ADVANCED SMALL SATELLITE CONSTELLATIONS FOR EARTH OBSERVATION SERVICES

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Abstract

Highly capable constellations comprising advanced, small and low cost satellites are dramatically changing the economics and scope of commercial remote sensing business and applications. The combination of extremely wide-swath medium resolution with agile high resolution imaging and low cost SAR from small satellites has provided a new class of highly responsive observations for disaster monitoring, land use and forestry, agriculture, natural resource monitoring urban planning and maritime surveillance. This paper introduces 3 generations of DMC constellations and summarises the successful applications of DMC micro/minisatellite missions such as Beijing-1, UK-DMC2 and NigeriaSat-2 and describe new service models to be provided by a constellation of high resolution optical small satellites (DMC3) and latest radar satellites (NovaSAR) planned for launch in 2015.

Introduction

The continuing advances in microelectronics over the last 20 years have dramatically improved the performance of consumer products – such as personal computers, mobile phones and digital cameras. The incorporation of commercial 'off-the-shelf' electronics that have been developed for this consumer-based market into small satellites has resulted in a remarkable increase in their capabilities, transforming in particular operational remote sensing at comparatively very low cost.

Terrestrial microelectronics tend to double their performance per unit cost approximately every two years – a phenomenon known as "Moore's Law" following Gordon Moore's observations made in the 1960's that "*the number of transistors on a chip doubles about every two years*".

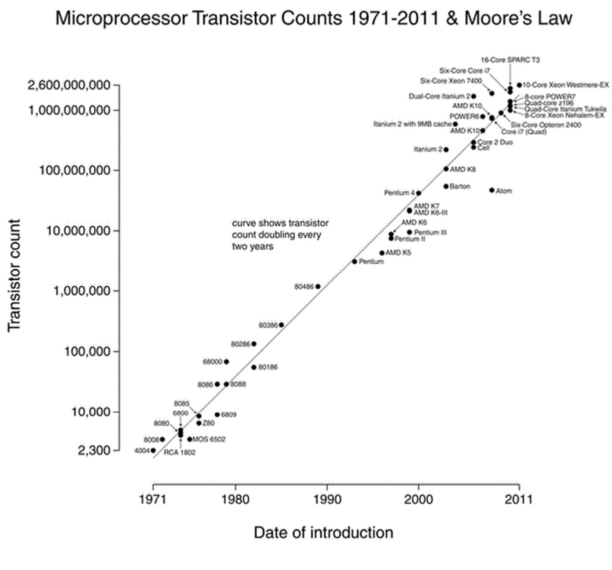

Fig.1 CPU transistor counts 1971-2011

A further dramatic example of this advance can be illustrated simply by comparing the weight and cost of large-scale digital storage devices over the period.

Fig.2 Mass data storage comparison: 1980-2010

Key to achieving this staggering advance has been a revolution on production techniques and processes that has gone largely unnoticed but is quite fundamental to producing billions of sophisticated devices that have enormously capable functionality and yet are physically tiny, have very low power consumption, produced at low cost and yet exhibit extreme reliability.

As a result of using such rapidly evolving technology and production techniques, the performance of small satellites is improving at something approximating to Moore's Law. These improvements are dramatic: over the last two decades we have seen around three orders of magnitude increase in image resolution (GSD), computing power, on-board data storage and data downlink speeds on small (micro and mini) satellites.

Between 1990 and 2010, the resolution, measured in terms of the size on the Earth's surface of the image pixels (GSD), has improved from 1km/pixel to 2.5metres/pixel – almost exactly tracking Moore's law. For example, the latest generation of SSTL EO small satellites will achieve 0.8-metre/pixel GSD by 2015; achieving three orders of magnitude improvement in 2 decades.

Indeed, SSTL's current generation of Earth observation satellites, weighing around 300kg, exhibit several performance measures that surpass the largest satellites ever launched, such as the 8-ton Envisat launched by ESA in 2002.

