Nationaal Lucht- en Ruimtevaartlaboratorium
National Aerospace Laboratory NLR

NLR TP 97359

P-band SAR mission dedicated to global monitoring of forests

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DOCUMENT CONTROL SHEET

	ORIGINATOR'S REF. NLR TP 97359 U		SECURITY CLASS. Unclassified

ORIGINATOR
National Aerospace Laboratory NLR, Amsterdam, The Netherlands

TITLE
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PRESENTED AT
the 48th International Astronautical Congress, October 6-10, 1997, Turin.

AUTHORS	DATE	pp	ref
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DESCRIPTORS

Data acquiaition
Downlinking
Environmental monitoring
Forest management
Frequency assignment
Ground stations
Parabolic antennas
Real time operation
Remote sensing
Synthetic aperture radar
User requirements

ABSTRACT
This paper describes the conceptual design of a synthetic aperture radar (SAR) sensor operating at P-band frequency (435 MHz). It is part of the FAME (Forest Assessment and Monitoring Environment) initiative for the realisation of a global end-to-end service to allow forests to be monitored at national and sub-national level. The system will cover all the global forest areas at least three times a year, providing timely information on deforestation and forest degradation processes at the resolution of 50 - 100 m. SAR processing and productgeneration are fully decentralized activities carried out by low-cost end-user stations. For standardisation and cost reasons the SAR data downlink is compatible to the NOAA HRPT link, with a data throughput capacity of 614kb/s. This limited data rate imposes a hard constraint on the instrument requirements. In order to achieve sufficient radiometric resolution, data buffering as well as data compression and basic SAR processing on-board the satellite are foreseen.

P-BAND SAR MISSION DEDICATED TO GLOBAL MONITORING OF FORESTS

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ABSTRACT

This paper describes the conceptual design of a synthetic aperture radar (SAR) sensor operating at P-band frequency (435 MHz). It is part of the FAME (Forest Assessment and Monitoring Environment) initiative for the realisation of a global operational end-to-end service to allow forests to be monitored at national and sub-national level. The system will cover all the global forest areas at least three times a year, providing timely information on deforestation and forest degradation processes at a resolution of 50 - 100 m. SAR processing and product generation are fully decentralized activities carried out by low-cost end-user stations. For standardisation and cost reasons the SAR data downlink is compatible to the NOAA HRPT link, with a data throughput capacity of 614 kb/s. This limited data rate imposes a hard constraint on the instrument requirements. In order to achieve sufficient radiometric resolution, data buffering as well as data compression and basic SAR processing on-board the satellite are foreseen.

1 INTRODUCTION

There is a growing concern about the world's forests. Deforestation and forest degradation are increasingly leading to environmental problems and loss of natural resources, calling for sustainable forest management.

Such management depends on a continuous flow of information on the state of the forests and the changes that are taking place, to ensure planning and control of management interventions. As the forests cover large areas that are difficult to access, only a combination of remote sensing and geographical information systems (GIS) can supply a suitable tool for acquiring such information.

Despite the existence of a wide range of remote sensing satellites and GISs, no operational systems for supporting forest management of large areas have been established yet. In a number of studies guided by FAO and aiming at revealing the "inhibiting factors" for operational use, numerous constraints have been identified as experienced by forest managers in over 20 countries. These constraints vary from political and financial matters to functional and performance requirements, of which the most significant ones are the following:

For many forest areas of interest the data are not *available*, because sensors are switched off, receiving facilities are lacking or data are not stored. Even if data are available, in many cases they are not *accessible*, meaning that problems of various nature prevent proper distribution of these data to the forest manager. For almost every forest manager involved in monitoring, remote sensing data are often not *affordable*, since monitoring requires repeated procurement of data for the area of interest. But even when the data are available and accessible and the funds are available, the data often arrives too late (months to years) to be able to support the decision making process, thus creating *timeliness* problems. In addition, the limited suitability of existing sensors to show features of interest for forestry applications poses *usability* problems: the existing optical sensors show limitations in discriminating forest from non-forest areas or in detecting forest degradation. However, even in the case where the usability is demonstrated, in the tropical belt persistent cloud cover inhibits the optical sensors to image the earth's surface, making these systems useless. Radar systems can penetrate the cloud cover. However, existing satellite radar sensors are not well suited for forestry applications, as they make even the forest/non-forest discrimination still very difficult.

