InSAR Newsletter

No. 2, February 2007

Introduction

This purpose of this issue is to give a comprehensive overview over civilian spaceborne and airborne SAR sensors that are currently in operation or planned for the near future. The main features of the sensors will be given, focusing on characteristics that are mostly relevant for Intermap's business.

Spaceborne SAR sensors

Overview

Table 1 lists the spaceborne SAR sensors (respectively missions) that either are currently in operation or scheduled for launch in the near future. They are ordered chronologically according to their (expected) launch date. Sensors highlighted in light green are not yet in operation, but the mission is confirmed. The ones highlighted in light red are planned, yet not finally confirmed. For the upcoming missions the indicated launch date is the best estimate available to date. Not included in this list are purely military missions like the US Lacrosse series of systems or Russian's Kondor-E satellite.

Most of the missions are configured for non-interferometric operation, TanDEM-X is the only one dedicated to InSAR DEM generation. A clear trend can be observed towards higher spatial resolution and also multiple polarization capability. Also, systems tend to become smaller and more flexible, yet configured in constellations of multiple satellites such as COSMO-SkyMed, SAR-Lupe, RADARSAT Constellation etc.

In the following, the different sensors and missions are portrayed in more detail. Most of the information has been collected from different publications and websites (especially http://directory.eoportal.org/res_p1_Earthobservation.html). For further reading on earth observation missions in general, an excellent overview can be found in the book of H. Kramer, "Observation of the Earth and its Environment - Survey of Missions and Sensors", Springer, 2002.

ERS-2

ERS-2 (*European Remote-Sensing Satellite-2*) is the follow-up of ESA's ERS-1 mission that started in 1991. ERS-2 was launched in 1995. It is a remote sensing satellite that amongst others carries a C-band SAR sensor called AMI (*Active Microwave Instrument*). With respect to the SAR instrument, ERS-2 essentially is a copy of ERS-1. Interferometric data has been primarily acquired with the 35-day repeat cycle, however, there had been various so-called *Tandem* missions with ERS-1 and ERS-2 flying in the same orbit, resulting in interferometric SAR data with a temporal separation of 1 day only.

After 11 years of operation, ERS-2 is still in operation yet has exceeded its nominal lifetime already significantly. A catalog of acquired ERS datasets can be accessed via the DESCW software which can be downloaded from the ESA website http://earth.esa.int/descw/.

RADARSAT-1

RADARSAT-1 is the first commercially operated spaceborne SAR sensor. Designed for a 5-year lifetime it enters now its 11th year of operation. RADARSAT-1 carries a C-band HH instrument introducing a great variety of different swath widths, illumination angles, and spatial resolutions as well as a ScanSAR capability. A fine resolution mode allows to collect data with 9 m ground resolution. For interferometric applications and particularly DEM extraction, RADARSAT-1 data are less suited due to mainly two reasons: its comparatively long repeat cycle of 24 days and the unavailability of precise orbit data.

ENVISAT

ESA's ENVISAT (*Environmental Satellite*) is a remote sensing satellite that carries various instruments, amongst others the ASAR (*Advanced SAR*) sensor. This instrument is of AMI heritage flown on ERS-1 and ERS-2. It can operate in various modes, e. g. Stripmap and ScanSAR acquisition modes, single and dual polarizations, various illumination angles and swath widths. The highest possible ground resolution is 28 m in VV or HH with a swath width of 100 km. The instrument transmits in the same frequency band as ERS-2 and thus has been used for several combined experiments such as ERS/ENVISAT cross interferometry operation. ENVISAT which was launched in 2002 reaches now the end of its nominal lifetime of 5 years.

ALOS/PALSAR

ALOS is an acronym for *Advanced Land Observing Satellite*, a project run by JAXA (*Japan Aerospace Exploration Agency*). ALOS carries besides other optical sensors the SAR instrument PALSAR (*Phased Array L-band Synthetic Aperture Radar*). It is the only L-band SAR sensor currently in orbit. Its main advantage over the other currently operating systems is the capability of a full-polarization mode. Also, both Stripmap and ScanSAR operating modes are available. A maximum spatial resolution of 10 m can be achieved.

SAR-Lupe

SAR-Lupe is a constellation of five SAR satellites in the X-band frequency range. The first satellite was successfully brought into orbit on December 19, 2006. The four remaining systems are going to be launched in half-year intervals such that the full constellation will be available by the end of 2008. SAR-Lupe is a military project led by the German Ministry of Defense with the main objective to provide imagery for reconnaissance purposes. Therefore, the main focus is on quick response times in a global context (about 10 hours) rather than on continuous coverage. The main image product will be generated from a Spotlight operating mode with a spatial ground resolution less than 1 m. Although the instruments can acquire in Stripmap mode as well, no image specifications have been published for those kinds of products. In principle, the satellite constellation could be used for simultaneous interferometric acquisition, however due to other priorities this is unlikely to happen except for demonstration purposes.

TerraSAR-X

TerraSAR-X is a German radar satellite project based on a public private partnership between DLR and EADS. The instrument can operate in Stripmap, ScanSAR, or Spotlight mode and in single or dual polarization. There will be no quad-pol capability. Highest possible Stripmap ground resolution will be 3 m, and an (experimental) Spotlight mode with 300 MHz range bandwidth will yield data with 1 m ground resolution. For DEM generation, TerraSAR-X is still not well suited due to the 11-day repeat cycle. However, as the basis of the TanDEM-X mission, this instrument will be capable of providing high-resolution DEMs (see below).

In addition to the standard modes TerraSAR-X can operate in dual-receive antenna mode, thus enabling to collect data in along-track interferometry (ATI) configuration. The ATI baseline of 1.2 m is expected to allow a velocity estimation accuracy in line-of-sight of 0.1 m/sec at a spatial resolution of 1 km. Also, this antenna splitting can be used for full quad-pol acquisition in an experimental mode.

As a result of problems with the launch vehicle, the launch of TerraSAR-X which was envisaged for October 2006 is currently being postponed to March 2007.