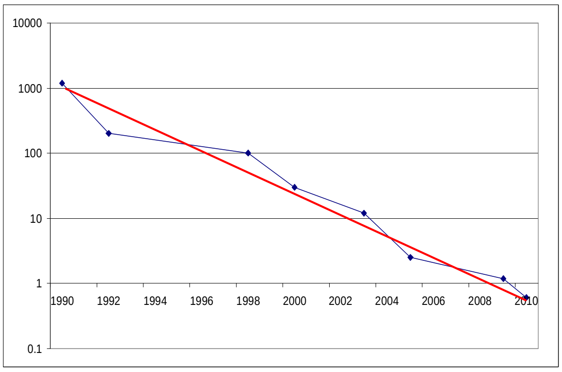

Fig.3 GSD of SSTL satellites 1980-2010

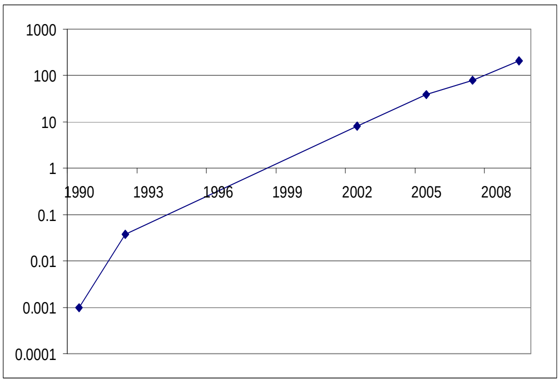

Fig.4 data rates (Mbps) of SSTL satellites 1990-2010

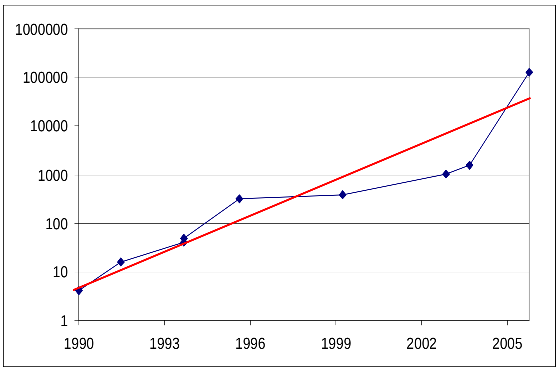

Fig.5 data volumes (kbytes) of SSTL satellites 1990-2006

The electronics is only part of the story for small EO satellites however – the other contributing factor is the ability to manufacture light weight optics to demanding tolerances using advances in materials science, such as carbon fibre structures, silicon carbide structures and optical surfaces. On the focal plane, the use of improved detectors incorporating time domain integration (TDI) allows the use of smaller optical apertures. The high performance optical systems are combined with capable electronics to create a lower cost per unit area of imagery generated over the lifetime of the satellites that then enables an improved value-for-money geo-information service.

The advent of high performance small satellites at very low unit cost compared to conventional aerospace approaches has, in particular, catalysed affordable constellations for optical Earth observation. Constellations enable the additional dimension of temporal resolution (i.e. rapid revisit) alongside the traditional measures of spatial and spectral resolution characterising which is prohibitively expensive to achieve with large satellites.

The first constellation of operational small EO satellites was the international Disaster Monitoring Constellation (DMC) initiated in 2003 and comprising 5 microsatellites providing 4-band wide-swath (600km at 32-metres GSD). This was followed in 2006 by the commercial 5-satellite RapidEye constellation providing multi-spectral imagery at 6.5 metres GSD. These constellations provide the ability to image anywhere in the world within 24hrs and both constellations combined were built and launched for considerably less than a single LANDSAT satellite.

DMC International Imaging Ltd

Exploitation of the resulting EO data and close interaction with the needs of the user community are essential and SSTL established a data services subsidiary company, DMC International Imaging Ltd (DMCii), in 2003 to co-ordinate the constellation partners, operate satellites, calibrate and process the image data, distribute the data to commercial value-added users and co-ordinate the response to declared disasters. DMCii also co-ordinates the international DMC Consortium, comprising the owners and operators of the individual DMC satellites, and promotes the commercial exploitation of the constellation with its members.

