INTRODUCTION

Nearly four decades of ESA technical leadership have succeeded in establishing a European space industry in the global front rank. Possessing a €6 billion annual turnover, Europe’s space sector employs 30 000 skilled professionals, and continues to grow in the midst of recession.

Space spending is a proven investment. Each euro invested in space typically returns six to seven euros to the wider economy. Space contributes to growth and employment across many economic sectors, while being largely immune from outsourcing. Space-based infrastructure and technology transfers have given rise to new businesses, jobs and entire high-value industries.

At the same time, Europe’s space successes come at a bargain rate. On average each European citizen invests only €10 per year, compared to €100 invested by their US equivalent. This is an industry relying not on government subsidy but on winning contracts on the worldwide open market. Commercial contracts make up about 40% of total European space activities and growing – twice the US percentage.

With overall spending so low, what accounts for European space’s continued commercial success? Innovation. The OECD notes a third of all new space patents are filed in Europe, second only to the US. Europe’s space industry stays smarter than its international competitors thanks to a steady stream of technology development, coordinated by ESA’s Technology programmes.

The Agency’s Technology research and development programmes are run on a five to 10 year timespan, running the whole gamut from investigating promising new ideas to finalising hardware for actual spaceflight – and commercial markets.

ESA’s Technology programmes also prioritise the transfer of high-performance technologies to terrestrial markets, fostering new businesses and boosting wider European competitiveness.

The success stories detailed in the pages that follow show how this process works on a project by project basis, making the case in practical terms for continued R&D investment to go on sowing the seeds of tomorrow’s space successes.

Franco Ongaro
ESA Director of Technical and Quality Management
Demonstrating the benefit of the European space programme to Europe’s citizens in a highly visible manner, ESA’s Technology Transfer Programme (TTP) facilitates the use of space technology and systems for non-space applications. TTP has enabled more than 260 technology transfers during the last two decades. A network of Business Incubation Centres across Europe support new start-ups based on space technologies.
A company called Insiteo is extending satellite navigation signals and services indoors with its ‘StarBox’ that produces the equivalent of GPS and Galileo signals coupled with high performance algorithms.

The technique is being transferred to various industrial sectors such as exhibitions, shopping areas, industrial sites, airports, transport stations and museums.

Insiteo, an alumnus of ESA’s Noordwijk Business Incubation Centre gained 19 employees by the end of 2010 with €300 000 turnover and more than €4 million raised from venture capital.

Reference customers include Equipbaie 2010, Verallia, ExpoProtectio 2010, Paris Motor Show and La Maquinista – a mall in Barcelona with 230 shops.

See www.insiteo.fr for more.
INTELLIGENT MOBILE CITY GUIDE

Satellite navigation is being combined with artificial intelligence as the basis of a location-based pedestrian travel guide, aimed at pedestrians in city environments.

The LatitudeN company, supported by ESA’s Business Incubation Centre in Darmstadt, has produced a smart location-based travel guide that automatically suggests fully-personalised city tours, based on the user’s preferences and time at their disposal.

‘Farol City Guides’ is currently entering the market, in partnership with MairDumont, a market leader for digital content in tourism.

LatitudeN received a best-practice award in 2010 as a small-medium enterprise (SME) working on the downstream satellite sector. See http://www.latituden.com/home_en.html for more.

MICRO- AND MESO-SCALE NUMERICAL WEATHER PREDICTION

Data from Earth Observation satellites are routinely assimilated within numerical weather prediction models to help provide more accurate weather forecasts.

A company called MeteoSim is investigating the development and use of micro- and mesoscale models in numerical weather forecasting for the private sector. MeteoSim is an alumnus of BarcelonaActiva, a member of the European Space Incubators Network (ESINET).

The company has more than 100 simulations operating on a daily basis – covering all continents, with different configurations and scales based on user needs. By the end of 2010, MeteoSim had 10 employees and €200 000 turnover. For more, see www.meteosim.com.
VERY FAST INFORMATION VISUALISATION

Control of Earth Observation missions such as Envisat, ALOS, CryoSat and GOCE is enabled by the visualisation of complex, high-throughput information.

A company called DEIMOS Space has applied the same visualisation technique to the control of Europe’s longest, deepest subway line: Barcelona’s driverless Line 9 is 47.837 km in length with 53 stations and, from 2010, the core area around Valencia.

The ALHAMBRA Information System helps manage and display the information coming from traffic, and general corporate information, incidents and emergencies, monitor hallways and platforms, in panels on the doors of the platform and the information panels of the trains.

The customer, ADIF, is Spain’s railway infrastructure manager.
For more, see http://tinyurl.com/b047yhm .
SPACE FOR HEALTH

VASULAR ACCESS GRAFT

Scaleable colloidal nan thrusters for extremely precise spacecraft attitude control — originating in ESA’s MEMS for Space programme — are being applied to the production of electrospun nanofibre scaffolds for regenerative medicine and drug discovery.

Electrospun nanofibres are fabricated into non-woven scaffolds which support the 3D growth of cells, being used in regenerative medicine and drug discovery. The Electrospinning company, a spin-off from the Rutherford Appleton Laboratory, has received investment of over €400 000 and initial sales of over €60 000.

The technology of electrospun nanofibres has further applications from rechargeable batteries to medical devices.

The Electrospinning Company has been assisted by ESA’s UK Technology Transfer Broker and is currently being incubated at ESA’s Harwell Business Incubation Centre. See http://www.electrospinning.co.uk/.

BLOOD VISCOSITY MEASUREMENT

Micro-switches first developed for the docking of nanosatellites and for spatial light modification modules based on MEMS technology are being applied to blood viscosity measurement by the Microvisk company.

MEMS sensors are incorporated on a disposable strip which features a small cantilever to measure blood viscosity, allowing for easy testing. The disposable strip contains all the necessary components required for a test with the Microvisk Prothrombin Point of Care device.

Besides the current application in healthcare, significant opportunities for further developments in other markets include oil and gas and aerospace. This technology is currently being marketed by ESA-funded Technology Transfer Broker STFC Innovations Ltd. See http://www.microvisk.com/ for more.
MORE DETAILED DENTAL X-RAYS

Miniature MEMS technology originally developed for micro-propulsion systems on Sweden’s Prisma microsatellite has been adapted to produce a new thinner and high-resolution scintillator – a device that converts X-rays into ordinary light – for dental X-rays.

The dental X-ray camera was designed by the Scint-X company with the key element – the scintillator – built by Nanospace, a subsidiary of the Swedish Space Corporation. Being much thinner than current X-ray cameras on the market its images are more detailed, and the camera can be inserted right into the patient’s mouth.

Scint-X has received SEK 10 million in growth capital during 2011. For more, see http://www.scint-x.com/.

MOBILE HEAT RATE MONITOR

ESA has developed a complex chest sensor for measuring astronauts’ blood oxygen levels as part of its Long Term Medical Survey system, to gather medical data on individual subjected to confined or extreme environments.

The CESM company has transferred this to a tiny unit embedded in a regular earphone that uses infrared signals to see how fast your heart is beating, able to be used via a smartphone.

CESM received a IPSP award in 2011, and partner agreements are in discussion. The company is being supported by ESA as a Technology Demonstrator Project, and currently marketed by an ESA-funded Technology Transfer Broker. See http://www.csem.ch for more.
GLASS FIBRE COMPOSITE FOR DENTISTRY

Pre-impregnated glass fibre reinforcement is an advanced composite based on glass fibres embedded into resin or plastic to reinforce high-performance aerospace structures such as the Airbus A380’s vertical stabiliser or the Space Shuttle’s liquid oxygen tabs.

A company called ADM has adapted this material to dentistry to produce a product called Dentapreg: supportive dental strips and pins for minimally invasive dentistry. The company is an alumnus of the South Moravian Innovation Centre (JIC) in Brno, a member of the European Space Incubators Network (ESINET).

By June 2010 the company had six employees with distributors in 19 countries worldwide. See www.dentapreg.com for more.
PUTTING SPACE TO WORK

LIDAR FOR WIND FARM MANAGEMENT

Lidar – best understood as the laser equivalent of radar – is being harnessed by ESA’s ADM-Aeolus satellite to provide global observations of atmospheric wind fields.

Leosphere is transferring this same lidar technology to optimise the setup and management of terrestrial wind farms as well as to related sectors such as climatology and environmental studies. ‘Windcubes’ placed on the ground perform 3D wind field scans.

Leosphere, an alumnus of ESA’s Noordwijk Business Incubation Centre had by the end of 2010 some 65 employees and an €8.5 million turnover. Prestigious reference customers include NASA, the Institute of Atmospheric Physics in Beijing and the Netherlands’ meteorology institute, KNMI. See http://www.leosphere.com/ for more.

HEATPIPES FOR ELECTRONICS

Satellites are commonly threaded with heat pipes for thermal control: they contain a liquid such as ammonium which evaporates when heated, carrying waste heat to a colder part of the satellite to be radiated out to space. At that point the liquid condenses so the process can repeat itself.

EHP is attempting a transfer of this technology to the aeronautical, defence and broader terrestrial markets, enabling the development of more powerful electronic systems better able to handle waste heat.

The technology is based in two-phase capillary pump loops and constant or variable conductance heat pipes, with fixed or deployable radiators.

