Industry Policy Committee (IPC) approved the pilot

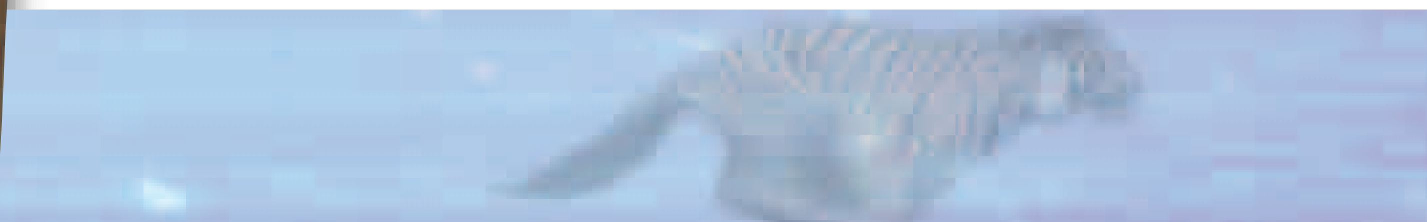


project and the hunt for the best scientists and engineers to work on it began.

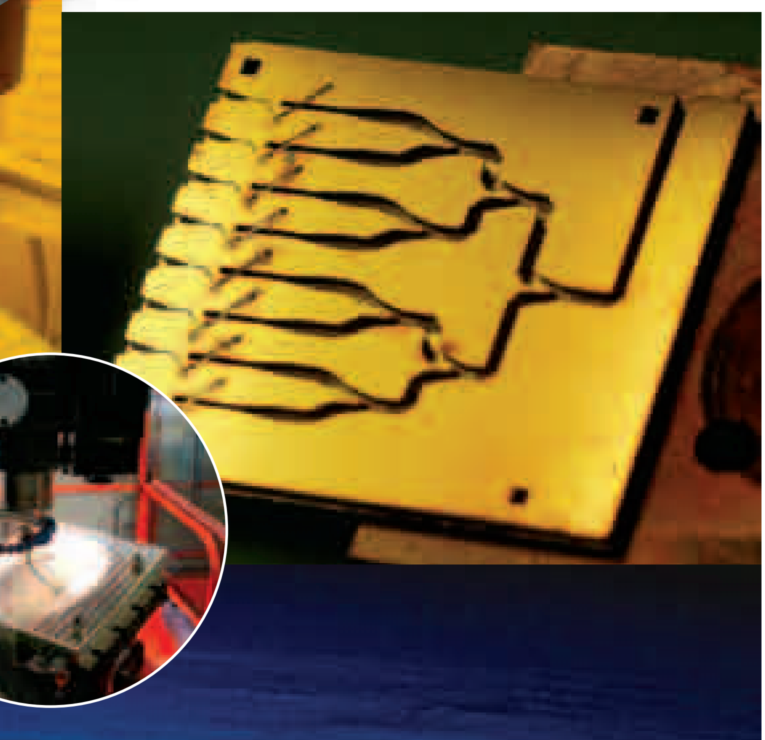
An advertisement was published in the 21 March 2002 issue of the science magazine 'Nature', as well as on its web site. On 2 April, an article announcing the project and the recruitment campaign was published on the ESA web portal and an extensive e-mail campaign was begun. With the tight deadline imposed by the planned project start in June, an unconventional approach to candidate selection was required: from 30 eligible applicants, 16 scientists and engineers were invited to an assessment weekend, on the 27 and 28 April, at a hotel near the planned 'home' for the StarTiger team.

In addition to the interviews and several selection tests – including personality, mental and physical awareness, as well as technical skills testing – it was important during this weekend to familiarize everyone with the engineering tasks ahead and the





special working demands of StarTiger. Everyone had to be able to concentrate 100% on the project for four months and to 'forget', as far as humanly possible, all other commitments. The multi-disciplinary research team finally selected consisted of 11 scientists and technical specialists from seven European countries – France, Germany, Ireland, Italy, Netherlands, Spain and the United Kingdom.

