Anais XIV Simpósio Brasileiro de Sensoriamento Remoto, Natal, Brasil, 25-30 abril 2009, INPE, p. 7611-7618.

Thales Alenia Space imaging SAR satellite solutions

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Abstract. The use of microwave data acquired from space through radar instruments is constantly increasing. The market for Earth radar images is getting strength from both commercial and military fields. Remarkable contributions spread out to different applications ranging from environmental protection, Graphical Information System (GIS), exploration of resources, disaster management, security and defence. In addition to traditional customers, since a few years, new emerging users belonging to private or national institutions, sometimes aimed at specific applications over a regional extension, are asking for "simple" SAR systems design in the view of getting an optimal compromise between quality (i.e. geometrical and radiometric resolution, sensitivity, ambiguity, etc….) and costs. This implies for "simple acquisition techniques" and "time limited operativity" over the orbit i.e. simple modes of operation and operativity. Trade-offs have been running about basic acquisition techniques, operativity, lifetime, performance, technology and involve the complete system in a systemic and systematic approach which could induce a positive feedbacks from both platform services (it asks for a proper configuration, mass allocation, power supplying, commanding, control, pointing, manoeuvring, thermal exchange, rf compatibility) and launcher passing for the mission aspects. In order to address the variety of needs coming from the customers Thales Alenia Space has developed SAR imaging satellite solutions based on the product line described in this paper.

Keywords. Earth Observation, SAR satellite, high performance, active antenna, reflector antenna.

1 Background

The use of microwave data acquired from space through radar instruments is increasing day-by-day. The radar is a powerful remote sensing instrument as can operate independent of solar illumination to produce images at night and under cloudy conditions. By using special signal-processing techniques (Synthetic Aperture Radar, SAR) it is possible to generate high-resolution radar images able to discriminate, outline the contour and also infer on the composition of objects. Remarkable contributions spread out to different applications ranging from environmental protection, thematic cartography, exploration of resources, disaster management, security to defence. In such view areas of applications grow day-by-day and new category users face the remote sensing space business. Few points are, clearly, in mind of this new category of users: high resolution images, possibly over wide swathwidths, over regional areas, highest achievable revisit time, large number of images per day, low time-to-market.International export scenario and the industrial role at international level as well, is more and more influenced by the results of: COSMO-SkyMed, SAR Lupe, Terrasar, Radarsat-2 and TecSAR.

Current Earth Observation (EO) export market scenario is going to be redefined by the possibility to directly compare HR/VHR optical systems (already in operation) and radar systems (for the first time on the market).

Emerging users belong both to private or national institutions whose objectives are related to specific applications/target over regional extensions. This implies for "simple acquisition techniques" and "time limited operativity" over the orbit i.e. simple modes of operation and operativity constrained from satellite fly-by over a limited number of selected regions.

It is expected from “emerging” Countries the need to keep low the Program economic budget, with a demand for 1-meter resolution EO systems but reduced operative capabilities.
It is duty of space industries to provide an adequate response to this increasing need in terms of products able to synthesize performance, reliability, low development time and low costs. Therefore the emerging need for the industries of the sector is to fill the gap between a class of instrument originally designed to demonstrate proof of concepts or scientific purposes and a new class of instruments aimed to meet market needs (e.g. low costs, low development time, easy embarkability on satellites, easy in operations, fast response time, distributed access and or downloading, etc..)
Since a few year Thales Alenia Space through its Observation Systems and Radar Business Unit have been working on such field to enrich its radar product catalogue by satisfying Customer needs. The feedback received from the market has been positive and took the form of the appreciation for Thales Alenia Space products. In particular to the date Thales Alenia Space have awarded the international competition for the KOMPSAT-5 Synthetic Aperture Radar sponsored from Korean Research Institute of Aerospace (KARI). They are in the short list of some other international competitions for SAR systems.
Objective of this paper is to present the overall Thales Alenia Space SAR Imaging Satellite solutions, both the consolidated products as well as the new class of space imaging radar products able to address emerging customer needs, presenting the main traded-off in defining a radar easy to be developed and launched while preserving the radar image performance. Different are questions to be analysed and answered.