RADARSAT-2

RADARSAT-2 is an advanced follow-on of the RADARSAT-1 mission. In terms of project setup and funding, it will be the Canadian analog to TerraSAR-X: a public private partnership between government (CSA) and industry (MDA). From a technical point-of-view, RADARSAT-2's main objective is to continue the RADARSAT programme and provide data continuity to the users. On top of that it will provide numerous enhancements such as extended design life (7 years instead of 5 years), increased ground resolution (3 m), quad-pol capability, left and right looking imaging capability, use of an active phased array antenna etc. Similar to TerraSAR-X, the RADARSAT-2 antenna can be operated in dual-receive mode, which is intended to be used for GMTI applications.

With respect to DEM generation, RADARSAT-2 as a standalone system will not be a significant improvement over RADARSAT-1 since the 24-day repeat cycle is the main limitation. There are two further scenarios currently under discussion: 1) a tandem mission together with RADARSAT-1, which can reduce the revisit time substantially, and 2) a RADARSAT constellation consisting of up to 6 additional small satellites that fly in formation (see below).

COSMO-SkyMed

COSMO-SkyMed stands for *Constellation of Small Satellites for Mediterranean Basin Observation*, a project funded by ASI (*Agenzia Spaziale Italiana*) and the Italian Ministry of Defense. It is a combination of four radar satellites and two optical satellites with global coverage that allow to revisit a certain area several times each day. The radar satellites are equipped with X-band SAR sensors each. Their active phased-array antenna can be operated in different ways, e. g. in dual-polarization mode or in split-beam along-track interferometry mode. The system can collect data in Stripmap, ScanSAR, or Spotlight mode. The satellite constellation can be configured in two different ways. The *nominal orbit configuration* is used for rapid ground track repeatability, whereas the *interferometric orbital configuration* is designed to allow acquisition of cross-track InSAR data (e. g. for DEM generation). In the latter case, a 1-day tandem-like operation is envisaged. Launch for the first of the four satellites is scheduled for May 2007. The constellation completion is expected by the end of 2008.

TecSAR

TecSAR is a SAR technology demonstration satellite developed in Israel. The mission is of military nature, but is included here since comparatively much detail has been published and there might be an option to obtain data for civilian purposes as well. The sensor operates in X-band in various polarizations and swath modes (Stripmap, ScanSAR, Spotlight). Highest possible stripmap resolution is 3 m. The launch of TecSAR currently is scheduled for July 2007.

RISAT

RISAT is an acronym for *Radar Imaging Satellite*. It is a project by ISRO (*Indian Space Research Organization*). In tradition of Indian SAR efforts it will carry a C-band radar sensor. It can operate in Stripmap, ScanSAR, or Spotlight mode and in different polarization modes (single and dual-pol). The highest possible Stripmap resolution will be 3 m with a 30 km swath. Estimated launch date is end of 2007.

TanDEM-X

TanDEM-X stands for *TerraSAR-X add-on for Digital Elevation Measurement*. It essentially is a second TerraSAR-X satellite that will fly in formation with TerraSAR-X-1 in bistatic mode in order to produce single pass-like interferometric products. The main mission objective is to generate a world-wide, consistent, timely and high-precision digital elevation model according to NGA's new HRTI-3 standard[1]. This is planned to be accomplished within 3 years of operation. Additionally, the generation of HRTI-4[1] DEMs in selected local areas is envisioned.

In addition to the primary objective of topographic mapping, TanDEM-X will be used as a research platform for various kinds of studies regarding new techniques and applications. The list of topics includes along-track interferometry (for measurement of ocean currents, traffic monitoring, and glacier mass balance analysis), multi-static SAR operation, digital beamforming, and SAR super resolution techniques.

TerraSAR-L

TerraSAR-L originally was planned to be an integral part of the TerraSAR mission concept consisting of one X-band and one L-band subsystem. In contrast to TerraSAR-X, TerraSAR-L is still in its evaluation phase led by ESA. A phase B study is currently undertaken by Astrium Ltd. If eventually realized, the system will likely consist of a quad-pol L-band SAR sensor with Stripmap and ScanSAR capability and maximum (Stripmap) resolution of 5 m. A potential launch was planned for 2008, however, the programme has been halted for the time being.

KOMPSAT-5

KOMPSAT stands for *Korean Multi-Purpose Satellite*, a program led by KARI (*Korean Aerospace Research Institute*). The KOMPSAT series of satellites is a family of Earth observation instruments designed to supply imagery for GIS applications and disaster management. KOMPSAT-5 would be the first in that series to carry a radar payload: a SAR instrument working in the X-band frequency range, developed by the company Alcatel. A potential launch is envisioned for the end of 2009.

MicroSAR

MicroSAR is a project of EADS Astrium with the goal to launch small low-cost SAR satellites in the X-band frequency range. The instrument will operate in quad-pol mode with a targeted resolution in the 1 - 3 m range. An airborne MicroSAR demonstrator with a weight of 50 kg only has been built and test flown in 2005.

AstroSAR-Lite

AstroSAR-Lite is a commercial X-band SAR platform that is under discussion at EADS Astrium. Technically, the AstroSAR payload is based on the MicroSAR concept: a low-cost image-only X-band SAR sensor with an active phased-array antenna and versatile imaging and pointing modes. Maximum resolution of this instrument will be in the order of a couple of meters (depending on the desired swath width).

A new initiative with respect to data sharing is under discussion for this concept. Potential customers that purchase one instrument are offered the possibility to share their system with others in a satellite constellation, thus enabling new fields of application by using several satellites for the price of one.

RADARSAT Constellation

RADARSAT Constellation is a concept in legacy of the RADARSAT programme that will consist of up to six small satellites equipped with C-band SAR instruments. The sensors will feature ScanSAR and Stripmap capability and a maximum spatial resolution of 5 m. The conceptual design and mission definition is currently carried out in a feasibility study by CSA. The main objectives of this mission are to ensure data continuity to RADARSAT users and to provide more frequent coverage for monitoring purposes.

1 HRTI-3 (*High-Resolution Terrain Information*) specifies an absolute vertical accuracy of 10 m (2σ) with a horizontal resolution of 12 m. HRTI-4 further increases the requirements to 5 m absolute vertical accuracy (2σ) and 6 m horizontal resolution. The relative vertical accuracy for both cases is 2 m and 0.8 m, respectively.