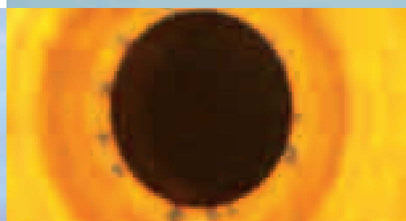


'As the StarTiger team attempted to combine technologies still in their infancy, it was clear that they needed to overcome some daunting tasks along the way,' says Chris Mann, RAL Team Leader. 'The members were handpicked for their expertise and their ability to work together, so we had the best chance of pushing the present state-of-the-art technology to its limit.'

The R&D 'race' began on 5 June 2002 with the goal to achieving a terahertz image of a human hand within four months.

THE IMAGER

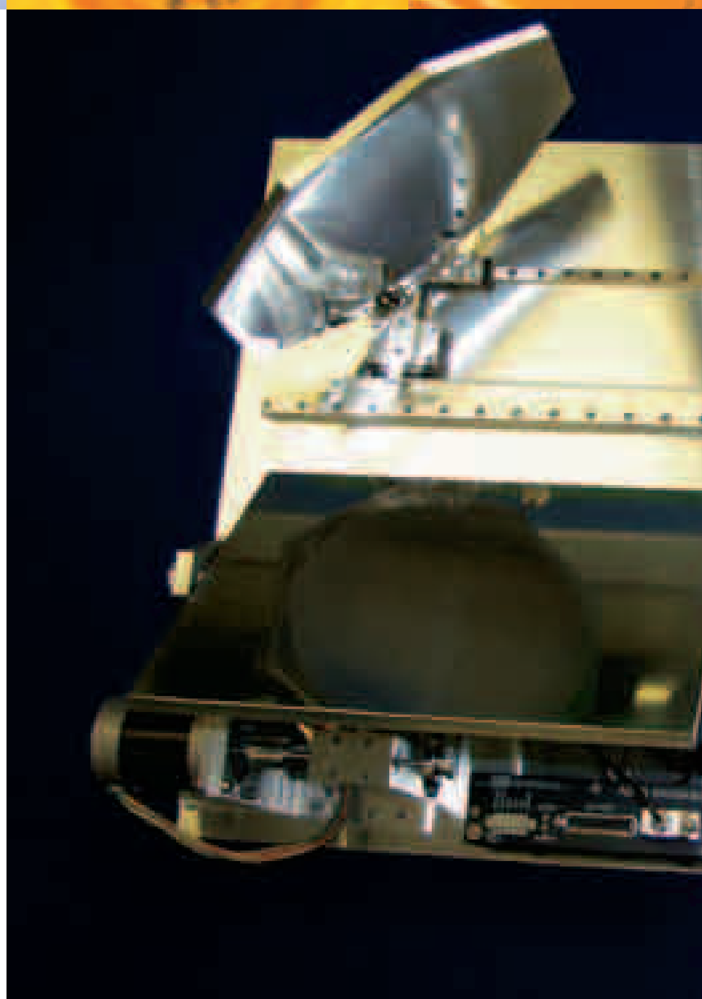
Although many options existed for a pilot project, the terahertz imager was chosen primarily because such a technology simply did not exist but was highly desirable. Development of the StarTiger 'colour' sub-millimetre-wave imager has integrated such innovative technological areas as planar antenna technology, planar detector technology, micro-machining technology, photonic band-gap materials and miniaturised back-end electronics.