And finally, when these constraints are resolved, several countries currently have insufficient *capacity* to make proper use of the technical possibilities. Human resources and institutional capacity urgently need to be developed, also because most countries wish to be *independent* from third parties with respect to data reception and interpretation.

The FAME concept that is currently being developed aims at resolving all of the limitations identified above. Within existing forestry and space programmes, no plans exist to set up a similar operational system in the next few decades.

2 THE FAME INITIATIVE

FAME is an operational forest monitoring programme enabling the forest manager to acquire information on changes in the forest, directly where it is needed: in the office of the forest manager. The programme comprises all components necessary to enhance sustainable forest management world-wide. It involves education and training as well as the development and use of a so called "end-to-end" system, comprising small PC-based receiving stations, data processing and archiving functions, optionally integrated with a GIS, to support the management decisions, as well as a satellite with a dedicated sensor covering the world's entire surface.

The concept includes a non-detachable coherence of the space and ground segments and envisages to overcome all "inhibiting factors" mentioned above.

The *availability* is secured by putting the satellite in an orbit in such a way that it covers the world's entire surface. The sensor on board the satellite will be operating continuously, as will the transmission of the data to the ground. The receiving stations will be programmed to record the area of interest directly during the satellite pass. The *accessibility* is guaranteed by the direct transmission from the satellite to the receiving station. The *affordability* is assured since the receiving station will be low-cost and the data from the satellite will be free of charge. Since the forest manager can receive the data directly from the satellite, there will be no *timeliness* problems. The *usability* will be secured by the integrated design of ground and space segments. The groundstation which will take care of the reception of the data, and the system will process the satellite data into thematic image "maps", which can be used for interpretation or as input for a GIS. This GIS can be set up in such a way that it will generate the locally required information, depending on the type of operations the forest manager has to perform. A specific radar sensor will be designed to enable the identification of processes relevant for forestry applications. The *capacity* will be built by dedicated education and training programmes. Training can be in the area of the interpretation of the satellite data, in the area of the application of the GIS tool, and at decision makers level. Training plays a vital role in enabling proper use to be made of the technological tools. The training can also be combined with research, or with the development of the GIS application tailored to a specific situation defined by the trainee. The *independence* from others is secured by the direct reception and, as a result of dedicated training, the capability to process and interpret the data locally.

3 MISSION REQUIREMENTS

The objective of the FAME programme is to enable forest managers, mapping agencies and decision makers world-wide, on a national and sub-national level, to acquire knowledge and information in order to strengthen sustainable forest management. World-wide implies tropical, sub-tropical, temperate and boreal zones.

In order to meet the objectives the following requirements are to be met:
- To provide an end-to-end service including effective tools to enable forest cover and forest cover changes to be detected and monitored in tropical, sub-tropical, temperate and boreal regions, with the capabilities to assess on a national scale (1:1.000.000) forest cover and forest cover changes, and to monitor on sub-national scale (1:250.000) forest-related processes such as deforestation, degradation, regrowth, and conversion;
- To provide tools which require minimal training;
- To assure the availability, accessibility, affordability, timeliness, and usability of the information;
- To assure the independence with respect to the information reception;
- To educate and train people involved in forest management at various levels in order to obtain the required institutional capacity.

These requirements lead to the definition of an end-to-end service comprising the following elements:
- A polar orbiting satellite equipped with a sensor dedicated to forestry monitoring
- Low-cost end-user stations with the capability to receive the data directly from the satellite and process the data into the envisaged final information products
- The implementation of an extensive training programme (ground station operation, product interpretation, forest management)
- To operate support entities such as a Satellite Control Centre, and User Support Centre(s).