1st generation DMC EO microsatellites

The first generation DMC constellation consisted of five 100kg microsatellites launched into a 684km sun-synchronous orbit on 3 separate rockets between 2003 and 2005 (UK-DMC, NigeriaSat-1, AlSat-1, Bilsat and Beijing-1). The 5 satellites were then manoeuvred and phased equi-spaced around the same orbit.

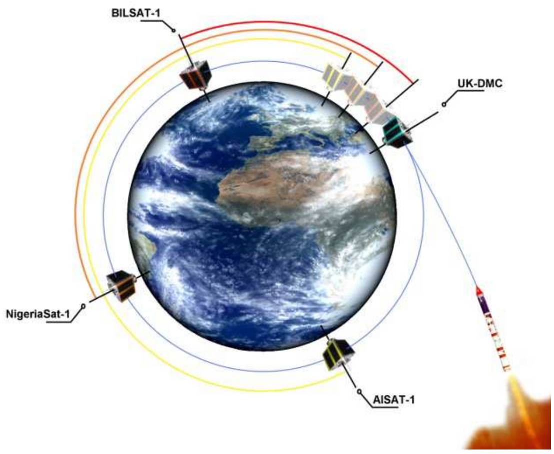

Fig.6 1st generation DMC constellation

The unique international cooperation in the DMC involved ownership of satellites built by SSTL for five different countries (UK, Nigeria, Algeria, Turkey and China). In addition to the national monitoring objectives of each consortium partner, the satellites are coordinated by DMCii for commercial applications and disaster response with a revisit time that could not be achieved by any individual satellite.

Each DMC satellite carried an identical wide swath (650km) multispectral sensor with spectral bands equivalent to LANDSAT bands 2, 3 & 4 with 32m GSD.

Fig.7 1st generation DMC satellites under test

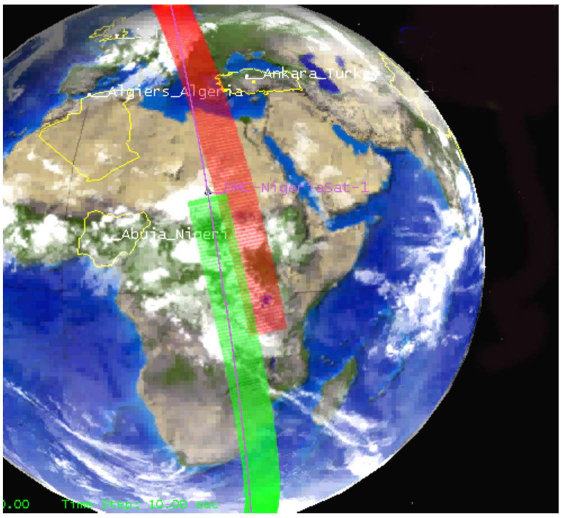

Fig.8 The 650km wide-swath on DMC satellites enables 24hr revisit

The DMC constellation imagers are calibrated in a 3-step process involving absolute calibration of a 'gold standard' satellite (using tests sites with available ground truth data, such as Railroad Valley in Nevada and Tuz Golu in Turkey), the transfer calibration to all detectors (using Dome C Antarctica test site) and then cross calibration to all satellites (also using Antarctica test site). The satellite calibration is also regularly tracked in relation to LANDSAT. The absolute calibration uncertainty for all satellites is 4-5%, and the relative calibration uncertainty between satellites is below 1%.

This well-calibrated constellation has been used widely for institutional and commercial applications such as tropical forest monitoring, European agricultural monitoring, land cover classification and precision farming.

Fig.9 DMC complete mosaic of Europe at 32m GSD acquired within a window of four months (2007)

An enhanced, 135kg, satellite (Beijing-1) launched in 2005 included a 4-metre GSD NIR panchromatic imager with a 25km swath capable of imaging strips over 3000km long. This extremely agile satellite owned and operated by 21AT/BLMIT from their ground station in Beijing, China is also able to image ±45˚off-nadir to increase temporal revisit and has exceeded its 5-year design lifetime by two years.

