NovaSAR – Bringing Radar Capability to the Disaster Monitoring Constellation

Philip Davies (1), Phil Whittaker (1), Rachel Bird (1), Luis Gomes (1), Ben Stern (1), Prof Sir Martin Sweeting (1), Martin Cohen (2), David Hall (2)

(1) SSTL, Tycho House, 20 Stephenson Rd, Guildford, GU2 7YE, UK, tel +44 1483 803875, email p.davies@sstl.co.uk
(2) Astrium UK Ltd, Anchorage Rd, Portsmouth, PO3 5PU, UK, tel +44 2392 705481, email martin.cohen@astrium.eads.net

ABSTRACT

Small satellites are playing an increasing role in addressing applications in Earth Observation for scientific, civil and military applications. With all optical systems, this leads to some obvious limitations to the time of day targets can be imaged, which geographic latitudes can be covered, and to a dependency on cloud cover. For some applications this limits the utility of space systems unless low-light and through-cloud imaging information can be obtained in a timely fashion by other cost-effective means. Typically, space based radar systems are significantly more complex, more expensive, and data is more difficult to utilise than equivalent optical systems. Existing radar satellite systems therefore predominantly address scientific and military needs, leaving room for smallsat systems that address commercial needs, maritime security, and disaster monitoring.

Advances in new technologies now have permitted a step performance improvement in radar systems, which will now be implemented in the NovaSAR mission which is under construction at SSTL. Gallium Nitride RF transistors enable high efficiency power amplifiers to be employed, reducing the power demand from solar panels, thus enabling a smaller radar satellite to be constructed. System innovations are also included to facilitate satellite operation in constellations, and in orbits other than the traditional dawn-dusk orbits. The spacecraft will also include an operational mode to operate in a maritime detection mode instead of imaging mode.

In November 2011 the UK government announced that they are investing in the first satellite in a NovaSAR radar constellation, allowing the construction of the first 400kg satellite to commence to be ready for launch in 2014. This paper will provide details on the satellite and payload design trades, results from airborne trials of the payload, and provides an overview of the planned mission applications.
1 INTRODUCTION

The Disaster Monitoring Constellation (DMC) has been a major success over the past decade demonstrating the real benefits that small satellites can bring in support of a variety of real-world applications. The current DMC is based on optical imaging technology with some key attributes: (1) the ability to image very large areas with wide swaths at medium resolutions, (2) very low costs compared to larger missions generating similar data and (3) a ‘constellation’ approach allowing timely imaging of areas of interest.

However, as with all optical imaging satellites, there is no ability to image at night and the system is at the mercy of the weather due to cloud cover. Thus, it is not possible to have guaranteed images at any particular time – the constellation approach allows daily imaging opportunities but it still may take several days for the area of interest to be cloud free. In contrast, radar imaging satellites are able to operate at night and also when the area of interest is cloudy so can be used when guaranteed imaging is required.

Thus, a radar imaging capability is an extremely attractive option to add to the DMC. The problem with radar systems is that the radar payload itself has, in the past, been rather costly to develop and manufacture and also the demands placed by the radar system on the platform have driven up platform costs as well leading to very costly missions – typically >€100M.

Recent developments in platform technology and some key elements of the radar payload have now enabled the development of a low cost radar imaging satellite - NovaSAR. A joint team of SSTL and Astrium has worked closely together and designed and prototyped the NovaSAR system. In November 2011 the UK government confirmed its support for NovaSAR by announcing it would support the development with €25M of finance. The preliminary design for the satellite is in place, with the platform being a new structure containing the avionics from the SSTL-300 satellite range – as used on the NigeriaSat-2 optical satellite launched in August 2011. The payload uses novel technologies and operates in S-band and the resulting satellite is consequently named NovaSAR-S. In single polar mode (HH or VV) spatial resolutions in the range 6-30m are achieved with corresponding swath widths ranging from 15-150km. Multi-polar (HH, VV, HV and/or VH) variants of these modes are also available either at coarser resolution or with a narrower swath width. A unique maritime surveillance mode with a surveillance swath of 750km width is also available for the detection of ships in the open ocean.

To complement the design activity and to provide examples of the form of data that will be available from the NovaSAR system, the team has also built an airborne multi-polar radar which has been used to image parts of the UK simultaneously in S and X bands. Additionally, a demonstrator using a portion of the actual NovaSAR antenna has been used to successfully image the space station from Earth.

