Model Library for Earth Observation End-to-End Simulators: Active and Passive Microwaves Instruments

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ABSTRACT

End-to-end mission performance simulators for Earth Observation missions are one of the prominent tools for system design and scientific validation in early mission phases. For more than 15 years GMV has been involved in a series of activities and projects aimed at modeling and simulating different remote sensing instruments. Some of these activities are the ARCHEO study, which defines a reference architecture for end-to-end simulators, [1], and the BIBLOS project, which implements and provides to the European Earth Observation community a library of models for the development of mission performance simulators, [2] [3].

This paper presents the work for the second stage of the BIBLOS project, currently performed by GMV under ESA contract. The first phase focused on Passive Optical imager sensors. In this stage, Active Microwave and Passive Microwave Instruments are being implemented to extend the functionality of end-to-end mission performance simulators. Additionally, Passive Optical instruments will be extended with several enhancements of the sensor acquisition and performance improvements. This paper describes the scope of the activity for the Active and Passive Microwave Instruments.

BIBLOS and BIBLOS2 projects

The main goal of the BIBLOS project is to provide a library of software units called “Building Blocks”, which are integrated into modules, in order to build an end-to-end mission performance simulator in an efficient manner. This architecture is the result of an extensive analysis performed in the frame of the ARCHEO study, [1].

The first stage of BIBLOS was focused on Passive Optical imager instruments, as they are one of the most frequent types of instruments in remote sensing, both historically and in the near future, [1]. Blocks and Modules corresponding to the geometry, scene generation and instrument modules were developed and made available in the BIBLOS website to the user community, [13].

BIBLOS2, which is the second stage of the BIBLOS project, is an ongoing activity with the purpose of expanding the BIBLOS library to include Passive Microwave instruments and Active Microwave instruments and enhancing the Passive Microwave Instrument modelling. Additionally, as part of a continuous improvement process, this second stage of BIBLOS will also update some of the most computational performance intensive blocks for Passive Optical instruments with parallel implementation for Graphics Processing Units.

ACTIVE MICROWAVE INSTRUMENTS

The conceptual diagram of an Active Microwave Instrument is shown in Fig. 1. The following modules are being implemented: the Geometry, Scene Generation and the Performance Evaluation Module. One of the distinguishing features of the Active Microwave models is that they include imaging capabilities for bi-static and multi-static geometry, one of the growing trends in Synthetic Aperture Radar (SAR) technologies. Additionally, apart from the sub-swath acquisition modes (by independent beams), BIBLOS2 will include the Terrain Observation by Progressive Scans (TOPS). A fully integrated demonstration mission for Active Microwave Instrument will be made available to the users, [4], [5], [6].

