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MAPSAR: A NEW L-BAND SPACEBORNE SAR MISSION FOR ASSESSMENT AND MONITORING OF TERRESTRIAL NATURAL RESOURCES

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Abstract. This paper introduces MAPSAR (Multi-Application Purpose SAR): a new SAR (Synthetic Aperture Radar) mission for Earth Observation. MAPSAR is the result of a joint pre-phase A study made by INPE and DLR targeting a mission with a small spaceborne SAR for day and night Earth surface observation independent of weather conditions for assessment, management and monitoring natural (renewable and non-renewable) resources. In the study, the applicability of the sensor system to the following themes was investigated: Cartography, Forestry, Geology, Geomorphology, Hydrology, Agriculture, Disaster Management, Oceanography and Urban Studies. To accomplish the overall requirements, an L-band SAR has been chosen as the only payload of a small satellite. The satellite, based on the INPE´s Multi Mission Platform, (MMP) is presented as well. The modular system consists of the satellite bus (platform) and a payload module for the SAR sensor accommodation. A dawn/dusk sun-synchronous orbit with a repeating cycle of 37 days at 620 km has been chosen for this study, but further orbit optimization based on mission simulations shall be performed in the phase A. The SAR sensor will be innovative with respect to overall mass, size and performance. The key component of the SAR instrument is the SAR antenna, which is designed as an elliptical parabolic reflector antenna with dimension of circa 7,5 m (azimuth) x 5 m (range). L-band (high spatial resolution, quad-pol) has been selected for the SAR sensor as optimum frequency accounting for the majority of Brazilian and German users requirements. The MAPSAR mission is tailored to optimally support the potential user groups in both countries taking into account the present status of current and planned SAR spaceborne programs, which should be complemented by the special mission characteristics of MAPSAR. At the moment, the pre-phase A has been concluded and the phase A is planned to start on 2003. The satellite launch is proposed for the year 2008.

Keywords: MAPSAR, Spaceborne L-band SAR, INPE/DLR joint mission, pre-phase-A study.

1. Introduction

Imaging radars are one the most recent alternatives to a variety of remote sensing devices available for assessment the Earth resources and for monitoring the environment. Distinct from the optical sensors that use the reflected sunlight to provide information about the chemical composition and physical structure of a target, imaging radar provides information about target geometrical and electrical properties by detecting the backscattered field of active microwave energy. Thus, the information content of radar imagery differs from the information content of optical imagery. The ability of a SAR to provide high-resolution imagery independent of weather or sun light is particularly important for regions of the planet that present restrictions to the use of optical sensors due to the presence of rain, perennial clouds, haze and smoke (e.g., the Amazon region) or where solar illumination is insufficient (polar regions). Imaging radars also have the ability to penetrate a vegetation canopy.

In general, the acquisition of information on the moist tropics, particularly on rain forests is complicated by the continental extension, poor accessibility, and complex nature of the environment. Brazil has a vast territory with a tremendous need for resource management information such as can be provided by orbital imaging radars. Many obstacles have been faced for the integration of the Amazon region to the rest of the country. This integration is necessary nowadays more than ever in view of the Brazilian population's increasing and of the immense natural (renewable and non-renewable) resources available in the region. SAR systems have the capability to image this kind of "difficult environment" in a systematic and repetitive manner in support of natural resource assessment and the monitoring processes that are essential parts of procedures for sustainable environmental management.

In the range of wavelengths used by imaging radar, backscatter intensity from terrain surfaces is strongly controlled by decameter-scale changes in surface slopes, or by centimeter-scale roughness of the surface. Thus, the sensitivity of SAR to the macro-topography (slopes, tilts, broad undulations in the terrain), the surface roughness (roughness on the scale of the SAR wavelength) and to the presence of moisture or liquid water content of a medium affecting the complex dielectric constant, makes it an ideal instrument for thematic mapping and resources management purposes in the moist tropics, and when stereoscopic capabilities are available, for topographic mapping. In addition, the large ratio of SAR return from land versus water is primary a function of contrast of dielectric properties and surface roughness, providing a striking interface which also facilitates coastal delineation and related mapping application (flooding, wetland and hydrological studies in the Brazilian Amazon).

