BRIDGING THE ABYSS – AGILE DATA DOWNLINK SOLUTIONS FOR THE DISASTER MONITORING CONSTELLATION

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ABSTRACT

NigeriaSat-2 is SSTL's most advanced Earth Observation spacecraft in-orbit, providing high resolution optical imaging to the Nigerian National Space Research and Development Agency (NASRDA) and the Disaster Monitoring Constellation (DMC). Due to NigeriaSat-2's high imaging resolution, the requirement for off-nadir imaging, and system level restrictions on DC power, a much more capable payload downlink solution was sought. SSTL's payload downlink chain consists of a High Speed Data Recorder (HSDR), X-Band Transmitter (XTx) and Antenna Pointing Mechanism (APM), offering high data rate acquisition, 16 GBytes data storage and a 105 Mbps agile downlink. The APM's wide range of motion allows NigeriaSat-2 to simultaneously track the groundstation whilst slewing by up to 45 degrees off the nadir vector; this gives the spacecraft the ability to image any part of the Earth's surface every two days. The two cold-redundant payload downlink chains can also be used simultaneously, transmitting in opposite polarisations to achieve a maximum data rate of 210 Mbps. NigeriaSat-2 was successfully placed into 700 km sun-synchronous orbit on 17th August 2011 and has been fully commissioned. As SSTL continues to develop more advanced Earth observation platforms, more capable payload downlink solutions are being developed in tandem to support them.

1 INTRODUCTION

DMC International Imaging Ltd (DMCii), a wholly owned subsidiary of Surrey Satellite Technology Ltd (SSTL), was established in 2004 to coordinate and capitalise upon the Disaster Monitoring Constellation (DMC). The DMC consists of a constellation of SSTL-built Earth Observation (EO) satellites, owned by a consortium of international customers including DMCii itself. Consortium members utilise their own satellite to meet their national or commercial objectives and to access the international commercial imaging market through DMCii. In addition, DMCii coordinates image acquisition from the constellation to contribute to emergency disaster response.

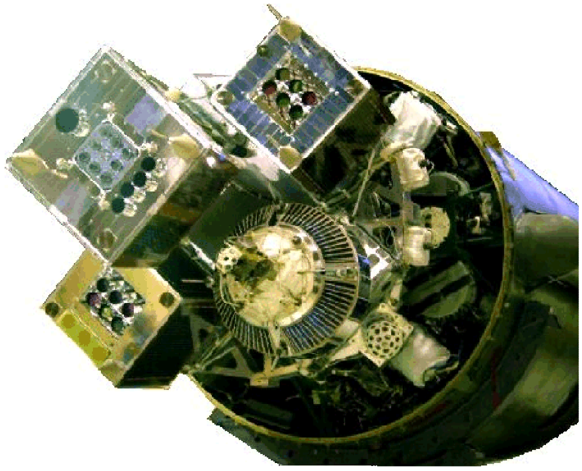


Figure 1 – UK-DMC-1, Bilsat & NigeriaSat-1 on launch vehicle

Alsat-1, owned by Algeria's Centre National des Techniques Spatiales (CNTS), was launched in 2002 as the first satellite in the constellation. The most recent satellites to join the constellation are NigeriaSat-2 and NigeriaSat-X, owned by Nigeria's National Space Research and Development Agency (NASRDA) and launched in August 2011. A total of nine satellites have been launched into the constellation, out of which four have completed their mission objectives. A further two advanced DMC missions are currently under development, DMC-3 and NovaSAR-S, both expected to launch in 2014. A list of past, present and planned DMC satellites is shown in Table 1.

A distinguishing feature of DMCii is the ability to offer imagery with a rapid revisit time. The combined constellation has the capability to image any part of the Earth's surface once every day. This feature is particularly useful for disaster response applications where it is extremely important to obtain up-to-date imagery. It is also important for precision agriculture applications where intensive and reactive imaging campaigns must be undertaken for delivery in a short timeframe. Other applications for DMCii data include forestry (deforestation and illegal logging detection), agriculture and land cover mapping.

Table 1 – DMC Missions Overview

Mission	**Customer**	**Platform**	**Launch**	**GSD**	**Swath width**	**Mission Status**
Alsat-1	CNTS (Algeria)	SSTL-100	2002	32 m MS	650 km	Completed
Bilsat	Tubitak (Turkey)	SSTL-100	2003	32 m MS	650 km	Completed
NigeriaSat-1	NASRDA (Nigeria)	SSTL-100	2003	32 m MS	650 km	Completed
UK-DMC-1	BNSC (UK)	SSTL-100	2003	32 m MS	650 km	Completed
Beijing-1	21AT (China)	SSTL-150	2005	32 m MS	650 km	Operational
UK-DMC-2	DMCii (UK)	SSTL-100	2009	22 m MS	650 km	Operational
Deimos-1	Deimos Imaging (Spain)	SSTL-100	2009	22 m MS	650 km	Operational
NigeriaSat-2	NASRDA	SSTL-300	2011	2.5 m PAN 5 m MS 32 m MS	20 km 20 km 320 km	Operational
NigeriaSat-X	NASRDA	SSTL-100	2011	22 m MS	650 km	Operational
DMC-3 a/b/c	DMCii, with 100% capacity leased to 21AT	SSTL-300 S1	2013	1 m PAN 4 m MS	23 km 23 km	In Development
NovaSAR-S	UK Government	SSTL-300 avionics	2014	6 – 30 m SAR	15 – 750 km	In Development