2 Imaging SAR main trade off

2.1 Choice of Radar Frequency

The first selection to be exercised concerns the radar frequency. It depends, basically, on the application. In the following table they are synthesized: user typology, frequency band and main applications.

Science	Civil	Military	Frequency	Application
(cyan)	(yellow)	(green)	P-band	• Biomass • Ground penetration
(cyan)	(yellow)		L-band	• Foliage / ground penetration; • Geology mapping; • Large features; Agricultural land use;
(cyan)	(yellow)		C-band	• Geology mapping; • Agricultural land use; • large features; • Ships and small vessels in coastal waters and open seas; • Vehicles in open or vegetated terrain use;
	(yellow)	(green)	X-band	• Man-made target detection/recognition; • small features; • Vehicles in open or vegetated terrain; • Ships and small vessels in coastal waters and open seas

Science	Civil	Military	Frequency	Application
			ku-band	• Man-made target detection/recognition; • Small features;
			ka-band	• Next future

Table 1 – Radar frequency band main applications

In general terms it can be stated that low frequencies:

- ✓ Need larger antennas and feeds
- ✓ Ask for simpler electronics
- ✓ Have greater mass
- ✓ Need more difficult processing

while high frequencies:

- ✓ Need more power
- ✓ Require more challenges in electronics
- ✓ Demand for component availability

2.2 Operations

It is the answer to questions: How many data takes per orbit? How many minutes of imaging per orbit? Which is the operating orbit? Reference values range from 1 minute up to 10 minutes or more. This choice impacts on several aspect of design:

- ✓ Energy to supply the power to the radar transmission; related to this is the battery capacity to dump the peak absorption and finally the dimension of the solar panels;
- ✓ Thermal design to device an effective heat flux exchange; related to this thermal capacitance is the mechanical design at instrument and spacecraft level;
- ✓ Data Storage to store acquired data and its capability to downlink as well as the number of contact points on ground.

Apart from the specific complexities and technological constraints final effects are measured in Mass and Dimensions of the spacecraft and the selection of the proper Launcher.

2.3 Access Area & Image Agility

It is the answer to questions: How fast is the instrument to access imaging area? From few seconds up to tens of minutes and How much time from one image to other? From a few seconds up to a few minutes

Answers impact on selection of proper technologies (see Figure 1):

- ➢ Electronical Steering to achieve Mid / High level of access and coverage which asks for Electronical beam steering
- ➢ Mechanical Steering to achieve Low level of access and coverage which asks for Platform steering

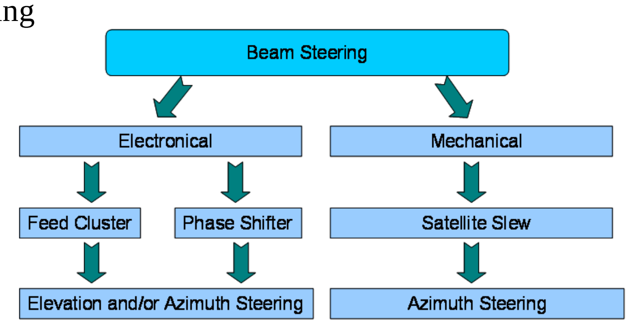


Figure 1 – Beam steering possibilities

2.4 Acquisition Techniques

It is the answer to question: Which imaging acquisition technique? Which is the balance between resolution and swathwidth? This choice impacts on several aspect of design:

- ✓ Stripmap where a Single beam is required;
- ✓ Scansar where Multiple non contemporary Beams are required;
- ✓ Spotlight where a single beam is mechanically steered or Multiple beams are electronically steered

Apart from the specific complexities and technological constraints final effects are measured in Mass, Dimensions, Power absorption of the spacecraft and the relevant selection of the proper Launcher.