EHP is an alumnus of, a member of the European Space Incubators Network. By the end of 2010, the company had 23 employees and a turnover of €3 million, having raised €750 000 in equity investment. Prestigious clients include Alcatel, EADS, Alstom and Alenia. For more, see www.ehp.be.
SELF-LUBRICATING MATERIAL

A self-lubricating metal matrix composite based on copper (CuMMC) tested by Europe’s space industry is being offered for transfer to the watch, automotive and oil and gas industries.

The composite has been tested for ESA by Aerospace & Advanced Composites. The results showed dimensionally stable cages with almost no wear, and good performance at 300°C with additional coatings – compared to competitor materials up to a maximum 250°C.

CuMMC is currently being marketed by ESA-funded Technology Transfer broker Brimatec. For more, see http://tinyurl.com/cgrsr69.

TOTALLY NON-MAGNETIC MOTOR GEARBOX

A gearbox system for high-speed ratios was employed in the deployable retrievable boom of the Shuttle’s tethered satellite TSS-1 in 1990.

A company called STAM has produced a motor gearbox based on nutation (or rocking rotation) instead of standard rotating made of nonmagnetic materials to be used as a robotic manipulator for tele-operated biomedical applications such as Magnetic Resonance Imaging, which involve a high density magnetic field.

The gearbox has a rotation speed reduction factor of 3000 in the presence of a very high density magnetic field (3 Tesla).

This SPACEGEAR design has a simple configuration with low production costs, avoiding the use of high-strength gear material and with high-torque transmittal capacity. It is currently being adapted to an MRI-compatible robotic manipulator developed by FeBo srl for tele-operations.

See http://www.stamtech.com/ for more.
CAMERA TRACKING FOR PRECISION AUTOMOBILE ASSEMBLY

Artificial vision technology based on an object recognition camera and tracking software originally developed to support optical guidance for ATV’s automatic docking with the ISS is being applied to the automobile sector, to assist in the assembly chains of car manufacturers.

The company involved, MDUSpace, is an alumnus of ESA’s Noordwijk Business Incubation Centre.

It has acquired prestigious clients including Autoeuropa in Portugal, producing cars for Volkswagen and Seat. For more, see www.mdu.pt.

COMPUTER SIMULATION FOR MULTI-PHYSICAL TECHNICAL SYSTEMS

Computer simulation of multi-physical technical systems is a new technology of wide promise derived from DLR’s development of space robots and other robotics applications.

Modelon – an alumni of ESA’s Bavaria Business Incubation Centre in Oberpfaffenhofen – is engaged on a technology transfer of the simulation focused on electric and hybrid cars. Prestigious reference customers include Audi, BMW, Daimler and MAN.

By the end of April 2011, the company had 20 employees and a €1.7 million turnover. See http://www.modelon.com/ for more.
The Advanced Procedure Executor (APEX) system was originally developed to assist astronauts in managing emergency situations aboard the International Space Station. The Skytek company is applying it to an advanced terrestrial mobile emergency communication system for fire fighting services to get crucial information about emergency situations while en route to the scene of an accident.

Crews on the move can download the layout of the building, identifying where the hydrants are located and what chemicals may be inside and where. In the case of a car crash, the crew on the way to a scene could download information about the types of vehicles involved.

The system is being used operationally by the Dublin Fire Brigade. See http://www.skytek.com/ for more.
CAR THERMAL PROTECTION SHIELDS

A new thermal mounting board derived from ‘superplastic’ forming of titanium alloy is being tested by the Formtech company, aimed at providing protection shields for the undersides of cars.

Superplastic forming involves deforming material past its usual breaking point to make it more robust, used by Europe’s space industry to produce spherical Ariane 5 fuel tanks.

Spinning-in this technology results in a shield able to operate at a higher temperature, with a better fit and with only 70% of the current amount of aluminium shielding.

The company is working on a prototype with a car supplier, undertaking discussions with BMW.
For more, see http://www.formtech.de .

GAS PROTECTION ON OIL RIGS

A MEMS controllable diffractive optical element that can be easily calibrated is built into a wireless sensor. The technology was originally developed by the SINTEF research organisation with the support of ESA’s GSTP.

GasSecure is a venture-funded company that has spun-off from SINTEF, targeting more reliable detection of dangerous gases in oil and gas installations. Testing of fully functional prototypes is being undertaken by Statoil. GasSecure received $10 million in 2010 and received a Frost & Sullivan award for best practice, including the category of uniqueness of technology.
See http://www.gassecure.com/ for more.
HEATING AND VAPORISATION BASED ON HYDRODYNAMIC CAVITATION

An innovative heating and vaporisation system based on patented ‘hydrodynamic cavitation’ technology is being applied to the industrial treatment of swine sewage to break down ammonium nitrate with very high efficiency, following the recommendation of EU Regulation number 91-676-CEE to prevent nitrates entering drinking water.

The system is dependent on advanced mechatronics used for mechanical ground support equipment for satellites, with hydrodynamic cavitation involving the formation and collapse of bubbles in liquid via mechanical forces.

The company involved, Wixta, is an incubatee of ESA’s Lazio Business Incubation Centre, gaining by the end of 2010 three employees and a and €10 000 turnover. For more, see http://www.wixta.com/.

FIRE SUPPRESSION INSIDE

In 2011 Proba-2’s resistojet fuel tank was repressurised with an influx of nitrogen that had not been stored in a tank under pressure but within a solid material kept at room temperature with no special storage requirements.

This ‘cool gas storage’ technology first developed by TNO Defence, Security and Safety is also being transferred to a fire suppression device in information and communication technology (ICT) equipment, usually placed inside data centres, by the company Fire Suppression Inside.

Intellectual property rights have been secured and the first round of investment has been attracted by entrepreneur Harm Botter. The company is currently being supported in ESA’s Noordwijk Business Incubation Centre. For more, see http://tinyurl.com/cwsp62d.
The European Components Initiative-Technology Non-Dependence (ECI-TnD) helps mitigate the risk of the European space industry becoming dependent on non-European sources for critical space components, potentially subject to export restrictions such as the International Traffic in Arms Regulations (ITAR) or End User certificates – thereby eroding European competitiveness as well as non-dependence. ECI-TnD is an open cooperative programme where the European Space Agency and National Space Agencies participate each and contribute to the programme objectives with their own funding.
NEW PRODUCTS TO MARKET

ECI Phase 1 was started in 2004 with the aim of reducing Europe’s dependence on the supply of EEE components from sources subject to export restrictions, targeting "pin-to-pin" compatible replacements for US ITAR-listed devices.

"We are an equipment supplier – which makes us more dependent on ESA technology programmes. We need innovation to keep our products competitive not only in Europe but across the world." Peter Möller, Chief Technology Officer of RUAG Space

SPACE QUALIFIED FUSES

Schurter is the only European manufacturer of SMD Fuses to fulfil the rigorously high requirements for space applications. Its extensive range of printed circuit board and surface mount "non-resettable" fuses for space applications have been developed specifically for space and then qualified against the ESCC requirements. The company has a family of 12 thin-film fuses, covering a range of 0.14 – 3.5 amperes.

More than 150 purchase orders have been received since 2008, amounting to more than 30,000 fuses.

As a result of the success and demand for these fuses, a second development was launch under ECI phase 2 to extend the range of fuses to higher currents.
RAD-HARDENED FPGAs

New satellite designs entail more and more complex functionalities implemented in Field Programmable Gate Arrays (FPGA). When existing standard integrated circuits (ICs) cannot provide the desired level of performance or integration, a custom IC design becomes imperative.

The increasing costs and complexities associated with developing project specific Application Specific Integrated Circuits (ASICs) has led to projects switching to the use of more flexible Field Programmable Gate Arrays (FPGA).

A growing family of ITAR-free FPGAs evaluated for space applications (rad hard) are now available in Europe starting with the 40Kgate and 280Kgate. Together with a new mid-range 450Kgate FPGA on a new SOI process which is nearing completion these devices will now start to challenge the US suppliers (Xilinx) which are all ITAR-controlled.

The European FPGAs have been used on ESA programmes including Sentinel-1 and BepiColombo, furthermore new designs based on using these devices are planned from the leading system integrators and equipment suppliers, provide them with a cost effective and more flexible solution to conventional ASICs.

ESCC QUALIFICATION OF 0.18 μM EUROPEAN FOUNDRY PROCESS

It was inevitable that the niche market for the space qualified radiation hardened 0.35 micron process would eventually become unviable, since foundries could no longer justify the high expense of maintaining this product line in favour of more profitable commercial processes. Following the ESCC process the 0.18 micron European foundry process has been evaluated and qualified, replacing the now obsolete 0.35 micrometre process previously relied upon for all space platform and payload ASICs.

0.18 μm is now the standard for all new ESA programmes.
PHASE-LOCKED LOOP FREQUENCY SYNTHESISERS

Starting in 2006 under an ECI contract, Peregrine (Europe) has developed and qualified a range of high-reliability UltraCMOS Phase-Locked Loop Frequency Synthesisers (PLLs) and provide the only source of rad-hardened PLLs worldwide that are free of any export restrictions. Three space-qualified variants are now listed in the QPL and EPPL which are comparable in performance to US ITAR listed parts. More than 800 PLLs have been delivered since their introduction in 2009.

Key customers include Thales Alenia Space France, NT Space, Tesat, TopRel, Spur and Astrium.

RELAYS

Launched in late 2005 with the objective of evaluating and qualifying both latching and non-latching T and TL type relays for space applications, Deutsch (now STPI) took on the challenge and since 2009 has been the only supplier in Europe of Space-qualified high-reliability relays (2 and 4 poles 15 Amps) in the popular T05 package. The relays have been designed for use in space launchers, vehicles and all satellite systems.