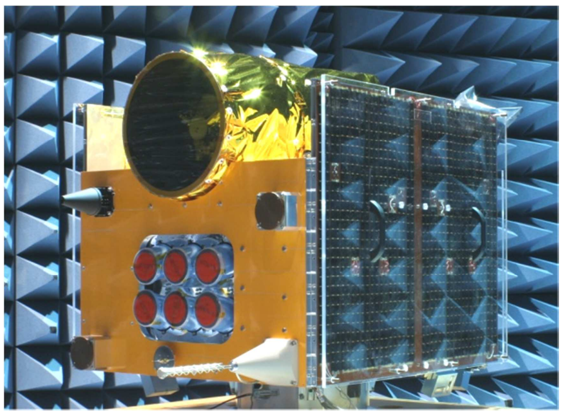

Fig.10 Beijing-1 enhanced DMC microsatellite 2005

Beijing-1 was used extensively to map China, assess crop yields, monitor land and water resources, desertification, urban development, biodiversity and environmental issues, and proved critical in responding to natural disasters such as the 2008 Wenchuan earthquake and extreme snowfall in southern China.

Fig,11 4-metre pan image from Beijing-1 © BLMIT

Fig,12 4-metre pan-sharpened multispectral data from Beijing-1 © BLMIT

2nd generation DMC EO microsatellites

UK-DMC-2, Deimos-1 and NigeriaSat-X launched in 2009 & 2011 form the second generation of the DMC constellation, bringing enhanced resolution, power, capacity and image quality.

Fig,13 UK-DMC-2 prior to launch (2009)

These satellites have the same 650km wide swath as the first generation satellites but have improved resolution of 22-metres GSD, resulting in more than double the pixel density, and with enhanced image modulation transfer function (MTF) and signal-to-noise ratio. A high data rate X-band downlink, coupled with enhanced on-board storage and direct downlink capability increases the constellation's total imaging capacity by a factor of ten.

Commercial EO Constellation

Using five of SSTL's 130kg microsatellite platform, the commercial RapidEye constellation provides multi-spectral imagery at 6.5 metres GSD with a 120km swath – primarily for the agricultural market.

Fig.14 Five RapidEye constellation satellites awaiting launch (2006)

3rd generation DMC EO minisatellites

Nigeriasat-2, the first of the new generation of SSTL's 300kg enhanced EO minisatellites, was launched in August 2011 and has the capacity to produce hundreds of images per day with both 2.5-metres GSD panchromatic and 5-metres GSD multispectral (27km swath) in addition to the wide-swath medium resolution images.

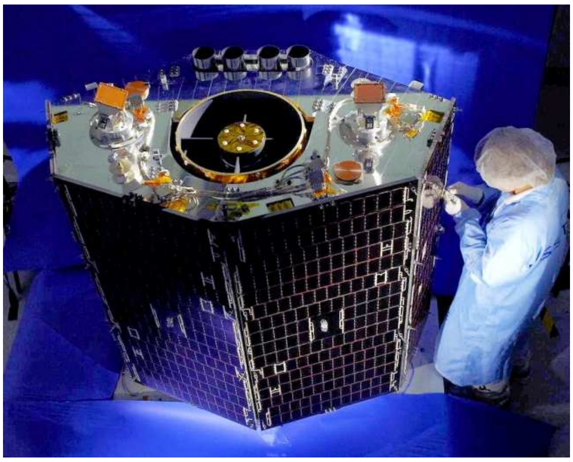

Fig.15 NigeriaSat-2 ready for launch (2011)

Fig.16pan-sharpened 2.5-metre GSD multispectral image of Salt Lake City airport ((© NASRDA 2011)