2 NOVASAR-S SATELLITE DESIGN

NovaSAR-S combines heritage avionics [1] with a new structural design to accommodate a payload developed under a joint initiative between SSTL and Astrium. The design lifetime of the satellite is 7 years. A trade-off between imaging requirements, drag and propulsion subsystem performance...
and cost settled on an optimum orbital altitude of 580km.

A comprehensive trade-off of structural concepts was carried out. The final design was selected for its simplicity and lack of deployable appendages.

Figure 1. NovaSAR-S – payload antenna (left) and solar panel (right) views

The S-band payload antenna is a micro-strip patch phased array of approximately 3x1m. The antenna size drives the satellite size which has been deliberately constrained to meet low cost launch vehicle requirements. The use of a lower frequency band (P- or L-band) would have led to a larger antenna and would not suit our primary applications so well. The use of a higher frequency band (C- or X-band) would have limited the choice of HPA technology which is a key enabler to our solution. Traditional space qualified TWTAs offer good efficiency but are relatively expensive. GaAs SSPAs can be implemented using COTS technology but do not offer such good efficiency. Recently, the terrestrial use of GaN in SSPAs has become mature at frequencies up to S-band and offers efficiencies >40%. Therefore, our payload has been designed around S-band GaN SSPAs.

Table 1. NovaSAR-S specifications

<table>
<thead>
<tr>
<th>Specification</th>
<th><strong>Value</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td>Imaging frequency band</td>
<td>3.1-3.3GHz</td>
</tr>
<tr>
<td>Antenna</td>
<td>Microstrip patch phased array (3m x 1m)</td>
</tr>
<tr>
<td>No. of phase centres</td>
<td>18</td>
</tr>
<tr>
<td>Peak RF power (W)</td>
<td>1.8kW</td>
</tr>
<tr>
<td>Polarisations</td>
<td>HH, HV, VH, VV</td>
</tr>
<tr>
<td>Imaging polisation</td>
<td>Single, dual or tri-polar</td>
</tr>
<tr>
<td>Design life (years)</td>
<td>7 years</td>
</tr>
<tr>
<td>Mass (kg)</td>
<td>&lt;400kg</td>
</tr>
<tr>
<td>Lead time (KO to FRR)</td>
<td>24 months</td>
</tr>
<tr>
<td>Optimum orbit</td>
<td>580km</td>
</tr>
<tr>
<td>Propulsion system</td>
<td>Xenon</td>
</tr>
<tr>
<td>Payload duty cycle</td>
<td>&gt;2min per orbit (~single image 800km long)</td>
</tr>
<tr>
<td>Payload data memory</td>
<td>32GBytes</td>
</tr>
<tr>
<td>Downlink rate</td>
<td>105Mbps</td>
</tr>
<tr>
<td>TTC frequency band</td>
<td>S-band (2025-2110MHz, 2200-2290MHz)</td>
</tr>
<tr>
<td>Downlink frequency band</td>
<td>X-band (8.025-8.4GHz)</td>
</tr>
</tbody>
</table>

By using GaN SSPAs and designing for an imaging duty cycle of ≥2min per orbit (~2%) the orbit average power consumption of the payload is in the region of 100W. This greatly helps to reduce the overall spacecraft mass and volume, and hence costs associated with manufacturing, test, transportation, launch etc. The 2min imaging period has been selected as a baseline to enable an 800km long strip of imaging each orbit that is well suited to regional observations, comparable with the size of many nation states. In fact, depending on operational mode and downlinking opportunities, larger payload...
duty cycles can also be supported by the NovaSAR-S satellite providing the overall 2% duty is respected across a number of orbits.

The NovaSAR-S satellite design supports 2min imaging per orbit for both near equatorial and sun synchronous orbits. Orbit specific hardware changes are limited to AOCS actuator placements (star trackers etc.).

The payload can transmit and receive on both horizontal and vertical polarisations. The baseline payload configuration can be operated to produce imagery in polarimetric mixes that include single polar (HH, VV), and then by trading swath width and/or resolution for more diverse polarimetric capability, dual polar (any 2 from HH, VV, HV or VH) or tri-polar (any 3 from HH, VV, HV or VH).