Key ESA customer include Sentinel-3.

POWER MOSFETS

ST Microelectronics provides customers with the only European source of ESCC space-qualified, rad-hardened power MOSFETS. Supplied in a hermetic package, these fast-switching MOSFETS (100 N-ch 100V P-ch) are 100% avalanche tested, hardened against single event effects.

Fully qualified by the ESCC, the devices have been commercially available since 2010.
SCHOTTKY DIODE WAFER FABRICATION

United Monolithic Semiconductors (UMS) has developed the only ESCC space qualified wafer fabrication process for gallium arsenide (GaAs) Schottky Diode components, based on their BES process.

More than 150 wafers have been produced and delivered since 2009. Key customers include Thales Alenia Space, Astrium and Tesat.

MICROPROCESSORS FOR SPACE

Atmel (Nantes) has a long history of developing microprocessors for space application, in 2006 building on their commercially successful ERC-32 Processor, development started on the LEON-2 microprocessor which together with the ERC-32 processor is now widely used in the majority of ESA programmes including the ISS, Gaia, Proba-V and Sentinel-1.

Confirmed sales orders top 1100 for engineering and flight models, with exports to Argentina, China, Russia and the US. The LEON-2 is manufactured by Atmel, marketed as the AT-697.

The Next Generation Multi-Purpose Processor (NGMP) will be a new multi-core processor currently under development at Aeroflex Gaisler, an activity initiated by ESA.
BUILDING CAPABILITIES

ECI Phase 2 (2009-2011) was started in 2009 with the aim of providing competitive alternatives – in terms of cost and time to market – in Europe. Seventeen activities were kicked off to address two product categories:

- Product technologies, where the deliverable is a space qualified component, replacing the non-European product.
- Enabling capabilities where the technology enables processes and capabilities to produce space qualified components.

The key developments included have included MMICs, PLLs, capacitors, fuses, optical connectors and FPGAs.

HYBRID MICROWAVE MIXERS AND AMPLIFIERS

ECI-TnD has helped foster Cobham's growing family of hybrid mixers (0.5-1500 MHz, double balance termination insensitive, image reject) and amplifiers specifically designed and qualified for space applications.

These hybrid mixers reduce the cost and lead times (compared to MMICs) as well as allowing specific tuning to match customer specifications, as a consequence 720 hybrid mixers have been ordered/delivered since 2008. Key customers include Thales Alenia Space, Tesat, Mier, CNRS and ESA's Sentinel-3, Galileo and ExoMars programmes.

MMIC MIXERS

Three space qualified variants of double balance MIMIC Mixers (0.7-10 GHz) are being produced by OMMIC. These popular MMICs have been well received by equipment suppliers resulting in more than 2500 mixers delivered since 2008, and a good revenue source for their manufacturer with sales now in excess of €1.5 million.

Key customers include Thales Alenia Space, Tesat and ESA’s Sentinels-1, -2, -3 and Galileo programmes.
SHIFTING DOWN TO NANO-SCALE

The challenge for telecommunication, Earth observation and scientific satellite manufacturers is to respond to growing requirements in terms of payload flexibility, scalability and performance and at a very competitive cost. Digital processors based on Deep Sub-Micron (DSM) technologies are pivotal to answering this need so that Europe can remain competitive vis-à-vis US players with improvement in processor mass and power consumption.

An initial high-speed serial link prototype based on European 65 nm process from ST Microelectronics have been completed paving a way for further optimisation and space qualification of the device. In addition 65 nm design kits and the first prototype of the European broadband/low power analogue to digital converters (ADC) has been completed in 2010.

2012 sees the introduction of the first equipment designs using the 65 nm technology. Full qualification of the 65 nm process is foreseen in the ECI 2012-2015 workplan. This innovation reduces the identified European to US technology gap from 10-15 years to 5-10 years.

GALLIUM NITRIDE TECHNOLOGY

The European Gallium Nitride (GaN) component development strategy for space applications was first presented in 2006. Its objective is to safeguard European access to strategic components subject to foreign export restriction and to secure European non-dependence and long term competitiveness by furthering the European R&D effort. A GaN technology roadmap has been formulated to (1): address GaN device reliability, (2): establish an independent European supply chain for microwave power components, (3): develop power switching transistors for use in DC-DC converters and (4): develop advanced thermal management and packaging techniques.

The GREAT2 initiative (see GSTP section) has reduced the GaN technology gap for RF applications between Europe and Japan/US from an estimated 10 to four years.

The first in-orbit demonstration will take place on Proba-V in 2013. Follow-on qualification activities are foreseen in the 2012-2015 ECI workplan.
ACCESS TO STRATEGIC COMPONENTS AND TECHNOLOGIES

ECI-TnD Phase 3 (2011-2013) is the most recent phase of the programme covering a further 26 activities. The focus is to target access to strategic components and technologies. The key developments will include baseline activities for the introduction of the 65nm DSM, large FPGA and High Pin Count assembly technologies.
Almost all the new technologies underpinning current ESA missions and programmes owe their origin to the Basic Technology Research Programme (TRP). Serving as the Agency’s underlying ‘ideas factory’, this programme’s activities develop promising new ideas from first principles to engineering breadboards that can be tested and evaluated, scaling the first few rungs on the Technology Readiness Ladder.
LOOKING INTO NEW IDEAS

STAR TRACKER, SUN SENSOR ON A CHIP

Star trackers and Sun sensors are crucial tools for satellite guidance and navigation. A TRP feasibility study for separate star tracker on-a-chip and Sun sensor on-a-chip designs has been completed with Galileo Avionica and CMOSIS.

The designs are based on active pixel sensor (APS) technology, fabricated using a CMOS process enabling detector-on-chip integration and eliminating CCD analogue electronics. They possess a smaller mass and footprint, with the star-tracker software running in the Command and Data Management Unit (CDMU). The mini-equipment mass is based on +5V secondary supply with no internal local current limiter or switching, incorporating a SpaceWire interface (see the GSTP section).

The Sun sensor on-a-chip has a mass of 0.06 kg with dimensions of 35x40x40 mm, with an accuracy of 0.075 degrees, running at 10 Hz and 0.2 W.

The Star tracker on-a-chip has a mass of 0.20 kg with dimensions of 42x37x83 mm including baffle, with an absolute pointing error of 10 arc seconds, running at 4 Hz and 0.4 W.
**TIME AND SPACE PARTITIONING SOFTWARE**

Time and space partitioning (TSP) is being used to manage the growing complexity of spacecraft flight software. The majority of spacecraft functions are implemented in the flight software. TSP enables these applications to be isolated into dedicated partitions with clearly defined interfaces between partitions which allow the applications to be developed independently. This independence means that faults from one application cannot propagate to other partitions, and also supports the concept of incremental validation – meaning applications can be validated in isolation of each other.

Through a TRP Innovation Triangle Initiative contract, GMV Skysoft has developed a TSP operating system called AIR (ARINC 653 interface in RTEMS) based on the space-proven RTEMS real-time operating system.

Both GMV Skysoft and its AIR product have been selected for use in GSTP’s Integrated Modular Avionics for Space (IMA-SP) activity to demonstrate input/output management in a partitioned system.

**NANO-MODIFIED FIBRE REINFORCED POLYMER FOR REFLECTOR MAKING**

The University of Patras undertook a TRP study to introduce carbon nanotube (CNT)-modified polymer materials as a novel material for the manufacture of antenna reflectors.

The presence of carbon nanotubes in resin systems offers enhanced electrical, thermal and radio frequency (RF) properties as well as easier and cheaper fulfilment of requirements for high reflectivity and good thermo-elastic stability for complex shapes, compared to conventional carbon fibre reinforced polymer (CFRP).

The study demonstrated that reinforcement with nanotubes offered the additional functionality of retaining the stability of other reflector properties.
In recent years the Ka-band frequency has become more popular for Earth Observation instruments, its short wavelength allowing interferometric instruments on a single platform, for generation of digital elevation models and instantaneous 3D monitoring. However a high resolution synthetic aperture radar (SAR) has not been proposed so far due to serious link budget problems. A solution to this almost fundamental problem was found in applying the already known ‘scan-on-receive’ technique to provide significant power savings and consequently making this kind of radar instrument feasible.

The feasibility of such kind of instrument is currently under study in two parallel industry contracts. The first team is led by Thales Alenia Space Italy supported by DEIMOS space S.L.U., Politecnico di Milano POLEIMI DEI, RUAG Space AB and Thales Alenia Space France, while the second team is under Astrium GmbH supported by DLR and InfoTerra GmbH – this second contract being Earth Observation Programme funding.

The initial Wavemill proposal was for a hybrid interferometric SAR instrument with squinted antenna beams to both sides of the sub-satellite track and looking both fore and aft of the sub-satellite point (nadir). The purpose of this arrangement was to be able to perform both across- and along-track interferometry (XTI and ATI). While XTI allows the elevation of a surface to be determined, ATI can be used to monitor movement in the line-of-sight direction of the radar. Wavemill’s key innovation is the direct measurement of sea-surface currents in two dimensions, of very high value to the oceanographic science community.

