TANDEM-L INSTRUMENT DESIGN AND SAR PERFORMANCE OVERVIEW

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ABSTRACT

Tandem-L is a proposal for an innovative interferometric radar mission to monitor the Earth system and its intricate dynamics. Important mission objectives are global inventories of forest height and above-ground biomass, largescale measurements of Earth surface deformations due to plate tectonics, erosion and anthropogenic activities, observations of glacier movements and 3-D structure changes in land and sea ice, and the monitoring of ocean surface currents. A detailed description of the mission goals can be found in [1]. The mission concept is based on co-flying two fully-polarimetric L-band SAR satellites in a close formation. Tandem-L employs new techniques and advanced technologies to achieve its ambitious mission goals. The feasibility of a joint DLR/JAXA mission is currently being investigated in the scope of a pre-phase A study.

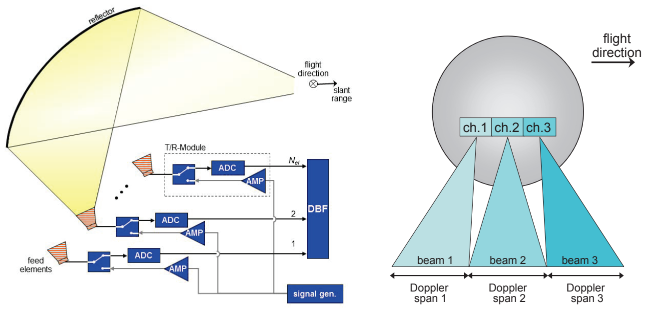
This paper provides an overview of the Tandem-L instrument design concept and its performance predictions. Innovative aspects like the employment of advanced digital beamforming techniques and operation in a variety of imaging modes are detailed.

1. ARCHITECTURE FOR DIGITAL BEAMFORMING

Tandem-L utilizes a reflector-based SAR system extended to a hybrid architecture through a digital feed [2, 3]. With this system it will be possible to image a swath width of 350 km utilizing a deployable 15 m diameter reflector. Such a hybrid architecture has the potential to combine both the flexibility and the capabilities of digital beamforming (DBF) with the high antenna gain provided by a large reflector aperture [4].

1.1. Digital Beamforming in Elevation

The SCan-On-REceive (SCORE) mode of operation, utilized here, is primarily based on generating a wide transmit beam that illuminates the complete swath and a narrow, high gain receive beam that follows the pulse echo traversing the ground. SCORE results in an increased signal-to-noise ratio compensating the low gain of the transmit antenna and provides a higher suppression of range ambiguities.



(a) elevation DBF (b) multi-beam azimuth DBF

Fig. 1: Conceptual system architecture for digital beamforming (DBF) operation.

The feed system (in elevation) consists of $N_{el} = 34$ patch-elements fed through transmit/receive modules, where an analog-to-digital converter (ADC) is placed after each T/R-module as shown in Fig. 1a. Activating all elements on transmit will generate a narrow beam illuminating a small portion of the reflector and by this gives a wide, low gain beam illuminating the complete swath. On receive the energy returned from a narrow portion of the ground illuminates the entire reflector and is focused on individual elements of the feed aperture. Each radar pulse traversing the swath thus results in the focused energy sweeping through all the feed elements.

The time it takes to sweep all the feeds is two to five times the pulse repetition interval PRI. This requires multiple SCORE beams simultaneously traversing different portions (sub-swathes), where each SCORE beam will activate a different sub-set of the feed elements.

1.2. Digital Beamforming in Azimuth

The requirement for the azimuth resolution varies between 10 m and 1 m depending on the application. Depending on the operation mode (cf. section 2) between one and three azimuth channels are required to sample the Doppler spectrum. A 1 m resolution requires a longer feed consisting of five channels.

The multiple azimuth phase centres are realized through feeds displaced in along-track direction as shown in Fig. 1b. Ideally, the beam of each azimuth channel "looks" at a different direction and by this covers a distinct angular (Doppler) segment. Each channel, thus samples a narrow Doppler spectrum corresponding to the half-power-beamwidth of the corresponding pattern. The PRF must be high enough such that the spacial sampling for each channel is adequate. If the Doppler spectra of the elements were contiguous, they jointly yield a higher azimuth resolution $\approx D/(2N_{az})$. For a realistic system, the Doppler spectra of the individual azimuth channels will overlap, in the case of the reflector this is actually an advantage, because it allows applying digital beamforming techniques to suppress the azimuth ambiguities, as detailed for example in [5].