The applications focused approach to the NovaSAR-S system design has resulted in a platform where both solar panels and the

Figure 2. Radiator units arranged in three columns of six

Figure 3. NIA payload backend

The front surface of payload frontend consists of the SAR antenna panel with a total of 18 pairs of sub-arrays, each pair forming an individually controllable phase centre. The payload frontend RF electronics are mounted on the reverse side of the antenna panel making the payload frontend self-contained. Six beam control units apply transmit and receive phase adjustments to the eighteen phase centres. Each phase centre consists of a transmit unit (100W RF o/p), a power conditioning unit, a receive unit and a radiator unit. The radiator units are arranged in three columns of six sub-array pairs, each having 24 patches, see Figure 2. The cold redundant payload backends are an S-band variant of the Astrium NIA equipment, see Figure 3 The NovaSAR-S platform has been designed to support payloads that operate in different frequency bands. Efficient SSPA technologies in other bands are being investigated so that alternate payload frontends can be implemented in the future.

The applications focused approach to the NovaSAR-S system design has resulted in a platform where both solar panels and the

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payload antenna can follow fixed, body mounted forms. Hence, the satellite is without deployable appendages, a unique achievement for a SAR satellite.

The NovaSAR-S design has the capacity to fly one or two additional payloads. Given the maritime focus of the mission it would be highly desirable to fly an AIS receiver. This option is currently being assessed for technical feasibility in terms of antenna accommodation and resource usage.

2.1 Baseline Imaging Modes

An orbit altitude of 580km has been used to derive the baseline imaging modes given in Table 2. Mode 1 is expected to be the mode most commonly used for the target applications identified. Mode 2 is an unconventional, ultra-wide swath mode intended for ship detection. Modes 1, 2 and 4 are ScanSAR modes. Mode 3 is a Stripmap mode which trades swath width for an improved resolution. However, this reduced swath can be selected from a 150km access range. Mode 4 is similar to mode 1 but trades resolution to get a wider swath. Modes 1, 3 and 4 have options to increase the available incidence angles and reduce revisit times.

<table>
<thead>
<tr>
<th>Mode</th>
<th>Resolution</th>
<th>Incidence angles</th>
<th>Swath</th>
<th>Sensitivity (N0σ)</th>
<th>Typical ambiguity ratio</th>
<th>No. of looks</th>
</tr>
</thead>
<tbody>
<tr>
<td>ScanSAR</td>
<td>20m</td>
<td>16-26°</td>
<td>100km</td>
<td>&lt;-18dB</td>
<td>&lt;-16dB</td>
<td>4</td>
</tr>
<tr>
<td>Maritime</td>
<td>30m</td>
<td>48-73°</td>
<td>750km</td>
<td>N/A</td>
<td>&lt;-18dB (range)</td>
<td>N/A</td>
</tr>
<tr>
<td>Stripmap</td>
<td>6m</td>
<td>16-31°</td>
<td>15-20km</td>
<td>&lt;-18.5dB</td>
<td>&lt;-16dB</td>
<td>3.7</td>
</tr>
<tr>
<td>ScanSAR Wide</td>
<td>30m</td>
<td>15-29°</td>
<td>150km</td>
<td>&lt;-19dB</td>
<td>&lt;-16dB</td>
<td>4</td>
</tr>
<tr>
<td></td>
<td></td>
<td>22-31°</td>
<td>100km</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 2. Baseline Single Polar Imaging Modes
The payload is highly flexible and is capable of delivering a wider range of imaging modes than those baseline modes presented above which have been designed for maximum coverage. In-orbit tuning of beam shape and pulse repetition frequency (PRF) can be used to define new modes.