2.5 Performance

It is the answer to question: Which performance? in terms of Resolution, Swathwidth, Access Area, Image Quality. This choice impacts on several aspect of design:

- ✓ Resolution for the Observation time of the scene and the related Acquisition technique;
- ✓ Swathwidth for Beamwidth and related antenna features;
- ✓ Image Quality basically for the sensitivity, radiometry and Ambiguity which constraint tx power, noise and Antenna

3 SAR Instrument configurations

A basic trade-off in the SAR design is dictated from sensitivity and acquisition geometry. A reference relationship is given from the following:

$$P_{ave} \cdot G^2 [WdB \cdot dB]$$

in which P_{ave} is the transmitted average power and G in the antenna gain (assuming Tx=Rx gain for sake of simplicity); see Figure 2 in which for a required level of sensitivity plots of relationship are reported. Two paths can be pursued; both lead to face technological constraints.

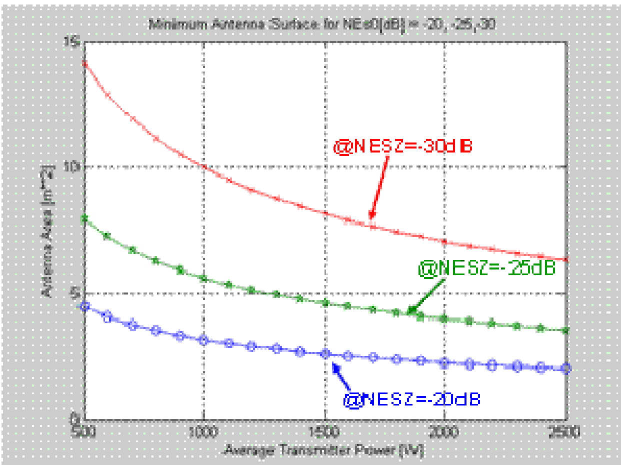


Figure 2 – Antenna area versus average transmitted power for a given NEs0

From one side the increase of RF power level (P_{ave}) request could lead to an unavailability of single RF device (see Figure 3) and power combining techniques need to be faced. In both cases, mostly, power devices need to subjected to space qualification.

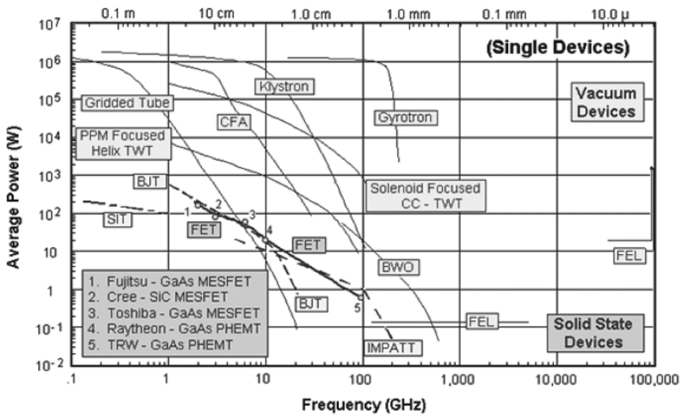


Figure 3 – Available average power versus frequency for single device and for on-ground applications [1]

On the other side the antenna area needs to be increased. Antenna dimensions are determined from acquisition geometry mainly to reduce radar ambiguities and allow the acquisition of desired swath width. In addition other trade-off area to be faced for the implementation of required functionalities is about the way the RF power and echo amplification are treated.

In the case where a radio-frequency power amplifier and a low-noise amplifier are directly connected to the radiating element or a group of radiating elements (sub-array) the relevant configuration is named “active” antenna configuration. Generally the RF power amplifier and low-noise power amplifier are grouped in a module called T/R (Transmit/Receive) often developed in MMIC technology. Each T/R module provides RF amplification Tx and Rx paths independently; such as are independent the phase control and polarization switching capabilities. In the case where a single or a limited number of RF power amplifiers and low-noise amplifiers are connected to a device (feed array) to provide optimum illuminator to a magnifying optical system (reflector) in order to generate the focused beam. This type of configuration is referred to as “reflector” based radar.