The following section presents a more detailed overview of the sensor concept. Section 5 summarizes the baseline of the end-user station.

4 P-BAND SAR SENSOR

The information availability requirement leads to:
- Synthetic Aperture Radar (SAR) instrument, in order to ensure forestry data availability including areas which are frequently cloud-covered
- P-band SAR frequency (< 1 GHz), in order to assess the wood volume with an acceptable accuracy. To determine changes in forest density, e.g. due to degradation or deforestation, higher frequencies (C, S, X) are not suitable. Only L-band would be useful to some degree. However, L-band backscatter signals saturate at wood volumes of 50 tons/ha, whereas P-band saturates at 200 tons/ha. Hence, P-band enables a significantly larger part of the dense forest areas of the world to be monitored (in particular rain forests).

The information usability requirement implies:
- primary resolution 50 m (pixel spacing 25 m) to support 1:250000 mapping, with radiometric resolution < 1.5 dB;
- derived resolution 100 m (pixel spacing 50 m), with radiometric resolution < 1 dB.

Related to the affordability of the end-user station:
- SAR payload data compatible to NOAA HRPT frame format and rate. This enables "standard" NOAA front-end receivers to be used. SAR data is transmitted directly to the end-user station (i.e. without on-board storage). The data rate is not higher than 614 kB/s.

The Synthetic Aperture Radar (SAR) instrument is a side-looking system transmitting in the P-band[1]. A frequency allocation in P-band for active satellite remote sensing is under consideration by the International Telecommunication Union (agenda point of the WRC'97 conference). The proposed band is 430-440 MHz (69 cm).

The main SAR parameters are listed in Table 1. The antenna baseline is an 8 by 8 metres planar array structure. The transmitted and received signals are circularly polarized in order to avoid the impact of the Faraday rotation effect due to the ionosphere. The incidence angle is fixed at 38 degrees. The squint angle is 0 degrees. The pulse bandwidth is 4.8 MHz, to achieve a single look complex range resolution of 50 m (i.e. pixel spacing of detected image 25 m). Pulse compression is applied to reduce the peak power to not more than 300 Watts. The selected pulse repetition frequency is 2100 Hz.
The downlink data rate is limited to 614 kb/s. In order to meet the spatial and radiometric resolution requirements the instrument includes an on-board SAR processor. The SAR instrument may operate in two different modes. In the 'target mode' the on-board SAR processor performs real-time processing of SAR data, followed by a multilooking process and image compression, supporting a 50 km swath. This swath width results in 60 days coverage (sunsynchronous polar orbit, 782 km altitude).
In the 'nominal mode' the SAR processor is not active and raw data are transmitted to the ground (compressed), however with, a lower radiometric resolution and a swath width of 30 km. In this case the SAR processing is carried out by the end-user station. The purpose of the nominal mode is:
- to check the performance of the on-board SAR processor
- to provide a fall-back option in case of a failure of the on-board SAR processor.

The on-board SAR processor will be designed in such a way that upgraded software modules can be uploaded during the course of the mission to improve the imaging process.

The two modes are specified by the following parameters:

Nominal mode
- Radiometric resolution of 1.5 Db over 30 km swath width
- Spatial resolution 100 m (pixel size of 50 m in detected image)
- Number of range looks: 1
- Number of azimuth looks: 8
- SAR duty cycle (burst operation): 0.35

Target mode
-Radiometric resolution of 0.75 Db over 50 km swath width
- Spatial resolution 100 m (pixel size of 50 m in detected image)
- Number of range looks: 2
- Number of azimuth looks: 20

Note that in target mode the system supports also the generation of products with 50-m spatial resolution at a lower radiometric resolution (1.3 Db).

