A Synthetic Aperture Radar Imaging Mode Syntax

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Dominik Thois, Marwan Younis

German Aerospace Center (DLR)
Münchener Straße 20
82234 Weßling, Germany
Email: dominik.thois@dlr.de

INTRODUCTION

Since the launch of the first spaceborne Synthetic Aperture Radar (SAR) in 1964, SAR systems have witnessed tremendous developments, leading to the highly capable multi-imaging mode instruments that we have today. SAR products and science have equally developed from rudimentary images accessible and interpretable only by specialists to a wide range of ubiquitous applications based on data freely accessible to a global user community. Nevertheless, SAR instrument performance calculation tools inherently lag behind the development of imaging modes and the reason is obvious: New imaging techniques emerge as ideas with back-on-the-envelope calculations, whereas the performance calculations are based on software tools developed for established (conventional) imaging modes. Things become even worse when considering next-generation SAR systems that utilize multiple digital channels. This is because the antenna radiation pattern, a major factor affecting the resulting performance, becomes digital, i.e., not a measurable RF antenna pattern, but instead a posteriori set through the data processing. [1]–[3]

To overcome the above-mentioned difficulties, the authors are developing a generic SAR Imaging Mode Syntax (SIMS), which is a unique description of instrument operation. Thus, SIMS is not specific to any imaging mode but instead describes the sequence of events and settings. This even allows describing future imaging modes, i.e., modes and techniques not known at the time the syntax was defined.

The SIMS is interpreted by the Simulator for Instrument Modeled Performance Estimator (SIMPLE) which is similarly generic and not explicitly "aware" of the specific imaging mode. Instead, it defines mathematical models for top-level imaging mode categories, e.g. burst mode for f-STEC [4]. The performance output parameters are defined a priori and calculated based on these models. SIMPLE is designed to be modular and easily extensible, making for an effortless integration of new models and therefore allowing for the description of an even wider range of imaging modes. Further, SIMS is only one component of a framework that includes an intelligent, well-documented user interface for both input and output.

This paper introduces the novel SAR syntax and the approach for performance calculation through examples of advanced imaging modes. We avoid elaborating on the software design as this is intended to be transparent to the (end-user) instrument engineer.

IMAGING MODE DESIGN AND SYNTAX

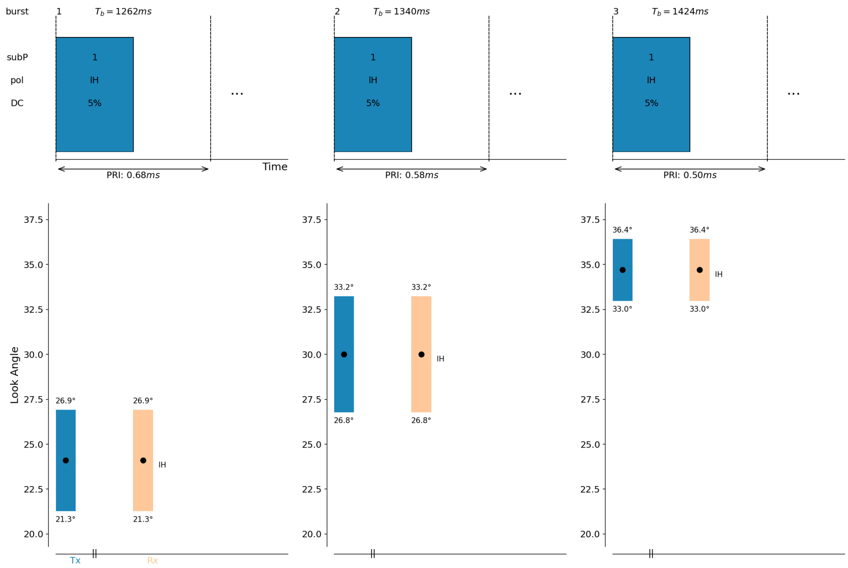
The description of the instrument is done by defining a set of general parameters, ranging from combinations of top-level imaging modes over antenna patterns to targeted resolution. This happens in a file that follows the *.ini*-configuration standards. It is divided into sections that contain different parameters. The parameter file can be dissected into three main parts: The *Mode Settings* specify everything that could be assigned directly to imaging, e.g. the imaging type, swath limits or parameters regarding the pulses, like pulse repetition frequency (PRF) or duty cycle. The *Instrument Settings* contain information about the antenna and the transmitters/receivers. This category also includes details about the movement path of the instrument, in case of a spaceborne SAR system this corresponds to orbit parameters. The last part consists of *Performance Settings*, i.e. parameters for the timing analysis, range and azimuth ambiguities performance and the resolution.

