WiSAR™: A New Solution for High-Performance, Smallsat-Based Synthetic Aperture Radar Missions

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ABSTRACT
To date, high performance Synthetic Aperture Radar (SAR) satellites have typically featured massive power generation, storage and distribution subsystems, together with complex, heavy and rigid deployable SAR antenna structures. The result is an expensive, heavy satellite.

MDA’s Wireless Synthetic Aperture Radar (WiSAR™) is a new SAR payload design that offers leading-edge performance in both X- and C-band at a significantly lower cost than the conventional state of the art. The key technology breakthrough is a modular, low mass phased array antenna technology that enables high performance multi-mode SAR imaging from a smallsat platform.

The WiSAR solution uses proven off-the-shelf technologies from the automotive and terrestrial wireless communication industries to enable an innovative space-fed active lens architecture that replaces the heavier and bulkier constrained feed design of traditional high performance SAR payloads. Key elements of the WiSAR payload include: self-contained active antenna nodes; low cost RF radiators; thin, lightweight, easily deployed antenna panels; and RF ranging for dynamic antenna distortion compensation.

This paper describes the WiSAR™ payload technology in various configurations; a High Resolution X-Band Smallsat SAR, a Dual Aperture X-Band GMTI SAR, a High Performance C-Band SAR, and a C-Band Smallsat SAR. The results of a project to build, test and operate a fully functioning C-band prototype WiSAR™ phased array antenna are presented, along with current developments in X-Band.
INTRODUCTION

WiSAR™ is a highly capable, low cost Active Phased Array Synthetic Aperture Radar suited to a wide range of SAR missions using small- and mid-sized spacecraft.

The WiSAR™ concept offers significant reductions in cost and mass over the current state of the art.

A number of key architectural elements make WiSAR™ possible, including the use of space feed, distributed power, reduced mass and thickness of the SAR Antenna Panels, and a means for maintaining the SAR Antenna patterns within requirements.

In particular, this unique approach includes the following innovations:

• a self-contained active antenna node known as a WiNode, that incorporates the RF circuitry of a Transmit Receive Module (TRM) with a Solar power source, Lithium-Ion cells, and control and monitoring functions. This eliminates power distribution cables and harnesses and the requirement for separate bus-mounted solar array panels and bus-mounted batteries to provide power for the SAR antenna.

• a wireless “space feed” as a means of eliminating the azimuth and elevation RF power distribution networks, including all the associated cables and harnesses on a typical SAR antenna. Within the WiSAR™ Payload, the Antenna Subsystem consists of the active WiNodes and RF radiators mounted on deployable RF antenna panels with the space feed antennas mounted on a boom. The WiNodes perform the frequency translation and gain and phase adjustments on the radiated transmit radar signal from the space feed boom and radiates the received radar returns after gain and phase adjustment, and frequency translation, back to the boom. The elimination of the Azimuth Power Distribution Networks (APDNs) and the Elevation Power Distribution Networks (EPDNs) provides considerable configuration flexibility and the space feed provides tolerance to mechanical distortion.

• Deployment of the SAR Antenna using low cost solar array deployment mechanisms to stow and deploy the WiSAR™ active phased array antenna. This is enabled by the antenna panel thickness and mass reduction that results from the elimination of the APDNs and the EPDNs. This eliminates the need for special purpose deployment and stowing mechanisms for the antenna, further reducing the overall mass.

• An active, dynamic antenna distortion measurement and compensation system is used for measuring the antenna geometry and dynamically computing the necessary phase corrections required to maintain the desired beam shape. This eliminates the need for heavy thermoelastically stable and stiff antenna panels and the associated complex extendable support structures (ESS) required to keep the antenna rigid and flat.

The individual innovations combine to impact all aspects of the Spacecraft: the Payload, the Bus, their Interface and the Launch.

These architecture and technology innovations enable WiSAR™ to achieve significant cost and mass reductions over traditional SAR Payloads.

WISAR SPACECRAFT

The WiSAR™ Spacecraft concept takes advantage of the unique features of the WiSAR™ Antenna to create a compact, efficient design.

Using the new WiSAR™ architecture and technology, the active phased array SAR panels are thin and can be stowed and deployed using conventional solar array mechanisms. The small size of the individual WiNodes allows flexible sizing of the antenna panels, allowing the panels to wrap around two or three faces of a variety of bus designs in the stowed configuration.

