THE Ka-BAND SWOT PHENOMENOLOGY AIRBORNE RADAR

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1. INTRODUCTION

We present an airborne sensor that will support pre-mission science and mission calibration and calibration for the surface water and ocean topography (SWOT) mission [1]. SWOT is unique and distinct from precursor ocean altimetry missions in some notable regards: 1) 100km+ of swath will provide complete ocean elevation coverage, 2) in addition to the ocean product, land surface water will be mapped for storage measurement and discharge estimation and 3) Ka-band single-pass interferometry will produce the height measurements introducing a new transmit frequency and measurement technique. The introduction of this new approach introduces additional algorithmic, characterization and calibration/validation needs. To uniquely fulfill these needs, we present here the Ka-band SWOT Phenomenology Airborne Radar (KaSPAR) to complement traditional ocean altimeter calibration/validation campaigns and existing and planned surface water gauge networks.

KaSPAR is a modular system with multiple temporal and cross-track baselines to fully characterize the scattering and statistics expected from SWOT, provide data for developing classification algorithms, and understanding instrument performance and limitations over the vast variety of scenes that SWOT will encounter (ie sea-ice, vegetation covered water, frozen/partially frozen rivers etc). Furthermore a wide-swath (>5km) high-accuracy elevation mapping capability provides the necessary framework to translate traditional point or profile calibration/validation measurements to the spatial framework of SWOT.

KaSPAR has several key design principals:

1. The receiver channel architecture is modular and receivers are essentially identical in terms of hardware to ensure channel-to-channel calibration and minimize risk and cost,
2. As much as possible, existing designs for key components (antennas, mechanical design and receiver hardware) will be leveraged to minimize cost, risk and schedule, and
3. The system is compact with the antenna "panel" being a drop-in design that is compatible between multiple platforms. For example, the KaSPAR design and performance is compatible with NASA Langley and NASA Dryden King Airs *with little to no aircraft modifications*. However, all hardware is specified for compatibility with high-altitude operation on a Global Hawk (e.g. hardware is conduction cooled, and altitude specifications are given to 70,000ft).

KaSPAR will support SWOT throughout all phases including science and algorithm development and calibration and validation. The ability of KaSPAR to collect data "on-demand" holds great potential to augment the science impact of SWOT since KaSPAR could be strategically deployed during time-critical events such as floods. Furthermore, KaSPAR can extend the scientific return on investment by extending SWOT observations in scientifically significant regions. For example, KaSPAR will be capable of providing interim data between overpasses for highly dynamic smaller rivers to validate data assimilation schemes, or KaSPAR data can quantify discharge contributions of tributaries too small to be imaged by SWOT.

2. SYSTEM DESIGN

Figure 1 shows a cartoon concept of KaSPAR which has a narrow "SWOT-like" sub-swath coupled with a wider high accuracy elevation-mapping swath. KaSPAR's goals are two-fold:

1. To mimic and characterize the SWOT geometry, scattering and sampling (i.e. be "SWOT-like") for a variety of targets and,
2. To provide a high accuracy, high-resolution elevation swath-mapping capability for pre-mission science interpretation and algorithm and for subsequently for mission calibration and validation.

2.1 Near-nadir System Requirements to Mimic and Characterize SWOT

A key requirement is to mimic the SWOT sampling geometry. Generally the objective is to provide more measurements and detail so that there is additional information for analyzing the results and applying the interpretation to predict SWOT's performance. This levies the following requirements on the near-nadir sub-swath:

1. An elevation baseline should approximate the phase wrap-rate of SWOT. For approximate range of airborne altitudes this results in a cross-track baseline $0.16\text{m}<B<0.3\text{m}$.
2. The bandwidth should be greater than or equal to SWOT (>200MHz)
3. The minimum range of incidence angles should be similar to SWOT where $1^{o}<\theta_{i}<6^{o}$.
4. The height accuracies for the sub-swath should be similar to SWOT at a higher spatial resolution (as scaled to the airborne swath).
5. Additional supporting measurements of temporal coherence time are required to characterize along-track resolution limitations.
6. A system dynamic range equal to or greater than SWOT (> 40 dB).

2.2 Swath Elevation Mapping Requirement

The second system requirement is to provide swath elevation mapping capability for sample science products and SWOT calibration and validation. The following is required for the swath product:

1. A swath of 5km over the ocean at 35kft altitude and 6m/s wind or greater.
2. Mean height precision of 2.5 cm for 50m range x 80m azimuth (as limited by the surface decorrelation with 6m/s wind) posting.

2.3 KaSPAR Overview

KaSPAR's basic system parameters are shown in Table 1. Key things to note in this table are a peak transmit power of 40W, now achievable with a solid-state power amplifier (SSPA). The inner swath has >200MHz bandwidth consistent with characterizing KaRIN, while the outer swath has a nominal 80MHz bandwidth due to signal to noise ratio (SNR) and data rate considerations. Note that generally the performance will be better than predicted here if either a) the altitude of operation increases since the swath can be achieved for a narrower range of incidence angles (σ_0 rolls off quickly with incidence angles beyond ~25 degrees), or b) there is more wind (6m/s is quite modest).

The nominal antenna configuration to meet both the phenomenology and the swath-mapping requirements of KaSPAR is shown in Figure 2. The slotted waveguide antennas are mounted within a single "drop-in" panel constructed from a low coefficient of thermal expansion (CTE) material. This modular low-profile panel will be oriented horizontally or downward looking with the antennas canted slightly off horizontal to one side of the aircraft.