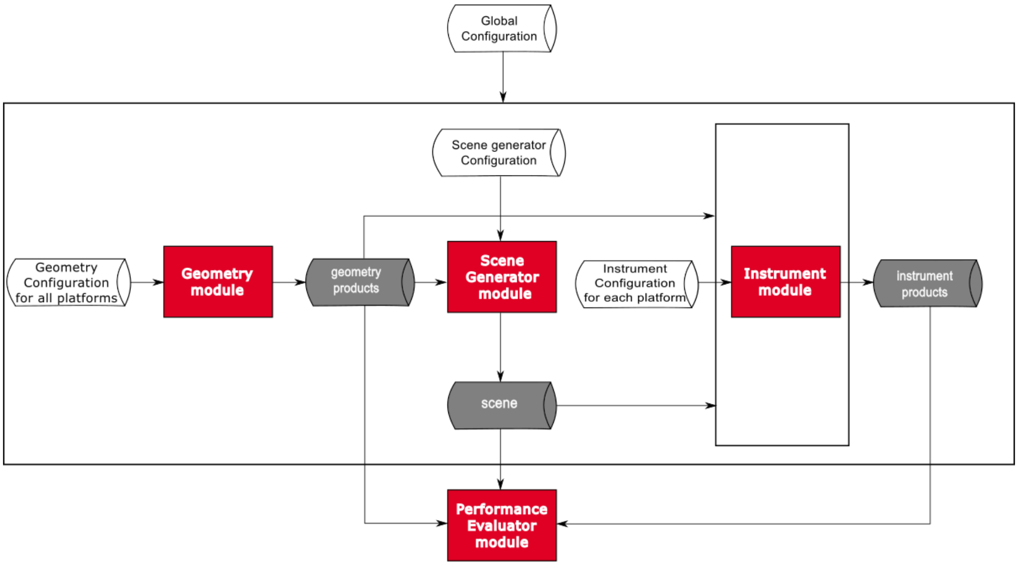

Fig. 1. Conceptual diagram of the Active Microwave Instrument

Geometry Module for Bi-static or Multi-static configuration

The Geometry Module includes the Orbit and Attitude Blocks, which have been re-implemented for bi-static or multi-static observation geometries. Fig. 2 shows the basic configuration for a bi-static mission, where the distance between the transmitter and the companion receiver(s) is defined by the along-track B_{AT} and across-track B_{XT} baselines. To perform a quasi-monostatic mission, both B_{AT} and B_{XT} can be set to zero.

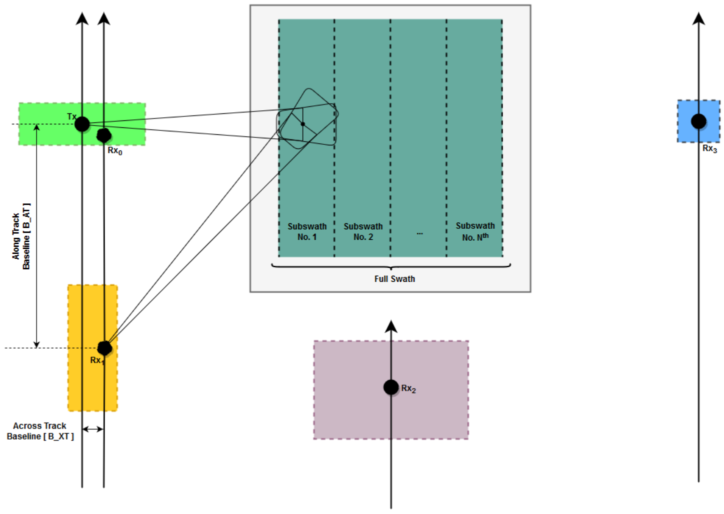

Fig. 2. Geometrical configuration between satellites in bi-static mission.

To be compatible with future missions, the Active Microwave modelling includes the Terrain Observation by Progressive Scans (TOPS) imaging capability in addition to the Stripmap mode, [7]. For the TOPS acquisition, the number of beams (equal to number of sub-swaths), number of bursts as well as others burs-dependent parameters are configurable. The difference between the Stripmap Mode and TOPS is shown in Fig. 3. Fig. 4 shows the application of TOPS for a bi-static mission with a passive Rx follower.

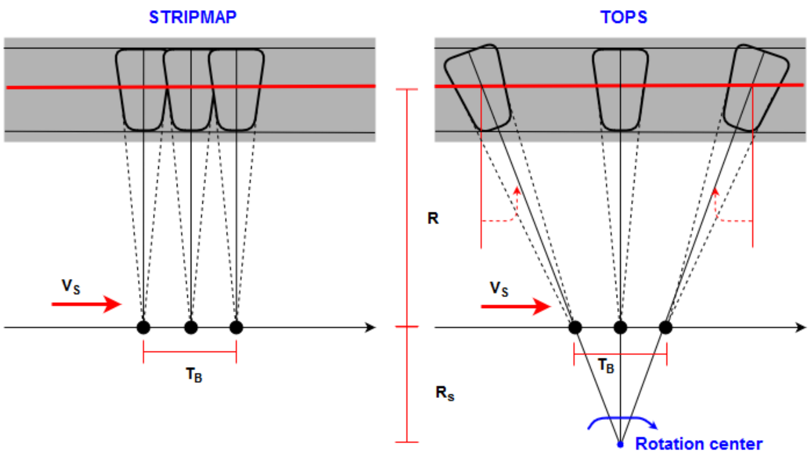

Fig. 3. Comparison between Stripmap and TOPS imaging modes.