A TRP contract with the title ‘Altimetric Measurements of 2D Ocean Surface Currents’ was placed with Starlab as prime and covering system aspects, supported by Astrium Ltd for the hardware study and IFREMER for establishing the scientific requirements of such an instrument. The contract showed very promising results. The scientific requirements could be met for practically all current strengths down to some centimetres per second and the relative sea surface accuracy (pixel to pixel) was of the order of a couple of centimetres. The value of such ‘game-changing’ data accuracy to the oceanographic community, to meteorologists, to climate change scientists and to ship operators everywhere including navies, would be immense.

The success of this TRP activity and CCN has led to the establishment of a Wavemill working group within ESTEC and a number of related activities funded by different ESA budgets.
COLD CATHODE VACUUM AMPLIFIERS:

Traveling Wave Tubes typically employ thermionic cathodes to generate a beam of free electrons in vacuum. The cathode is heated at a typical temperature of 1000°C, operating continuously to deliver up to 2.5A/cm². Recent developments in the field of semiconductors, have demonstrated the capability of some advanced devices to emit free electrons in vacuum at room temperature ('Cold Cathodes') with high current densities (in excess of 10A/cm²). With such devices, the free electron emission can be modulated directly at microwave frequencies, dramatically reducing the size and mass of the TWT.

A TRP contract was started to design and test two types of Cold Cathode technologies: carbon nanotubes (CNTs) and “Active Semiconductor Cathodes” (ASC). Prototypes have been manufactured and tested and have demonstrated current densities ranging from 0.2A/cm² (CNTs in CW mode), to 0.4A/cm² (CNTs in pulsed operation), up to 1mA/cm² (ASC). In the frame of this activity, a complete TWT was also assembled with a cold cathode-based gun and was then successfully operated at 3.3GHz, with 115μA and 3.3kV. Such semiconductor cathodes may be controlled electronically which allows the TWT to be continuously biased at optimum efficiency. And simulations have shown that if the cathode of a TWT could be directly modulated by the RF signal, its travelling wave section could be reduced threefold. However, this implies a very high frequency cathode which could be developed in a second step. In the long term, one can imagine this cold cathode TWT as an hybrid between traditional TWTs and SSPAs, combining the best of both worlds. In this respect, an additional TRP activity was started in 2011 with the goal of designing, realising and testing a Vacuum Electronic Device Power Amplifier.
MAINTAINING COMPETITIVENESS

TRP FOR AVIONICS SYSTEMS AND HARDWARE

New avionics systems and hardware developed by ESA through TRP activities offer high performance and functionality making use of novel architecture, components and fabrication processes. Those activities are coordinated through the Space Avionics Open Interface Architecture (SAVOIR) initiative with a strong support from major stakeholders.

For instance, Astrium France’s Spacecraft Controller On a Chip combines all spacecraft computer elements on a single 75 MIPS, 7 MHz chip, embedding SpaceWire, CAN and UART interfaces.

Sweden-based Aeroflex Gaisler’s LEON family of microprocessors is highly configurable, supporting system-on-chip applications. The LEON FT-3 has 22,000 gates at 180 nm scale, incorporating single event upset detection and correction. It is currently being exported to US customers.

ESA is also working with ST Microelectronics in France on future 65 nm scale chip fabrication (see ECI-TnD section). Reducing the footprint of chips in turn cuts the mass, power and size of their electronic boards, making a significant contribution to European competitiveness.

COMPETITIVE SOLAR CELLS

The current state-of-the-art technology is based on the ‘lattice-matched’ GaInP/GaInAs/Ge triple-junction solar cell. Worldwide, there are three major manufacturers of space solar cells based on III-V semiconductors, with Europe’s Azur Space GmbH in competition with the US Emcore and Spectrolab.

The development process involves improvements and fine-tuning of the structure, which lasts more than 10 years. The maximum practically achievable efficiency for space is 30% at the beginning of life and 25% end of life.

In 2003 Fraunhofer ISE and RWE SSP realised the first generation of fully European triple-junction space solar cells in the RWE-27% class, with a second generation RWE-28% following in 2009 being employed by missions including Alphabus and Galileo. The current third generation RWE-30% class represents the final stage of lattice-matched triple junction solar cell technology.

The next generation will target cost and mass reduction, and pushing efficiency up to 33%, with new technologies under study including lattice-matching on germanium, lattice mis-matching, quantum cells and thin cells.
Dual gridded reflectors (DGRs) have been used in the past for Ku-band geostationary telecommunication satellites but are traditionally heavy and have become less common with the advent of larger platforms and high power components. The use of DGRs in Ka-band allows a reduction in the number of antennas needed to be embarked to provide contiguous multibeam coverage.

TRP undertook two parallel and independent concept developments in Ka-band DGRs, applying new concepts and materials in order to remove transmission losses due to dielectric substrates and to improve thermo-elastic stability. Both effects causing significant performance degradation at Ka-band.

RUAG Space in Sweden has implemented a Ka-band DGR design with metallised carbon-fibre reinforced (CFRP) plastic vanes and Kevlar support ribs.

A German consortium consisting of HPS, ASD, ASC, Invent and Technical University of Munich produced a Ka-band DGR based on CFRP wires for the front grid and a full CFRP sandwich for the rear.

The reported Ka-band DGR activities were initiated when Ka-band was used in linear polarisation. Ka-band systems now almost exclusively use circular polarisation, however, both the Swedish and German activities have proven the individual concepts. Activities have been initiated for further development of a concept for use at Ku-band where the additional advantage of greatly reduced mass, due to CFRP construction, can make the DGR attractive.
Future mobile satellite missions will feature ever larger antenna systems and provide higher capacity. As the number of beams grows, improved beamforming capabilities are required in addition to greater flexibility both in routing between beams and in frequency planning. The demands of such complex missions require high-performance digital signal processors (DSPs).

A TRP contract with Astrium UK targeted a DSP design for next-generation mobile missions, targeting a capacity 10 times greater than the current Inmarsat 4 processor. The design implements a downsized architecture of the return processor across three separate FPGA-based modules, with 16 input elements and two feeder outlets.

The design is capable of emulating a larger 160 element antenna, demonstrating advanced beamforming functionalities, developed within the contract, that will in turn enable the Alphasat Inmarsat XL mission.

This R&D work has been paving the way to the follow-up Next Generation Processor development to fly on the Inmarsat XL Alphasat satellite co-funded by the ESA Telecom Advanced Research in Telecommunication Systems (ARTESS) program. Furthermore the innovative transparent processor architecture devised and prototyped in this contract has been pivotal for other R&D activities related to the design of OBP for broadband satellite telecommunication missions which will benefit from the on-going digital Deep Sub-Micron technology development.

“This programme is proving very useful in consolidating mobile processor issues relevant to the Next Generation Processor (NGP) and the Alphasat Processor, and in exploring exciting new architectural options such as FFT-based beamforming” Tony Craig (EADS Astrium)
EFFICIENT LOW COST POWER CONVERTER

DC/DC power converters are widely used in space platforms and payloads, and are normally tailored to mission needs. The main concern is to obtain a sufficiently high level of reliability, which can be difficult considering the relatively low production values and highly challenging space environment.

To reduce costs, off-the-shelf hybrids can be used and adapted to space applications. Through a TRP study, RUAG has assessed the feasibility of a low-cost European alternative to current non-European suppliers.

A competitive 10W converter has been developed for standard and digital electronics. While the converter is very thin, it nevertheless accommodates many convenient features, including spacecraft protection, accurate over voltage protection, a flexible telecommand interface and so on.
SUPPORTING ESA PROGRAMMES

FLEXIBLE LOW-WEIGHT AEROGEL FOR INSULATION

TRP’s Innovation Triangle Initiative (ITI) supports the introduction of disruptive new technologies. In 2009 Active Space Technologies (ASP) and the University of Coimbra’s Faculty of Sciences and Technology (FCTUC) won a €150 000 ITI contract for Aerogel Thermal Insulation Systems for Mars Applications.

The resulting aerogels by AST/FCTUC have thermal conductivity of 0.032 W/m.k, bulk densities of about 50 kg/m³ and are extremely flexible (with a modulus of elasticity of around 20 kPa).

Work continued in TRP’s €300 000 Adaptation of Aerogel Materials for Thermal Insulation activity to develop and test multifunctional aerogel for Mars landers and rovers, aimed at reducing thermal insulator mass.

Encapsulated aerogel is now being considered as an enabling insulator for ESA’s Mars Network Science Lander (Mars-NEXT).

EUROPEAN SCHOTTKY DEVICES FOR MILLIMETRE WAVES

TRP and GSTP activities have been carried out for many years in order to develop discrete and monolithic Schottky devices that enable millimetre and sub-millimetre wave receivers of Earth observation and Space Science. This work has been successful, and state-of-the-art performance has been demonstrated at frequencies above 600 GHz. Actions are now on-going to ensure that also the quality and reliability of European Schottky devices are adequate for employment in the future MetOp Second Generation mission.
INTELLIGENT PLANETARY SITE SELECTION

In 2008 Uninova and Astrium ST won a TRP Innovation Triangle Initiative contract called Intelligent Planetary Site Selection (IPSIS), for developing innovative software dedicated to autonomous decision making for selecting a safe landing site during an interplanetary landing.

As part of the current Lunar Lander phase B1 study, the baseline safe site selection algorithm, developed by Portugal’s Deimos Engenharia, will be compared with IPSIS. It is expected that the real-time performance of this new solution will be better than the baseline one.

This is an important performance criterion in view of the limited computing resources of space-qualified PowerPC boards. However other metrics such as design tuning and validation efforts will have to be taken into account for the benchmark. A GO/NO-GO decision for IPSIS will be taken at the end of the phase B1 study.