1.3. Digital Feed

For Tandem-L, a digital feed architecture as was suggested in [2, 3] is utilized. As shown in Fig. 2 the feed system consists of 34x6 (elevation x azimuth) dual polarized patch-elements. Two patches are combined in azimuth to form one digital channel. The number of azimuth channels which need to be active (i.e. digitized) depend on the operation mode (see section 2). For the high azimuth resolution mode, four rows of the feed array are extended in length adding azimuth channels. As a consequence the feed array, shown in Fig. 2, has a cross-shape.

In elevation, the signal of all patches are digitized as shown in Fig. 3. A digital channel is formed by digitally weighting and then combining the data streams of

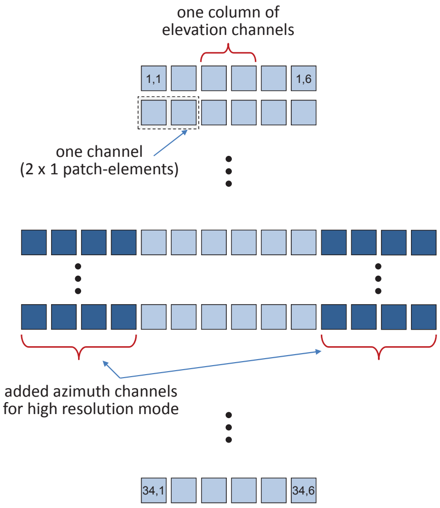


Fig. 2: Patch arrangement for the digital feed antenna.

the three patches receiving the ground echo at that instance of time. Thus, a digital channel does not correspond to fixed patches, but rather sweeps through the elements. Further, there are multiple (up to five) simultaneous active elevation channels, because multiple sub-swathes are imaged simultaneously.

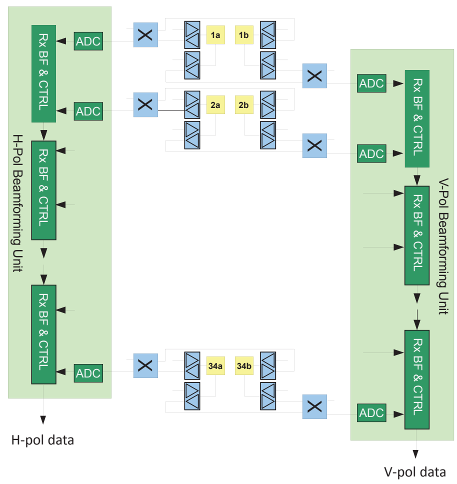


Fig. 3: Schematic hardware block for the digital feed.

2. MODES OF OPERATION

The digital feed in combination with the large reflector allows flexible operation in various modes. From an instrument point of view each mode is characterized by the activated elements on transmit, and the selection of the digital data streams which are stored on receive. In addition, radar parameters such as pulse repetition frequency, polarization channels etc. are adapted to the specific mode. The following modes are being considered:

	swath width	**azimuth res.**	**range res.**	**polar-ization**
B1/B2	350 km	10 m	< 5 m	single/dual
B4	$\geq$ 175 km	10 m	< 5 m	quad
D1/D2	350 km	3 m	< 5 m	single/dual
D4	$\geq$ 175 km	3 m	< 5 m	quad
C	50 km	1 m	< 5 m	quad

Table 1: Matrix relating the required performance to an operation mode.

Multi-Beam Stripmap: Here multiple sub-swathes are imaged simultaneously (the same PRF) allowing an increase of the total swath up to the access range. The imaged swath contains gaps caused by the transmit instances; a low pulse duty cycle is desirable to reduce the gaps width. The requirements of D1/D2, and D4 in table 1 can be served with this mode.

Two-Burst ScanSAR: A two burst ScanSAR is sufficient to image the required swath in B1/B2 and B4 (table 1). This mode avoids the gaps and the pulse duty cycle may be increased offering a better noise performance. Since ScanSAR requires a wider azimuth pattern, three azimuth channels are utilized which increases the data volume.

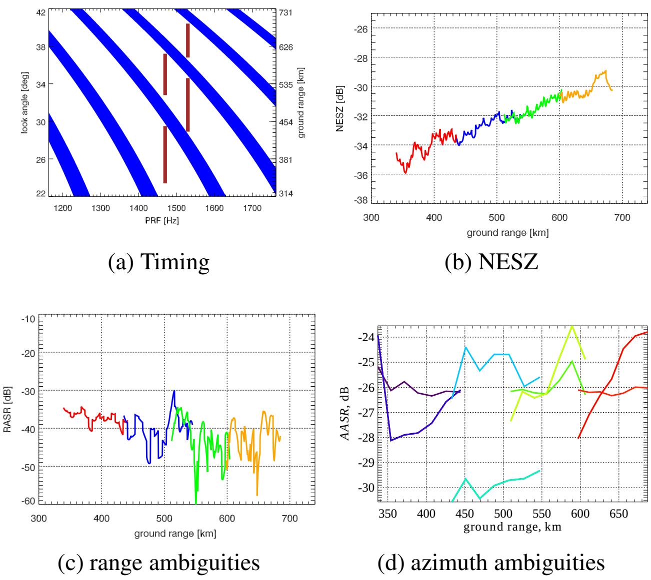
High Resolution Stripmap: A 1 m azimuth resolution is feasible for a narrow 50 km swath by activating 7 azimuth channels. The additional azimuth elements provide a wider transmit beam and multiple partially overlapping receive beams. A dedicated azimuth processing algorithm is required for unambiguous Doppler spectrum reconstruction [5].