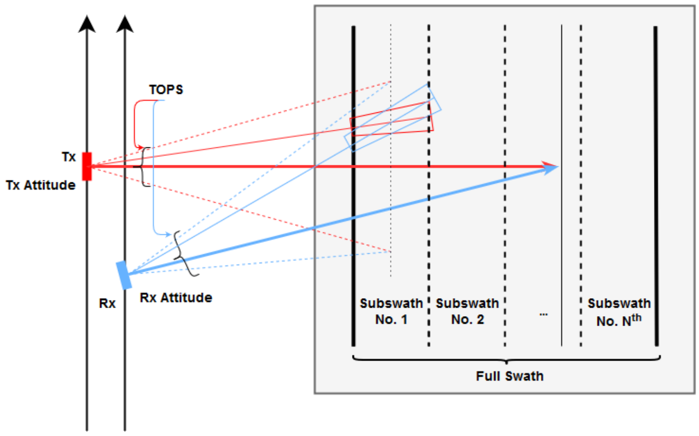

Fig. 4. Bistatic mission with TOPS acquisition.

When the position of the companion receiver(s) in consecutive orbit times is calculated in relation to the transmitter position based on along-track and across-track shifts, the attitude steering of the receivers is defined to follow the (full) swath centre of transmitter, as shown in Fig. 4.
The antenna rotation rate for the nth (n) sub-swath is calculated as follows:

$$k_{\psi}^{(n)} = -\left(\frac{2 \cdot \rho_{az} \cdot v_o^{(n)}}{\lambda} - 1\right) \frac{v_s}{R_0^{(n)}} \quad (1)$$

Where ρ_{az} is constant with the azimuth resolution (assumed constant for each sub-swath), $v_o^{(n)}$ and $R_o^{(n)}$ are the angular interval and slant range to sub-swath centre, respectively. Both these parameters are sub-swath dependent.

Performance Evaluation Module

This Module is in charge of evaluating the imaging capabilities of bi-static or multi-static configurations performed with user-defined inputs. Besides the visualization of intermediate products and the outputs of each Module, the PEM calculates a set of performance figures, which include, among others:

- *Diamond diagram*, to evaluate PRF (PRI) values in relation to SAR beams,
- *2D resolutions*,
- *Noise Equivalent Sigma Zero* (NESZ),
- *Signal-to-Noise Ratio* (SNR),
- *Ambiguity Ratio*: across and along track.

Fig. 5 shows two diamond diagrams calculated for two quasi-monostatic configurations: on the left, the constant pulse length is set to 60 ms, and on the right, the duty cycle is set to 5% of the Pulse Repetition Interval (PRI). For both cases, the off-nadir angle is set to 5 deg.

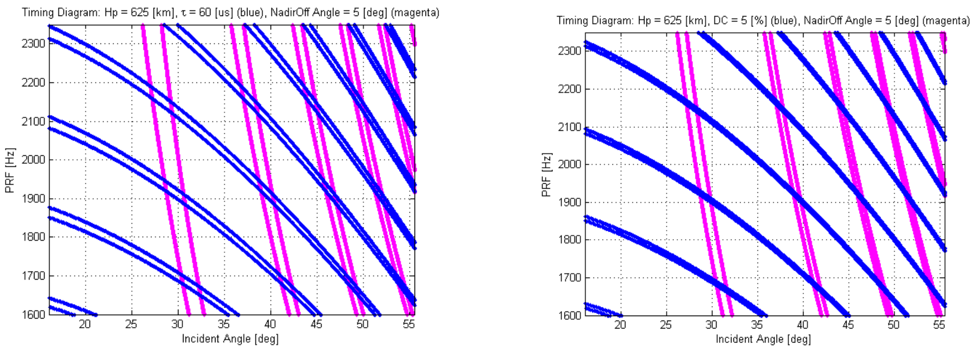

Fig. 5. Diamond Diagrams for a quasi - multi-static mission:
(left) 60 ms constant pulse length, (right) 5% constant duty cycle.

For a user-defined number of the SAR beams (defined by incidence angle and elevation beam width) the PRF can be correctly assigned to each beam to avoid overlapping between transmitted pulse and backscattered echo.