MARTIAN DUST SIMULATION FACILITY

TRP has supported development of Europe’s first Martian Dust Simulation Facility for Solar Cells and Assemblies at Aarhus University.

Adapted from an existing wind tunnel by Kirkholm Mechanical Engineering A/S, extensive work has been performed to guarantee a reproducible representative Martian atmosphere.

The facility blows Mars-like dust over samples for specific dust adhesion experiments and characterising the performance of photovoltaic components in Martian conditions. The facility has been employed in ESA ExoMars testing.
SILICON PORE OPTICS

Highly-energetic X-rays reflect only at very shallow angles, so sideways arrays of telescope mirrors are needed to focus them. ESA's TRP has contributed significantly to the development of silicon pore optics across a decade of effort, involving precision-mounted stacks of silicon, based on significant spin-in from the semiconductor industry. The result is a unique, superior European technology that ensures Athena — ESA's next-generation X-ray telescope — will represent a major leap forward in high-energy observational capabilities.

The work has been undertaken by an international consortium consisting of cosine Research, Micronit, KT, the Max Planck Institute and the Danish Space Research Institute.

TRANSITION EDGE SPECTROMETER

As well as its revolutionary X-ray optics technology, ESA's Athena X-ray telescope will also benefit from new high-resolution X-spectroscopy capabilities based on superconducting Transition Edge Sensors (TESs).

The TESs will be employed within the X-ray Microcalorimeter Spectrometer (XMS), one of the two instruments aboard ATHENA. The XMS works by converting individual incident X-ray photons into heat pulses to measure their energy via precise thermometry and should provide unique sensitivity to absorption features from galaxy clusters to supermassive black holes.
The XMS Consortium includes companies, universities and research and development centres from the Netherlands, Belgium, France, Italy, UK, Switzerland, Spain and Germany. The effort includes the TES sensor array, XMS focal plane and surrounding cryogenic cooling chain to maintain the instrument’s superconducting operating conditions.

OPTICAL BEAMFORMING NETWORK FOR MULTI-BEAM PHASED ARRAY ANTENNAS

Current 'bent pipe' telecommunications satellites with a fixed coverage and data rate are being supplanted by reconfigurable systems with multiple spot beams and on-board processing to enable variable coverage and data rates. But operating numerous multiple narrow beams spells high complexity, and threatens cross-talk and electromagnetic interference (EMI).

Photonic technology offers reduction in mass coupled with very high bandwidth capability, free of EMI. In 2005 the University of Valencia and DAS Photonics together with Thales Alenia Space France started the Optical Beamforming network for multi-beam satellite onboard phased-array antennas activity through the TRP’s Innovation Triangle Initiative.
An 8x8 port optical Butler Matrix in Silicon-on-Insulator (SOI) technology was successfully designed, fabricated and characterised, paving the way for constructing large feed array antennas using OBFN. A follow-up TRP activity called Opto-microwave based front-end for a multi-beam large direct radiating array antenna is planned for 2012. The aim is to build and test a proof-of-concept demonstrator for an innovative opto-microwave based front-end for a large dielectric resonator antenna targeting broadband multi-beam communications mission in Ka-band, such as multimedia via satellite or HDTV.

The aim is to demonstrate the expected mass, volume and power consumption savings, coupled with enhanced performance. This includes the ability to generate additional beams with increasing complexity compared with pure microwave or digital beam-forming options.

**VOICE-ACTIVATED PROCEDURE VIEWER**

SyberNet commenced on an innovative Voice-Activated Procedure Viewer (vaPV) in 2005 through a TRP Innovation Triangle Initiative contract.

It involved integrating a speech command and control interface into an existing procedure document viewer already established and deployed within the space community. Operators would be free to use the viewer on an 'eyes-busy' as well as 'hands-busy' basis.

An on-board experiment for Columbus called Crusade – Crew Usability Demonstrator – is now being planned for execution in December 2012. The VaPu software will essentially be reused, with additional validation work taking place to increase the prototype's robustness and reliability. This €300 000 activity is being pursued by ESA's ISS Programme, with Astrium Germany – the prime for all Columbus operations and sustaining engineering activities – acting as prime.
MODEM FOR HIGH-ORDER MODULATIONS

TRP has been pioneering the development of a laboratory demonstrator for Higher Order Modulation Schemes (MHOMS). The MHOMS programme led by Thales Alenia Italy was aimed at research, design development, and demonstration of a state-of-the-art very-high-speed, on-the-fly reconfigurable satellite digital modem prototype, with maximum bit rate of 1 Gb/s supporting a wide range of spectral efficiencies (0.5–5.4 b/s/Hz).

This truly innovative modem technology (SCCC coding, modulation framing) was demonstrated and successfully spun out in two key application areas. The first one is the high-speed Earth observation payload data downlink for which a Consultative Committee on Space Data Systems (CCSDS) standard dubbed Flexible Advanced Coding and Modulation Scheme for High Rate Telemetry Applications (CCSDS 131.2-B-1) has been recently approved.

ESA Earth Observation missions will benefit from this new standard, for which a ground demodulator has been developed in France by Zodiac Data System and another one is being developed by Konsberg under the GSTP program. An on-board high speed modulator based on this new CCSDS 131.2-B-1 standard (SCCC) is being developed by Tesat under GSTP. The second spun-out of the MHOMS TRP contract is related to a high performance flexible turbo code for the return link dubbed Turbo-Phi devised by ENST Bretagne which has been adopted by the second generation of the Digital Video Broadcasting Standard DVB-RCS2.

MILLIMETRE-WAVE LOW NOISE AMPLIFIERS

European Metamorphic HEMT (MHEMT) technology has reached the global state-of-the-art level that allows the realisation of low-noise amplifiers (LNAs) even for the highest frequencies above 100 GHz. LNA MMICs and modules with excellent performance have been successfully developed in TRP activities for various frequencies and missions at breadboard level. Current actions focus on ensuring the quality and reliability of these devices for the employment in the mm-wave receivers of the MetOp Second Generation mission.
LAYING FOUNDATIONS FOR COMMERCIAL SUCCESS

TUNABLE LASERS

A tunable laser was developed to serve a water vapour LIDAR. Intune Networks, a start-up working with Trinity College Dublin’s Physics Department, created a unique laser through a TRP contract for use in a lidar system that could be tuned to match the wavelength of water vapour absorption lines.

The project was successful but not pursued further because its planned space-based application, the WALES Earth Explorer mission was abandoned.

However the company pursued further laser development, but for optical computer networks instead. Intune Networks now employs 150 people, receiving a €10 million contract from the Irish government to build a fibre-optic network.

“The core technology created for ESA is applicable to a vast array of industries”
John Dunne, Intune Networks co-founder

AUTOMATED IDENTIFICATION SYSTEM (AIS) DETECTION FROM SPACE

The Automated Identification System (AIS) is a ship-based transponder system designed to transmit information such as vessel identity, position, heading, nature of cargo and so on to other ships and the shore. While AIS was not originally designed for detection from space, there is an identified need to develop a global maritime surveillance and security capability.

A TRP study by the Norwegian Defence Research Establishment (FFI), KDA and Surrey Satellite Technology Ltd considered the feasibility of space-based AIS detection to monitor global ship traffic, comprising technology reference and proof-of-concept through two test-vehicle ASICs and a large more than 1 Mgate digital signal processor ASIC.

The study has resulted in a follow-on GSTP In Orbit Demonstration hosted aboard Columbus on the ISS, with one receiver from FFI and Kongsberg and one receiver from Luxembourg-based Luxspace. In addition, the requirements and the concept design of the TRP activity stemmed a new development of Space based AIS on-board receiver funded under GSTP programme where more advanced algorithms for AIS message detection that was originally developed internally at ESA has been further investigated and implemented. In early 2012, a Norwegian consortium led by FFI successfully upgraded the detection algorithm used in the AIS receiver hosted aboard of Columbus and demonstrated a significant improvement in vessel detection. This work has inspired ESA Telecom’s follow-on SAT-AIS activity.
ON-BOARD GPS NAVIGATION RECEIVER

On-board GNSS navigation receivers can be used as a platform receiver, computing spacecraft navigation as part of the GNC subsystem and providing time synchronisation. TRP has been instrumental to support the development of the first generation of the Topstar3000 GPS L1 navigation receiver. ESA, in partnership with CNES and TAS-F, developed the first European multipurpose space qualified receiver (TOPSTAR 3000) based on previous developments for airborne receivers. Its most outstanding characteristics were its low acquisition and tracking threshold and its ability to navigate in all kind of orbits (LEO/GTO/GEO) thanks to its internal orbit propagator able to operate in code-only mode.

During last years, a second generation has been developed under the ARTES-5 programme, incorporating the L2C signal and significantly reducing the mass and power consumption.

This receiver has become a best-selling on-board GPS receiver. Around 160 flight units have been produced for missions including Proba-2, Demeter, GlobalstarG2 and the O3B satellite constellation.

RAD-HARDENED-BY-DESIGN ASIC LIBRARY

Application specific integrated circuits (ASICs) are those tailored for a given task, however simple or complex. ASICs are as essential for space technologies as they are in other domains, but ASICs for space require mitigation of radiation-induced effects. ESA’s technology roadmap includes various TRP activities on radiation hardening by ASIC design, and that of the underlying cell libraries.
Undertaken by IMEC, these activities are based on a modified library, allowing today the manufacturing of space grade components on a commercial CMOS 180 nm manufacturing process. This will be extended to 90 nm processes. The library/foundry was developed, tested and pre-qualified by means of two test-vehicle ASICs and a large, more than 1 Mgates ASIC.