MS: Multi-spectral
PAN: Panchromatic

NigeriaSat-2 is SSTL's most advanced and agile EO satellite launched to-date, designed to provide high quality imagery with a high geolocation accuracy. Placed into a 700 km sun-synchronous orbit, the satellite is able to revisit and image any point on the Earth's surface every two days [1]. It is fitted with two imaging payloads, the Very High Resolution Imager (VHRI), to acquire 2.5 metre Ground Spectral Density (GSD) panchromatic and 5 metre GSD multispectral images, and the Multi-Spectral Imager (MSI). The MSI acquires 32 metre GSD multispectral images; this allows for a continuation in 32 metre GSD image acquisition following completion of the NigeriaSat-1 mission. The data generated by the platform is being used to support Nigeria in a number of applications including agriculture, security, and land mapping. It can also be provided to third parties for commercial or disaster response applications, through coordination with DMCii.

NigeriaSat-2 operates in four main imaging modes [1] comprising Scene, Strip, Stereo and Area. Scene mode makes use of the platform's agility to make a number of rapid slews in roll and pitch during flight, imaging individual ground scenes way off the nadir vector. This mode allows the satellite to image a number of graphically diverse targets, as shown in Figure 2, using the VHRI, MRI or both. Strip mode allows the satellite to image a continuous strip of ground up to 2000 km in length, as in Figure 3. This mode is most useful when performing mapping operations where specific points on the ground do not need to be targeted. Note that the satellite can image using the VHRI or MRI at an angle of up to 45 degrees off the nadir vector.

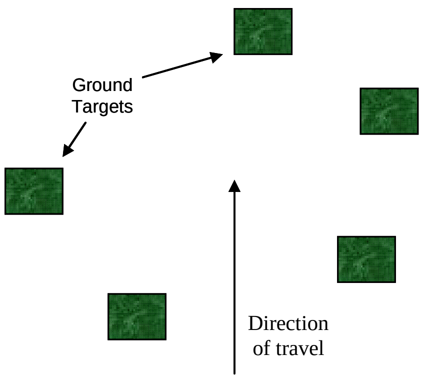


Figure 2 – Scene imaging mode

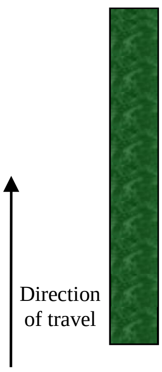
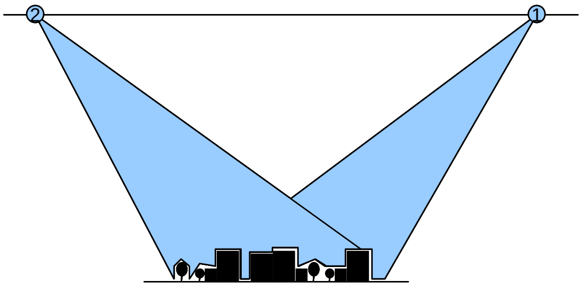


Figure 3 – Strip imaging mode

Stereo mode allows a ground target to be imaged by the VHRI from two points of view and then processed to produce a "stereographic" image. The two images should be symmetrical, with the first image taken as the satellite approaches the target and the second taken once it has passed overhead and is moving away from the target, as shown in Figure 4. The pitch angle, between the satellite's vector of travel and the ground target, should be greater than 10 degrees. This mode is useful for extracting information on the height of the target, for example mountains or buildings. Area mode allows imaging of wide swaths of ground, providing a resultant image size of 65 km x 80 km. In this mode the VHRI is used to take a number of images adjacent (with overlap to allow image stitching) to one another both cross-track and along-track. The advantage of performing Area mode imaging is that the complete image is relatively homogeneous in time. Through performing a number of slew manoeuvres, an Area mode image can be assembled from a set of three by three images, as shown in Figure 5, or by a set of four by four images.



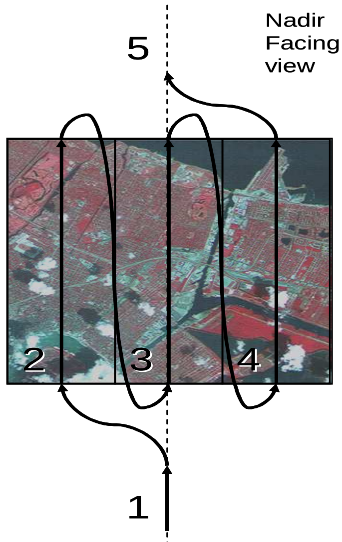


Figure 4 – Stereo imaging mode   Figure 5 –Area imaging mode

In addition to the flexible imaging modes outlined above, NigeriaSat-2 also has the capability to perform Near Real-Time (NRT) downlink, whereby images are simultaneously acquired and downlinked to a groundstation. The groundstation does not need to be in the same location as the imaging target, allowing a distance of 1000 km between the ground observation target and groundstation. This adds to the flexibility of NigeriaSat-2, minimising both the ground point revisit time and downlink latency.