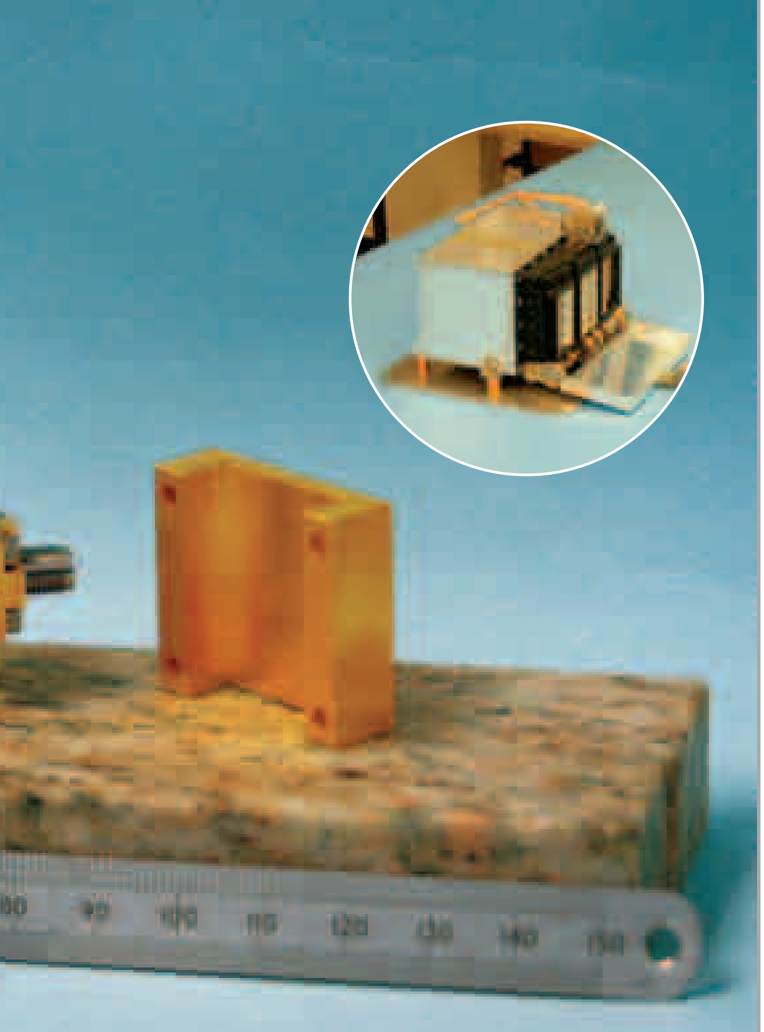


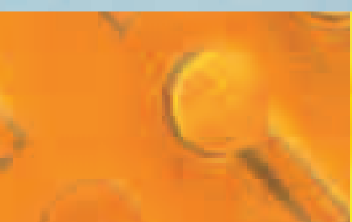
Previous attempts at making an imager for the terahertz frequency range have primarily been based on waveguide-based technology and assembled from discrete elements, making them bulky. Cost also restricts the maximum number of pixels available with this approach. Recent advances in lithography and micro-machining offered the potential for making a much larger, truly two-dimensional imaging array. Such an approach greatly simplifies manufacture and assembly and enables a much larger scientific throughput.

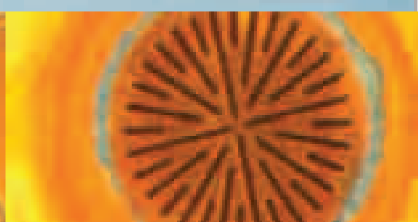
Micro-machining technology had been investigated through ESA funding. It had proved possible using Micro Electro Mechanical System (MEMS) fabrication techniques to produce micro-machined structures for the first time and at very low cost.

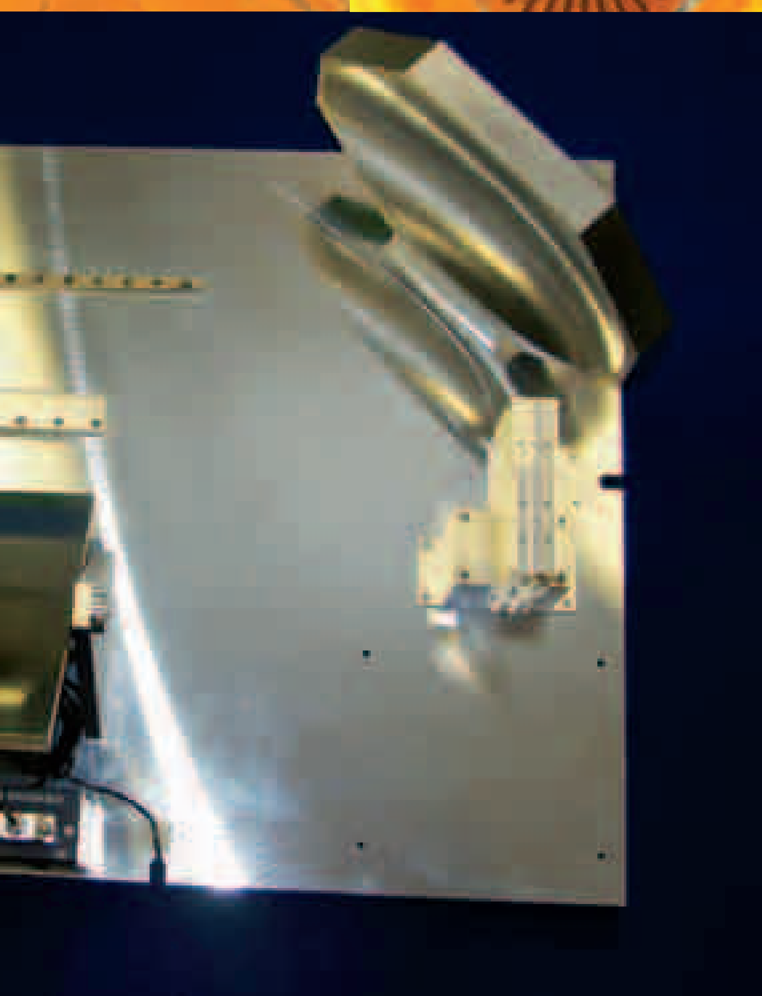
The photonic band-gap material is silicon-based and can be machined in very much the same way. Instead of absorbing the terahertz radiation as a