On the other hand, forest biomass is today one of the most unknown parameters in dynamic ecosystem change especially with respect to a reliable global Carbon-flux modelling. In many regions of our planet even a mere forest classification is missed. Parallel to the ecological dimension, and under the light of the Kyoto protocol, this problem has also a political dimension that increases the responsibility of the scientific community to provide exact answers. The fact that biomass information is especially missed in remote areas (i.e. tropical and boreal forest ecosystems) combined with the fact that these ecosystems contain the biggest amount of forest biomass make remote sensing techniques a challenge. However, optical remote sensing sensors are in general not capable of measuring forest biomass or monitoring the dynamics of deforestation and biomass regeneration. An alternative methodology is the estimation of forest biomass based on the estimation of forest height from radar remote sensing data. One of the key challenges facing imaging radars is to force evolution from high-resolution qualitative imaging to accurate high-resolution quantitative measurement. One very promising way to extend the observation space is the combination of interferometric and polarimetric observations. SAR interferometry is today an established technique for estimation of the height location of scatterers through the phase difference in images acquired from spatially separated locations at either end of a baseline.

2. Context and User Requirements

The initiative of the joint study of a small spaceborne SAR is a consequence of a long term Brazilian-German scientific-technological cooperation that was initiated between INPE-DLR in the seventies. The decision to perform a pre-phase A study for MAPSAR was established in 2001 following several meetings in both agencies.

The MAPSAR mission is tailored to optimally support the potential user groups in both countries taking into account distinct aspects of specific applications and scientific SAR issues to be addressed. Thus, in April 2002, a working group of Brazilian SAR scientists and technical experts (potential SAR end-users) met on the campus of INPE (São José dos Campos) to perform a review of the use of imaging radar to derive surface characteristics important for tropical applications. The First MAPSAR Potential End-Users Workshop was structured for the purpose of (1) performing an assessment of the current understanding of the applications of SAR in Brazil and (2) developing end-user requirements and recommendations aiming at a joint INPE-DLR small spaceborne SAR program. The Workshop involved 83 participants from 28 Brazilian governmental and private institutions. The list of the participants can be found at the web address www.obt.inpe.br/satelite/mapsar. Activities for the first part of the meeting consisted of sequential plenary sessions, organised by general application topics, with invited presentation by selected participants and a short discussion after each talk. The last part of the Workshop was concentrated on defining an optimal SAR system configuration and specific requirements to provide information necessary for distinct application areas in Brazil, particularly for the Amazon region. The following fields were considered relevant themes for SAR applications in Brazil: (1) Agriculture (crop type, crop condition, crop yield), (2) Cartography (stereoscopy for DEM generation, plannimetric feature extraction, map updating), (3) Disaster Management/Security (floods, natural hazards, tropical storms, oil spills), (4) Forestry (forest type, clearcuts, deforestation, fire-scars, biomass), (5) Geology (terrain mapping, structural analysis, lithological discrimination, mineral exploration), (6) Hydrology (floodplain hydroperiod assessment, wetlands and reservoirs monitoring), (7) Oceans (waves, currents, ships, winds, coastal zones), (8) Urban Analysis and Settlement Detection (land use and land cover mapping, infrastructure planning) and (9) Antarctic region. The user requirements were considered taking into account the (A) SAR parameters (frequency, polarization, polarimetry, look azimuth, incident angle, spatial resolution, radiometric resolution, swath width, stereoscopic capability), (B) orbit configuration (polar, sun-synchronous, inclination, site-revisit capability, control), (C) Mission Characteristics (lifespan, series of SAR satellite, data format, SAR-derived information products, acquisition planning and time-sensitive applications, etc.).

The consensus of the working group was that a spaceborne SAR mission will provide a powerful new tool to acquire data and to derive important unique information of vegetated terrain of the Amazon Region. Due to the enormous scarcity of up-to-date information, with is fundamental for planning and strategic decision-making about environmental assessment, management and monitoring of natural resources in the Brazilian Amazon, the proposed small spaceborne SAR initiative should be strongly oriented to an quasi-operational ("application-oriented") system dedicated to thematic mapping purposes (topographic mapping, vegetation type and deforestation mapping, geological mapping, hydrological mapping, etc.). Furthermore, it was strongly recommended to have a series of satellites aiming at the operational aspects and the program continuity. In addition, the MAPSAR concept should also address aspects of integration with the Brazilian Surveillance the Amazon System (SIVAM/SIPAM), due to the complementary nature of both source (spaceborne/airborne) of multi-polarized and fully polarimetric L-band data. Finally, although recognised in most application fields, the effects of the polarization, polarimetry and interferometry on the image information content are not well understood in many of those fields. Thus, the primary R&D challenge lies in the development of strategies focussing on minimizing the lack of understanding concerning the extraction and application of the information as contained in the data acquired in polarized, polarimetric and interferometric image modes for application fields in the tropical environment. One effective way shall be through the use of application projects to demonstrate to operational "final-end" users the many benefits of SAR data to better inform assessment, management and monitoring activities. As the fully utility of SAR for tropical environment application is now emerging, it is also reasonable to expect that these new technological enhancements will result in improved applications potential. However, this potential will not be fully realized without a well-focused national SAR R&D program under the MAPSAR initiative.