An important feature of the Spacecraft concept is the decoupling of the Bus and Antenna power systems. Each WiNode TRM in the WiSAR™ antenna generates and stores its own imaging power using solar cells and Lithium-Ion cells mounted on the backside of the Antenna. As a result of this decoupling, the Bus power system is much smaller than for a conventional SAR satellite - the Bus solar array, battery, and Power Control Unit are significantly reduced in size. The distributed nature of the SAR Antenna power system has a very significant direct effect on the SAR Antenna power system reliability, and an indirect effect in that the Bus power subsystem is so much smaller and thus more reliable.

The self-contained SAR Antenna active node, the WiNode, eliminates power distribution cables and harnesses and the need for separate power subsystem by incorporating a solar power source, Lithium-Ion Cells, RF circuits, and control and monitoring functions. This results in cost reductions that are enabled by minimizing
the interface to the Bus, in particular because no SAR
Antenna DC Power is required from the Bus, there is thus
no DC Harness between Bus and Antenna, no Bus
mounted Battery capacity required for SAR Imaging and
no Payload Power Distribution Unit.

A distinctive feature of the WiSAR™ concept is the RF
space feed deployed atop a boom. This feed eliminates
the need for a complex RF distribution network across the
deployed hinges and throughout the Antenna.

X-BAND HIGH RESOLUTION SMALLSAT SAR

As an example of the flexibility of the WiSAR concept,
the WiSAR™ antenna can be readily configured as a high
resolution X-Band SAR for launch on a Smallsat into a
400km orbit. The antenna is configured for just 4 panels,
resulting in a 4m by 1.2m phased array.

The X-Band Smallsat SAR provides high resolution as
well as wide area surveillance capability with a ScanSAR
mode, while providing 8 minutes of imaging per orbit.

The high resolution Spotlight Mode uses the higher
available bandwidth at X-Band to produce images of
20km swath width with resolution of less than 1m in both
range and azimuth. Image quality parameters are a Noise
Equivalent Sigma Zero (NESZ) of better than -19dB,
with both ambiguity ratios below -18dB.

This remarkable performance is delivered with an antenna
mass of just 154kg, including all bus mounted
deployment and tie down hardware, and including a 15%
margin.

An X-Band WiNode Prototype developed in cooperation
with Defence Research and Development Canada (DRDC) is currently in test. This represents the second
generation of WiNodes; the first will be later discussed in
more detail in the section on the C-Band WiSAR™
demonstration.

The prototype X-Band WiNode is shown in Figure 1 X-
Band WiNode Prototype

Figure 1 X-Band WiNode Prototype Parts

DUAL APERTURE X-BAND GMTI SAR

The WiSAR™ concept provides great flexibility for
reconfigurable SAR Payloads. This results largely from
the space feed of the antenna—there are no inherent
constraints on antenna length, width, or the number of
rows and columns. Thus, a Bus may be configured with a
4 panel antenna in support of a high resolution mission or
an 8 panel antenna in support of a Ground Moving Target
Indication (GMTI) mission. There are no RF harnesses
from the bus that need to be changed and no RF
distribution networks or beamforming networks that have
to be reconfigured or reterminated.

The flexibility and reconfigurability of the WiSAR™
architecture is dramatically demonstrated by the GMTI Mission. To support GMTI with enhanced sensitivity to
moving targets, the SAR Antenna aperture aspect ratio
must be high, to maximize the phase centre separation of
the two subapertures. The WiSAR™ architecture supports
the straightforward addition of antenna panels at either
end to increase the antenna length with minimal impact to
the RF interface to the Bus, and no impact on the Bus
power.

Just as important as the reconfigurability of the antenna
size, shape and frequency, is the Bus power subsystem.
The power subsystem is simplified because the SAR
antenna average and peak power requirements are de-
coupled from the Bus, dramatically lowering the required
Bus peak and orbit average power. Thus, a 9.5m² antenna
draws exactly the same power from the bus as a 4.8m²
antenna—exactly zero Watts.
WiSAR™ also eliminates the SAR Power Harness between the Bus and the SAR Antenna, reducing the Bus to Payload Interface across the deployed hinge to the absolute minimum of simple redundant CAN control busses and the unavoidable mechanical and thermal interfaces. The deployment of the WiSAR Antenna will be simpler, and thus more reliable, than a traditional phased array, with fewer complex harnesses across the hinge.