While in the “active” antenna the beam steering is electronically controlled, in the “reflector” antenna the beam steering can be electronical, mechanical or mixed.

In principle the following approaches can e followed for mechanical steering:

- ✓ Movement of the platform considering the antenna as rigid body on it;
- ✓ Movement of the main or secondary radiator (e.g. reflector) of the antenna.

In the case of electronical steering, it can be pursued through:

- ✓ Phase shifter
- ✓ Voltage Power divider.

4 Architectural solutions

Starting from the simple observation that it cannot exist a unique approach able to satisfy requirements rising from new user categories, Thales Alenia Space have envisaged two classes of products: one based on “active“ antenna and the other based on “reflector” antenna.

In fact for the Microwave Imaging Radar, they have:

1) “Active” antenna configuration based on AESA (Active Electronically Steerable Antenna) concept allowing both elevation and azimuth beam steering.

2) “Reflector” antenna configuration using ESA (Electronically Steerable Antenna) for elevation beam steering and MSA (Mechanically Steerable Antenna) for azimuth beam steering.

The SAR architecture consists of sub-systems and equipments that implement the radar functions needed to carry out the instrument tasks. All the radar functions are distributed between two major assemblies: the SAR Sensor Electronics (SSE) and the SAR Antenna Assembly (SAA).

4.1 Microwave Imaging Radar based on "Active" antenna

It is based on a tile architecture. Each tile is a self standing phased array able to provide RF power amplification, beam steering along both azimuth-elevation plane and polarization selection. The Tile is considered the fundamental brick to realize SAR antenna apertures of different size, mass and power: changing the number of tiles it is possible to realize antennas having a number of T/R modules ranging from few hundreds active elements up to more than a thousand of modules.
Tile different antenna architectures can be arranged allowing the definition of a product line capable to meet Customer requirements at a minimum tailoring effort. The following Antenna Architectures have been configured according to rows and columns:

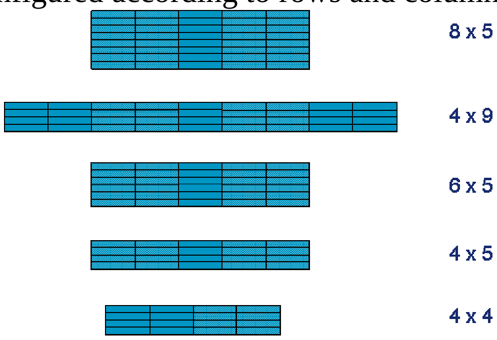


Figure 4 – "Active" antenna SAR product family

The beam management policy allows to minimise the on-board computational resources required by the antenna and makes the antenna a programmable device. Thanks to the amplitude and phase control of transmit/receive modules, beams shaping can be synthesized according acquisition scenarios. Thales Alenia Space Italy has recently developed and flown an large X band active phased array antenna for the Cosmo/Sky-Med Mission. A pictorial via of satellite configuration with "active" antenna is reported in Figure 5.

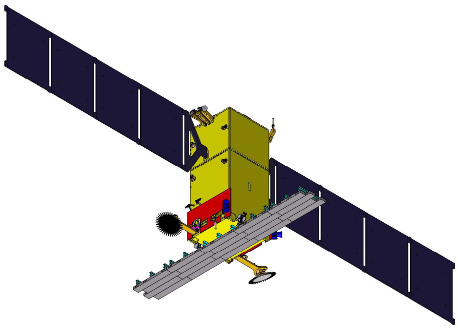


Figure 5 – Example of "Active" antenna SAR satellite configuration for inclined orbit