SENTINEL-1

SENTINEL-1 is the name of ESA's concept for a European Radar Observatory, consisting of a constellation of SAR satellites in continuation of the ERS and ENVISAT programmes. The main mission objective is to provide continuity of data for user services. The baseline concept currently encompasses two C-band satellites that can operate in a variety of acquisition modes in order to meet the diverse user requirements. The constellation of two sensors is primarily used to decrease the revisit time for specific areas, there is no single-pass like operation envisaged at the moment. A potential launch is scheduled for 2011.

MAPSAR

MAPSAR stands for *Multi-Application Purpose SAR*. It is a concept for a small L-band SAR satellite for land monitoring developed in a joint Brazilian-German partnership between INPE and DLR. The L-band instrument will operate in quad-pol polarization and in a variety of acquisition modes. The high-resolution Stripmap mode will yield a maximum spatial resolution of about 4 m. Pol-InSAR is one of the most important applications that the mission is designated for. The design phase A study has been completed, and a potential MAPSAR launch is scheduled for 2011.

SAOCOM

SAOCOM is a planned Argentinian SAR satellite constellation that eventually will consist of four fully polarized L-band sensors with a targeted spatial resolution of 10 m. The project is led by the Argentinian space agency CONAE (*Comision Nacional de Actividades Espaciales*). At present it is planned to combine the system with the COSMO-SkyMed activities to form the SIASGE constellation (*Sistema Italo-Argentino de Satélites para Gestión de Emergencias*).

HJ-1-C

HJ-1-C is part of a small satellite constellation under development in China. Carrying a single-pol SAR sensor in the S-band frequency range, it will complement HJ-1-A and HJ-1-B which will be equipped with optical instruments. This three-satellite constellation will serve as a disaster monitoring tool. The maximum SAR spatial resolution will be 5 m. In a second phase of this project, another four optical and four SAR sensors (with quad-pol capability) are planned to be launched.

Table 1: Overview over spaceborne SAR sensors

Satellite or Mission	*Launch Date*	*Orbit Repeat Cycle*	*Frequency Band*	*Polarization*	*max. Spatial Resolution (single-pol)*	*Swath Width (for max. Resolution)*
ERS-2	21 April 1995	3 days / 35 days	C	VV	20 m	100 km
RADARSAT-1	4 November 1995	24 days	C	HH	9 m	45 km
ENVISAT	1 March 2002	35 days	C	dual-pol	28 m	100 km
ALOS/PALSAR	24 Jan. 2006	46 days	L	quad-pol	10m	40 - 70 km
SAR-Lupe	12 December 2006	< 1 day	X	single-pol	< 1 m in Spotlight mode	8 km
TerraSAR-X	March 2007	11 days	X	dual-pol	3 m (1 m Spotlight)	30 km
RADARSAT-2	March 2007	24 days	C	quad-pol	3 m	20 km
COSMO-SkyMed	May 2007	< 1 day	X	quad-pol	3 m (1 m Spotlight)	40 km
TecSAR	July 2007	36 days	X	quad-pol	3 m	n/a
RISAT	late 2007	19 days	C	dual-pol	3 m	30 km
TanDEM-X	March 2009	11 days	X	dual-pol	3 m	30 km
TerraSAR-L	2008	14 days	L	quad-pol	5 m	70 km
KOMPSAT-5	2009	tbd.	X	tbd.	tbd.	tbd.
MicroSAR	tbd.	tbd.	X	quad-pol	1 m	tbd.
AstroSAR	tbd.	tbd.	X	n/a	3 m	10 km
RADARSAT Constellation	tbd.	12 days	C	HH	5 m	20 km
SENTINEL-1	2011	12 days	C	dual-pol	5 m	80 km
MAPSAR	2011	37 days	L	quad-pol	4 m	20 km - 40 km
SAOCOM	tbd.	16 days	L	quad-pol	10 m	60 km
HJ-1-C	tbd.	2 - 4 days	S	single-pol	5 m	40 km

Airborne SAR sensors

Overview

Table 2 at the end of this section summarizes current and future civilian airborne SAR and InSAR instruments. They are categorized according to their operational status (*in operation* or (highlighted in light red) *in planning/under construction*). Within each category a chronological order is maintained.

By far most of the systems are of experimental nature. Only a few of the instruments can be considered as fully operational in a commercial sense: besides the Intermap systems those are GeoSAR, OrbiSAR, BioSAR 30, Lynx, and (if still in operation) DO-SAR. Not included in this compilation are military-operated instruments.

In the following, each sensor is briefly described. Fur further reading a reference to a website or recent publication is provided.

Airborne SAR sensors in operation

AIRSAR

AIRSAR is the NASA testbed for demonstrating and developing new radar technology. Its first flight was in 1988. Currently, it comprises a C-band, L-band, and P-band capability of which C and L can be operated in single-pass InSAR mode (formerly called TOPSAR). All frequencies are fully polarimetric. In addition, an ATI mode can be selected. In terms of resolution, AIRSAR's capabilities are rather poor as the system has not been upgraded significantly during its almost 20 years of existence. Nevertheless, the system has been regularly used for extended mapping campaigns all over the world.

Reference: *http://airsar.jpl.nasa.gov/documents/genairsar/airsar_paper1.pdf*

ASAR

ASAR (*Airborne SAR*) has been developed by ISRO as an Earth observation monitoring tool in the early 1990s. After the first successful flights in 1992 the original aircraft got lost, and only from 1997 onwards the system could be used again in a regular manner. The radar operates in C-band single-pol with a maximum spatial resolution of 6 m.

Reference: *http://www.prl.ernet.in/~library/Hari%20Om/Hari%20Om%20Lecture/Tapan_final.htm*

BioSAR 30

BioSAR 30 is a low frequency SAR sensor recently developed by NASA and the company ZAI (Zimmerman Associates International). The system works in the VHF spectrum and aims at mapping forest biomass and embedded carbon. The development was originally funded within the framework of NASA's *Small Business Innovation Research* (SBIR) programme. Commercialization of this project has been assigned to the company Terresense (*http://www.terresense.com*), a spin-off of ZAI who offers commercial BioSAR 30 services.

BioSAR 30 is, unlike a conventional airborne SAR, a nadir-looking sensor. A strip of 300 m width is illuminated which is not further resolved by range processing. In along-track direction synthetic aperture processing yields a 30 m spatial resolution. The instrument is operated at low power (1 Watt) and low altitudes (1,000 ft) in order to avoid interference with commercial radio and television transmission in the same frequency range. It is reported that a coverage of 30 square miles per day can be achieved.