An artists rendition of a dual aperture X-Band WiSAR™ GMTI Spacecraft is shown in Figure 2. The antenna supports dual aperture operation (two independent receive phase centers), which in conjunction with dual receive channel processing enables GMTI.

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HIGH PERFORMANCE C-BAND SAR

Reconfiguring from X-Band to C-Band is a simple matter of changing the antenna panels, with a small change to the Sensor Electronics and Space Feed Boom. A single aperture High Performance C-Band Spacecraft configuration is shown in Figure 3. This C-Band configuration results in a total Spacecraft wet mass of 850kg including margin of 180kg. Compare this with RADARSAT-2, a conventional C-band SAR spacecraft of similar performance, and a total mass at launch of 2,200kg.

This multi-mode SAR provides for a 7 year design lifetime, with Single, Dual and Quad Polarization options in StripMap and ScanSAR modes. Imaging time per orbit is a peak of 20 minutes, with orbit average of 12 minutes. The equivalent power storage on the 9.5m² WiSAR antenna is a huge 5.5kWh operated at a maximum depth of discharge of less than 12%.

The single aperture C-Band Spacecraft configuration shown in Figure 3 fits in a 2.35m diameter fairing, occupying 1.7m in height, with a minimum mass margin of 300 kg relative to the 600km lift capability of a number of low-cost launch vehicles.

Launch vehicle options include:

- DNEPR (standard fairing)
- PSLV
- Vega
- Falcon
- Eurockot
The WiSAR™ Spacecraft shown in Figure 3 and Figure 4 will provide a variety of swath widths from 20 km up to 500 km. In the 20 km swath mode, the resolution is 3 meters. In the 500 km swath mode, the resolution is 100 meters. NESZ values range from worst case values of –17dB to –25dB, depending on the mode of operation.

C-BAND SMALLSAT SAR

The exceptional image quality and imaging times of the High Performance C-Band SAR are not required of every mission, and the WiSAR concept readily allows image parameters and imaging time to be traded off to result in a reduced spacecraft and payload mass. Although X-Band typically allows a smaller antenna aperture, WiSAR may be configured as a very capable C-Band SAR and still fit within typical Smallsat constraints.

In single polarization configuration, with a 6.75m² antenna, the C-Band antenna mass drops below 140kg, bringing the total payload mass well within the realm of a nominal 175kg Smallsat payload. A SAR of this mass and size produces a remarkable NESZ of -19dB, ambiguities below -18dB, 3m resolution over 10km swaths, and a wide area surveillance capability in ScanSAR mode, while providing 8 minutes of imaging per orbit.

ANTENNA DISTORTION COMPENSATION

In the WiSAR™ design, the SAR Antenna flatness is corrected electrically by using a real time measurement compensation system known as the Antenna Distortion Measurement System (ADMS) which facilitates the implementation of the Dynamic Antenna Distortion Compensation.
Compensation (DADC), effectively updating all phase information multiple times per second.

A typical requirement for the deployed stability of a SAR Antenna is that the antenna be within one twentieth of a wavelength of a best fit plane; or within 1.5 to 2mm at C-Band. The space feed architecture of WiSAR™, together with the ADMS allows the antenna to be anywhere within one quarter of a wavelength of a best fit plane; the resulting phase errors are corrected electronically.

In a conventional SAR antenna, the Bus may impact antenna flatness through distortion at the interface points between the deployed antenna on its Extendable Support Structure and the Bus. Constraining this interface creates a challenging requirement if the Bus acts as a connecting structure between two independent SAR antenna wings—in this case non-uniform Bus or antenna support structure thermoelastic distortion would cause the overall antenna shape to warp. The WiSAR™ architecture decouples the antenna from distortion at the bus to antenna interface, transferring this to a simpler requirement on the angular stability of the space feed boom in the +X/-X directions only; Z and Y direction motion of the boom tip does not manifest itself as azimuth beamsteering. The remaining sources of error are the thermoelastic distortion of the SAR Antenna itself, and the dynamic low frequency motion of the antenna excited by attitude changes in the spacecraft.

Distortion of the boom and antenna panels in the dimension along their respective lengths is small and the impact of this distortion is negligible; the geometry compensation does not need to measure in this dimension.

The ADMS System contains an array of RF ranging sensors (WiSense modules) distributed over the antenna panels (4 WiSense nodes per panel), and processing electronics located inside the Receiver/Exciter subsystem onboard the bus. The ranging system measures antenna distortion in real time, and supplies compensating phase information to the antenna WiNodes, performing Dynamic Antenna Distortion Compensation with no interruption to the normal imaging process.