When designing KaSPAR, Table 2 summarizes the error sources assumed in predicting elevation performance. For random error sources we have considered the signal-to-noise-ratio (SNR), geometric decorrelation and “zero-range” ambiguity explicitly (zero-range ambiguity is the uncorrelated return from the opposite side of nadir that will contaminate the height error). Other terms such as azimuth and range ambiguities, amplifier jitter, filter ripple etc have been conservatively lumped into the integrated sidelobe ratio (ISLR) and multiplicative noise ratio (MNR) term of -13dB. For systematic errors we have considered three terms that we would consider the dominant sources, 1) baseline dilation, 2) receiver phase-drift (*knowledge* of 0.2° (over 10 minutes) is challenging but achievable with careful design and thermal packaging [2]) and 3) range-timing accuracy. The resulting mean error across the two swaths can be seen to meet requirements of less than 2.5cm under the stated design assumptions.

Table 1: Basic system parameters and geometry.

Parameter		Value	Unit
Center Frequency		35.75	GHz
Peak Transmit Power		40	W
Platform Height		35	kft
Swath Coverage (at 35kft AGL)	Inner	0.2-1.4	km
	Outer	0.8-5.0	
Bandwidth	Inner	>200	MHz
	Outer	80	
Incidence Angle Range	Inner	1-6	°
	Outer	4-25	
Noise Figure		6	dB

Table 2: Error sources and allocations assumed in predicting the elevation accuracy of KaSPAR The performance quoted for the inner swath assumes no calibration of systematic biases and a 20m range posting. For the outer-swath – the performance assumes calibration with a nadir-altimeter (using existing KaSPAR hardware) and a 50m range posting**.**

Error Source		Quantity	Unit
Random	SNR	Derived from system radar-range equation for ocean at 6m/s wind	Unitless ratio
	Geometric	Derived for each baseline	
	ISLR/MNR	-13	dB
	Zero-range ambiguity	Relative gain of 2-way antenna pattern from opposite side	Unitless ratio
Systematic	Receiver phase-drift *knowledge* error	0.2	°
	Baseline dilation	20	microns
	Range-timing accuracy	3	ns
Mean Height Error Performance (35kft, 6m/s winds over ocean)			
Inner subswath		1.8	cm
Outer swath		2.3 [1]	

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[1] Calculated as the root sum square of the residual calibration error (1 cm) and the random errors.

4. CONCLUSIONS

KaSPAR is a system motivated in support of SWOT pre-mission and mission needs. The design incorporates multiple baselines in a modular and compact architecture for maximal versatility in terms of measurement capabilities and also multiple platform compatibility. An inner "SWOT-like" swath is coupled with a larger "mapping" swath in this unique sensor that will provide highly accurate science, algorithmic and calibration/validation measurements.

5. ACKNOWLEDGMENT

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6. REFERENCES

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[2] H. Vedantham, P. R. Siqueira, K. Srinivasan, E. Insanic, A Ka-Band Interferometer For Cryospheric Applications - Instrument Description And First Results, Proc. IGARSS 2008

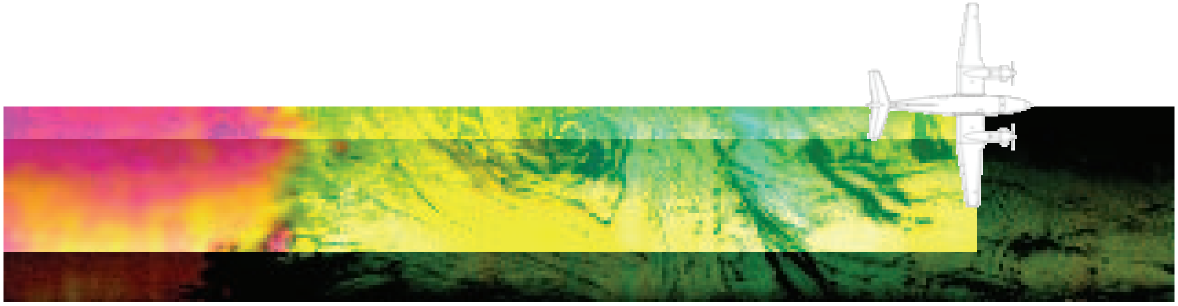

Figure 1: Cartoon concept of KaSPAR on a King-Air with two overlapping swaths.

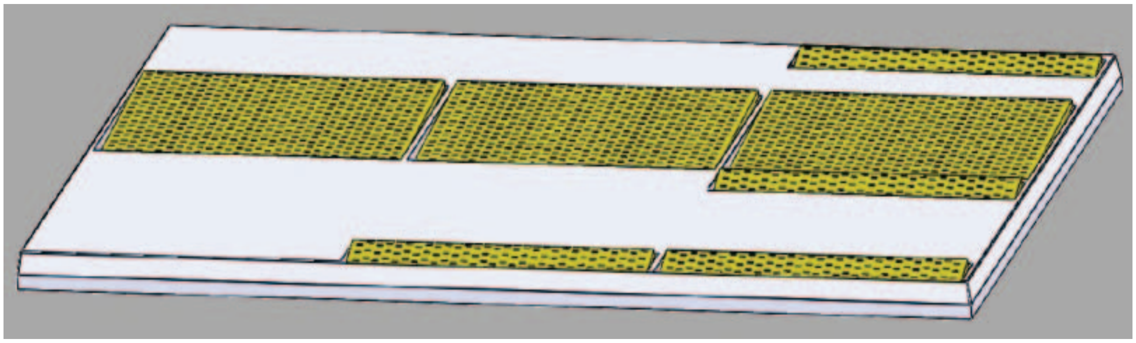

Figure 2: Solid works model of the antenna baseline configuration (along-track dimension is oriented horizontally). The smaller antennas have a larger beamwidth for "mapping".