PASSIVE MICROWAVE INSTRUMENTS

The BIBLOS2 project activities in the Passive Microwaves field focus on a conical scanning radiometer, similar to the MetOp-SG-B Microwave Imaging Radiometer instrument, [10]. Following the Reference Architecture proposed in ARCHEO, [1], the Modules that are being implemented for Passive Microwave Instrument Data Simulators are:

- Geometry Module – covering all the activities related to satellite movement and pointing on ground
- Scene Generation – covering all the activities related to scene definition
- Instrument Module – covering the reception of the echo, and the transformation to digital counts that constitute the raw data (on-board processing, compression and binning are excluded).
- L1 processing module – covering all the activities related to obtaining L1 products from the raw data

Geometry Module

The Geometry Module is responsible for calculating the orbit, attitude and acquisition with a conical scan geometry, as shown in Fig. 6. The footprint of the antenna is projected on the Digital Elevation Model.

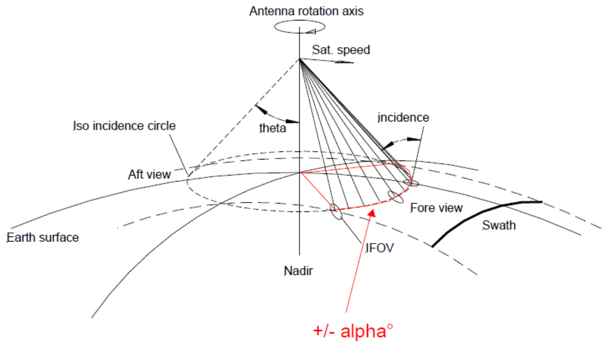

Fig. 6. Conical scan geometry. Antenna rotates creating full circle, but data is taken only for limited angle +/- alpha. Adapted from EUMETSAT through **Error! Reference source not found.**

Scene Generation Module

The Scene Generation Module covers all the activities related to the definition of scene, calculation of the brightness temperatures on ground and the propagation through the atmosphere for the observation area. The Building Blocks that compose this Module are:

- Class Map Block
- Forward Model Block
- Sun and Sky Noise Block
- Atmosphere Simulator Block
- Ionosphere Model Block
- Add Contributions Block
- Radio Frequency Interference (RFI) Generation Block

The calculation starts from the ground classification. For that purpose, several landcover type maps are used:

- World Vector Shorelines (WVS) – see [11]
- Corine Land Cover (of the Europe) – see [12]

The Scene Generation Module models the brightness temperatures, using different models for different types of landcover types (water, land, sea ice, snow, bare soil, vegetation, etc.). The models take into account the effect of the attenuation caused by the water vapour, oxygen, clouds and rain, the effects of the propagation of the electromagnetic wave in the ionosphere, and a range of natural contributions such as the extra-galactic component. Algorithms for passage through atmosphere are based on [8]. The Scene Generation Module includes Radio Frequency Interference (RFI) modelling, which impacts negatively the sensor's performance.

Instrument Module

The Instrument Module simulates the acquisition of the sensor, the receiver antenna, and all the effects and noises. The output of this block is the raw data (no on-board processing, compression or binning is simulated here). The Blocks that compose the Instrument Module are:

- Antenna Block
- Receiver Block & Observable Generation Block
- RFI Detection and Mitigation Block

The Antenna model includes two options: to be computed by the simulator or defined by the user via input file. The modelling takes into account nonlinearities and calibration errors, as well as the noise of the receiver. The algorithms to simulate the instrument performance are based on [9]. The detection and mitigation of the RFI effects is also included in the Instrument Module using look-up tables, as a full modelling of this process is too performance-intensive.

Level 1 Processing Module

The Level-1 processing is part of the Ground segment. The data sent by the satellite, as recorded by the instrument, has to be geo-referenciated, calibrated and transformed to physical quantities. The data processing is performed is several steps which include the correction for cross-polarization effects. The Blocks that constitute the L1 Processing Module are:

- Instrument Calibration Block
- Transformation of the Reference Frame and Geolocation Block

CONCLUSION AND FUTURE WORK

The BIBLOS project provides unique capabilities for users who want to develop an Earth Observation mission performance simulator. Active and Passive Microwave Instruments, developed in the current BIBLOS2 activity in progress, extend the scope of BIBLOS with two new instrument types (which already includes Passive Optical instruments). The new instruments and functionality blocks offer greater benefits for the Earth observation by reducing the cost of reengineering and promoting standardisation and reuse.

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