PARTS PHILOSOPHY AND OBSOLESCENCE

The basic choice of commercial components for the WiSAR™ antenna is driven by the economics and technological advantages to be gained by leveraging components developed for huge, mainstream terrestrial markets.

In the case of the WiNodes, the WLAN, WiMAX and UWB markets have developed a wide array of powerful GaAs microwave components. WiSAR™ uses a “medium” level of COTS IC integration, avoiding lower levels of integration that require low level design, as well as the high levels of integration which use specialized proprietary MMICs that cause cost, availability, single source and obsolescence issues. There is a broad spectrum of components available at the chosen level of integration; a large number of manufacturers are making RF parts that have 50ohm input/output matching. At this level, RF components are almost “drop-in” replaceable, with minimal impact.

Similarly, Lithium-Ion cells and single chip cell and battery management systems are driven by the cell phone market, and in the same way CAN Bus communications and microcontrollers are drawn from the automotive industry.

By the judicious use of COTS technologies and parts, the WiSAR™ Antenna thus avoids the ongoing obsolescence issues that typically plague long programs where multiple missions are staged over many years.

WiSAR™ PROTOTYPE DEMONSTRATION

Since the WiSAR™ Antenna architecture is radically different from that of a conventional SAR antenna, MDA embarked on a technology development and risk reduction program. The MDA program included: establishing the system architecture; developing the design of the key WiSAR™ technology elements; building fully functional prototype hardware; and undertaking functional and performance tests. The culmination of this effort was an innovative ground demonstration completed in July 2007 where the prototype WiSAR™ antenna was assembled using prototype WiNodes on an antenna panel and used to image the International Space Station (ISS) in an inverse SAR mode.

The C-band ground demonstration system had the following characteristics:

• An antenna comprising 56 C-Band WiNodes with a total aperture of 2.84m x 1m. The full prototype WiSAR™ space fed phased array that was used in the ground demonstration is shown in Figure 5.

• The WiNode prototype design was representative of the final space flight design in the following ways: the
physical size, mass and power consumption, functionally representative RF components and use of a rechargeable Lithium-Ion cell. The prototype WiNode is shown in Figure 6.

• A space fed RF distribution and beam-forming system using a geometry similar to that proposed for WiSAR™ and using representative patch antennas for RF distribution.

• The phase relationship between the WiNodes was determined by setting up the Sensor Electronics to perform the measurements normally done by the Antenna Distortion Measurement System (ADMS), and adjusted by programming compensating phases through a mechanism similar to the Dynamic Antenna Distortion Compensation (DADC). This used a small probe at the front of the antenna to measure the phase from each WiNode. In this manner the demonstration confirmed that the ADMS/DADC is a valid and verified way of performing dynamic antenna distortion compensation.

• The Peak RF Transmit power was ~350W and the Mean RF Transmit power was ~75W.

It should be noted that the WiSAR™ demonstration was performed without any use of an antenna range of any sort, near field or otherwise. Instead, the demonstration relied entirely on measuring the beam phase relationship between the WiNodes in much the same way as done by the ADMS.

The image of the ISS, moving at approximately 7.5km/s, was successfully captured at an elevation of 89 degrees and at a range of 343km. The imaging configuration and the image itself, along with a plot of the Signal to Noise Ratio, are shown in Figure 7. The limited range (vertical axis) extent of the image results from the imaging geometry, in particular the extreme elevation angle.

The ISS image was perfectly focused, with range and azimuth resolution exactly as expected. The measured Signal-to-Noise ratio was somewhat higher than anticipated, with a peak of 31dB. This is attributed to the difficulty in predicting the reflectivity of the ISS.
CONCLUSION

WiSAR™ is a demonstrated, reconfigurable SAR Payload architecture that dramatically increases mission-specific flexibility and responsiveness, while at the same time significantly reducing cost and mass.

The C-Band WiSAR™ prototype demonstration has shown that a SAR antenna may be assembled and aligned with a minimum of specialized equipment, and without requiring an antenna range of any sort. The second generation X-Band prototype WiNode has been successfully built is currently in testing.

The WiSAR™ architecture thus supports the goals of highly capable low cost smallsat missions with multiple launcher compatibility, with the modularity and flexibility that simplifies configuration, assembly, test and deployment for a wide variety of satellite SAR missions.