Figure 1 presents the SAR instrument's architecture. The high power amplifier uses solid state devices for the generation of the output pulses. The chirp generation, demodulation and filtering functions are full-digital designs. No long-time data storage is foreseen: the raw data will be directly relayed to local groundstations.
It is assumed that the groundstations are able to receive the satellite signal at 5 degrees elevation to ensure sufficient ground coverage and to allow short term data buffering for data rate reduction in the nominal mode.
The average power consumption of the SAR is estimated at 230 Watts and 60 Watts for target and nominal mode, respectively. However, the SAR payload is only active over designated land targets, resulting in an average power consumption of 75 W in target mode.
The targets are generated by the User Support Centre and forwarded to the spacecraft by the Satellite Control Centre. The target information together with the position information from the on-board GPS receiver is used to switch the SAR on or off (this function is carried out by the Instrument Control Unit ICU).
The raw SAR data or the compressed SAR image data (nominal and target mode, respectively) is forwarded to the communication subsystem. The communication subsystem formats the data and after inclusion of the necessary house-keeping data, the formatted data is sent to the end-user station. In view of

the target mode, it will be possible to update on-board processing programs and SAR processing parameters when such a program or set of parameters is received from the Satellite Control Centre.
Justification of these updates is granted by the User Control Centre. Since the SAR instrument requires a rather high level of power consumption during operation, the SAR is equipped with a dedicated thermal control sub-system.

The relatively large antenna surface area (more than 60 m^2) is mainly required because of ambiguity constraints. This calls for a novel structure since the overall antenna mass should be limited to about 100 kg, the stowage volume should be kept low, and the deployment mechanism should be sufficiently reliable. Possible candidate antenna structures appropriate for P-band with potential low weight are i) helix array; ii) parabolic reflector; iii) unfurlable membrane structure.
P-band frequency allocation to active remote sensing will probably be based on a *secondary* status. This means that interference to *primary* users of the same frequency band has to be sufficiently low. Therefore, during the design process, it has to be ensured that the applicable interference criteria will be met. Ongoing consultation of representative organisations of these primary users during the various design phases will be necessary.
P-band radar implies large phase variations of the echo signal due to ionospheric effects. If this effect should occur within an aperture (which is not yet confirmed by literature or tests) autofocussing techniques are needed to obtain sharp images. One method is to maximize the image contrast by iterative processing. This would significantly increase the processor load of an on-board real-time SAR processor. Consequently, the feasibility of the on-board processing function would not be obvious[2]. Hence, a more detailed and complete assessment of ionospheric phase variation effects on P-band SAR has to be performed.

5 END-USER STATION

The following baselines have been adopted for end-user station design:
- Low-cost, which can be achieved by applying standardized off-the-shelf equipment. Software cost are low due to the large user community.
- Serviceability, to be obtained by using PC-based systems due to the extensive user areas worldwide.
- Independency, enabling end-users to extract data directly from the satellite without the intervention of a central processing centre.
- User friendly, allowing the user to operate with a minimum of training or space system experience.

The end-user station is a relatively low-cost and independent data reception and processing facility. The front-end is a "standard" NOAA HRPT receiver equipped with a small tracking antenna (1.5 m dish) connected to a PC-based data acquisition system which includes the satellite tracking and scheduling functions. This system acts as a (raw) data server to the processing facilities.
For data processing and product generation the system is extended with a PC-network for SAR data processing, validation, archiving, and presentation functions.
The processing tasks are: SAR processing (if the nominal mode is selected); validation; archiving; geocoding; mosaicking; thematic processing; information management tools. The geocoding includes terrain coding based on digital elevation map data.
SAR processing requires a large amount of computational effort. However, it has been shown[1] that the current generation of high-end PCs allows the data received during one satellite pass to be processed within a few hours.

6 CONCLUSIONS

The conceptual design of a space-based synthetic aperture radar sensor has been described dedicated to scan all the global forest areas at least three times a year, providing timely

information on deforestation and forest degradation processes at 50 - 100 m resolution.
This instrument is one of the essential elements of the FAME end-to-end system. Distributed processing at low-cost end-user stations is one of the key items of the FAME approach. To this end, the SAR instrument will include on-board SAR processing and compression functions to reduce the down-link data rate and to allow the use of NOAA compatible reception stations.