The Brazilian user requirements were further integrated with the German users requirements following discussions carried out at DLR with SAR experts from both countries. The merge of the two requirements resulted in an additional capability based on polarimetric-interferometry for a Global Biomass Mission aiming at the mapping of major forests biomes of the globe (Tropical and Boreal) followed by canopy height estimation as a proxy for forest biomass. The final Brazilian-Germany Users requirements for MAPSAR are presented in Table 1.

Table 1. User Requirements for MAPSAR (normal = Brazil, italic = Germany)

Application /MAPSAR parameters	Agriculture	Cartography	Disaster (Oil slick/ Ship Monitoring)	Forestry	Geology/ Geomorphology	Hydrology	Oceanography	Urban Mapping
Frequency	L *L*	L *C*	C *L*	L*, C *L*	L *L*	L, C *L*	C *L*	L *C*
Polarization/ Polarimetry	quad. pol *quad. pol*	N. E. *N. E.*	VV, HH *quad. pol*	quad-pol. *quad. pol*	HH, HV *quad. pol*	quad. pol. *quad. pol*	quad-pol *quad. pol*	quad-pol *quad. pol*
Incidence Interval	variable *25°-45°*	variable(45 ° *) *(45 ° *)*	20°-30°/ 45°-60° *variable*	20°-45° *20°-45°*	large interval *large interval*	20°-45° *20°-45°*	High (45-60°) *(45-60°)*	40°-45° *variable*
Spatial Resolution	30 meters *3-5 meters*	5 meters *3-5 meters*	30-50/15 m *3-5 meters*	10 meters *10 meters*	5 – 10 meters *3-5 meters*	10 meters *3-5 meters*	variable(High/ Moderate) *(High/Moderate)*	5 meters *3-5 meters*
Swath	30 km *30 km*	N. A. *variable*	150-350 km *variable*	100 km *variable*	40-100 Km *40-100 Km*	100 km *variable*	350 km(ScanSAR and FineModes) *variable*	40-100 km *40-100 km*
Orbit Inclination	N. A. *sun-syn*	sun-syn *sun-syn*	sun-syn *sun-syn*	sun-syn *sun-syn*	sun-syn *sun-syn*	sun-syn *sun-syn*	sun-syn *sun-syn*	sun-syn *sun-syn*
Look Direction	N. A. *asc/desc*	asc/desc *asc/desc*	asc/desc *asc/desc*	N . A. *asc/desc*	asc/desc *asc/desc*	asc/desc *asc/desc*	N. A. *asc/desc*	asc/desc *asc/desc*
Revisit	15 days *< 15 days*	N. A.. *seasonal*	< 1 day *< 1 day*	monthly *monthly*	seasonal *seasonal*	10 –15days *< 15 days*	daily *daily*	N.A. *yearly*
Access to data	real-time *real-time*	N. A. *regularly*	real-time *real-time*	N. A. *regularly*	N. A. *regularly*	N. A. *regularly*	real-time *real-time*	N. E. *regularly*
Additional Requirement	- *InSAR*	stereoscopy *InSAR (opt.)*	- *InSAR*	- *InSAR*	stereoscopy *InSAR*	- *InSAR(opt.)*	raw data *InSAR*	- *InSAR (opt.)*

[illegible]

Due to several restrictions related to the INPE´s Multi-Mission Platform (Mass, Power generation, Geometric Envelop and Data Rate) the following main limitations were imposed upon the satellite configuration: single band, light weight antenna and maximum swath width of 55 km according to Table 2.

Table 2. MAPSAR final specification taking into account user requirements and MMP constraints

Frequency	**L**
Polarization	**single,dual and quad. pol.**
Incidence Interval	**20°- 45°**
Spatial Resolution	**3-20 meters**
Swath	**20 km - 55 km**
Orbit Inclination	**sun-synchronous**
Coverage	**global**
Look Direction	**ascending/descending and left/right looking**
Revisit	**weekly**
Access to data	**near real time**
Additional Requirement	**Stereoscopy and InSAR**

3. MAPSAR satellite

The MAPSAR satellite utilizes a modular concept (figure 1), consisting of a payload module and the Brazilian MultiMission Platform (MMP).