The resulting European library for rad-hardened ASICs offers an cost-effective alternative to the very few European library/foundry options available.

**SURFACE ACOUSTIC WAVE RESONATOR FILTER**

Quartz-based Surface Acoustic Wave (SAW) resonators are commonly employed in voltage controlled oscillators (VCO) with demanding phase noise requirements. They take advantage of quartz and similar piezoelectric materials’ conversion of electrical energy into mechanical energy, in the form of acoustic waves.

However the use of SAW devices is mainly limited to frequencies below 1 GHz. The goal of this activity by Kongsberg Norspace was to extend the SAW resonator technology to L- and S-band, and to estimate the possible performance improvements of VCOs. The innovative SAW device developed, is based on a different propagating mode (the Surface Transverse Wave – STW) that allows the achieving of a much higher power handling in comparison to conventional SAW devices whilst maintaining a high resonator quality factor.

A STW-mode based VCO breadboard in L-band was designed and tested. Phase Noise improvement relative to other products in the order of 20 dB was demonstrated without increased power consumption or a larger footprint. The technology is now further developed into a new product line of VCOs in the ESA ARTES program.

**EUROPEAN LUBRICANT REPLACING DUROID5013/PGM-HT**

A TRP study led to follow-up GSTP test activity of possible new materials to replace the out-of-production lubricant Duroid5013 and its current replacement PGM-HT – both US made.

The European candidate technologies for replacement were Solid Lubricant Polymer Matrix Composite (SLPMC) and Solid Lubricant Metal Matrix Composite (SLMMC). Aerospace & Advanced Composites GmbH performed studies and tests at the material structure level, with emphasis on friction and wear resistance as well as thermal range.

For SLPMC, prototyping of filled polymer with PTFE/MoS2/GF was performed, with an investigation of its main mechanical, thermal and tribological properties.

For SLMMC, a preliminary ball bearing test on the possible materials candidates and comparison to PGM-HT was performed, with extended thermal range and cycle (-196 C/ 250 C, 600 million cycles 20-times accelerated plus not accelerated test) and improvement of SLMMC+Ag to cover both high (about 300 C) and ambient temperatures.
To scale the Technology Readiness Levels up to orbit demands progressively more complex and demanding R&D, as the technology becomes integrated with larger systems and tested in more realistic environments – which gets costly. The optional General Support Technology Programme aims to prevent promising technologies ending up in ‘Death Valley’, their progress stalled in the mid TRLs, all the way into orbit, and the marketplace.
OPERATING IN ORBIT

SPACEWIRE

SpaceWire has become the de-facto world standard for high-speed links and networks aboard spacecraft, like USB for home computers, easing the interconnections of sensors, mass memories, processing units and downlink telemetry subsystems.

The SpaceWire standard was developed through TRP and GSTP as a collection of specifications, European Cooperation on Space Standardization (ECSS) standards, electrical ground support equipment (EGSE) tools, protocol analysers and software interfaces that support on-board Payload Data Processing Systems through the course of their development, verification and operations.

The recent introduction of real-time transfer services opens the way to using SpaceWire networks for monitoring and control applications. Along the same lines, SpaceFiber will extend the concept to very high speed links and networks.

SpaceWire is being widely used by space missions, including ESA’s Mars Express, Rosetta, Herschel, BepiColombo, ExoMars, Gaia, CryoSat, GOCE, Sentinel-1, -2, -3 and the Sentinel-5 precursor. NASA has used it in JWST, LRO, LCROSS, Swift, GOES-R, PnPSat and TacSat. JAXA has employed it for its BepiColombo module, ASTRO-H, SPRINT-A, ASNARO and NEXTAR. It is considered by Roscosmos as a key technology.

Defining the standard has created a fast-growing global market, with upwards of 15 suppliers and 150 customers of SpaceWire products worldwide.
PROBA-1 AND PROBA-2: PROJECT FOR ON-BOARD AUTONOMY

Small, low-cost technology demonstration missions give small companies access to space, providing them with the flight experience that is essential for Europe's space industry to remain innovative and competitive.

QinetiQ Space nv has served as prime contractor for the two Project for On-board Autonomy missions flown to date.

Proba-1 has surpassed 10 years in orbit, with nearly 500 user groups and more than 20,000 products, pioneering technologies and techniques now in common use, including the ERC-32 processor, software autocoding, Li-ion batteries and automatic ground segment functions.

Proba-2, launched in 2009, has involvement from 10 European countries and Canada, with 31 participating institutions with 17 new technology demonstration payloads and four scientific experiments. Its new technologies include miniature reaction wheels, a digital Sun sensor, guidance and navigation control (GNC) algorithms for full autonomous navigation, autocoded attitude and orbit control system (AOCS) software, the LEON-2 FT processor and a solar panel with flux concentrator.

Proba-V, motivated by the need to provide continuity to SPOT 4 and 5 for global vegetation monitoring, is due to fly in 2013. It includes significant technology advances such as compact telescope, new SWIR detectors, compact communication systems in S- and X-band, the first GaN transmitter in space, the first ADS-B receiver in space and other experiments. A further mission in the series, Proba-3, will be a formation flying testbed incorporating a solar coronagraph.
WEAR: WEARABLE AUGMENTED REALITY SYSTEM FOR ISS

The Wearable Augmented Reality (WEAR) system is a wearable head-mounted augmented reality display to support hands-free operations, giving location and context-sensitive support to the user as required. Belgium-based Space Applications Services has served as WEAR’s prime contractor, working with the Katholieke Universiteit Leuven as subcontractor in charge of the vision-based localisation software.

For space applications (WEAR++) the system is intended for use within the ISS and comparable indoor environments, supporting step-by-step procedures. The system demonstration aboard the station provided valuable feedback on the different technologies employed in this project: head-mounted displays, non-invasive tracking systems and augmented reality.

For ground applications (WEAR_GA), the system is intended to support architects or civil engineers for outdoor operations in a variety of contexts. Based on WEAR++’s good results, a new GSTP activity, named mobiPV, is being started to maximise potential ergonomics issues.

SMOS

ESA’s Soil Moisture and Ocean Salinity (SMOS) Earth Explorer satellite is an example of how TRP and GSTP activities were key in the selection of an Earth Observation mission, proving that the technologies needed to achieve long sought scientific objectives – in this case global measurement of soil moisture and ocean salinity from space – were ready. The SMOS project ran smoothly without any major technological problems mostly thanks to such pre-development.

SMOS is also an example on how countries who decided to support the development of a new instrument concept within the GSTP program, well before the project was selected, saw their effort pay off. Had those countries waited for events to develop instead of deciding to fund it, it is very likely that the SMOS project would have not been selected due to lack of technology maturity.

Instead SMOS has positioned ESA and European industry at the lead of aperture synthesis radiometry world-wide, which has been recognised internationally by other space agencies and engineering bodies.
SLOHSAT POST-FLIGHT ACTIVITIES

The microgravity ‘sloshing’ of fuel and other liquids in their tanks can affect the attitude control of launchers and space vehicles. Slohsat FLEVO was a mini-spacecraft build and flown for the experimental study of liquid dynamics and liquid problems in space. It was launched on Ariane 5 ECA flight V164 in 2005.

Slohsat FLEVO post-flight activities (phases Fa and Fb) were carried out by the National Aerospace Laboratory (NLR) of the Netherlands.

The Slohsat FLEVO Motion Sensing Subsystem (MSS) served to measure and monitor the satellite's motion, with the MSS providing data from which angular velocity and linear acceleration could be determined or offline experiment processing carried out.
PREPARING FOR SPACE

GPS-POD: GPS-BASED PRECISE ORBIT DETERMINATION

On-board GNSS navigation receivers can be used to determine spacecraft orbit position and velocity. An industrial team comprised of RUAG Austria and Sweden has developed a spaceborne GPS L1/L2 receiver that computes real time position to the metre level. The receiver also serves as a sensor in support of ground-based post-processing of the precise orbit determination (POD), to sub-centimetre accuracy. The receiver incorporates AGGA-2 and LEON-2 chips, and implements an accurate navigation filter developed by DLR.

The GPS POD Instrument Engineering Quality Model (EQM) consists of electronics boards and mechanical box, the digital boards and DC/DC converter with an antenna plus software, including dual frequency processing in GPS semi-codeless mode as per adaptive semi-codeless tracking techniques implemented in ESA’s GRAS instrument.

The receiver has been baselined for Swarm (six units), Sentinels-1-2 and –3 (two units each) and EarthCARE (two units). An upgraded version of this receiver, including the new GPS L2C signal, has been selected for follow-on Sendinels.

GALLIUM NITRIDE FOR MICROWAVE SPACE APPLICATIONS

Generally regarded as the most promising semiconductor since silicon, Gallium Nitride (GaN) offers a major improvement in radiation hardness, a five-to-ten-fold increase in RF power output and the opportunity to reduce the mass and size of cooling systems. ESA’s GaN Reliability Enhancement and Technology Transfer Initiative (GREAT2) aims at establishing a European supply chain for the manufacture of highly-reliable space-compatible GaN-based microwave transistors and integrated circuits that would be free from any ITAR or end-user licence restrictions.