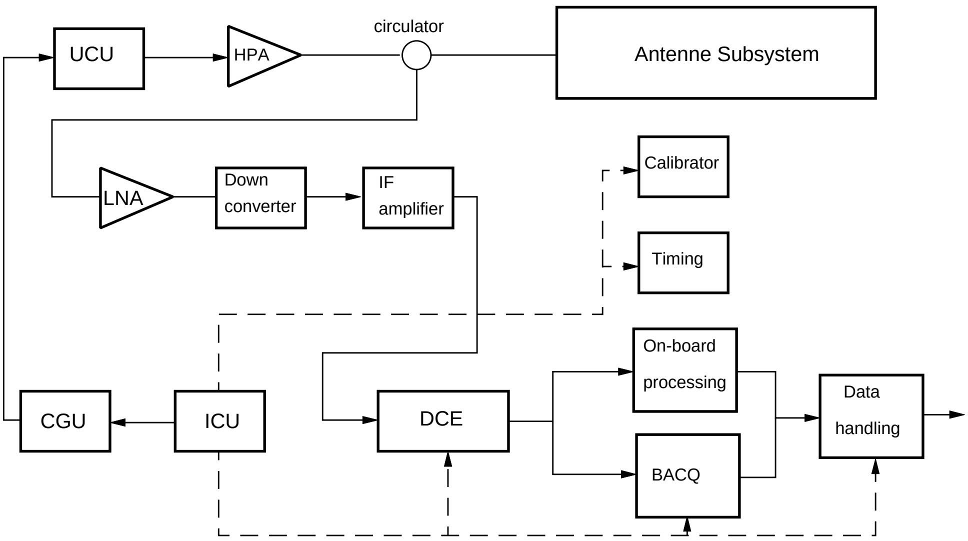
7 REFERENCES

[1] Algra, T., W. Looyen, M. de Brouwer, "P-band SAR Mission; Concept for a Dedicated Infrastructure for Global Monitoring of Forests (FAME)", NIVR Contract Report, NLR CR 95678 L, NLR Amsterdam, 1996

[2] Algra, T., W. Looyen, M. de Brouwer, "Study into Critical Issues of the FAME Mission", NIVR Contract Report, NLR CR 97005 L, NLR Amsterdam, 1997

Table 1 Main SAR parameters

Parameter	Nominal	Target
Altitude	782 km	782 km
Nominal ground speed	6646 m/s	6646 m/s
Antenna length	8 m	8 m
Antenna width	8 m	8 m
Antenna type	planar array	planar array
Polarization	Circular (RR or RL)	Circular (RR or RL)
Gain	32.3 dB	32.3 dB
Incidence angle	38.4 degrees	38.4 degrees
Frequency	435 MHz	435 MHz
Pulse bandwidth	2.4 MHz	4.8 MHz
Pulse Repetition Frequency	2100 Hz	2100 Hz
Peak power	300 W	300 W
Pulse duration	25 µs	25 µs
Swath (ground range)	30 km	50 km
Range looks	1	2
Azimuth looks	8	20
Samples per burst	990	NA
Duty cycle	0.35	1
Range resolution (complex)	100 m	50 & 100 m
Azimuth resolution (complex)	100 m	50 & 100 m
Radiometric resolution	1.5 dB	0.75 dB (100 m) 1.3 dB (50 m)
Azimuth extended ambiguity ratio	-21.5 dB	-23 dB
Range extended ambiguity ratio	-23 dB	-23 dB
Noise equivalent σ_o	-32.8 dB	-30.1 dB
Buffered data rate	614 kb/s	614 kb/s
Average transmitted power	5.5 W	15.7 W



UCU = Up Converter Unit
HPA = High Power Amplifier
LNA = Low Noise Amplifier
CGU = Chirp Generator Unit

ICU = Instrument Control Unit
DCE = Digital and Control Electronics
BACQ = Block Adaptive Complex Quantizer

Fig. 1 Architecture of the SAR instrument