Reference: Imhoff, M. L., P. Johnson, W. Holford, J. Hyer, L. May, W. Lawrence, P. Harcombe, "BioSAR™: An Inexpensive Airborne VHF Multiband SAR System for Vegetation Biomass

Measurement", IEEE Transactions on Geoscience and Remote Sensing, Vol. 38, No. 3, 2000

CARABAS-II

CARABAS-II (*Coherent All Radio Band Sensing*) is a low-frequency SAR system operating in the VHF band (20 MHz - 90 MHz). It has been developed by the Swedish Defence Research Agency (*FOI*) in 1996 as a successor to the CARABAS-I system which first flew in 1992. Both sensors have widely been used for mapping campaigns with a focus on foliage penetration. CARABAS-II can be considered as a fully operational production system. Due to its very long azimuth integration times the system imposes severe requirements on accurate processing. In the course of the CARABAS development parallel progress took place in the field of processing techniques (e. g. motion compensation, focusing using backprojection).

Reference: Ulander, L.M.H., P.-O. Frölind, A. Gustavsson, H. Hellsten, T. Jonsson, B. Larsson, G. Stenström, "Performance of the CARABAS-II VHF-band Synthetic Aperture Radar", *Proceedings of IGARSS '01*, pp. 129 - 131

CASSAR

CASSAR (*Chinese Academy of Science SAR*) has been developed by the Institute of Electronics at the Chinese Academy of Science (*CAS*) in the late 1980's. It is a multipolarized image-only X- and L-band system. The system mainly serves as a research testbed related to SAR at CAS. Not much has been published about CASSAR.

Reference: Peng, H., Y. Shao, F. Song, Y. Wu, L. Wang, L. Li, "DEM generation using L-band airborne SAR data", *Proceedings of IGARSS '00*, pp. 764 - 766

DO-SAR

The DO-SAR (*Dornier SAR*) development goes back to 1989 when the company Dornier (now EADS) built a first SAR system into one of their DO228 aircraft. Since then the radar has been upgraded multiple times and now encompasses four frequency bands (S, C, X, and K_a) of which C and X can be operated in interferometric mode and S, C, and X are fully polarimetric. The current system is reported to reach less than 0.5 m spatial resolution in X-band. DO-SAR has been used for extended mapping campaigns in Indonesia (1997, 120,000 km^2) and Thailand (2000, 14,000 km^2). Since then, not much has been published about the system, and it is not clear whether DO-SAR is still in operation.

Reference: Hoffmann, K., P. Fischer, "DOSAR : A Multifrequency Polarimetric and Interferometric Airborne SAR-System", *Proceedings of IGARSS '02*, pp. 1708 - 1710

E-SAR

E-SAR is DLR's *Experimental SAR* testbed. The system has been constantly developed and enhanced since its first flights in 1988. Currently, it has quad-pol capability in the bands P, L, C, and X, of which only X can be operated in single-pass interferometry mode. All bands have 100 MHz bandwidth, and only recently X has been upgraded to 200 MHz by incorporating stepped frequency transmission. E-SAR has been used in various mapping campaigns in recent years, and especially its L- and P-band Pol-InSAR experiments have set the standard for polarimetric interferometry applications. E-SAR will be succeeded by F-SAR within the next few years (see below).

Reference: *http://www.dlr.de/hr/institut/abteilungen/sar_technologie/flugzeug_sar*

EMISAR

The EMISAR (*Electromagnetics Institute SAR*) system has been developed by the Technical University of

Denmark in the 1980's and has been operated since 1989. It serves as a research testbed for the Danish Centre for Remote Sensing (*DCRS*). EMISAR has full-pol capability in both C- and L-band and single-pass InSAR capability in C-band. Maximum spatial resolution is 2 m in both channels. Together with JPL's AIRSAR, EMISAR was one of the first quad-pol airborne sensors. Today, it heavily suffers from the fact that it can be operated only very limited time of the year due to unavailability of the aircraft (which is owned by the Danish Air Force).

Reference: *http://www.oersted.dtu.dk/English/research/emi/dcrs/airborne_sensors.aspx*

GeoSAR

GeoSAR is a commercial single-pass InSAR platform operated by the company *EarthData International*. It was originally developed by JPL. Its main unique feature is the simultaneous X- and P-band dual-look capability which turns the system into a very cost-effective mapping instrument. Cost efficiency is further supported by its high flight altitude of 39,000 ft that allows for wide swath coverage (12 km strip width on either side). The company specifies a maximum coverage rate of 288 km^2 per minute. Another unique feature of the system is the single-pass P-band instrument with the two antennas mounted underneath the aircraft wings, spanning an interferometric baseline of 20 m. The spatial resolution in both bands reaches 1 m. In addition to the SAR sensors the aircraft is equipped with a profiling Lidar that collects supplementary data in order to help remove systematic errors in InSAR DEM extraction. The achievable InSAR DEM height accuracy is reported to be 2.5 m for X-band (DSM) and between 2 and 5 m for P-band (DTM). Extended commercial GeoSAR missions have been conducted so far in Columbia (250.000 km^2), California (45.000 km^2), and Papua New Guinea.

Reference: Hoffman, G. R., "Integration of a Profiling Lidar with GeoSAR", *ASPRS 2006 Annual Conference*, Reno, Nevada, May 1-5, 2006

IMARC

IMARC is a multi-frequency and multi-polarization SAR sensor developed by the Moscow Scientific Research Institute of Instrument Engineering. The system is now operated by the company VEGA-M, a commercial spin-off of that research institute which is being tasked with marketing of the sensor. The instrument comprises the four bands VHF, P, L, and X with a maximum spatial resolution of 1.5 m in X. All bands are quad-pol. In addition, the system includes a real-time processor.