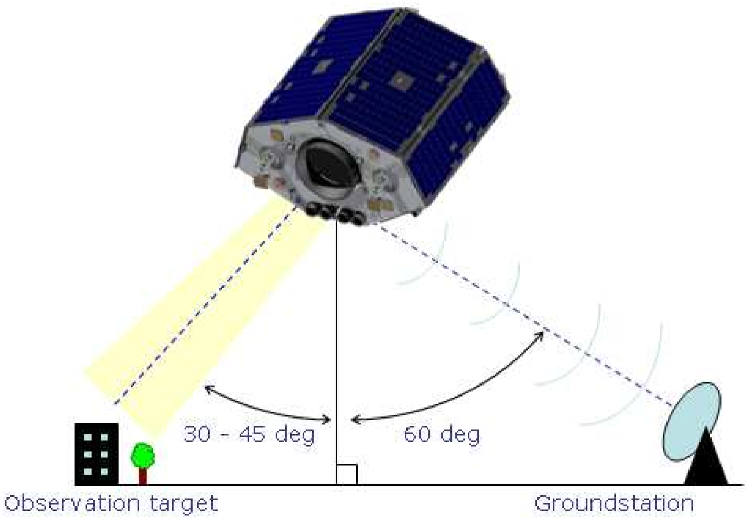


Figure 6 – Near Real-Time (NRT) imaging and downlink

2 NIGERIASAT-2 PAYLOAD DOWNLINK CHAIN DEVELOPMENT

Given NigeriaSat-2's operational concept as outlined above, a number of key requirements for the payload downlink chain were identified. Firstly, the on-board payload data storage needed to acquire up to 8 GBytes of payload data at high speed from the VHRI. Secondly, the X-Band transmitter needed to be able to deliver a data rate of 105 Mbps through the downlink antenna whilst keeping the Bit Error Rate (BER) below $1x10^{-6}$. This latter requirement also needed to be met whilst simultaneously off pointing the satellite up to 45 degrees off the nadir vector in any direction.

A generic payload downlink chain can be broken into three main constituents, as shown in Figure 7; mass memory to store payload data., a transmitter to modulate the data onto an RF carrier and an antenna to transform the RF energy into free-space. The mass memory also commonly performs data processing (e.g. compression, encryption) whilst the transmitter adds Forward Error Correction (FEC). Prior to the development of NigeriaSat-2, the most advanced complete payload downlink chain was that flown on SSTL's Beijing-1 mission, comprising a 2 GByte Solid State Data Recorder (SSDR), 40 Mbps X-Band Transmitter and a commercially available Helix antenna.

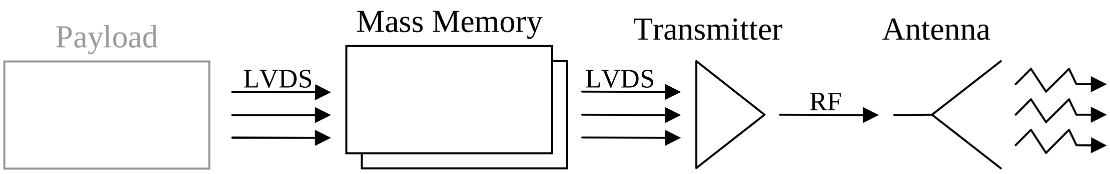


Figure 7 – Payload downlink chain key elements

2.1 High Speed Data Recorder (HSDR)

Having been flown on at least nine missions, the SSDR has significant flight heritage. However, its storage capacity, data acquisition rate and data processing capability is limited. Just to meet the data storage requirements of NigeriaSat-2 it would have been necessary to utilise four SSDRs simultaneously; as highlighted in [2] this would have required a volume, mass and power that was unfeasible to accommodate. It was clear that a new mass memory solution would need to be developed.

In order to handle the very high data acquisition rates required to collect data from the VHRI, it was proposed that a Field Programmable Gate Array (FPGA) was used to handle the data flow. SSTL has significant experience using anti-fuse (i.e. one-time programmable) Actel FPGAs on its modules, but unfortunately these did not have a sufficient number of gates, data Input / Output (I/O) or embedded features for this application. Instead, it was decided to use the Xilinx Virtex-4 FPGA family, as this offered very high performance and had gained favourable results from third party radiation tests. In addition, the Virtex-4 is reconfigurable, potentially allowing for the FPGA configuration to be reconfigured in-orbit. This significantly increases the flexibility of the product as its firmware can be upgraded at a later date to modify its data processing capability. Unlike the SSDR, which used Synchronous Dynamic Random Access Memory (SDRAM), Double Data Rate 2 (DDR2) memory was selected for the HSDR. The use of high speed DDR2 memory contributes to the HSDR's exceptional data I/O processing capability, in excess of 5 Gbps.