Table 3. Single satellite revisit times in days

<table>
<thead>
<tr>
<th>Mode</th>
<th>Sun Sync LTAN 10.30 orbit</th>
<th>15deg equatorial orbit</th>
<th>Sun Sync LTAN 10.30 orbit</th>
<th>15deg equatorial orbit</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Av 3.7</td>
<td>Av 1.3</td>
<td>Av 1.5</td>
<td>Av 0.4</td>
</tr>
<tr>
<td></td>
<td>Max 14</td>
<td>Max 6.2</td>
<td>Max 3.5</td>
<td>Max 1.0</td>
</tr>
<tr>
<td>2</td>
<td>Av 0.9</td>
<td>Av 0.5</td>
<td>Av 0.3</td>
<td>Av 0.2</td>
</tr>
<tr>
<td></td>
<td>Max 8</td>
<td>Max 0.9</td>
<td>Max 0.5</td>
<td>Max 0.8</td>
</tr>
<tr>
<td>3</td>
<td>Av 3.2</td>
<td>Av 0.9</td>
<td>Av 1.1</td>
<td>Av 0.3</td>
</tr>
<tr>
<td></td>
<td>Max 12.5</td>
<td>Max 2.2</td>
<td>Max 3.5</td>
<td>Max 0.9</td>
</tr>
<tr>
<td>4</td>
<td>Av 3.7</td>
<td>Av 1.0</td>
<td>Av 1.2</td>
<td>Av 0.3</td>
</tr>
<tr>
<td></td>
<td>Max 13</td>
<td>Max 2.4</td>
<td>Max 3.5</td>
<td>Max 0.9</td>
</tr>
</tbody>
</table>

For applications where revisit time is important the baseline modes 1 and 4 have been extended by adding alternate, narrower, higher incidence angle swaths, see Table 2. Mode 3 can be steered to higher incidence angles with a 1dB compromise in minimum sensitivity.

Not only does NovaSAR-S support flexible modes of operation but it also achieves relatively high throughput of image data, see Table 4.

Table 4. Typical average daily imaging throughput

<table>
<thead>
<tr>
<th>Mode</th>
<th>10⁶ km² per day</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1.2</td>
</tr>
<tr>
<td>2</td>
<td>8.8</td>
</tr>
<tr>
<td>3</td>
<td>0.4</td>
</tr>
<tr>
<td>4</td>
<td>1.8</td>
</tr>
</tbody>
</table>

3 LAUNCH

Most SAR systems are launched into dawn/dusk orbits due to power considerations (no eclipses). However, since NovaSAR is not driven by a fixed imaging duty cycle requirement we can consider other orbits. This development has considered three target orbits:

- Dawn/dusk (LTAN 06.00)
- Sun-synchronous (LTAN 10.30)
- Equatorial (inclination 15degrees)

A dawn/dusk orbit is considered the conventional SAR orbit. The sun-synchronous (LTAN 10.30) orbit is well understood in power and thermal respects from optical EO missions. It also offers far more options for shared launches, and potential for phasing with optical satellites in the same orbital plane. The equatorial orbit offers maximum imaging and downlinking opportunities for customers.
based in that region or customers who want to image that region.

A variety of launches have been considered to provide an envelope for mass, volume, shock and vibration environments. However, particular attention has been paid to accommodation on launches commonly used by low cost LEO missions.

![Figure 4. NovaSAR-S Dnepr Accommodation](image)

**4 APPLICATION AREAS**

Discussions with potential customers of a low cost system have identified the following applications as being those most commonly of scientific or commercial interest:

- **Maritime Services**
  - Ship detection and tracking (including AIS augmentation if the secondary payload is flown)
  - Oil spill detection and monitoring
  - Iceberg detection and tracking
  - Ice edge Monitoring
- **Tropical Forest Monitoring**
  - De-forestation monitoring
  - De-forestation prevention
- **Disaster Monitoring**
  - Floods

However, applications that can be served by a medium resolution (6-30m) system are not limited to the list above.

**5 DEVELOPMENT PROGRAMME & PLANS**

**5.1 Airborne Demonstrator**

The S-band ITU frequency allocation for radar payloads has been less frequently used than the C- and X-band allocations which offer comparable (C-band) or higher (X-band) bandwidth. However, the 200MHz available at S-band is more than sufficient for the medium resolution applications proposed for NovaSAR-S.
A particular contribution from the Astrium side of this joint development has included an airborne imaging campaign to validate the utility of the S-band data generated by a spaceborne system for various applications. The existing Astrium airborne SAR demonstrator has been modified to function simultaneously at both S-band and X-band and a number of datasets have been recorded of urban, rural and coastal scenes over the UK. The airborne demonstration has also exercised an early generation of the payload backend New Instrument Architecture (NIA).

Visually, a similar level of information is contained in the S-band images compared to X-band images captured simultaneously, see Figure 5. Astrium and SSTL have initiated research at the University of Surrey’s Space Centre to characterise S-band SAR data with respect to various applications to get maximum benefit from spaceborne systems [2].
The airborne data can also be processed to indicate what images from a spaceborne system would look like. Figure 6 shows an example processed to Mode 3 resolution single/dual/tri-polar imagery.