semiconductor normally does, it reflects it and focuses it onto the detector elements. This is done by making short parallel grooves on both sides of a thin wafer of silicon, by a combination of lithographic processing and plasma etching. Silicon layers are then built up so that the lines form a 'wood pile' structure, with the spacing between the grooves determining the operating frequency.

Both technologies can be used together to integrate the active devices in the complete imaging front-end. The single-pixel demonstrator focuses the radiation onto oscillators, mixers, amplifiers and detectors all embedded in the silicon. A 32 x 32 pixel image is built up using moving mirrors to scan radiation from different parts of the object across the sensor.

The StarTiger terahertz image demonstrator operates at 0.25 and 0.3 THz. By responding to natural submillimetre waves at these two frequencies, it can discriminate between materials with different transmission and reflection properties, effectively creating two colours.

FOUR MONTHS IN THE MAKING

Two core matters that had to be settled before starting the activity were the question of Intellectual Property Rights (IPR) and the criteria for success. An IPR agreement was drawn up to facilitate the free exchange of ideas and technical information needed to foster an innovative and collaborative environment. The contract was also driven by the need for the fair treatment of all participants in order to ensure sound multidisciplinary teamwork.

The approach chosen was that the eleven team members would be the co-owners of any invention made during the work undertaken within the framework of StarTiger, allowing them to protect inventions by patenting or another form of IPR in accordance with applicable laws. As the host institute, RAL is entitled to a free, non-exclusive and irrevocable licence to use and copy the information resulting from the project for its own needs in the field of space research and technology and their space applications, without the right to grant sub-licences.

ESA and the Member States are entitled to a free of charge, non-exclusive, irrevocable licence to use the invention for their own purposes in the field of space research and technology and their space applications and are allowed to grant sub-licences for these purposes within the territories of the Member States.

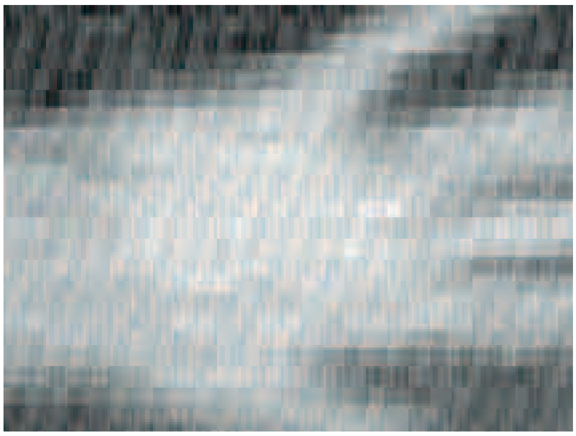
Secondly, criteria had to be defined to measure the (expected) success of the project, and to provide a clear, simple and undisputable way of assessing the outcome. If the capture of a passive terahertz image of a hand was the criterion defining technical – and consequently project – success, the team had been provided with a technical achievement scorecard range of 1-5. The conservative approach would result in the minimum success achievement of 1, whilst a fully electronically scanned system would receive a score of 5.

The following five items had to be progressed from a design on paper to hardware realisation:

- the micro-machined room-temperature detector
- the two-colour micro-machined wave-guide array
- the photonic band-gap mixer
- the two-dimensional array
- the electronically scanned array.

The last three items were thought to be pretty much unattainable given the time scale, but everything was now in place and StarTiger could start.