The key elements of the system definition can be seen in the fragment of the corresponding parameter file in Figure 1a. The user can modify these parameters directly in the file or use a graphical user interface which provides assistance and a well-structured representation of the parameters, while also ensuring the input is valid. The parameter file is parsed by SIMPLE and translated into the SIMS, which is used by the actual SAR performance calculation modules. This paper will look at two of these elements in more detail: The Minimum Periodic Pulse Sequence (MPPS) and the Transmit Receive Illumination Map (IM), which are applied individually to each burst. The former describes the shortest (sub-) pulse sequence repeating periodically. The latter describes the angular segments illuminated on transmit and receive, respectively. Both are represented as a collection of matrices that are not easily interpretable by humans, which is why the SIMS also gets translated into a visual representation, aimed to show all important features of an imaging mode and make them comparable to another.

For example examine a SAR system operating at C-band, imaging a 250km swath in a single polarization. A ScanSAR imaging mode utilizing a sub-pulse technique is considered [2], [5], [6]. The system uses a planar direct radiating phased array antenna with digital beamforming capabilities. In each burst one part of the swath is imaged, so that they complement each other, yielding a contiguous swath. For this system, the swath is divided into three sub-swathes, which are illuminated in one burst with one sub-pulse each. A selection of the relevant parameters, as well as the visual representation of the corresponding SIMS can be seen in Figure 1.

```
[modesSAR]
modename: ScanSAR
scan_burst_type: seq

[polarization]
pol_type: single
pol_TxName: [ '1H' ]
pol_RxName: [ '1H' ]

[swathPara]
start_El:[ 21.3 , 26.8 , 33.0 ]
stop_El:[ 26.9 , 33.2 , 36.4 ]
squint0_flag: True

[pulsePara]
duty_cycle: 5
freq_cent: [ 5.405e9 ]
prf: [ 1465 , 1735 , 2000 ]

[resolutions]
bwChirp: [ 150e6 ]
az_TargetRes: [ 2.0 ]

[timeDiagrm]
spec_ext_deg: 3.0
ovlp_Tx: 0
ovlp_Tx: 0.4
```

(a) Excerpt from parameter file



(b) SIMS visual representation

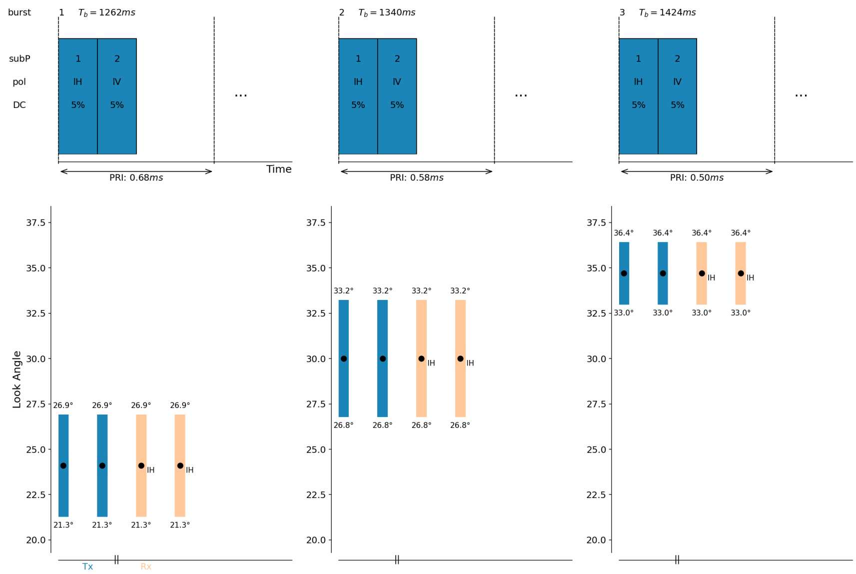
Figure 1: System A - With basic ScanSAR imaging mode using three sub-swathes to form one larger, continuous swath. Sections from the parameter file can be seen on the left (a), whereas on the right (b) the SAR Imaging Mode Syntax is visualized for fast and easy understanding