5.2 Payload Hardware Demonstrator and Inverse SAR Test

A ground based payload demonstrator has been built to prove the functionality and performance of the spaceborne payload. The demonstrator consists of a complete payload backend and a payload frontend which is one third of the full payload frontend i.e. six phase centres.

The RF frontend of the payload demonstrator has been built to near flight standard and characterising it has provided confidence about the performance that can be achieved with a spaceborne system.

The demonstrator implements the full functionality involved in capturing data to the platform data recorders. Thus, it provides significant risk mitigation to the implementation of the spaceborne system.

To test a SAR payload in a realistic imaging mode a target is needed at several hundred km distance and with a realistic relative velocity with respect to the instrument. The only way to achieve this without launching a payload is to image an object in orbit with the payload stationary on the ground. Hence, the payload hardware demonstrator was used to capture an inverse SAR image of the International Space Station (ISS), see Figure 8. With only one third of the full payload frontend the demonstrator has one third of the transmit power and one third of the antenna gain in transmit and receive. Processed to 30m resolution in range and 1m resolution in azimuth, and with the achievable sensitivity, only the ISS main body can be identified. However, this achievement validates the payload design and provides confidence about the performance of the full payload.

Figure 7. Payload hardware demonstrator
5.3 TechDemoSat-1 Experiment
The first flight of NovaSAR-S payload hardware will be on the UK government funded TechDemoSat-1 (TDS1) in-orbit test bed mission. TDS1 is being built by SSTL and is planned for launch in 2012. Amongst its payloads TDS1 will carry the Sea State Payload (SSP) with both active and passive experimental technologies for measuring sea state.

5.3.1 SSP GNSS Receiver
Passive measurements will be made by GNSS reflectometry and will make advances from those demonstrated with UK-DMC1. TDS1 will carry the SGR-ReSI, SSTL’s highly capable, reconfigurable, multi-channel GNSS receiver. The SGR-ReSI will collect data from multiple antennas to carry out a variety of reflectometry experiments.

5.3.2 SSP Altimeter
Active measurements will be made by an experimental radar altimeter based on one phase centre of the NovaSAR-S payload frontend. The altimeter is being built by SSTL/Astrium to:

- Provide flight heritage for SAR hardware
- Demonstrate altimeter functionality
- Provide a stepping stone to a low cost altimeter instrument
- Measure background noise and spurious signals at S-band
The PFM altimeter will be implemented using PCU, transmit and receive units built to near flight standard for the SAR payload ground demonstrator. An antenna will be built based on the SAR radiator unit but with a square rather than rectangular array of patches. The transit unit will be one of the first GaN amplifiers in orbit.

The altimeter design has been kept deliberately simple to minimize NRE. It transmits chirp modulated pulses and records the deramped echoes without any tracking or onboard processing. Collected data will be processed offline on the ground. The priority will be demonstrating measurement of significant wave height (SWH). However, relative sea surface height (SSH) and wind speed will also be possible. Absolute SSH measurements of limited accuracy will be possible if good orbit knowledge is available from the onboard AOCS system but this is not a priority. It will also be possible to configure the altimeter as a receiver to take measurements of background noise and characterize the in orbit spectrum at S-band allocated frequencies.

5.4 Planning

The project is now well underway – the design activities will be completed by autumn 2012 and flight readiness is currently planned for the first half of 2014. The number of satellites launched in 2014 will depend upon how many organisations become partners in the programme. NovaSAR-S “full operational capability” will require a constellation of 4 satellites so will require at least two launches.
6 CONCLUSIONS

The NovaSAR-S development has progressed both platform and payload designs to a mature stage. Efforts are now focused on the following areas:

- Characterising S-band airborne data
- Increasing payload duty cycle
- Accommodation of secondary payloads (AIS, others)
- Introducing upgrades to platform data storage and downlinking subsystems
- Investigating mission scenarios for specific applications
- Investigating applications of NovaSAR-S

Our applications driven approach has resulted in a SAR system which is truly low cost and within the small satellite arena. NovaSAR-S is compatible with low cost launches, supports flexible imaging modes, provides attractive imaging throughput, and is supported by a development programme that includes ground and airborne demonstrators. NovaSAR-S represents a major leap forward in the cost-effectiveness of SAR systems.

7 REFERENCES


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