Key to the StarTiger principle was the bringing together of a team from several different backgrounds, including chemistry, material science, lithography, physics, as well as RF design. Consequently, many of them had never even heard of terahertz technology before, but it was hoped – and subsequently shown – that such a broad range of experience would provide different approaches to the problem and thus enable innovative solutions. To speed up the team-building process, they spent the first weekend surfing and cliff-climbing together, but also that weekend devised their basic strategy for the task ahead!



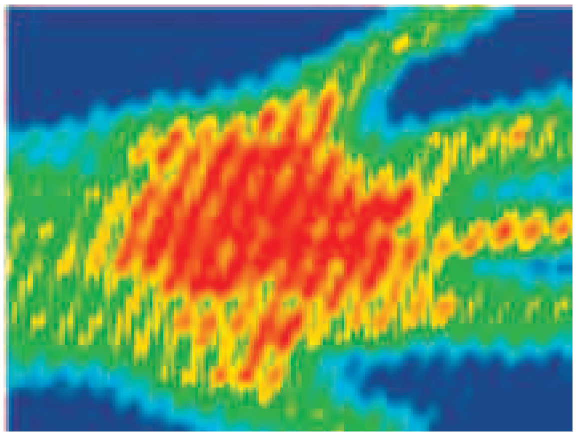
The pixellation and scan lines

They decided to split their approach into two phases. Initially they would build a system relying on conventional mechanical scanning technology to enable an early demonstration and uncover any underlying problems. Whilst this system - dubbed the 'conservative approach' – was being designed and built, in parallel the team would study possible options for the final 'advanced approach'. The team also quickly identified the critical technology needed to meet the fifth level of success, namely a low-loss phase shifter. The team also worked in parallel on photonic band-gap electronics, bolometer arrays and novel fabrication technologies.

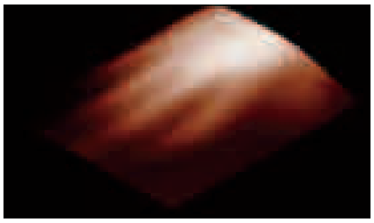
The team worked extremely hard, achieving many successes and also overcoming many difficulties. Morale was kept high by the constant successes, but also by persevering with attempts to overcome seemingly impossible challenges. They made use of mobile telephones in more ways than one - not only were they used to communicate quickly across the site, but the latest miniature electronic components developed for the mobile industry were exploited to build some of the hardware !

The first image was captured six weeks before the end of the project using the conservative system. Not surprisingly, a great shout went up when it appeared on the computer screen. However, the greater task, namely to capture a colour terahertz image with an array of sixteen detectors, was still to be achieved in the time remaining.

Among the other new technologies demonstrated was the world's first active photonic band-gap component, designed using finite-element analysis and built in just 16 days. The team also demonstrated novel room-temperature bolometers, and the key new technology needed to enable electronic scanning at sub-millimetre wavelengths, namely an electronic phase shifter. The details of some of these items have to remain confidential for the time being for patent reasons. However, the fact that five patent applications are in process is a good indicator of the degree of innovation that has taken place under the StarTiger umbrella.



Introducing false-colour brings out more subtle features



Three-dimensional representation, in which the height represents intensity

After four months of intensive work, and right on schedule, the StarTiger team presented its results at ESA/ESTEC on 25 October 2002. The team had indeed successfully built an image demonstrator and had managed to capture the world's first picture at 0.25 and 0.3 terahertz of a human hand !

ALIVE AND KICKING: THE POTENTIAL APPLICATIONS

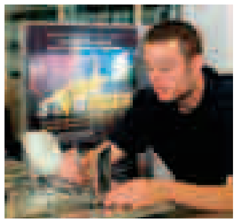
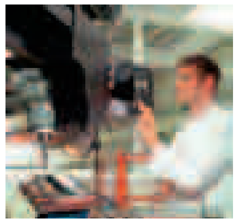
The unique properties of terahertz waves can undoubtedly pave the way for numerous, as yet unforeseen space and non-space R&D applications based on their colour-imaging capability.