This SIMS illustration is a part of SIMPLE and gets automatically created for all parameter files. The upper part contains information about the bursts and sub-pulses. Each burst gets a plot which is numbered and labeled with its duration and the pulse repetition interval (PRI). In each burst, all sub-pulses for one PRI are plotted and contain information about the sub-pulse number, polarization, and duty cycle. Note that the time is represented on the abscissa, but the sub-pulses are not scaled to the PRI but rather have a width that is easy to read for the user. The actual sub-pulse duration can be acquired through the PRI and duty cycle. Below each burst the information about the (sub-)swathes is visualized. The transmit illumination is colored in blue, whereas the receive illumination is colored in orange. The abscissa is divided into transmit (Tx) and receive (Rx) and does not represent the time, unlike in the burst plot above. On the ordinate the look angle is shown. Illumination is always represented as a coherent rectangle. All gaps between rectangles in the direction of the ordinate, also denote gaps in the illumination. Next to the receive illumination, its polarization is noted. Additionally, the analog beam center is marked by a black dot.

The before-mentioned system A is extended to incorporate dual polarization. The corresponding excerpt of the parameter file and the visualization of the SIMS can be seen in Figure 2. The burst plot now has two sub-pulses, one with linear-horizontal and one with linear-vertical polarization. In the bottom part of the SIMS representation, there are now two transmit and two receive illuminations, one of each for every sub-pulse.

```
[modesSAR]
modename: ScanSAR_subP
scan_burst_type: seq
subP_ssw: tgl_pol
subP_delay:
subP_bw: [ 1 , 1 ]

[polarization]
pol_type: dualTx
pol_TxName: [ '1H' , '1V' ]
pol_RxName: [ '1H' ]

[swathPara]
start_El:[ 21.3 , 26.8 , 33.0 ]
stop_El:[ 26.9 , 33.2 , 36.4 ]
squint0_flag: True

[pulsePara]
duty_cycle: 5
freq_cent: [ 5.405e9 ]
prf: [ 1465 , 1735 , 2000 ]

[resolutions]
bwChirp: [ 150e6 ]
az_TargetRes: [ 2.0 ]

[timeDiagrm]
spec_ext_deg: 3.0
ovlp_Tx: 0
ovlp_Tx: 0.4
```