4.2 Microwave Imaging Radar based on "Reflector" Antenna

SAR Instrument based on array-fed "reflector" antenna is a valid alternative to active phased array, if a focused set of operative functionalities are requested (e.g. reduced steering range and limited beamwidth flexibility). A suitable reflector antenna configuration based on single pol (V-Pol) and elevation electronic scan functionality, is here considered, allowing the azimuth steering to the platform manouver. This configuration is the result a good compromise between SAR performance, flexibility and complexity. The SAR reflector concept is based on a single offset reflector illuminated by a feed cluster, whose number of elements and dimension is dependent from the reflector optics geometry (focal length along both planes), the scan angle and the steering granularity. Two different approaches are applicable to elevation scan functionality:

- Discrete scan
- Continuous scan

In the first case the feed system is greatly simplified since each realisable beam has its dedicated feed. It can be a single large horn or a horn segmented in a certain number of sub-apertures . Each feed or feed cluster is properly oriented to provide the correct beam pointing and reflector illumination.

The main advantage of this configuration is its simplicity and the possibility to use a fully passive network; as drawback once the beams are optimised the beam-forming network (BFN) doesn't offer any degree of freedom. Since these horns are stacked in the focal plane along two or three layers, to avoid physical interference, a shift of the beams along the azimuth plane has to be accepted, as illustrated in Figure 6-left.

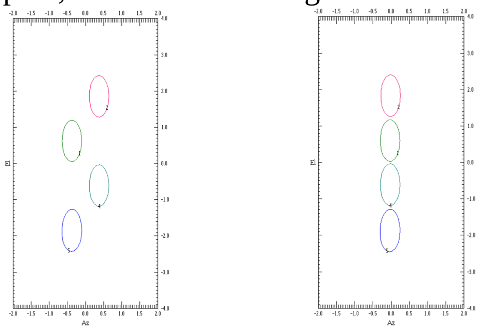


Figure 6 – Typical achievable beam footprint by stacked feed cluster configuration (left) and by long linear array of shared apertures (right)

In case of continuous scanning in elevation, a linear array of shared feed elements can be envisaged. The achievable beams cover the whole accessible range allowing no mis-alignment in azimuth (Figure 6 right), but at the expense of added complexity in the feed cluster BFN. Defining the BFN architecture is a trade-off between number of HPA, maximum peak power per HPA, and number of medium/high power components to be taken into account. Considering the case where power is maximally distributed among the HPA (i.e. lower peak power per HPA and low power Phase shifter) a multiport type beamforming where the number of feeds elements equals the number of amplifiers can be envisaged.

An alternative amplification approach based on a single or a reduced number of amplifiers can also be managed: in this case the use of medium power ferrite phase shifters is requested.

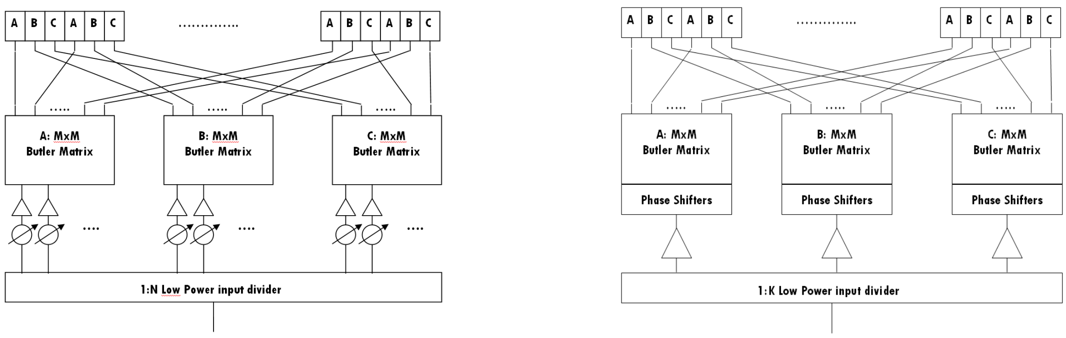


Figure 7 – BFN architecture for maximally low peak power amplifier (left) and for medium/high power amplifier (right) .