The use of optical-wavelength focal-plane arrays (e.g. CCDs) in imaging applications for astronomy, high-resolution still and video cameras, star trackers, etc., has become commonplace within both the defence and civilian sectors. Detection systems capable of high-resolution imaging in the millimetre and sub-millimetre wavelength region are still far less common, due to technical difficulties and perceived costs associated with the development of arrays with sufficient sensitivity. Even if much still remains to be done before a terahertz camera flies in space, the StarTiger image demonstrator has definitely broken down many of the intervening barriers.

Cosmology, the science of how the Universe formed and is now evolving, has become one of the richest fields of experimental research. It has been discovered that there are very many small variations in the cosmic microwave background and that these form the fingerprints of what happened in the very early stages of the Universe. The precise shape and intensity of these temperature variations can be determined accurately by combining millimetre and sub-millimetre wave measurements.

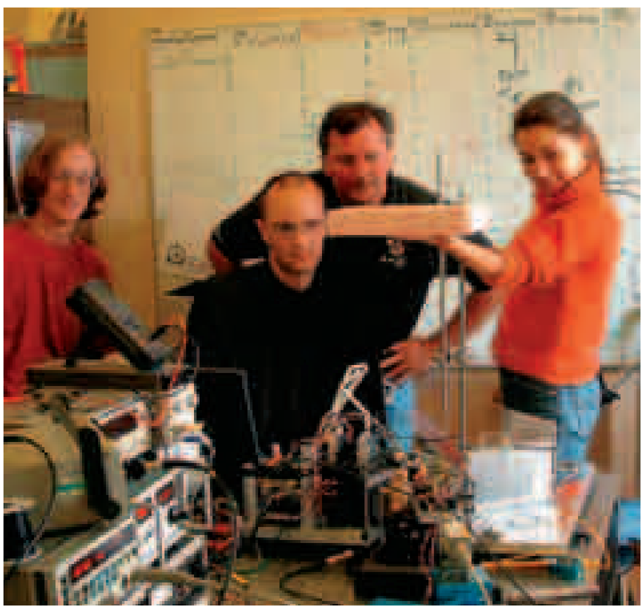
Space astronomy observations at sub-millimetre wavelengths will also open up a virtually unexplored part of the electro-magnetic spectrum that cannot be well observed from the ground. This could help answer some of the big questions as to how stars and galaxies formed in the early Universe, and how they are continuing to form.

In the area of Earth environmental monitoring too, there are several very important processes taking place in the atmosphere that deserve our attention, not least the greenhouse effect and ozone depletion. There is an ever-growing awareness of the possible detrimental effects of



The StarTiger team at ESTEC on 25 October 2002

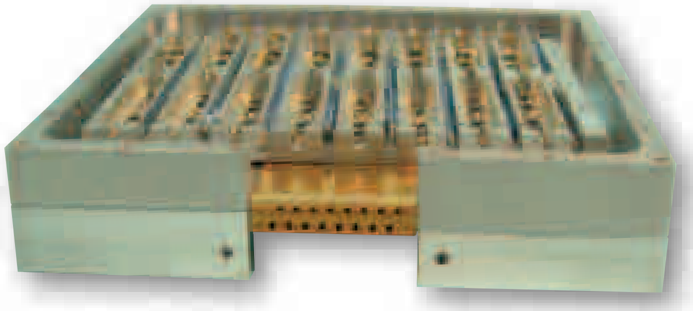


man's activities on climate. Sub-millimetre wave frequencies can be used to obtain important data for studies of ozone-depletion mechanisms, while millimetre-wave frequencies can focus on exchanges between the troposphere and stratosphere, providing very useful complementary information for global-change studies.

Apart its uses for space missions, a terahertz imager also has considerable potential for non-space applications. In the medical field, for example, terahertz imaging is fast being recognised as a totally new diagnostic technique. It can provide an X-ray-like image without the use of harmful radiation. Terahertz waves may also be able to investigate the uppermost layers of skin, making the early detection of skin cancers an exciting possibility. Several such non-space applications were anticipated before the start of the project, but numerous others popped up somewhat unexpectedly during the team's ongoing work.

Media-wise, StarTiger received unusually large coverage for an R&D activity. Articles were published on numerous web sites, in the specialist press, in leading scientific magazines (Science, New Scientist) and in daily newspapers (Die Zeit, Sunday Telegraph, NRC Handelsblad). This media coverage generated many requests for information about the use of terahertz waves in such non-space fields as: dental imaging, antique authentication, antipersonnel-mine detection, airport security and aircraft visibility in poor conditions. Others ideas put forward included the checking of how injuries are heeling under surgical bandages, as well as a system for the automatic detection of chemical and biological postal threats – for which the exact frequency to be used will have to be established, but the demonstrator has already shown promising results when used to see through books.