(a) Excerpt from parameter file



(b) SIMS visual representation

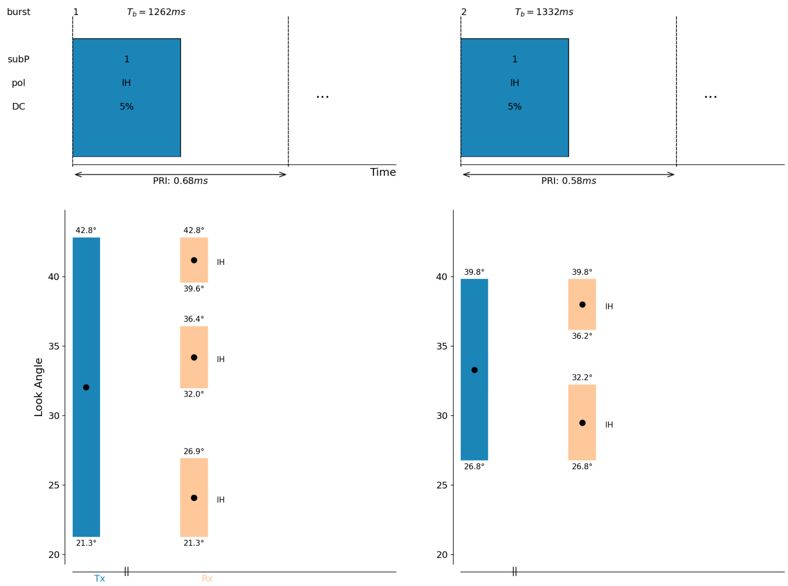
Figure 2: System B - A ScanSAR imaging mode extended with sub-pulses and dual polarization on transmit

To demonstrate the versatility of the visualization, examine a third option, system C. Instead of the illuminating on sub-swath per burst (*sequential* ScanSAR) now consider a two-burst (*alternating*) ScanSAR, where the whole swath is illuminated within two bursts and the sub-swathes complement each other, to again form a contiguous swath [5]–[7]. As in the first example, only a single polarization is considered here. The burst information again consists of only one sub-pulse, but the illumination plot is more interesting in this example. For the first burst the swath is divided into three sub-swathes, whereas for the second burst is divided into two sub-swathes, covering the gaps introduced in the first burst. The sub-swathes are illuminated as a whole, i.e. without gaps in between, while the echo is received with one beam per sub-swath, using digital beamforming.

As a final example, system C is extended by sequentially illuminating each sub-swath with a single sub-pulse, which is easily recognizable in Figure 4b. For the reception of the echo, Scan-On-Receive (SCORE) [1], [2], [8], [9] is used to achieve full antenna gain in elevation thus compensating loss due to the wide illumination and allowing for range ambiguity suppression. Looking at the receive rectangles in the illumination plot, it now shows a small beam (solid rectangle) is being scanned across the (sub-)swath (hatched rectangle), with an arrow indicating the scan direction, in this case from near to far range. The information of the scan direction, among other things, can be used to distinguish between other beam scanning imaging modes, like f-STEC, where the scanning direction is from far to near range [4].

```
[modesSAR]
modename: ScanSAR
scan_burst_type: alternate

[polarization]
pol_type: single
pol_TxName: [ 'lH' ]
pol_RxName: [ 'lH' ]

[swathPara]
start_El:[ 21.3 , 26.8 , 32.0 , 36.2 , 39.6 ]
stop_El:[ 26.9 , 32.2 , 36.4 , 39.8 , 42.8 ]
squint0_flag: True

[pulsePara]
duty_cycle: 5
freq_cent: [ 5.405e9 ]
prf: [ 1465 , 1735 ]

[resolutions]
bwChirp: [ 150e6 ]
az_TargetRes: [ 2.0 ]

[timeDiagrm]
spec_ext_deg: 3.0
ovlp_Tx: 0
ovlp_Tx: 0.4
```