GREAT2’s industrial team consists of TESAT Spacecom, IMEC, Ferdinand Braun Institut für Höchstfrequenztechnik, the Fraunhofer Institute for Applied Solid-State Physics, United Monolithic Semiconductors, the University of Bristol and the University of Tor Vergata.
The GREAT2 initiative has reduced Europe’s GaN technology gap relative to the US/Japan from 10 years to four years. GSTP’s newly-proposed Element 2 (Competitiveness) will include thematic Announcement of Opportunity reminders for openings in the supply chain due to GaN use. A GaN X-band transmitter is scheduled to fly on Proba-V.

The Energetic Particle Telescope (EPT) is an instrument that measures the energy deposited by charged particles into 12 sensitive elements and processes the information to identify the particles (0.2-10 MeV electrons, 4-300 MeV H and 16-1000 MeV He ions) and to determine their energy spectra and angular distribution.

Built by a consortium consisting of QinetiQ Space, the University of Louvain, Belgian Institute of Space Aeronomy (BIRA) and Aboa Space Research Oy, the EPT effectively consists of two ‘particle telescopes placed in series, adapted to low and high-energy ranges respectively.

This high-fidelity performance of this instrument enables as accurate modelling of the space environment, coupled with in-orbit calibration of a growing network of radiation monitors in space on-board other ESA and non-ESA spacecraft. The EPT is ready to fly as a techno-guest payload aboard Proba-V in 2013.
SPC: SCALABLE PAYLOAD COMPUTER

The Syderal company developed the Scalable Payload Computer (SPC) for a wide range of roles such as an instrument control unit (ICU) and/or payload data processor.

Based on the AT697 (LEON2-FT) and incorporating the SpaceWire Router SpW-10X (AT7910E), this SPC is the prototype of a new generation of payload computers replacing the previous version, which is based around a processor that will soon become obsolete.

The single-board computer shall be usable to host the software to control several simple instruments or else a single complex one, such as an advanced radar. In the case of a radar, the SPC would provide the interface to the satellite platform on one side and on the other command and control a number of modules in the radar electronics and front end.

The SPC is being used in the payload data handling unit for Gaia and the instrument control module for the radar instrument on Sentinel-1.
NEW POSSIBILITIES

“ESA-led innovation remains imperative – we need to keep Europe a key player, otherwise in the future we will be dependent on Chinese communication satellites, on US navigation, Earth observation from India or similar scenarios.” Fritz Merkle, Chief Technology Officer of OHB System AG

COMPACT IN-ORBIT SAR OPTICAL IMAGE PROCESSOR

Synthetic Aperture Radar (SAR) images are typically processed digitally using dedicated Fast Fourier Transform (FFT) algorithms. This project aimed at the development and testing of a real-time SAR processor based on direct optical processing instead, giving image quality parameters comparable to a digital processor while exhibiting finder sampling distance than the equivalent Envisat performance.

The project was undertaken by INO. The on-board SAR image generation enabled by optical processing would provide local access to processed information, paving the way for on-board processing and decision-making in real time, with a possible operation up to 180 frames per second.

A compact in-orbit SAR processor could benefit a spacecraft’s autonomous navigation strategy and instrument orientation decisions and – for interplanetary missions – helping to select the appropriate images to be transmitted to Earth, helping bandwidth management.

Predictions indicate that optics should be faster than electronics for at least the next 10 years, considering commercially available display technologies and the typical trends of electronics development.
NACO: NANOTUBE-REINFORCED COMPOSITE FOR SPACE APPLICATIONS

Carbon nanotube (CNT) composite materials have been developed for space applications by an industrial team consisting of HPS, Invent, Future Carbon, Astrium Germany, AAC, the University of Patras and INEGI.

The focus has been on the creation of ‘CNT-skeletons’—thick non-woven papers or felts that can be embedded in metal, ceramic and polymeric matrices.

The envisaged applications for space for such CNT-skeleton composites are for ‘metals’—such as heat sinks and structural materials as well as ‘ceramics’—including optical mirrors and benches—as well as ‘polymers’—such as surfaces, carbon fibre reinforced polymer (CFRP) laminates, adhesives, deployable booms and structures, highly thermal/mechanical loaded sections and highly stable CFRP structures.

LOW-COST AND WEIGHT PLANAR TRANSFORMER

This project involved the production of a family of thin but efficient planar transformers at low weight and cost meeting ESA standards of design and manufacture, suitable for use in low (10W) and medium (50W) power converters.

Working with the Flux company, differently-sized transformers with different winding technologies and for different converter topologies—categorised as normal use for space applications—were designed, built and tested. This was the first attempt in Europe to qualify such a product for power applications.

Planar transformers have gained momentum in the commercial market in recent years as a means of reducing the cost of magnetic components within DC/DC converters. The products are of potential interest for any company producing power units, from platform PCDUs to payload DC/DC converters.

A continuation of this activity is being pursued in GSTP for the manufacturing of representative qualification models and their qualification through a thorough test campaign.
CCSDS IMAGE COMPRESSION ASIC

A radiation-hardened ASIC was developed that implements the CCSDS 122.0-B-1 standard for image data compression.

Produced by a consortium consisting of EADS Astrium France and Germany with Italy’s Techno Systems Developments, this new CCSDS Wavelet Image Compression Module (CWICOM) ASIC image compressor will be available in rad-hardened 18 nm technology by the end of 2012, with a data throughput of up to 80 Msamples/s, with no need of external memory.

Its use of a SpaceWire interface for command and control and very low power consumption make the CWICOM ASIC the fastest image compressor on the market that can be used for on-board applications.

Several upcoming ESA missions show interest in using the new device, namely Solar Orbiter and Euclid.

COATING EVALUATION FOR CHEMICAL-FREE BLACK COATING ON METALS

This activity, undertaken by the Enbio company, involved evaluating deposition techniques for chemical-free black coating on metals using the Co-Blast technique, in order to down-select the most promising metal-coating systems for further process optimisation and test the performances of the optimised substrate-coating systems in terms of generic space requirements.

The project includes hardened surface coating locally and globally, evaluating optical surface properties with post polishing, the tribological properties of surface and functional coatings including functionally graded surfaces.

The activity provides a successful solution for black coating on titanium and is considered to be a potential coating for the thermal shield of Solar Orbiter.
ENABLING TECHNOLOGIES FOR SPACE SITUATIONAL AWARENESS (SSA)

Telespazio has carried out the first step towards the implementation of the ESA Space Situational Awareness (SSA) Near Earth Orbits (NEO) Segment, which aims to monitor the NEO population for the timely provision of reliable data to external customers.

This activity included the definition of the SSA-NEO element, the analysis and characterisation of European ground- and space-assets, a NEO End-To-End (E2E) simulator and the NEO Segment design validation and concept demonstration with real and simulated data and scenarios.

The SSA-NEO E2E simulator, including almost-operational algorithms, has shown its potential not only to validate the proposed SSA-NEO system, but also for investigating new and competitive concepts.

A follow-on activity has been defined and proposed through GSTP: Synthetic generation with a NEO population would have the objective of defining and developing a tool for the simulation of observations of NEOs from ground- and space-based radar and telescopes. The output of this activity will be used for validating the SSA-NEO Segment performances and observation strategies.
SPECTROSCOPY SENSOR WITH CONFIGURABLE DIFFRACTIVE OPTICAL ELEMENTS

Sintef in Norway has developed a novel sensor for infrared spectroscopy that can be ‘tuned’ to detect particular gases of interest. The sensor is based on silicon gratings that can be moved when a tiny voltage is applied to them – known as configurable diffractive optical elements (CDOE).

Derived from optical Micro-Electro-Mechanical Systems (MEMS) technology, the CDOE filter is attached and wire-bonded to a ceramic package. The sensor can be tailored to detect hydrogen-gases such as carbon dioxide and nitrous oxide. For a spin-off application, see the TTP section.

DIGITAL SPACE PRESSURE SENSORS

The Presens company performed spin-in silicon sub-sea flow measurements techniques from the oil sector into silicon based MEMS sensor technology and applied it to low pressure and differential measurement in the aerospace sector.

Further development of precision digital pressure sensors has been undertaken to cover a wide range of space pressure sensor applications, both for satellites and launchers – mostly for fuel tanks.

Currently an extended range of absolute pressure sensors is being developed for use in ADM-Aeolus oxygen tanks.

The sensor is targeting existing gas sensor markets such as medium- to high-end gas sensors used for industrial safety in offshore installations, mines and aviation, where the onus is on high reliability, selectivity and accuracy, as well as low-cost gas sensors for fire and domestic gas detection, plus distributed low-cost sensors for industrial process control and emissions monitoring.

According to market studies, these markets constitute more than two thirds of a global gas sensor market worth €300 million annually.
The Enhanced Service Infrastructure Technology (ESIT) activity – carried out by SpaceBel and GIM and co-funded by industry – aimed at developing a new set of service infrastructure technologies to answer forthcoming needs, encompassing both Earth Observation and domains beyond it.

These technologies are identified, prototyped and tested for their capabilities to provide seamless access to remote sensing data and geospatial data, offer more complete, complex and automated orchestration of services and improve the exploitation of existing and new Earth Observation facilities, and permit an internet-based telecommunication architecture supporting more mobility.