A possible allocation of antenna on the spacecraft is reported in Figure 8, where in order to avoid deployment mechanisms, the BFN and feed cluster are fixed on the S/C.

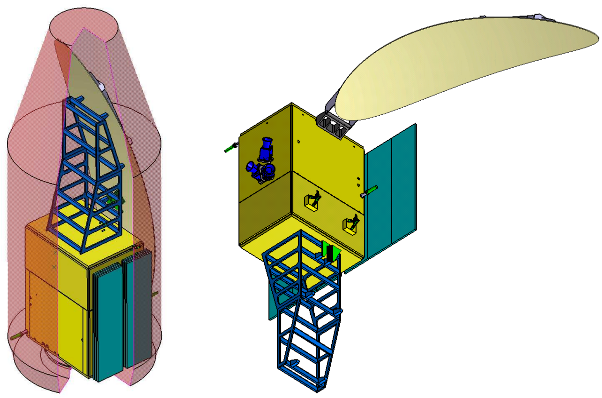
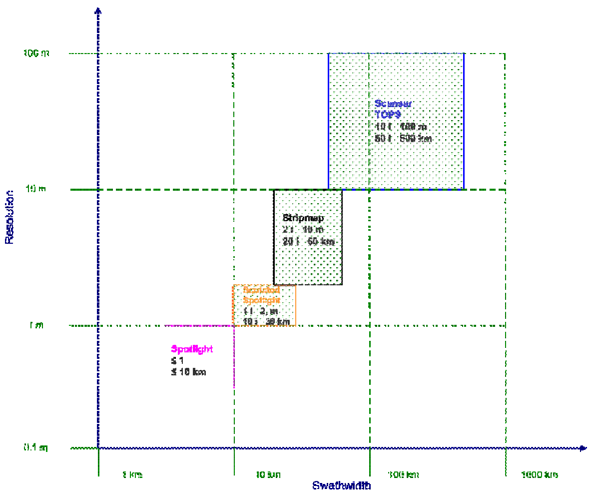


Figure 8 – Stowed and deployed "reflector" antenna configuration

5 Performances

In the following Figure 9 are respectively reported the performances of the two classes: "active" and "reflector" antenna SAR configuration.



TOPIC	INFORMATION TYPE				REFLECTOR antenna
SAR PERFORMANCE	Incidence angle				24°÷50°
	STRIPMAP		Swath width	R	up to 35 km
				A	? 25 km
			Resolution	R	3 m
				A	3 m
	SPOTLIGHT	Enhanced Spotlight	Swath width	R	5 km
				A	5 km
			Resolution	R	1 m (1)
				A	1 m
		Advanced Spotlight	Swath width	R	35 km
				A	40 km
			Resolution	R	1.6 m (2)
				A	1 m
	SCANSAR		Swath width	R	up to110
				A	up to110
			Resolution	R	15 m
				A	15 m

Figure 9 – Reference Performance for "active" class antenna(left) and for "reflector" class antenna - (1) constrained from ITU regulations, (2) depending on incidence angle, R = range, A= azimuth

From Figure 9 it can be noted that the "active" SAR is able to satisfy different requirements in the various family configuration, while it can be noticed that also with the architecture based on "reflector" antenna very good performance can be reached.

6 CONCLUSIONS

In this paper it has been presented the Thales Alenia Space SAR imaging solutions capable to address the requests of all possible customers and users, in particular new user of microwave imaging data giving rise to an easy embarkability of radar on platform preserving radar imaging quality. Stress has been put on the "reflector" antenna solution to demonstrate that good performance can be reached.

7 REFERENCES

[1] Robert J. Trew, High Frequency Solid State Electronic Devices, IEEE Transactions on Electronics Devices, Vol. 52 No. 5, May 2005