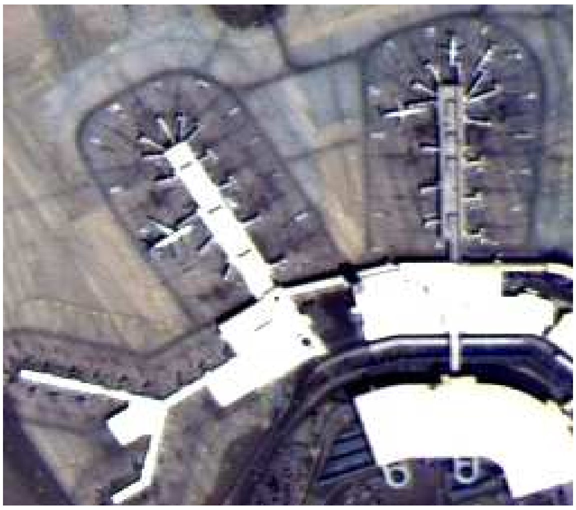

Fig.17 expanded section of above 2.5-metre GSD pan sharpened m/s image ((© NASRDA 2011)

New EO Constellation Business Model

Learning from the commercial arrangements commonly used for geostationary communications services whereby service providers typically lease transponders as required rather than actually own and operate the satellites themselves, DMCii is offering a novel EO downlinks will be operated within a novel EO leased capacity business concept. In 2015 DMCii will launch a constellation of three high resolution highly agile mini-satellites that will provide 1m GSD panchromatic and 4m GSD multispectral data with 480Mbps X-band downlinks. The spacecraft will be owned and operated by DMCii, whilst the imaging payload capacity has been leased to 21AT in China who will be able to task and retrieve data directly to their own ground stations.

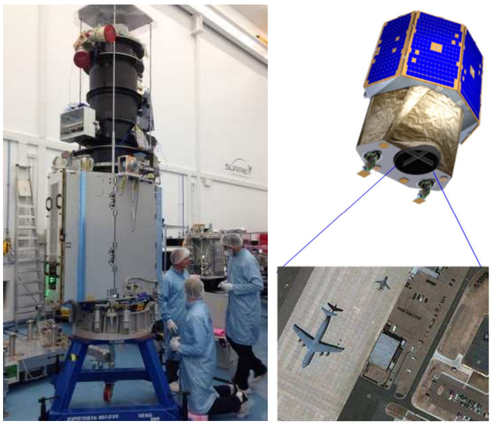

Fig.18 DMC3 1-metre GSD in test and in orbit (simulated image)

Applications

The original headline application for the DMC constellation was disaster monitoring and this remains an important commitment, with active participation in the International Charter for Space and Major Disasters providing over 200 images each year. However, this now represents a relatively small fraction of this powerful and well-calibrated constellation's capability that is now used widely for institutional and commercial applications – such as tropical forest monitoring, European agricultural monitoring, land cover classification and precision farming.

The additional capacity provided by the 2nd generation satellites has enhanced the DMC global monitoring and rapid response applications since November 2009. A prominent example is tropical forest monitoring. The DMC constellation has performed intensive imaging of the Brazilian Amazon Basin each year since 2005, to achieve either an annual coverage of the entire Basin or two coverages of the Southern Arc of Deforestation within a 3-month period (figure 5). The DMC has also performed joint imaging campaigns over the Congo Basin and Indonesia. The addition of the new satellites raises the possibility of routine monitoring of all of the world's tropical forests with high resolution optical imagery, achieving very low cloud percentage in these traditionally challenging environments through routine repeated wide-swath daily imaging.

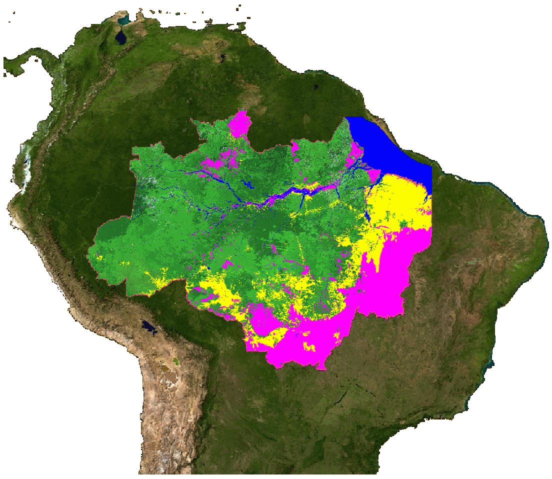

Fig.19 'Land cover/Forest map of Brazilian Amazon basin (© INPE)

Another rapidly expanding application for the DMC is precision agriculture. This application requires high resolution optical data over large areas of land at highly specific crop growth stages, which is very difficult to achieve with any data source other than DMC. The data are used for rapid estimation of biophysical parameters and then converted into recommendation maps to guide farmers' fertiliser and agrochemical applications.