Reference: Kutuza, B., M. Bondarenko, A. Dzenkevich, A. Kalinkevich, M., Krilova, O. Shishkova, V. Verba, E. Vostrov, V. Manakov, V. Pluschev, "First Results of Radar Images Obtained by Improved Multi-Frequency Polarimetric SAR Complex “IMARC”", *Proceedings of EUSAR '06*

Ingara

Ingara is an X-band single-antenna SAR system developed by the Australian Defence Science and Technology Organization (*DSTO*) for research purposes. It has been first flown in 1993, and since then has undergone numerous upgrades. It is being used for Stripmap, Spotlight, and MTI acquisitions. Quad-pol capability has been added recently. The 600 MHz range bandwidth provides a maximum spatial resolution of about 0.3 m.

Reference: Stacy, N. J. S., D. P. Badger, A. S. Goh, M. Preiss, M. L. Williams, "The DSTO Ingara airborne X-Band SAR polarimetric upgrade: first results", *Proceedings of IGARSS '03*, pp. 4474 - 4476

KOMSAR

KOMSAR (*Korean Miniature SAR*) has been developed by the Agency for Defense Development in Korea as a demonstrator and research testbed for SAR technology. It operates at X-band with a maximum spatial resolution of 1.5 m. KOMSAR is a lightweight system (37 kg) that eventually is going to be installed on UAVs. The first testflight took place in 2004.

Reference: Lee, S., B. Koh, Y. Hwang, "An Airborne SAR Development Demonstration in Korea", *Proceedings of IGARSS '05*, pp. 4057 - 4060

LORA

LORA (*Low-Frequency Radar*) is a wideband low-frequency SAR system operating in VHF/UHF-band. It has been developed by FOI and can be considered, from a SAR perspective, as an expansion of the CARABAS-II capabilities towards shorter wavelengths. LORA additionally encompasses GMTI capability. The system is used as a generic research tool with respect to foliage penetration SAR applications.

Reference: Ulander, L.M.H., M. Blom, B. Flood, P. Follo, P.-O. Frölind, A. Gustavsson, T. Jonsson, B. Larsson, D. Murdin, M. Pettersson, U. Rääf, G. Stenström, "Development of the Ultra-wideband LORA SAR Operating in the VHF/UHF-band", *Proceedings of IGARSS '03*, pp. 4268 - 4270

Lynx

Lynx is an image-only K_u-band SAR developed by the Sandia National Laboratories for the company General Atomics. Its capabilities include Stripmap and Spotlight SAR mode as well as GMTI. Maximum stripmap resolution is specified to 0.3 m, and spotlight resolution goes down to 0.1 m. With a total weight of 52 kg for the flight segment it is designed to fly on a variety of UAVs. Lynx is a commercial off-the-shelf product being distributed by General Atomics (http://www.ga-asi.com/products/lynxSAR.php).

Reference: Tsunoda, S. I., F. Pace, J. Stence, M. Woodring, W. H. Hensley, A. W. Doerry, B. C. Walker, "Lynx: A high-resolution synthetic aperture radar", *SPIE Aerosense 1999*, Vol. 3704

MEMPHIS

MEMPHIS is an acronym for *Millimeterwellen - Experimental - Multifrequenz - Polarimetrie - Hochauflösungs - Interferometrie – Sensor* (millimeter wave experimental multi-frequency polarimetric high-resolution interferometric sensor). It is FGAN's (*Forschungsgesellschaft für Angewandte Naturwissenschaften* - research establishment for applied science) radar testbed for millimeter wave applications. SAR (in K_a- and W-band) is only one of various operating modes of this sensor. It is particularly characterized by its high-resolution capability (as a consequence of the 800 MHz range bandwidth). As the fundamental chirp bandwidth is limited to 200 MHz, such high range bandwidths are achieved with a stepped frequency mode. The system is installed on a Transall C-160 aircraft where the parachute door is used for antennae mount. Experimental modes also include ATI and single-pass cross-track interferometry operation.

Reference: Essen, H., H. Schimpf, S. Boehmsdorff, T. Brehm, "MEMPHIS - a fully Polarimetric Experimental Radar", *Proceedings of IGARSS '02*, pp. 1714 - 1717

µSAR

µSAR has been recently developed at Brigham Young University (*BYU*) by students with the aim to build a small, low-cost, yet high-resolution SAR sensor. The system works in FMCW mode in the C-band frequency range and achieves a maximum spatial resolution of 1.8 m. It is designed such that it also can be operated in dual-channel interferometric mode by adding a second antenna and receiver board. The total weight including antennas is less than 2 kg, thus making the system perfectly suited to fly on small UAVs.

Reference: Zaugg, E. C. , D. L. Hudson, D. G. Long, "The BYU µSAR: A Small, Student-Built SAR for UAV Operation", *Proceedings of IGARSS '06*, pp. 411 - 414

MiniSAR

MiniSAR is a miniaturized SAR system in development at Sandia. It operates in K_u-band and achieves a resolution down to the 10 cm level in spotlight mode. Another feature is real-time onboard image formation. Due to its low weight of only 12 kg it can be installed on small UAVs. First test flights have been undertaken. The system is designed to be readily adaptable to K_a- or X-band.

Reference: *http://www.sandia.gov/RADAR/minisar.html*

MiSAR

MiSAR is a highly miniaturized SAR system in development at EADS since 2002. Its first flight tests have been undertaken in 2003. It is an image-only FMCW SAR sensor working in the K_a-band frequency range. The maximum spatial resolution is stated to be in the half-meter range. The system is designed to fly on very small UAVs with its extremely lightweight (4 kg) and compact (10 liters volume) hardware.

Reference: Edrich, M., "Lessons learnt from the design and flight testing of a highly miniaturised mmW SAR sensor system", *Proceedings of EUSAR 2006*

NEC-SAR

NEC-SAR is an image-only X-band system developed in 1992 by NEC Corporation in Japan. Its maximum spatial resolution is reported to be 5 m. The instrument has been used for various research missions (e. g. repeat-pass differential InSAR measurements for crustal deformation estimation). Not very much is published about the system, and it is not clear to date whether the system is still existing and in operation.

Reference: Miyawaki, M., H. Nagata, M. Sugawara, H. Shinme, M. Murata, H. Nohmi, M. Shimada, T. Sakurai, S. Kobayashi, N. Fujii, K. Nomura, H. Kitani, "Airborne Repeat-Pass INSAR System", *Proceedings of IGARSS '98*, pp. 2677 - 2679

OrbiSAR

OrbiSAR is a commercial InSAR system operated by the Brazilian company OrbiSat SA. It consists of a single-pass X-band and a repeat-pass P-band subsystem that can be operated simultaneously. The P-band part has fully polarimetric capability. There is very little published about this system, but it is assumed that it essentially is a (slightly modified) copy of the former Aero-Sensing AeS-1 sensor. OrbiSAR has been used for at least one extended mapping campaign in Venezuela with data acquisition of an area of about 250.000 km^2. Currently, another campaign is reported to be conducted in Indonesia.