With such wide-ranging potential applications, therefore, the development of a compact terahertz imager is clearly very much in line with ESA's policy of serving Europe's citizens.



THE WAY AHEAD

The StarTiger pilot project has proved very successful, clearly validating the relevance and efficiency of the approach and achieving technical success – namely the imaging of a human hand - six weeks before the deadline. Success in terms of the five criteria established at the outset was rated as follows:

- Micro-machined room-temperature detector: 100%
- Two-colour micro-machined waveguide array: 90%
- Photonic band-gap mixer: 100%
- Two-dimensional array: technology route identified
- Electronically scanned array: key technology demonstrated.

The next step would be to develop an electronically scanned array, for which the key component – the phase shifter – has already been demonstrated. A system would need to be built around it to demonstrate that the beam can indeed be scanned electronically.

The network-building capability of StarTiger was also extremely interesting. A multi-disciplinary team of European engineers and scientists was created, the members of which have acquired substantial insight into each other's fields of expertise. As a result, the team could now confidently tackle problems in areas unrelated to terahertz imaging. Also, a network now exists whereby someone from the team either knows the answer or knows someone who does!

The media coverage generated – equivalent to more than 650 kEuros of paid advertising space – was unexpectedly high and portrayed space technology as forward-looking and dynamic. It also gave StarTiger the high profile needed to recruit good people.

From a planning point of view, with the short time-scale for development, the StarTiger approach brings the future closer to the present, which is something that should not be overlooked.

ESA is now working on continuing StarTiger through other projects. In order not to stifle the innovation dimension, they might not all follow the route traced out by the pilot project. But before deciding, all of them should be confronted with the invaluable lessons learned through this first, pioneering undertaking. The challenges to be overcome in order for StarTiger to succeed were very high and need to remain so in order to maintain excellence. To build on the unique opportunity that StarTiger has provided, it is essential to keep the pioneering spirit alive, remembering that people are at the heart of every such success, and to encourage a sense of enthusiasm.

The StarTiger story continues!

ESA Technology Programmes

Without the availability of suitable technology, the successful exploration and exploitation of outer space would be impossible.

The eventual success or failure of a space mission may ultimately be decided by the performance of one piece of technology – an antenna for telecommunications, a radar to observe the Earth, or special lenses for a space telescope. Each individual component is crucial.

To have a technology ready when a satellite flies, Technology Research and Development (TRD) must start years in advance. The scale of this activity can be judged by the fact that, each year, ESA manages TRD contracts worth around 250 million Euros.

PREPARING FOR THE FUTURE

ESA ensures that Europe is technically prepared for the needs of future satellite programmes. This establishes a skilled workforce and makes European industries more competitive on the world markets, for instance by reducing costs and development time. In some technical areas, such as launch vehicles, antennas or solar cells, Europe has achieved world leadership.