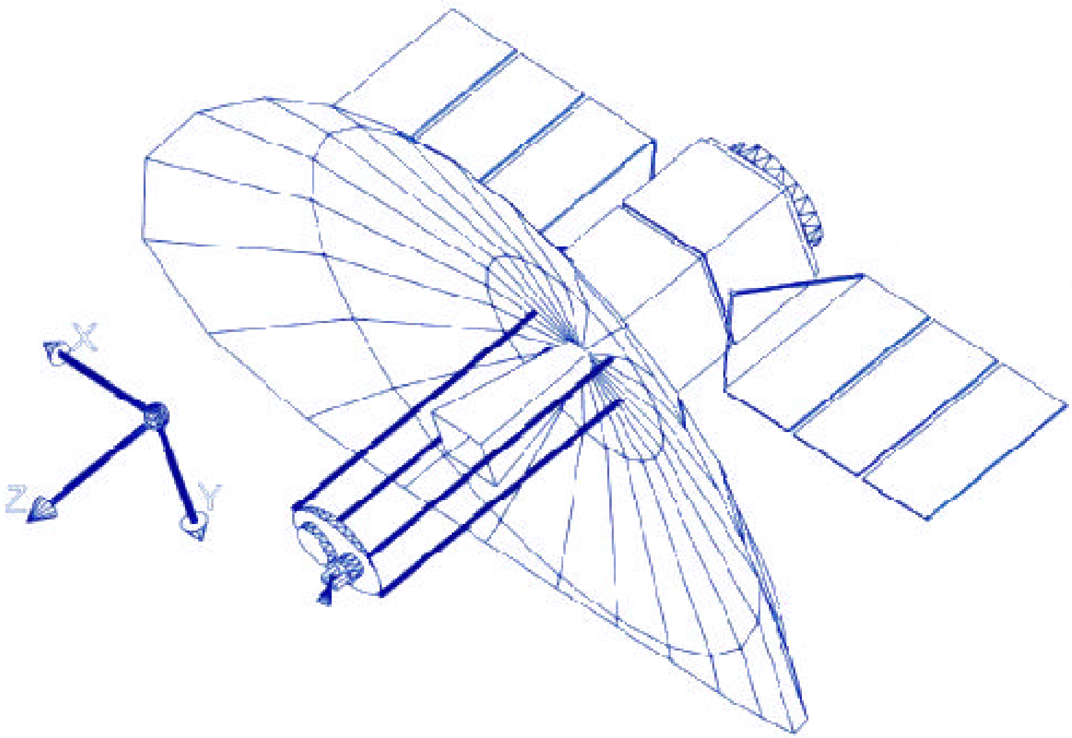

Figure 1. MAPSAR satellite configuration

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The multi-mission platform concept provides for a capability to support a variety of low Earth orbit missions using the same basic three-axis stabilized platform with different payload modules. The MMP block diagram and pictorial view are shown in Figure 2 and Figure 3. The MMP is already being developed by INPE and its first flight model shall be ready by the end of 2005.