(a) Excerpt from parameter file

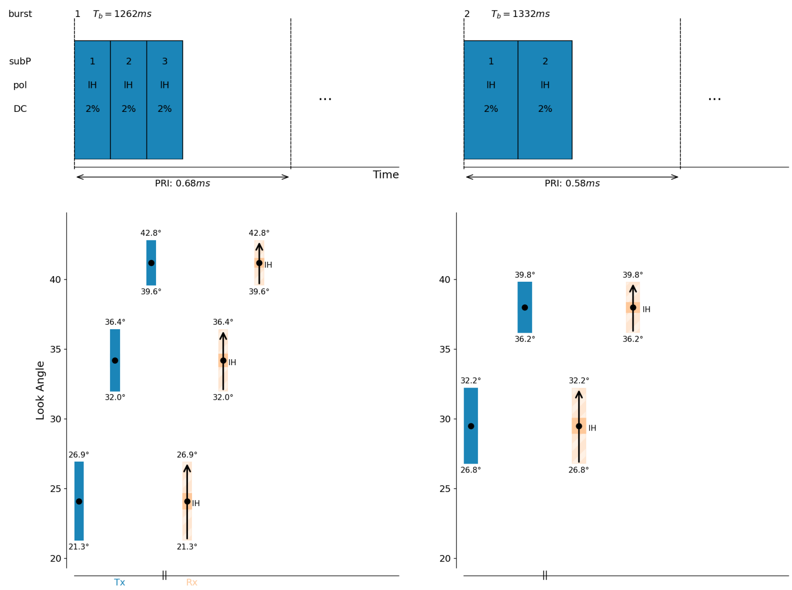


(b) SIMS visual representation

Figure 3: System C - Two-burst (alternating) ScanSAR with five sub-swathes and single polarization

```
[modesSAR]
modename: ScanSAR_subP_score
scan_burst_type: alternate
subP_ssw: seq
subP_delay:
subP_bw: [ 1 , 1 ]

[polarization]
pol_type: single
pol_TxName: [ 'lH' ]
pol_RxName: [ 'lH' ]

[swathPara]
start_El:[ 21.3 , 26.8 , 32.0 , 36.2 , 39.6 ]
stop_El:[ 26.9 , 32.2 , 36.4 , 39.8 , 42.8 ]
squint0_flag: True

[pulsePara]
duty_cycle: 5
freq_cent: [ 5.405e9 ]
prf: [ 1465 , 1735 ]

[resolutions]
bwChirp: [ 150e6 ]
az_TargetRes: [ 2.0 ]

[timeDiagrm]
spec_ext_deg: 3.0
ovlp_Tx: 0
ovlp_Tx: 0.4
```

(a) Excerpt from parameter file

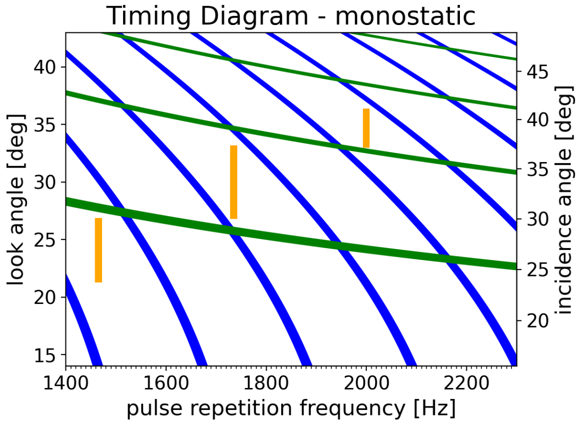


(b) SIMS visual representation

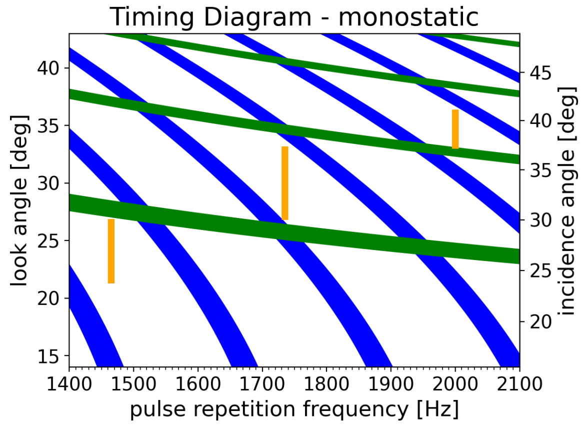
Figure 4: System D - Two-burst ScanSAR with sub-pulses and SCORE