As well as handling data flow, the HSDR also needed to operate a file system and SSTL's Saratoga Automatic ReQuest (ARQ) downlink system. Saratoga allows image data to be acquired and downlinked almost completely independently of the platform On Board Computer (OBC), whilst also allowing retransmission of any lost packets. It was decided that instead of using a separate microprocessor, the HSDR would make use of the Virtex-4 FX variant's integral PowerPCs. Note that provided the BER is sufficiently good it is also possible to operate the payload downlink chain in a "Broadcast mode", with no ARQ. The advantage of broadcast mode is that no uplink is required to handle the ARQ, hence the groundstation setup is more straightforward.

Figure 8 – High Speed Data Recorder (HSDR)

2.2 X-Band Transmitter (XTx)

The majority of changes required to the transmitter to enable it to output 105 Mbps (versus 40 Mbps outputted from the Beijing-1 XTx) were relatively straightforward. Firstly, the FPGA VHDL (VHSIC Hardware Description Language) was updated to support the higher data rate, using QPSK modulation and ½ rate k=7 convolutional encoding. Secondly, the I&Q channel anti-aliasing filters were updated for the higher data rate. Thirdly, filter and amplification sections were updated to the higher bandwidth required to support 105 Mbps operation.

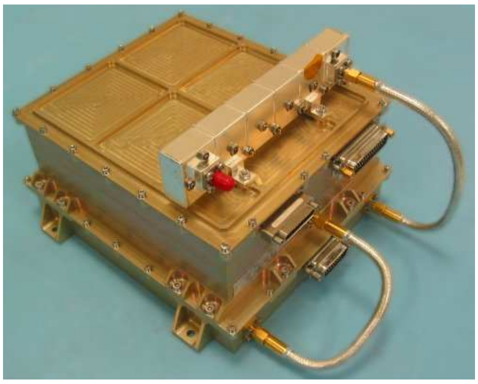


Figure 9 – X-Band Transmitter (XTx)

2.3 Down-link Budget

One of the most significant considerations when designing an RF system is whether the downlink budget is strong enough to support the required data rate, in this case 105 Mbps @ $1x10^{-6}$ BER. Several parameters can be changed in order to support a higher data rate, a number of which are outlined below:

- Groundstation
  - Antenna Gain / Temperature (G/T); determined by:
    - Dish diameter
    - Receiver noise temperature

        - Antenna noise temperature
- Transmission
    - Free space loss, determined by:
        - Altitude
        - Orbit
        - Transmission frequency
    - Data rate
    - Forward Error Correction (FEC) coding scheme
    - Polarisation & pointing losses
- Satellite
    - Effective Isotropic Radiated Power (EIRP), determined by:
        - Transmitter RF output power
        - Downlink antenna gain
        - RF feed insertion loss

In the case of NigeriaSat-2, it would have been very difficult to change the groundstation and transmission parameters in such a way to enable a higher data rate without affecting the satellite design. The only remaining parameter that could be changed relatively easily is the EIRP, through increasing the transmitter's RF output power, increasing the downlink antenna gain or reducing the RF feed insertion loss. As standard, SSTL uses RF feed cables with a low insertion loss per metre length and routes them carefully on the spacecraft to minimise the length; as a result it was not considered possible to improve the RF feed insertion loss by any significant amount.

In order to allow transmission at 105 Mbps, maintaining similar link margin as delivered by the heritage 40 Mbps transmitter, the EIRP would need to have been increased by approximately 4 dB. Keeping the antenna gain pattern the same, this corresponds to an increase in RF output power from 6 W to 15 W. Whilst it would have been feasible to design an X-Band High Power Amplifier (HPA) capable of outputting 15 W RF, it would have been difficult for the platform to deliver the corresponding DC power requirement with the acceptable duty cycle.

Moreover, NigeriaSat-2's operational concept means that it should be able to maintain payload downlink when off-pointing from the nadir vector by up to 45 degrees. Note that the horizontal distance between the groundstation and spacecraft is limited to 1000 km – this limits how far off the spacecraft's Earth Facing Facet (EFF) tangent the APM needs to point and therefore minimizes interactions between the horn antenna's main lobe and the spacecraft structure. In the worst case scenario, the platform could slew 45 degrees from the nadir vector, in such a way that the gain from the downlink antenna in the direction of the groundstation falls considerably. Assuming the use of a fixed X-Band helix antenna (as used on Beijing-1), this could cause a reduction in gain, and hence EIRP, in the order of 20 – 30 dB. Due to power and thermal design issues it is completely impractical to make up this shortfall through increasing the transmitter's RF output power, the only solution being to increase the downlink antenna gain.