Staggered PRI Multi-Beam Stripmap: Multiple subswathes are imaged at the same time but in addition the PRI is varied from pulse to pulse. By this the gaps of the Multi-Stripmap mode can be avoided [6, 7]. This mode offers a highly attractive way to image an ultra wide swath, but requires innovative interpolation approaches and an increased average PRF; its value is the limitation of this mode due to the higher range ambiguities.

3. SAR PERFORMANCE

A dedicated SAR performance software tool is used to compute the performance of the various modes. Specific effects of reflector antennas such as feed blockage are taken into account when generating the 2-D patters. The following figures show the performance for the various modes listed in table 1.

The timing of B1/B2 when implemented in a two-burst ScanSAR is shown in Fig. 4a. The mode profits from the 12 % pulse duty cycle to reach a good NESZ as shown in Fig. 4b. The corresponding range- and azimuth-ambiguity-to-signal ratio (RASR) is shown in Fig. 4c and Fig. 4d, respectively. To achieve the azimuth performance a dedicated processing of the multi-channel data is applied which combines the channels such that the signal power is maximized.

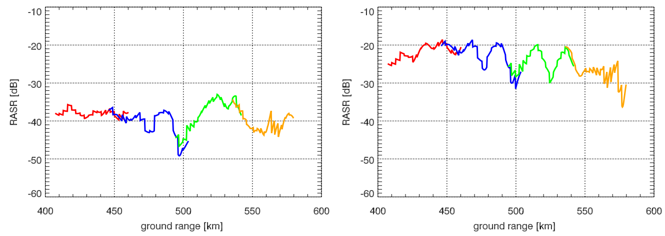


(a) Timing (b) NESZ

(c) range ambiguities (d) azimuth ambiguities

Fig. 4: Performance of Mode B1/B2

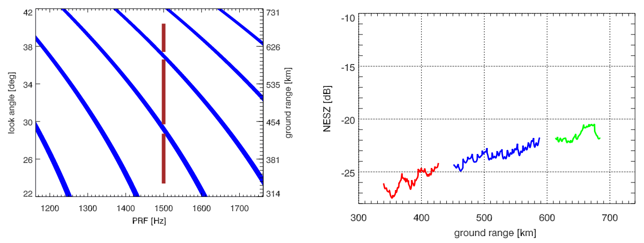
Similarly B4 utilizes in ScanSAR but at a reduced swath due to the higher PRF required for quad pol operation. The main difference to B1/B2 is the performance in terms of range-ambiguity-to-signal ratio which is shown Fig. 5. Here a linear polarization scheme is used, for which the co- and x-polarization RASR performances are different. Using hybrid circular polarization, i.e. alternating left and right circular, on transmit and dual linear on receive would yield similar performance for the two polarization channels. The azimuth resolution is 10 m and three channels are used.



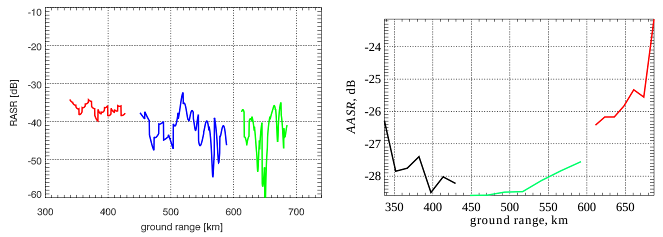
(a) co-polarization (b) x-polarization

Fig. 5: range-ambiguity-to-signal ratio of co- and X-pol of mode B4

Finally the performance of mode D1/D2 is shown in Fig. 6 which operates in the stripmap mode at a reduced pulse duty cycle of 4 %.



(a) Timing (b) NESZ



(c) range ambiguities (d) azimuth ambiguities

Fig. 6: Performance of Mode D1/D2

4. CONCLUSION

This paper presents the instrument concept and SAR performance of Tandem-L, an innovative single-pass interferometric radar mission to monitor the Earth system and its intricate dynamics. The SAR is based on a reflector antenna combined with a digital feed array. It is shown how digital beamforming techniques in azimuth and elevation are combined with dedicated modes of operation. This yields an instrument which flexibly operates in multiple modes, serving different applications.

5. REFERENCES

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