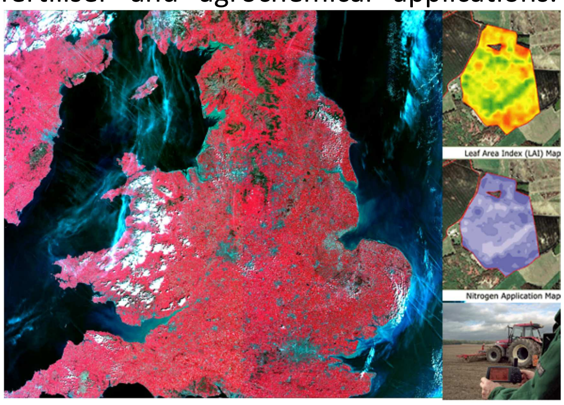

Fig.20 A single image of the UK acquired by the Beijing-1 satellite (2007 © BLMIT)

DMCii has for several years supplied intensive imaging campaigns for several precision agriculture service providers in Europe and North America, but the addition of the new satellites greatly enhances its ability to meet the same strict timeliness requirements over much larger areas – potentially at continental level. The higher resolution of the new satellites is also an advantage for precision agriculture applications, particularly in parts of the world with relatively small field sizes.

A second type of agricultural monitoring application is for global crop area estimation, yield prediction and food security. This requires systematic multi-temporal monitoring at continental level, on behalf of institutional customers and international agri-business & commodities companies. The ten-fold increase in DMC constellation capacity brought about by the new satellites makes this application perfectly feasible.

A similar systematic multi-temporal monitoring capability is required for large scale land cover mapping projects. For example, in 2007 the first generation DMC constellation acquired a complete coverage of 38 European countries (Fig.8) with less than 5% cloud cover within four months, each country having its own specific narrow acquisition window within that period. The capability to cover very large areas within narrow time windows is powerful for land cover mapping at continental scale, and solves traditional problems of having to work with thousands of small scenes from different sensors and from an inconsistent mixture of seasons and years. The DMC constellation is now capable of complete multi-temporal coverages of whole continents within discrete seasons of each year.

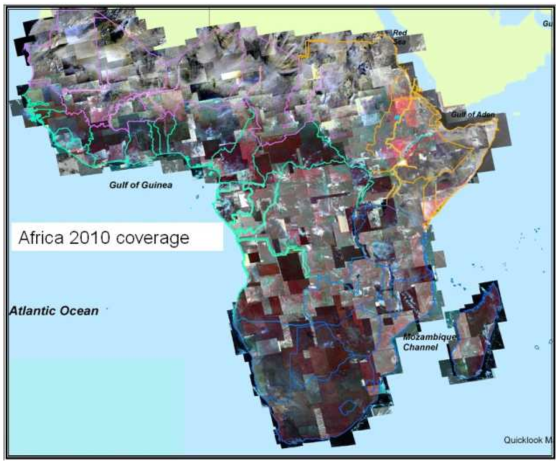

Fig. 21 DMC quick-look mosaic of Sub-Saharan Africa, acquired in 12 months 2009-10.

The DMC acquired a complete coverage of sub-Saharan Africa in 12 months (between mid 2009 and mid 2010) for the European Space Agency and the European Commission. This dataset is being used for multiple applications under the EC 'Global Monitoring for Environment and Security' (GMES) program, including land cover mapping, environmental monitoring and humanitarian emergency preparedness & response. The availability of a consistent dataset over this huge area from a discrete 12-month period is a unique and powerful asset for these applications. We expect to continue supporting the GMES services through the DMC over the coming years.