2.4 Antenna Pointing Mechanism (APM)

Several approaches existed to increase the downlink gain, and EIRP, in the spacecraft to groundstation vector. Firstly, it would be possible to use the spacecraft's Attitude and Orbit Control System (AOCS) to physically point a fixed, high gain antenna to ensure sufficient gain in the direction of the groundstation. However, NigeriaSat-2's agility is specifically required to optimise imaging and not data downlink, so this solution is not feasible. Secondly, a number of fixed, high gain antennas could be connected to the transmitter through an RF switch. Depending upon the spacecraft's attitude with respect to the groundstation, the RF signal could be switched to the most appropriate antenna. The disadvantage to this solution is that a large amount of space is required to mount the antennas, also that the addition of a mechanically actuated RF switch adds some risk. Fourthly, a mechanically or electrically steerable antenna could be developed. A mechanically steerable antenna would consist of a mechanism (normally including a rotating bearing geared to a motor) to physically point a fixed gain antenna within a range of attitudes with respect to the mechanism's mounting interface on the spacecraft. An electrically steerable antenna, or phased array, would consist of mechanically fixed antenna with a number of radiating elements. Through varying the strength and phase of the signal into each radiating element it is possible to change the shape of the antenna pattern, pointing the high gain beam in the required direction. This solution was not acceptable as the axial ratio of a phased array is expected to degrade significantly off-boresight; the resultant polarisation loss could not be tolerated within the link budget.

Although a mechanically steerable antenna could suffer from issues due to mechanical wear, SSTL has significant experience in the development and qualification of reaction wheels and other space mechanisms so selected this antenna type. Three different types of mechanically steerable antennas were investigated. The first, Azimuth / Elevation (AE) 90, shown in Figure 10 (left), utilised two axes of rotation placed 90 degrees to one another. This scheme also used a worm-wheel transmission between each motor and axis. The second, AE60, placed the two axes of rotation 60 degrees to one another, shown in Figure 10 (middle). This scheme used a spur-gear transmission between each motor and axis. The third was an X / Y scheme as shown in Figure 10 (right).

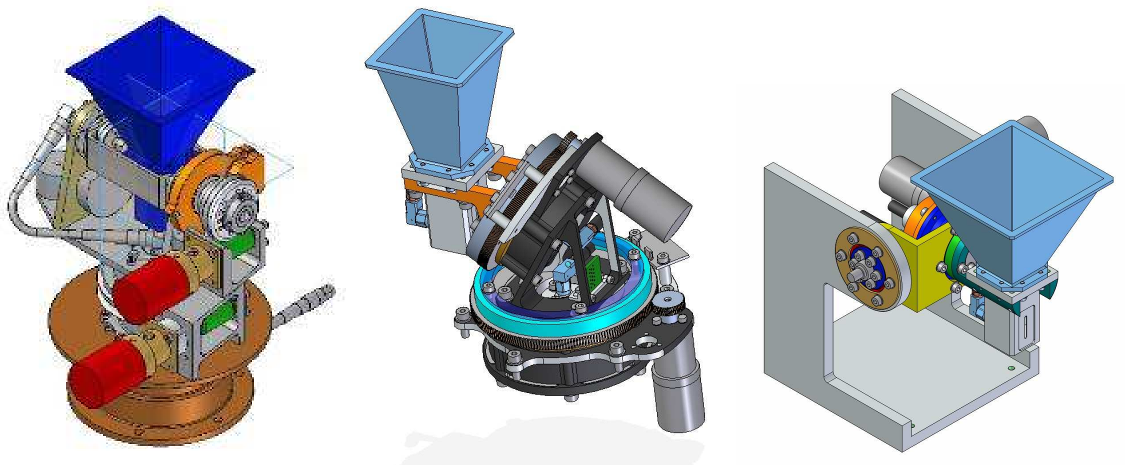


Figure 10 – Mechanically steerable antenna options: AE90 (left), AE60 (middle) & X/Y (right)

It was decided that the X / Y scheme was unsuitable as it did not provide a sufficient range of motion. Following this, the AE60 (Figure 11, left) and AE90 (Figure 11, right) schemes were both built to Engineering Model (EM) level and subjected to life testing and vibration testing. The life-test consisted of 36,000 cycles, in excess of the NigeriaSat-2's mission level requirements of 28,000 cycles. SSTL chose to progress a design derived from both schemes, including the AE-60's spur transmission (which had performed better in the life test) and the AE-90's axes orientation (which significantly simplified mission planning).