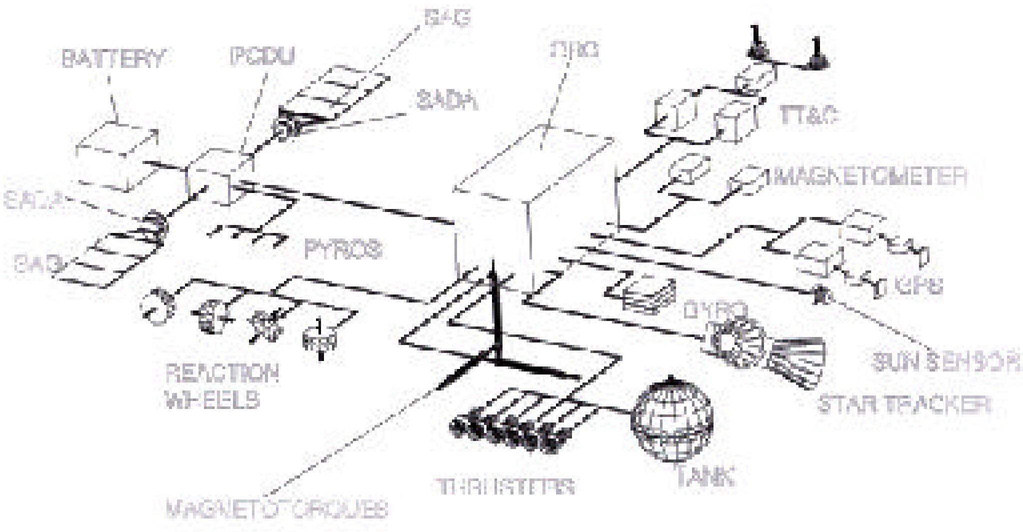

Figure 2. MMP Block Diagram

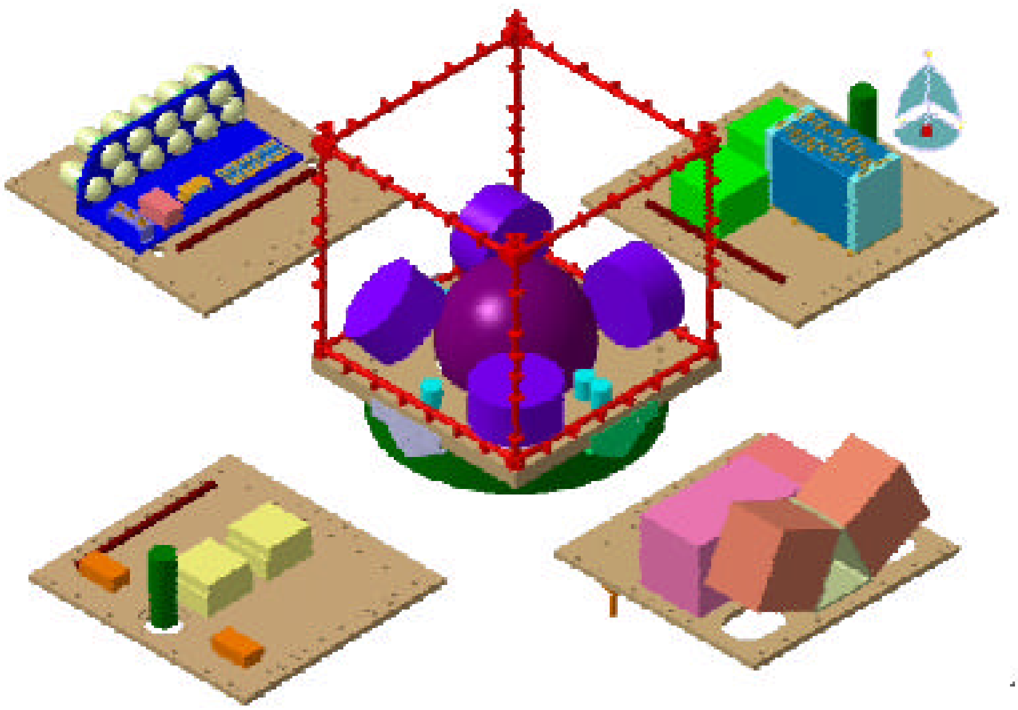

Figure 3. MMP Pictorial View (blow-up)

The MAPSAR payload module includes the SAR sensor, data storage and transmitter, mechanical structure and thermal control. The estimated payload module mass is 270 kg. The payload power consumption is 750 W during operation and 120 W in stand-by. To comply with the user requirements and to provide for sufficient power generation, a dawn/dusk sun-synchronous orbit with repeating cycle of 37 days at 620 km was chosen for this study. Based on mission simulations, this orbit shall be further optimized in the next project phases, taking into the requirements of stereoscopic and interferometric capabilities.

A Cassegrain type antenna with a parabolic reflector was chosen for the SAR, mainly due to limitations imposed by the MMP (Table 3). The size of the reflector is of 7.5 meters in length and 5 meters in elevation. With respect to active phased-array antennas, the reflector type is lighter and allows use of higher bandwidths and multi-polarization with less additional complexity. As a disadvantage, the reflector antenna doesn't allow electronic beam steering and ScanSAR mode. In MAPSAR, the required range of incidence angles and the left/right looking are achieved by rolling the satellite (Figure 4).