This activity also aimed at extending even greater support to service providers in e-commerce/e-business and explore cooperation and e-collaboration environments. ESIT managed to achieve further development of a Java-based Web Map Viewer, configurable symbology using Styled Layer Descriptor Language, the development of Web Feature Service client, prototyping Open GIS Consortium (OGC) services and support for the Region Portal in Senegal.

This activity involved the design, manufacture and qualification of an engineering qualification model of a telemetry and telecommand and control (TTC) antenna operating in circular polarisation in S-band.

This antenna would be mounted primarily on a Earth Observation satellite platform where toroidal coverage is required for TTC.

Developed by the Rymsa company, this helix antenna works in normal mode, complying with pattern requirements in both transmit (1.81 GHz) and receive (2.25 GHz) bands.

It increases the company’s product portfolio, enabling them to propose to customers a smaller and lighter solution to generate toroidal patterns, compared to the bigger bicone TTC antennas currently employed for generating this coverage type. The design is flexible enough to be adapted to different radiation patterns and electrical requirements, to be used as a basis for new projects.
REACTION WHEEL PRODUCT TRANSFER

The activity sought to achieve technology and knowledge transfer of reaction wheels, originally developed by Astrium UK.

Bradford Engineering worked to consolidate the supply chain and perform some obsolescence management activities, manufacture and qualify a reaction wheel unit to successfully demonstrate an updated reaction wheel design that meets state-of-the-art requirements for demanding missions.

The focus has been on increasing yield and wheel performance in terms of key performance criteria. New insights accounting for heritage wheel characteristics have been gained while a range of wheels (W18 and W45) were successfully qualified.

Technology transfer, reaction wheel upgrades and the qualification of Bradford Engineering as a supplier of high-end reaction wheels have been successful. Bradford Engineering reaction wheels have been selected for the following flight projects: BepiColombo, Sentinel-2A and B and EarthCARE.

X-BAND PAYLOAD TELEMETRY TRANSMITTER FOR SMALL SPACECRAFT

The Syrlinks company, in collaboration with CNES, has developed a compact, efficient and versatile X-band transmitter based on commercial off-the-shelf (COTS) components for small platforms, mainly addressing EO missions.

The product was developed and qualified within a remarkably short two-year timeframe, enabling this telemetry transmitter to fly aboard ESA’s Proba-V mission in 2013.

This transmitter will fly along with an extra X-band transmitter incorporating a GaN amplifier sourced through GSTP’s GREAT2 initiative, increasing the overall reliability and robustness of the communication subsystem.
Omnisys Instruments undertook the design of a single-chip Highly-integrated full-custom autocorrelation spectrometer (HIFAS) ASIC that incorporates 1024 effective channels and supporting two sampling modes. It provides potential for up to 8 GHz of processed bandwidth with 4 GHz as a minimum requirement.

The spectrometer chip consists of two main blocks: the digitiser/quantiser and the correlator core.

The HIFAC ASIC has passed all performance tests, including dynamic range, linearity, channel shape and other criteria. Performance and power consumption largely exceed the minimum specification set at the start of the activity.

The HIFAS ASIC is under consideration for ESA’s Premier mission and for post-EUMESAT Polar System (EPS) radiometer instruments.
ESA'S TECHNOLOGY PROGRAMMES

The suite of technology development programmes overseen by ESA’s Directorate of Technical and Quality and Management are the Agency’s main ‘innovation factories’, tailored to transform promising new ideas into flight-ready technology and products while also exploiting their spin-off potential.

Technology development is embedded in ESA’s DNA. Above all, this is a research and development agency: each new mission marks a significant step forward in science or services. And bringing future plans into the realm of the possible demands a steady stream of new technology.

ESA’s Directorate of Technical and Quality Management maintains a suite of flagship preparatory technology programmes designed to generate such a supply of new technologies, mature them to flight ready status while also making them available to terrestrial markets to help strengthen wider European competitiveness:

Basic Technology Research Programme (TRP)

For more than 30 years, TRP has been advancing innovative ideas through successive stages of engineering, resulting in feasible technology and product concepts ready for qualification and eventual adoption by future missions.

All ESA Member States contribute to the TRP on a mandatory basis. It is based upon a three-year work plan and organised according to application areas, such as Earth Observation, Space Science and Human Spaceflight, as well as other technology domains such as data systems, software, propulsion, optics, and radio frequency (RF).

In line with its strong focus on basic technologies, the TRP allocates about forty per cent of its effort to Generic Technologies, meaning advanced basic technologies of common interest to all applications. Such ‘basics’ include component design, spacecraft propulsion or power generation.

Notable initiatives within and in addition to TRP include the Star Tiger scheme, the Innovation Triangle Initiative and the Networking/Partnering Initiative. The Star Tiger scheme targets the rapid development and prototyping of advanced technology—typically ‘spin-ins’ from non-space sectors—in a timescale of months rather than years. The Innovation Triangle Initiative, which accepts unsolicited innovative proposals from industry and/or academia, is focused on non-space technologies to solve space problems. The Networking/Partnering Initiative tackles spin-in addressing non space university and research centre competences which could bring benefit to space technologies.

General Support Technology Programme (GSTP)

ESA’s General Support Technology Programme (GSTP) exists to convert promising engineering concepts and technologies initially developed within TRP into a broad spectrum of mature products—everything from individual components to subsystems up to complete satellites—right up to the brink of spaceflight and beyond.

It does this by developing them into ‘breadboard’ engineering models whose space-worthiness can be verified not only in laboratories but also within the less forgiving space environment simulated by ESTEC’s facilities—including exposure to vibration, temperature or radiation extremes—and increasingly all the way up to orbit aboard demonstration missions.
GSTP also includes work on product and process improvements, aiming for a flexible response to the needs of ESA programmes, Member States and European industry.

In operation for the last two decades, GSTP is an optional ESA programme, open for ESA Member States (including Canada as an associate member) to choose whether or not to participate and at what level. GSTP activities cover all ESA application domains plus Generic Technologies, excepting Telecommunications which has its own ARTES programme.

The current GSTP operates on a five-year work plan and is based around the following elements:

**Element 1 - Support Technology Activities for Projects and Industry:** developing technologies and products needed by future space missions. The Element also covers the initial phases of small missions for in-orbit demonstration (IOD) of breakthrough concepts and implementation approaches. Selected IOD missions are then implemented under new dedicated Elements.

**Element 2 - Competitiveness:** strengthening worldwide competitiveness and strategic positioning of European actors in the near and mid-term in existing and new markets.

**Element 3 - Technology Flight Opportunities:** responding to industrial requests by making berths available for in-orbit demonstration of technology and products aboard carriers of opportunity. This is the last step up the ladder of technology readiness levels. Additional Elements may be created, in particular to implement the agreed IOD missions previously studied under Element 1.

**Element 4 - Precise Formation Flying Demonstration:** implementing the Proba-3 mission. This is the first of the Elements devoted to IOD missions. It will implement the Proba-3 mission for the demonstration of satellite precise formation flying techniques and technologies.

**Technology Transfer Programme**
TTP works to share with terrestrial sectors the benefits of ESA research and development efforts for space. The Agency’s TTP Office identifies industrial needs then maps them to suitable space technologies, as a way of enabling new applications and business opportunities. The TTPO also provides support to new businesses based on the transfer and use of space technologies.

Most transfers are achieved through TTP’s pan-European network of technology transfer brokers who scan the space market for exciting technologies and match them to the needs of the industrial world.

ESA Business Incubation Centres located across Europe foster the creation of viable companies from start-ups that base their business on the use of space solutions in terrestrial sectors. With its TTP, ESA further reaps the benefits of investments in Space, and its business incubation initiative is a direct measure for job creation, especially among the youth. Start-ups can also originate from company spin-offs, generally small to medium sized enterprises, which contributes to the viability of space’s small business sector.
European Components Initiative – Technology non-Dependence (ECI-TnD)

The European Component Initiative (ECI) exists to reduce the dependence of Europe’s space sector on non-European component suppliers, focusing on one of the building blocks of space missions - Electrical, Electronic and Electromechanical (EEE) components. The industrial base for space products in Europe is small. Changes in the commercial landscape, financial difficulties in key companies and lack of interest in space are a constant threat to European capabilities. Collapse of key supply chains is not impossible, and becoming increasingly likely as industry struggles to support the niche markets for space applications, leading to an irrecoverable loss of European capabilities.

The ECI works to increase the availability of European EEE-components used in European space missions by identifying critical space technologies and devices for developing capabilities to manufacture and qualify them within Europe.

These programmes between them make up about three quarters of overall ESA technology R&D. Much of the actual spending goes to European (and Canadian) companies and institutions, with 30% of all ESA technology contracts awarded to small-and medium-sized companies and 20% awarded to universities and research institutes.

Cross-cutting initiatives

Further coordination is being achieved between ESA’s Technology programmes through a set of four user-driven cross-cutting initiatives:

**Clean Space** - with environmental legislation set to change the way the space industry works, this initiative aims to convert a challenge into an opportunity for Europe’s competitive advantage, favouring the development of new green technologies and working techniques, and preserving the orbital environment from the mounting threat of space debris.

**Future Instrument Technologies** - Promising new science instruments for future breakthroughs will be selected through the Agency’s science advisory bodies to give Europe a portfolio of science technologies ready for mission adoption.

**Space Technology for Energy** - allowing the space sector to benefit from synergies with a much more widely established and wealthy partner, energy.

**Exploration Technologies** - combining together the roadmaps of developments needed in all technologies to implement the three-destination strategy of Low-Earth Orbit, the Moon and Mars.