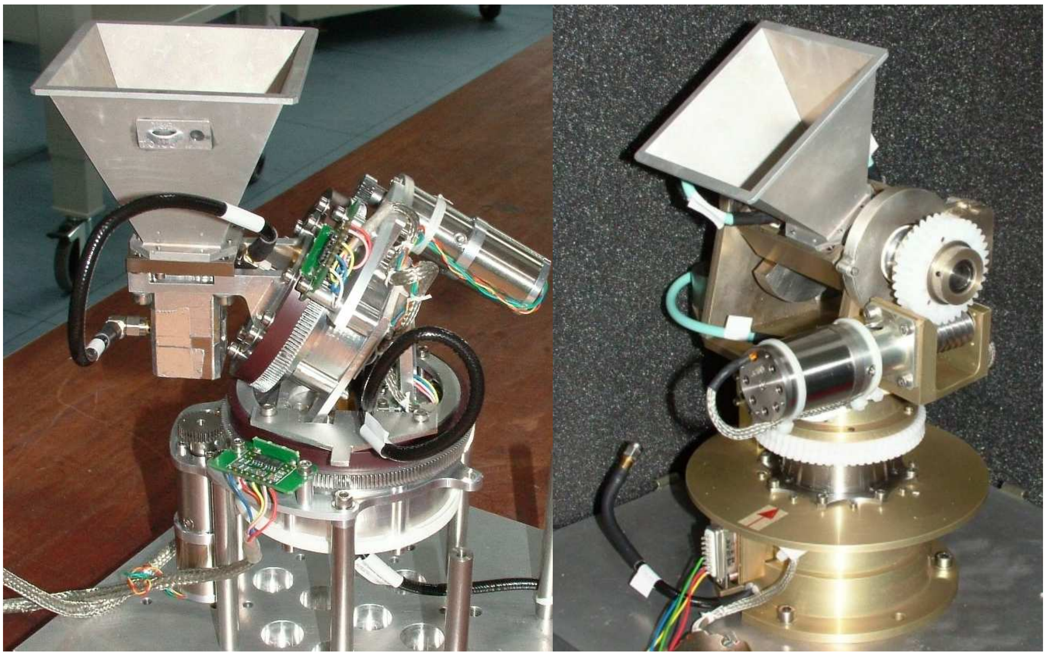


Figure 11 – AE60 (left) and AE90 (right) engineering models

Two other major design decisions were required for the mechanically steerable antenna. Firstly, a means to transmit the RF power from the coaxial input through the rotating axes to the horn antenna was sought. A length of flexible coaxial cable would offer the best insertion loss performance, but there was concern as to whether it could be qualified for a large number of thermal and mechanical cycles. Instead, SSTL was able to find a commercial non-contact rotary joint supplier and work with them to ensure suitability for the space environment. Secondly, a means to transfer power and telemetry channels from the control axes through the first axis was sought. A coiled flexible Printed Circuit Board (PCB) wrap design was chosen over a slip-ring, the bend radii kept sufficiently high to avoid any damage to the harness from repeated cycling.

Following this iterative process, a final design for a steerable high gain antenna was identified. This design consisted of a high gain X-Band horn antenna fitted to onto two rotating axes. The first axis rotated in azimuth, whilst the second was offset by 90 degrees so that it rotated in elevation. Both axes used a spur-gear transmission, non-contact rotary joints for RF power transmission and a flexible PCB harness for transfer of power and telemetry channels. This design was built to a Qualification Model (QM) standard and subjected to lifetests as required for NigeriaSat-2. A total of 28,500 cycles were performed under Thermal Vacuum environmental conditions, with an extended lifetest of 280,000 cycles performed under ambient pressure thermal conditions.

As a whole, the NigeriaSat-2 X-Band Downlink Chain comprises an HSDR, XTx and APM. Although the HSDR has support for alternative high data rate interfaces such as 1 Gbps SERializer / DESerializer (SERDES), a single 105 Mbps Low Voltage Differential Signalling (LVDS) interface was used between the HSDR and XTx. As per all standard SSTL subsystem products, a CAN Telemetry and Telecommand (TTC) interface was implemented, utilising CAN-2B electrical level and CAN-SU protocol. This CAN interface is also used for file transfer, to allow loading of new Xilinx Virtex-4 FPGA configurations into Flash and for loading of pointing profile files into the APM. The pointing profiles are assembled by SSTL's Mission Planning System (MPS) on the ground and command the APM to follow a time-synchronised profile, tracking the groundstation during each pass. Note that the HSDR, XTx and APM are all hardware ready for use with an RS422 TTC interface.

SSTL designs its missions at system level to be robust against failure of any one module. NigeriaSat-2 therefore uses two cold-redundant payload downlink chains, with cross-strapping between each HSDR and XTx105. Provided that each horn antenna is set up with opposite polarisation, it should be possible to transmit simultaneously through both, thus doubling the data throughput. It is essential that the horn's cross polar discrimination is high enough so that the cross-polar gain from the Right Hand Circularly Polarised (RHCP) APM does not interfere significantly with the co-polar gain from the Left Hand Circularly Polarised (LHCP) APM and vice versa. The NigeriaSat-2 chains can therefore be operated as either cold redundant 105 Mbps or non-redundant 210 Mbps with graceful degradation (whereby the data rate drops to 105 Mbps in the event of a payload downlink chain module failure).

Figure 12 – APM X-Band horn antenna pattern

As outlined in [4], ground based tests were performed using the NigeriaSat-2 hardware to validate operation of both X-Band downlink chains simultaneously. The degradation in performance from operating both chains simultaneously was measured to be less than 1 dB. The NigeriaSat-2 link margin at 5 degrees elevation (the minimum operational requirement) is sufficient that this degradation should not have a noticeable impact upon the overall downlink performance.

3 IN-ORBIT EXPERIENCE WITH NIGERIASAT-2 PAYLOAD DOWNLINK CHAIN

NigeriaSat-2 was launched onboard a Dnepr rocket from Yasny, Russia, on 17th August 2011. It was launched alongside NigeriaSat-X, a Know-How Transfer and Training (KHTT) satellite built by NASRDA engineers with support from SSTL, and six other third party payloads. The satellite was successfully commissioned over a number of months, by SSTL engineers and SSTL-trained NASRDA engineers operating from NASRDA's Abuja groundstation (Figure 13, right) in Nigeria.