INNOVATION: TARGET TECHNICAL BREAKTHROUGHS

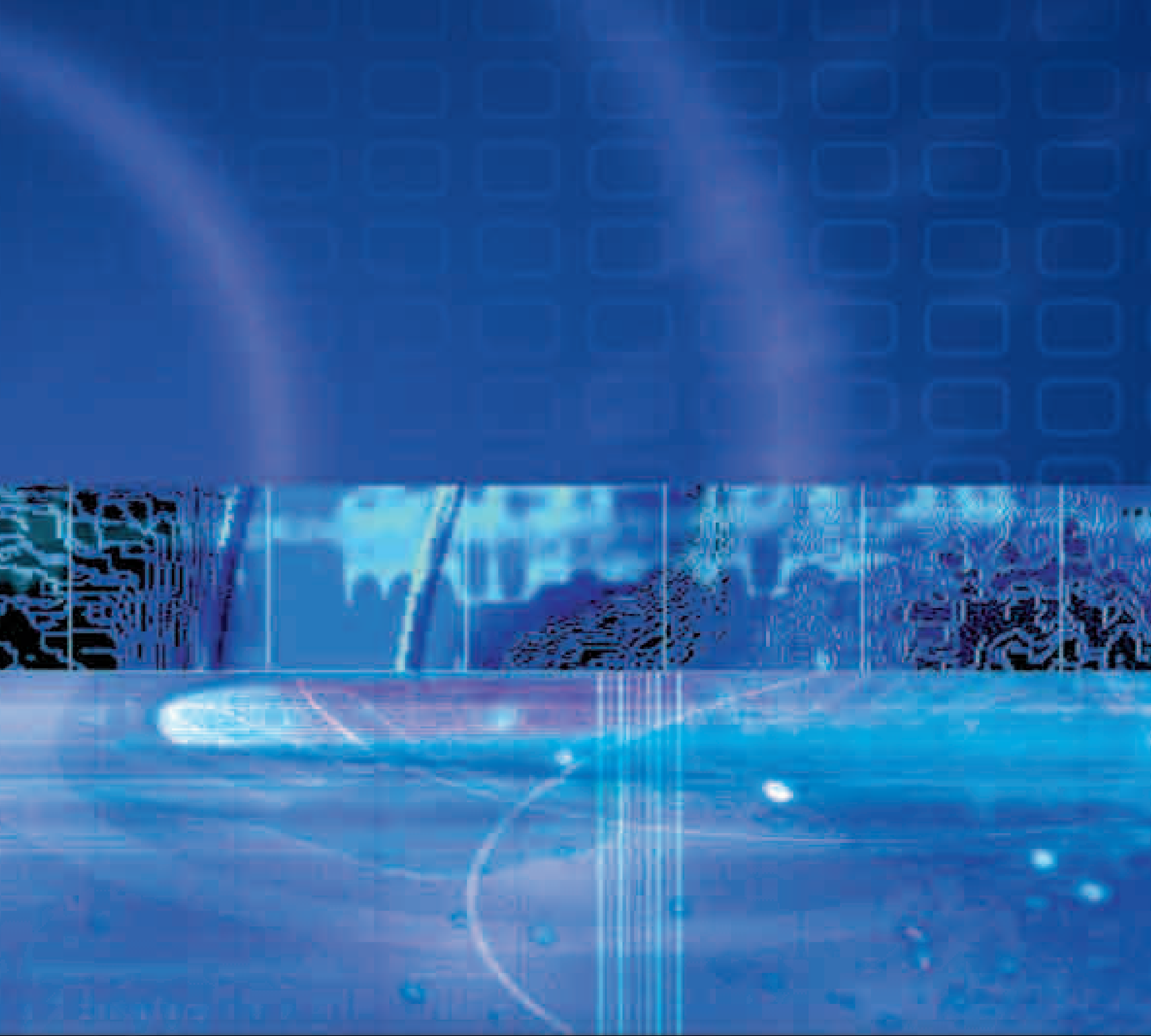
New ideas are vital to progress and success. In addition to the technologies needed by markets in the short term, Europe also invests in the research for the longer term.

In this way, Europe lays the foundations for new services and products. Some of these may still be in the early stages of development while the potential of others may not yet have been recognised. However, such research may eventually open up entirely new scientific and commercial opportunities.

CAREFUL PLANNING

ESA fosters a balanced European space industry, so that the expertise needed to develop space programmes is distributed in a balanced way. As a result, all strategic areas in satellite development are covered, avoiding overlaps between countries or among the activities of the national governments and the EU. In addition, ESA encourages small and medium industries, facilitating their access to space activities and granting them a technically rewarding role in the Agency's exciting and innovative space programmes.

Space promotes an industry of innovation and high added-value services, fostering economic growth and employment.



For further information contact:

Eike Kircher
Head of TRP Section
Directorate of Industrial Matters
and Technology Programmes
eike.kircher@esa.int

Peter de Maagt
Antenna Section
Directorate of Technical and Operational Support
peter.de.maagt@esa.int

Margherita Buoso
Coordinator of Communications
ESA Directorate of Industrial Matters
and Technology Programmes
margherita.buoso@esa.int

Published by:
ESA Publications Division
ESTEC, PO Box 299
2200 AG Noordwijk
The Netherlands

Editor:
Bruce Battrick

Design & Layout:
GPB leiderdorp, Erik Strik
The Netherlands
www.gpb.nl

ISSN No: 0250-1589
ISBN No: 92-9092-675-9