Table 3. MMP Capabilities

Payload mass	280 kg
Satellite mass (dry)	520 kg
Volume	Compatible with launchers for medium-sized satellites
Payload Power	175 W (average), 900 W (peak)
Pointing accuracy	0.05 degrees (3σ)
Agility in roll axis	40 degrees in 2 minutes

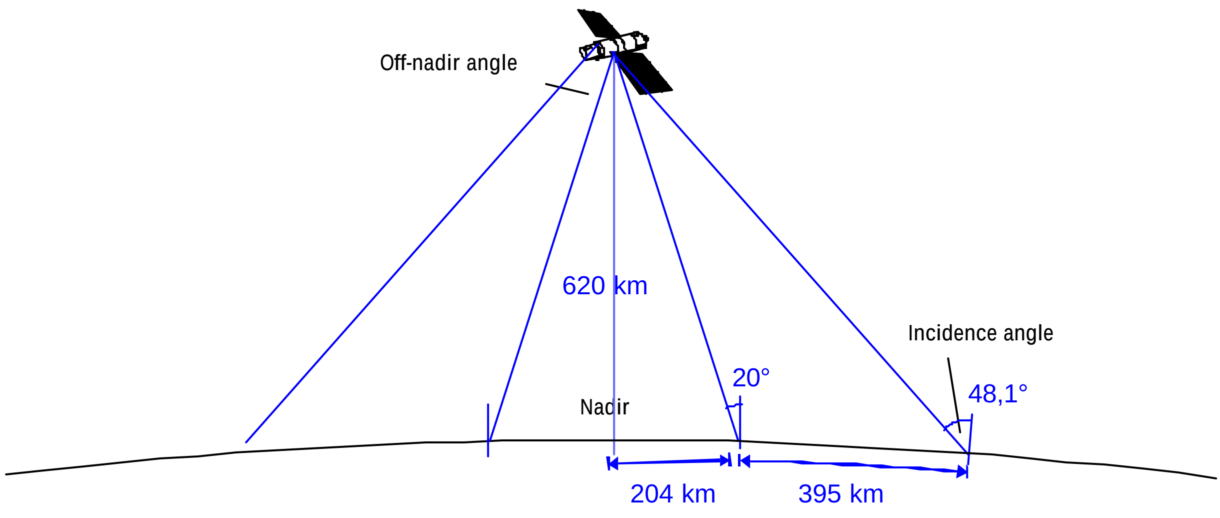

Figure 4. MAPSAR incidence angles and access regions

MAPSAR operates in three resolution modes (3m, 10m, 20m) and three polarization modes (SPM, DPM, QPM). A summary of important modes is shown in Table 4. A RF output power of 1000 W was selected, to be supplied by a Solid State Power Amplifier (SSPA). The swath width for each mode was limited either by the range ambiguity ratio, by the antenna beamwidth or by the maximum data rate of 300 Mbps. The SAR performance varies over the access region. The table summarizes the values at the near and far edge of this region. The maximum of instantaneous swath width in low resolution mode is 55 km and can be achieved in the middle of the access region. The output data is transmitted to the ground in X-band and an onboard solid state data recorder of 200 Gbits is provided to store data which is acquired out of visibility of the ground stations.

Table 4. MAPSAR Operation Modes

Parameter	unit	High Resolution Mode SPM		Medium Resolution Mode QPM		Low Resolution Mode QPM	
Access region							
Resolution Range	m	4.8	3.1	10	10	20	20
Azimuth	m	3.1	3.1	10	10	20	20
Off-nadir angle	º	20.0	41.8	20.0	32.1	20.0	32.1
Incidence angle	º	20.3	46.5	21.0	34.9	20.0	34.8
Swath width	km	38.3	20.5	23.2	22.0	43.4	28.0
Polarization		SPM	SPM	QPM	QPM	QPM	QPM
Pulse Bandwidth	MHz	85.0	85.0	2x42.5	2x42.5	2x21.3	2x21.3
Bit rate	Mbps	262	300	300	300	247	300

The deployment of the reflector antenna and the SSPA are main technological challenges for this project, but nevertheless, after careful analysis, the SAR sensor was considered feasible and its development is estimated in 5 years. The estimated time for the satellite launch is 6 years.

4. Conclusions

A small satellite mission with an L-band SAR was described. The study was prepared by INPE and DLR, taking into account Brazilian and German user requirements. Preliminary feasibility was demonstrated for a reflector antenna concept. High degree of innovation is presented in the design: small SAR satellite, reflector antenna and remarkable sensor performance. The applications will take advantage of high spatial resolution L-band SAR with enhanced capabilities (polarimetry, stereoscopy, interferometry), particularly suitable for the Amazon region and Boreal forest operations. As critical items, the following are identified: antenna deployment mechanism and solid state high power amplifier. MAPSAR launch is envisaged for 2008.

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