It is worth noting that although the HSDR development was directed at NigeriaSat-2, this module actually gained flight heritage on UK-DMC-2, which launched two years earlier. The unforeseen delay by the launch provider had a positive outcome, allowing SSTL to accumulate considerable operational flight heritage with the HSDR prior to its use on NigeriaSat-2.

Figure 13 – NigeriaSat-2 integrated into Dnepr fairing (left) & NASRDA Abuja groundstation (right)

Along with the rest of the spacecraft systems, the X-Band payload downlink chain has been fully commissioned and is now being used supporting nominal operations. The Eb/No levels received on the demodulator from NASRDA's 7.3 metre X-Band groundstation in Abuja and SSTL's groundstation in Guildford, UK, have been in line with that expected and a successful X-Band downlink achieved from both chains.

Figure 14 – Salt Lake City airport, NigeriaSat-2 (courtesy NASRDA)

In addition, two key functionalities have been demonstrated. Firstly, simultaneous imaging and downlink is being performed on a nominal basis. Secondly, simultaneous use of both downlink chains has been demonstrated, validating the concept of doubling data rate through polarisation diversity. When operating both downlink chains simultaneously, a total sustained data rate of 210 Mbps has been achieved with no noticeable degradation in received Eb/No levels. Although NigeriaSat-2 will not be using this mode as standard, it is likely that future SSTL missions will take advantage of it as a means of increasing the total downlink capability.

Figure 15 – Burj Khalifa, Dubai, NigeriaSat-2 (courtesy NASRDA)

4 NEXT GENERATION X-BAND DOWNLINK CHAIN FOR UPCOMING MISSIONS

As the performance of SSTL's missions steadily improves beyond that offered by NigeriaSat-2, the need for higher data storage and downlink rates continues. SSTL's DMC3 mission is a constellation of three high resolution (one metre GSD panchromatic) optical imaging satellites, based upon NigeriaSat-2's avionics and a more advanced imaging payload. Further ahead, SSTL's NovaSAR-S mission is an S-Band Synthetic Aperture Radar (SAR) satellite. Not only will these missions generate a larger amount of data to downlink, they will also continue to utilise NigeriaSat-2's agility to perform off-pointing imaging and simultaneous imaging and downlink.

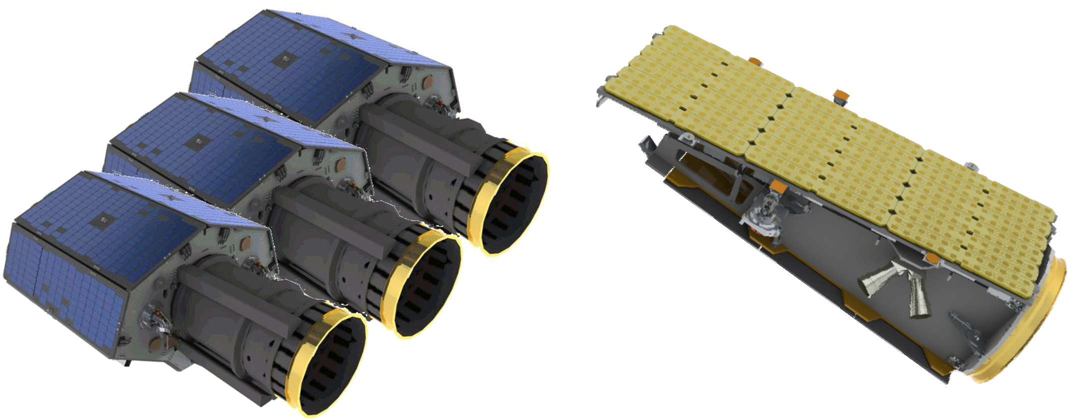


Figure 16 – DMC-3 constellation (left) and NovaSAR-S (right)

A second generation X-Band payload downlink chain has been developed for use on SSTL's future missions, incorporating a HSDR with Flash Mass Memory Unit (FMMU), next generation XTx and higher gain APM.

The FMMU, shown in Figure 17 (left), utilises commercially available non-volatile flash memory to deliver total data storage of 128 GBytes (i.e. one Terabit). Since the data read / write speed of flash memory is relatively low compared to that of DDR2 and since the mass memory must be able to acquire data at extremely high data rates from the payload, the FMMU is being used as second-level storage, with the HSDR still used for data acquisition, processing and downlink. Note that the FMMU will also be upgraded in due to course to allow it to function as an independent, high capacity storage solution for missions with a lower payload data acquisition rate.