TIMING DIAGRAM COMPARISON

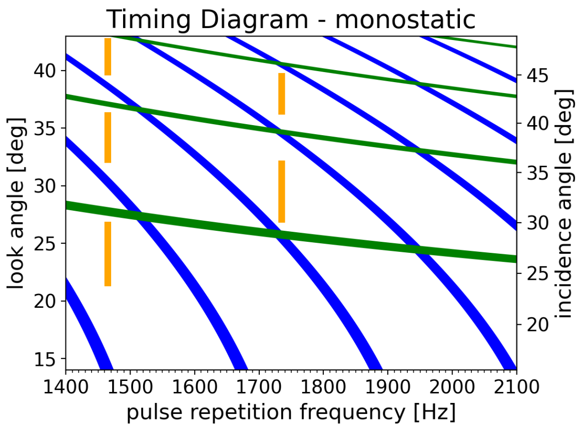
An output of SIMPLE is the diamond (timing) diagram, cf. 5, which shows the transmit pulse instances (blue) and nadir returns (green) versus a range of PRF values on the abscissa. These are related to the geometrical swath parameters, here, the incidence and off-nadir look angle on the ordinate. The timing diagram visualizes the echo window positions and allows the system engineer to decide on the number, placement, and extent of the imaged sub-swaths.



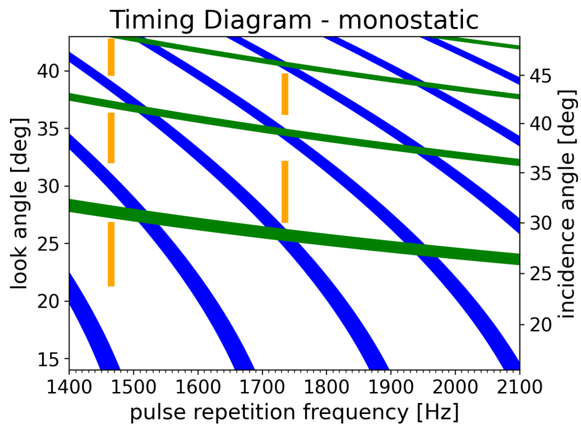
(a) System A - ScanSAR



(b) System B - ScanSAR with sub-pulses and dual polarization



(c) System C - Two-burst ScanSAR



(d) System D - Two-burst ScanSAR with sub-pulses and SCORE

Figure 5: Timing (diamond) diagrams showing imaged (sub-) swathes, orange bars versus PRF for system A to D. The transmit instances and nadir return are shown as blue and green bars, respectively.

Looking at the timing diagrams of the aforementioned systems highlights the significance of SIMS. System A images three sub-swathes with 3 different PRFs, which is, apart from the swath look angles, the only information about the imaging mode that can be extracted from the timing diagrams. There is no detail about polarization, pulse duration, or possible sub-pulses. This becomes even more clear when looking at systems C and D. There, three and two sub-swathes are imaged at PRFs of 1465 Hz and 1735 Hz corresponding to bursts 1 and 2. The transmit instances of three sub-pulses are combined into a single transmit (blue). A 40% overlap has been allowed between the nadir (green) and SAR return echoes. Again, the timing diagram itself does not reveal the full information about the imaging mode. Compared to system C, the individual sub-pulse duty cycle has to be reduced, because adding sub-pulses while keeping their duty cycle constant, increases the duty cycle of the burst, which can be seen by the increased size of transmit instances in Figure 5d. This is the only visual difference in the two timing diagrams and the only information one can extract form this is that system D uses an overall higher duty cycle, all other differences can not be spotted from the timing diagram only, even though the two imaging modes differ drastically.

CONCLUSION

The extended abstract introduced a syntax for describing imaging modes of SAR systems. The syntax is generic in the sense that it allows the description of a wide range of non-conventional sophisticated imaging modes that may be defined in the future. The value of SIMS is that it provides a structure that can be interpreted by a suitable SAR performance calculator independently of the operation mode and can be visualized for a fast understanding of the imaging mode. This provides a new flexibility in the SAR performance calculation which is especially useful for multi-channel digital beamforming SAR.

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