Reference: Rombach, M., A. C. Fernandes, D. Luebeck, J. Moreira, "Newest technology of mapping by using airborne interferometric synthetic aperture radar systems", *Proceedings of IGARSS '03*, pp. 4450 - 4452

PAMIR

PAMIR stands for *Phased Array Multifunctional Imaging Radar*. It is FGAN's successor of the AER-II SAR system. PAMIR has been developed with the aim to demonstrate high resolution SAR imaging at long distances (10 cm @ 30 km and 30 cm @ 100 km) and also high-resolution 3-dim. mapping using single-pass InSAR. It was first flown in 2002. Currently, a range bandwidth of 1820 MHz (according to 9 cm range resolution) can be transmitted for Spotlight image-only acquisition. Interferometric operation is limited to 380 MHz bandwidth (or 35 cm spatial resolution).

Reference: Brenner, A. R., J. H. G. Ender, "Very wideband radar imaging with the airborne SAR sensor PAMIR", *Proceedings of IGARSS '03*, pp. 533 - 535

PHARUS

PHARUS is an acronym for *Phased Array Universal SAR*. The system was developed between 1987 and 1995 by a Dutch consortium consisting of TNO (*Netherlands Organisation for Applied Scientific Research*), NLR (*Dutch National Aerospace Laboratory*), and TUD (*Delft University of Technology*) and since then has been operated in various research projects. One of the main initial objectives was to study and implement the phased array antenna technology on an airborne SAR platform. The system consists of a single-antenna quad-pol C-band SAR. For today's measures it has a rather coarse spatial resolution of just 3 m.

Reference: Greidanus, H., P. Hoogeboom, P. Koomen, P. Snoeij, H. Pouwels, "First results and status of the PHARUS phased array airborne SAR", *Proceedings of IGARSS '96*, pp. 1633 - 1635

Pi-SAR

Pi-SAR stands for *Polarimetric and Interferometric SAR*. It was jointly developed in Japan by JAXA and NICT (*National Institute of Information and Communications Technology*) and was first flown in 1996. The system consists of a single-pass quad-pol interferometric X-band subsystem and a quad-pol L-band part that can be operated simultaneously.

Reference: *http://www2.nict.go.jp/y/y221/PI-SAR/E/index.html*

RAMSES

RAMSES stands for *Radar Aéroporté Multi-Spectral d'Etude des Signatures*. It is an experimental radar that is being operated by the French Aerospace Research Agency ONERA (*Office Nationale d'Etudes et de Recherches Aerospatiales*) for the purpose of developing and testing new technologies. The system can be operated in a variety of different modes and frequency bands. It is in constant evolution. Currently, its highest possible resolution is in the decimeter range for the bands X, K_u, and K_a. X- and K_u-band are equipped with a second antenna for interferometric operation.

Reference: Dubois-Fernandez, P., O. Ruault du Plessis, D. le Coz, J. Dupas, B. Vaizan, X. Dupuis, H. Cantalloube, C. Coulombeix, C. Titin-Schnaider, P. Dreuillet, JM. Boutry, JP. Canny, L. Kaisersmertz, J. Peyret, P. Martineau, M. Chanteclerc, L. Pastore, JP. Bruyant, "The ONERA RAMSES SAR system", *Proceedings of IGARSS '02*, pp. 1723 - 1725

SAR-580

The development of this system goes back to the mid 1970s when CCRS bought the core radar instrument from ERIM and installed it on a Convair 580 aircraft. In 1996 the system was taken over by Environment Canada who still owns and operates it. During those years the SAR-580 has undergone various upgrades, the most notable one being the addition of a second C-band antenna in the early 1990s which turned it into a single-pass interferometer. Operation in both XTI and ATI as well as quad-pol polarimetric mode can be carried out, yet the system's range bandwidth of only 50 MHz limits its usability for high-resolution applications.

Reference: Hawkins, R. K., C. E. Brown, K. P. Murnaghan, J. R. Gibson, A. Alexander, R. Marois, "The SAR-580 facility - system update", *Proceedings of IGARSS '02*, pp. 1705 - 1707

SASAR

SASAR stands for *South African SAR*. It is a fully polarimetric instrument operating in the VHF frequency range. The original development was carried out by the University of Cape Town and CSIR (*Council for Scientific and Research*). The system was first flown in 1999. Since then it has mainly be used as a testbed for development of various kinds of SAR and InSAR applications. Currently, a follow-up system called SASAR II is under development which will consist of a X-band sensor. This system is designed as a demonstrator for a potential spaceborne mission.

Reference: Wilkinson, A. J., R. T. Lord, M. R. Inggs, "Repeat Pass SAR Interferometry at VHF Band", *Proceedings of IGARSS '01*, pp. 123 - 125

Star-3/4/5/6, TopoSAR

Intermap's SAR systems are well-known to the company and therefore are not subject of this report.

Twin-Otter SAR

The Twin-Otter SAR is a research testbed developed by the Sandia National Laboratories in the early 1990s. It encompasses the 4 frequency bands VHF/UHF, X, K_u, and K_a. The K_u-band subsystem includes a second antenna for interferometric operation. As with most of the SAR testbeds a variety of different operating modes can be realized. In Stripmap mode, a resolution of up to 0.3 m is achieved. Not very detailed information has been published recently about this system, but impressive image examples can be found on Sandia's website (*http://www.sandia.gov/RADAR/imagery.html*).

Reference: Walker, B., G. Sander, M. Thompson, B. Burns, R. Fellerhoff, D. Dubbert, "A High-Resolution, Four-Band SAR Testbed with Real-Time Image Formation", *Proceedings of IGARSS '96*, pp. 1881 - 1883

YINSAR

YINSAR is the name of an experimental SAR system developed at BYU in the late 1990s. The aim was to build a low-cost, compact interferometer that can be flown on small aircrafts like the currently used Cessna Skymaster. The radar operates in X-band with a 200 MHz bandwidth, yielding a theoretical range resolution of 0.75 m.