Figure 17 – FFMU (left) and +18 / +15 dBi APMs (right)

As with many of SSTL's products, the next generation XTx has been developed from a heritage design in order to maximise confidence in its suitability for the space environment. This transmitter variant is initially designed to deliver a maximum data rate of 400 Mbps, using 8PSK modulation and 2/3 Trellis Coded Modulation (TCM) FEC. The use of this higher order modulation scheme allows the signal bandwidth to be reduced, whilst the 2/3 TCM coding adds a lower coding overhead (albeit with reduced FEC coding gain). This means that it is possible to support a data rate approximately four times higher than the previous variant with a bandwidth less than double; this is advantageous as it makes better usage of the limited X-Band spectrum and simplifies the HPA design. Two major changes have been made to this transmitter to enable the higher data rates. Firstly, the modulator module has been upgraded to use a Xilinx Virtex-5 SX FPGA; initial radiation characterisation performed on this FPGA has been favourable and its high performance means that it can be used to support higher data rates and higher order modulation schemes such as 16PSK. Secondly, the HPA has been upgraded to support the higher bandwidth required and to deliver a total RF output power of 12 W. The next generation XTx has been designed with an eye to the future, potentially allowing the development of higher data rate solution. In the short term, it is planned to develop VHDL to operate the transmitter with more efficient FEC coding scheme of 5/6 TCM, allowing a data rate of 500 Mbps to be supported whilst keeping the symbol rate unchanged at 200 MSps.

A new variant of the APM has also been developed, using a +18dBi carbon fibre horn antenna. The advantage gained from carbon fibre over aluminium (as used on the +15 dBi variant) is that the motor and bearing does not need to be modified to accommodate a higher mass antenna. In turn, this maximises the flight heritage that can be inherited from NigeriaSat-2. It was found that the composite horn was electromagnetically opaque, hence did not need addition of a metallic coating for use as an antenna.

SSTL's next generation payload downlink chain, comprising 128 GByte FMMU, HSDR, 400 Mbps XTx and +18 dBi APM will fly for the first time on SSTL's TechDemoSat-1 mission, currently expected to launch during the first quarter of 2013. In the longer term SSTL is looking to make use of the higher bandwidth available at Ka-Band; the next generation XTx modulator has been designed with this in mind. In addition, SSTL is investigating the development of an Ka-Band APM capable of supporting data downlink over the 1.5 GHz bandwidth available at Ka-Band, potentially enabling data rates at one Gbps and above.

5 SUPPORTING ALTERNATIVE MISSION CONCEPTS

One of the limiting factors in the operational capacity of an imaging satellite is the maximum amount of payload image data that can be downlinked to the operator's groundstation during available passes. However, if a customer is able to use their own groundstation, a satellite can be tasked to simultaneously acquire and downlink imagery as it passes overhead, in a NRT downlink mode. Provided that the system-level power budget can support the increased duty cycle of the imaging payload and payload downlink chain, the satellite's operational capacity can therefore be increased. In addition, this potentially allows for image data to be acquired with a very low latency. DMCii is now supplying 22m GSD imagery from SSTL's UK-DMC-2 satellite to multiple customers using this NRT downlink mode.

UK-DMC-2, as per most heritage SSTL satellites [5], is operated with a nadir-pointing attitude; this ensures that the X-Band helix antenna gain in the spacecraft to groundstation vector is sufficient to support the high data rate NRT downlink. However, use of the next generation payload downlink chain and APM would allow the link budget parameters to be traded, enabling alternative NRT downlink mission concepts. For example, it is estimated that an 80 Mbps broadcast mode NRT downlink could be supported by a customer groundstation dish of two metres diameter or less, potentially resulting in a substantial infrastructure cost saving for certain customers. Alternatively, the spacecraft XTx RF output power could be reduced, potentially allowing operation of the X-Band downlink at a higher duty cycle and maximising the amount of time that can be used to support NRT downlink opportunities.

6 CONCLUSION

SSTL's payload downlink chain has been proven as an enabling subsystem for SSTL's high performance EO missions, most recently NigeriaSat-2. The use of this subsystems suite maximises both the quantity of data that can be acquired and the area of ground that can be targeted per day, whilst the APM's agility and narrow antenna beamwidth add significant flexibility to the operational mission concepts that can be supported. As the data handling requirements of SSTL's EO missions continues to increase, SSTL has a clear roadmap to develop supporting payload downlink solutions.

7 REFERENCES

[1] A. Cawthorne, M.Beard, A.Carrel, G.Richardson, A.Lawal, *Launching 2009: The NigeriaSat-2 mission – High-performance Earth observation with a small satellite*, Small Satellite Conference 2008.

[2] P.Garner, D.Cooke, A.Haslehurst, *Development of a Scalable Payload Downlink Chain for Highly Agile Earth Observation Missions in Low Earth Orbit*, 4th Recent Advances in Space Technologies Conference 2009.

[3] M.Ferris, N.Philips, *THE USE AND ADVANCEMENT OF AN AFFORDABLE, ADAPTABLE ANTENNA POINTING MECHANISM*, 14th European Space Mechanisms and Tribology Symposium 2011.

[4] P.Garner, N.Phillips, A.Cawthorne, A. da Silva Curiel, P.Davies, L.Boland, *Follow that Ground Station! And double the data throughput using polarization diversity*, Small Satellite Conference 2009.

[5] M.Brenchley, P.Garner, K.Maynard, T.Butlin, E.Krabel, *Supporting Omni-Directional Communications Capability in Variable Attitude Spacecraft*, Microwave Radar and Wireless Communications (MIKON), 2010 18th International Conference.