RADAR Remote Sensing Constellation

Whilst optical EO satellites are now commonplace, their usefulness is constrained by cloud cover and inability to operate at night. Synthetic Aperture Radar (SAR) remote sensing satellites are able to operate in all weather (i.e. through cloud) and at night, however conventional SAR satellites have been large and extremely costly – and the data retrieved requires expert analysis and interpretation.

SSTL has developed a small (400kg) and comparatively low cost 'NovaSAR' minisatellite specifically to be able to form a new radar constellation to augment the optical DMC

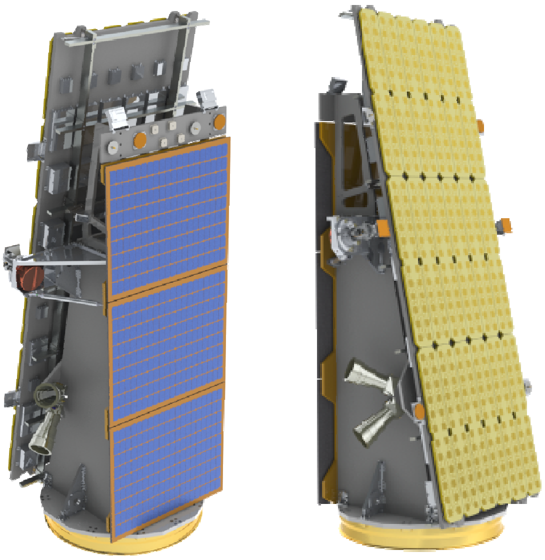

Fig.22 NovaSAR satellite configuration

The NovaSAR constellation, which will in due course comprise 4-5 satellites, carries an S-band SAR payload specifically optimised to address maritime surveillance, and monitoring floods and deforestation. NovaSAR is capable of operating in several modes for spot-light and broad area monitoring over 1.000,000 sq.km per day in different polarisations (HH,VV,HV) throughout its 7-year design lifetime. The S-band SAR payload has be demonstrated using airborne trials and first NovaSAR satellite in the constellation is due to be launched in 2014.

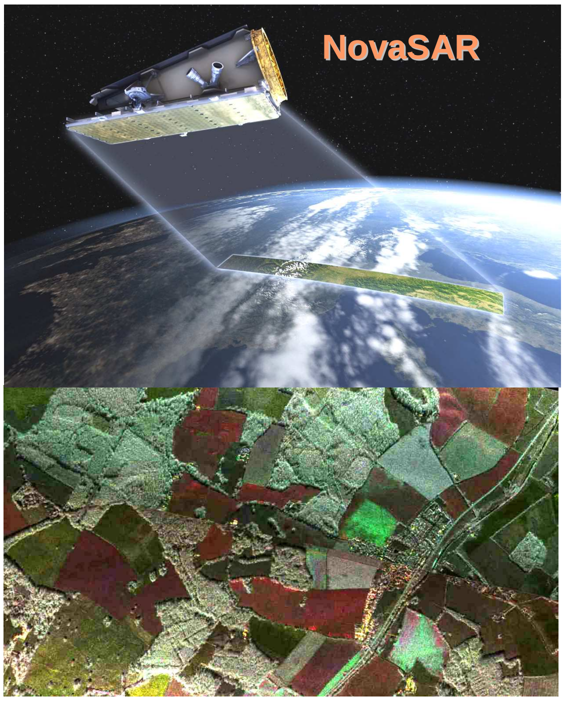

Fig.22 NovaSAR and airborne SAR payload image

Conclusions

The use of modern COTS microelectronics, largely developed for the consumer market, has enabled low cost yet high performance small satellites to provide high quality operational Earth observation services addressing both the commercial market and supporting humanitarian disaster monitoring. The affordability of constellations of both optical and upcoming radar small satellites provides greatly increased temporal resolution and has stimulated new business models.

Acknowledgements

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