Reference: Lundgreen, R. B., D. G. Thompson, D. V. Arnold, D. G. Long, G. F. Miner, "Initial Results of a Low-Cost SAR: YINSAR", *Proceedings of IGARSS '00*, pp. 3045 - 3047

Airborne SAR sensors in planning/under construction

ARTINO

ARTINO stands for *Airborne Radar for Three-dimensional Imaging and Nadir Observation*. It is a radically new concept developed by FGAN that will allow to map in all three dimensions. The idea is to use beamforming in addition to the conventional technique of range/azimuth mapping so that the third dimension can be captured. To this end a sparse array of antennas is mounted underneath the wings of the carrier platform. With this configuration, range is sensed in nadir direction, azimuth (as usual) in flight direction, and beamforming is used to resolve in cross-track direction. The system is designed as small and low-cost in order to be deployed on small UAVs (4 m wing span, 25 kg total weight). The radar will operate in K_a-band in FMCW mode. Since only short ranges have to be captured only a few Watts of transmitting power are necessary. At the moment, the system is under construction. First tests are expected to take place this year.

Reference: Klare, J., "A New Airborne Radar for 3D Imaging - Simulation Study of ARTINO", *Proceedings of EUSAR 2006*

DMSAR

DMSAR (*Disaster Management SAR*) is ISRO's planned new airborne sensor for disaster management purposes. Together with RISAT it will establish a combined airborne/spaceborne monitoring system. As its predecessor ASAR it carries a C-band image-only radar with single polarization. The maximum resolution is reported to be 1 m.

Reference: *http://www.aprsaf.org/data/vietnam_ws/vws_16.pdf*

F-SAR

F-SAR is DLR's successor of the experimental E-SAR system. Development of this system was initiated by the user's need for simultaneously acquired multi-frequency and multi-polarized data in a higher resolution than E-SAR was able to provide. F-SAR will encompass the five frequency bands P, L, S, C, and X. Second antennas for interferometric operation will be mounted for S- and X-band. The maximum ground range resolution in X-band will be 0.3 m (according to 800 MHz range bandwidth). The system release is planned for 2007.

Reference: *http://www.dlr.de/hr/institut/abteilungen/sar_technologie/f_sar/*

SOSTAR-X

SOSTAR-X stands for *Stand-Off Surveillance and Target Acquisition Radar*. It is a demonstrator system for the future SOSTAR programme that was founded by the five European countries Germany, France, Italy, Spain, and The Netherlands in response to NATO's requirement of an Airborne Ground Surveillance (*AGS*) system. The main system capabilities include simultaneous high-resolution SAR and GMTI mode, Stripmap and Spotlight acquisition, and real-time onboard processing. The SOSTAR-X demonstrator has been installed in a Fokker 100 aircraft, yet the final system is designed to fly on a variety of aircraft (UAV, business jets, commercial airliners) and especially at high altitudes above 50,000 ft. There is no single-pass interferometric mode envisioned. Final system availability is scheduled for the end of this decade.

Reference: Hoogeboom, P., E. Herpfer, P. Fournet, G. Canafoglia, A. de Carvajal, C. Hofkamp, "SOSTAR, A European system for airborne ground surveillance", *Proceedings of the International Symposium on Information Superiority*, Paris, France, 2001

UAVSAR

UAVSAR is NASA's future radar science and technology testbed. It will consist of a single-antenna fully polarimetric L-band sensor with 80 MHz bandwidth. The main purpose is to study surface deformation using repeat-pass (polarimetric) interferometry. Future upgrade plans include single-pass interferometry and multi-frequency operation. Envisioned to eventually fly on UAVs, the initial tests are conducted on a Gulfstream III aircraft. First flights are planned for Spring of 2007.

Reference: *http://esto.nasa.gov/obs_technologies_uavsar.html*

Table 2: Overview over airborne SAR sensors. Sensors highlighted in red are planned or under construction.

Airborne Sensor	*Organization*	*Carrier*	*typical Flight Altitude*	*Frequency Band*	*Interferometric Baseline*	*Polarization*	*Range Bandwidth*	*max. Spatial Resolution (single-pol)*	*Swath Width (for max. Resolution)*
AIRSAR	NASA/JPL	DC-8	26,000 ft	C	2 m	quad-pol	40 MHz	5 m	10 km
				L	2 m	quad-pol	80 MHz	2.5 m	6 km
				P	-	quad-pol	40 MHz	5 m	10 km
ASAR	ISRO	Superking B-200	26,000 ft	C	-	HH or VV	n/a	6 m	25 km
BioSAR 30	ZAI	Twin Otter	1,000 ft	VHF	-	linear	40 MHz	30 m x 300 m	0.3 km
CARABAS-II	FOI	Rockwell Sabreliner 40A	16,000 ft	VHF	-	HH	70 MHz	2.5	5 km
CASSAR	IECAS	Cessna Citation II	28,000 ft	L	-	quad-pol	60 MHz	n/a	n/a
				X	-	quad-pol	n/a	n/a	n/a
DO-SAR	EADS	DO228	13,000 ft	S	-	quad-pol	400 MHz	0.5 m	9 km
				C	1 m	quad-pol	400 MHz	0.5 m	9 km
				X	n/a	quad-pol	600 MHz	< 0.5 m	9 km
				K_a	-	VV	400 MHz	0.5 m	9 km

Airborne Sensor	*Organization*	*Carrier*	*typical Flight Altitude*	*Frequency Band*	*Interferometric Baseline*	*Polarization*	*Range Bandwidth*	*max. Spatial Resolution (single-pol)*	*Swath Width (for max. Resolution)*
E-SAR	DLR	DO228	15,000 ft	P	-	quad-pol	100 MHz	2 m	n/a
				L	-	quad-pol	100 MHz	2 m	n/a
				C	-	quad-pol	100 MHz	2 m	n/a
				X	1.62	quad-pol	100 MHz	2 m	n/a
EMISAR	DCRS	Gulfstream G3	41,000 ft	C	1.14 m	quad-pol	100 MHz	2 m	12 km
				L	-	quad-pol	100 MHz	2 m	12 km
GeoSAR	EarthData	Gulfstream II	39,000 ft	P	20 m	dual-pol	160 MHz	1 m	2 x 12 km
				X	2.6 m	VV	160 MHz	1 m	2 x 12 km
IMARC	VEGA-M	Tupolew Tu-134A	16,000 ft	VHF	-	quad-pol	n/a	8 m	24 km
				P	-	quad-pol	n/a	6 m	24 km
				L	-	quad-pol	n/a	4 m	24 km
				X	-	quad-pol	n/a	1.5 m	24 km
Ingara	DSTO	Beach 1900 C	n/a	X	-	quad-pol	600 MHz	0.3 m	n/a
KOMSAR	Agency for Defense Development	KT-1	n/a	X	-	n/a	n/a	1.5 m	5 km
LORA	FOI	Rockwell Sabreliner 40A	16,000 ft	VHF/UHF	-	HH	600 MHz	< 1 m	n/a

Airborne Sensor	*Organization*	*Carrier*	*typical Flight Altitude*	*Frequency Band*	*Interferometric Baseline*	*Polarization*	*Range Bandwidth*	*max. Spatial Resolution (single-pol)*	*Swath Width (for max. Resolution)*
Lynx	General Atomics	UAV	25,000 ft	K_u	-	n/a	n/a	0.3 m	1 km
MEMPHIS	FGAN	Transall C-160	n/a	K_a	-	linear, circular	800 MHz	0.2 m	n/a
				W	-	linear, circular	800 MHz	0.2 m	n/a
µSAR	BYU	UAV	1,000 ft	C	-	linear	80 MHz	1.8 m	1 km
MiniSAR	Sandia National Laboratories	UAV	n/a	K_u	-	n/a	n/a	0.1 m (Spotlight only)	n/a
MiSAR	EADS	UAV	6,000 ft	K_a	-	n/a	n/a	0.5 m	1 km
NEC-SAR	NEC Corporation	Cessna 208	10,000 ft	X	-	n/a	n/a	5 m	n/a
OrbiSAR	OrbiSat	Gulfstream Aerocommander	23,000 ft	P	-	quad-pol	45 MHz	5 m	14 km
				X	n/a	HH	400 MHz	0.5 m	14 km
PAMIR	FGAN	Transall C-160	n/a	X	n/a	HH	1820 MHz	0.1 m	n/a
PHARUS	TNO	Cessna Citation II	18,000 ft	C	-	quad-pol	45 MHz	3 m	11.2 km
Pi-SAR	JAXA	Gulfstream II	40,000 ft	X	2.3 m	single-pol	100 MHz	1.5 m	20.6 km
				L	-	quad-pol	50 MHz	3 m	42.9 km
RAMSES	ONERA	Transall C-160	12,000 ft	P	-	quad-pol	75 MHz	0.2 m	30 km
				L	-	quad-pol	200 MHz	0.75 m	n/a

Airborne Sensor	*Organization*	*Carrier*	*typical Flight Altitude*	*Frequency Band*	*Interferometric Baseline*	*Polarization*	*Range Bandwidth*	*max. Spatial Resolution (single-pol)*	*Swath Width (for max. Resolution)*
				S	-	quad-pol	300 MHz	0.5 m	n/a
				C	-	quad-pol	300 MHz	0.5 m	n/a
				X	n/a	quad-pol	1200 MHz	0.13 m	n/a
				K_u	n/a	quad-pol	1200 MHz	0.13 m	n/a
				K_a	-	VV	1200 MHz	0.13 m	n/a
				W	-	LR, LL	500 MHz	0.3 m	n/a
SAR-580	Environment Canada	Convair CV-580	23,000 ft	C	n/a	quad-pol	47 MHz	6 m	n/a
				X	-	quad-pol	47 MHz	6 m	n/a
SASAR	CSIR	Dakota DC3	13,000 ft	VHF	-	quad-pol	12 MHz	12 m	24 km
Star-3	Intermap Technologies	Learjet	30,000 ft	X	0.9 m	HH	135 MHz	1.5	10 km
Star-4	Intermap Technologies	King Air	28,000 ft	X	1 m	HH	270 MHz	0.75	10 km
Star-5	Intermap Technologies	King Air	28,000 ft	X	1 m	HH	270 MHz	0.75	10 km
Star-6	Intermap Technologies	Learjet	30,000 ft	X	0.9 m	HH	270 MHz	0.75	10 km
TopoSAR	Intermap Technologies	Gulfstream Aerocommander	24,000 ft	X	1.2	HH	135 MHz	1.5	10 km
				P	-	quad-pol	70 MHz	3	10 km

Airborne Sensor	*Organization*	*Carrier*	*typical Flight Altitude*	*Frequency Band*	*Interferometric Baseline*	*Polarization*	*Range Bandwidth*	*max. Spatial Resolution (single-pol)*	*Swath Width (for max. Resolution)*
Twin-Otter SAR	Sandia National Laboratories	DHC-6 Twin-Otter	n/a	VHF/UHF	-	quad-pol	n/a	2 m	n/a
				X	-	dual-pol	n/a	0.3 m	n/a
				K_u	n/a	dual-pol	n/a	0.3 m	n/a
				K_a	-	VV	n/a	0.3 m	n/a
YINSAR	BYU	Cessna Skymaster	1,000 ft	X	1 m	single	200 MHz	1 m	n/a
ARTINO	FGAN	UAV	700 ft	K_a	-	single	750 MHz	0.2 m	230 m
DMSAR	ISRO	n/a	n/a	C	-	HH or VV	n/a	1 m	5 km
F-SAR	DLR	DO 228	20,000 ft	P	-	quad-pol	100 MHz	2.25 m	12.5 km
				L	-	quad-pol	150 MHz	1.5 m	12.5 km
				S	tbd.	quad-pol	300 MHz	0.75 m	12.5 km
				C	-	quad-pol	400 MHz	0.6 m	12.5 km
				X	tbd.	quad-pol	800 MHz	0.3 m	12.5 km
SOSTAR-X	SOSTAR GmbH	business jet	50,000 ft	X	tbd.	tbd.	tbd.	tbd.	tbd.
UAVSAR	NASA/JPL	UAV	tbd.	L	-	quad-pol	80 MHz	tbd.	tbd.