A Ka-band to Baseband RF Testbed for the SWOT mission

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Abstract: **As part of the effort for the design and testing of a Ka-band two-channel interferometric receiver for the SWOT mission, a baseband to Ka-band (35 GHz) and Ka-band to baseband testbed system has been constructed. This system is capable of monitoring the performance of key RF subsystem components as a function of temperature and other operating conditions. Primary to this development has been the construction of a direct Ka-band to L-band downconverter, followed by two channels of direct sampling at L-band (3 GSamp/sec). This system can record low data rate telemetry into an FPGA (Xilinx-4) architecture for the purpose of signal compensation for measured environmental changes.**

I. Introduction

The Surface Water and Ocean Topography (SWOT) mission is a second tier National Research Council (NRC) decadal survey mission intended to measure sea level and river stage height at a higher spatial resolution and over a wider swath than what is currently available through more traditional altimetric methods. A key technology of the SWOT mission is a near-nadir looking Ka-band (35 GHz; 200 MHz bandwidth) cross-track interferometer, KaRIn, capable of providing single-look resolutions on the order of 5 m in azimuth and 10-70 m in ground range. Measures of topography at these resolutions will be averaged to achieve 1 km^2 topographic estimates with accuracies on the order of centimeters in vertical height. To achieve the accuracies required by SWOT, the interferometer will operate in what is known as ping-pong, or double-baseline mode, which alternates the transmission of high-power microwave energy between the two antennas that make up the interferometric baseline. While the use of the double-baseline interferometric mode improves the height accuracy of the interferometric measurements, it also brings the phase stability of the transmit and receive systems into the overall height error budget. For this reason, and for basic mission readiness, researchers at the University of Massachusetts have constructed a 35 GHz RF testbed for the SWOT mission (Figure 1) and are in the process of using this testbed for testing various transmit and receive configurations. Features related to signal stability and system bandpass characterization are also under analysis.

II. Functional Components

The basic functions of the RF testbed consist of signal generation and transmission, signal routing, and signal reception, storage and analysis. Brief description of each function follows subsequently.

A. Signal Generation and Transmission

The tranmitter is composed of the functional blocks which perform baseband signal generation (200 MHz bandwidth), signal upconversion to 35 GHz, and high power amplification. Signal generation takes place using an Agilent N8242A arbitrary waveform generator, which is capable of generating a 12 msec duration, 10-bit waveform sampled at 1.25 GSamples/second. This setup is sufficient to simulate a string of transmit, wide bandwidth waveforms that might be used by the SWOT mission.

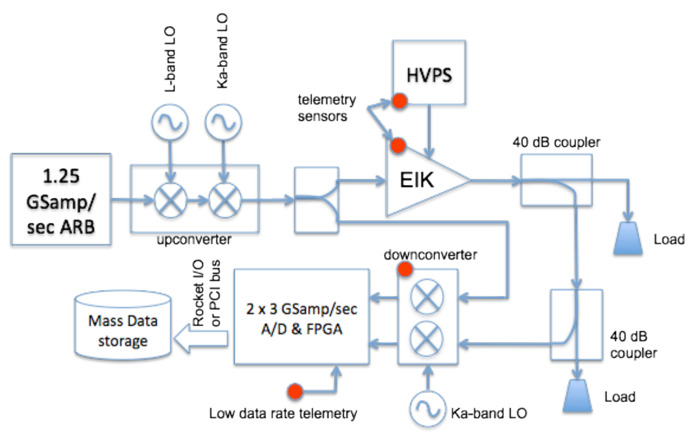

Figure 1. *Block diagram of the RF subsystem testbed under construction for the SWOT mission. Temperature, voltage and current telemetry sensors are collected throughout the system in order to characterize how variations in these parameters affect the overall performance of the system.*

The conversion of the baseband signal to the 35 GHz RF carrier used by SWOT takes place through a two-stage upconverter, where in-phase and quadrature components are used to create a 10 mW single-sideband signal (35.65 - 35.85 GHz) suitable for high power amplification and transmission. Additional controls are provided on the upconverter to allow for a transmit-enable signal and telemetry measures for monitoring overall upconverter health and performance.

High power amplification (1.5 kW) takes place through an Extended Interaction Klystron (EIK), a microwave tube technology similar to the high power amplifier being flown on NASA's Cloudsat mission. The amplifier operates at 94 GHz and performs a primary measurement of reflected power.

Because SWOT is an interferometric measurement and therefore primarily sensitive to phase, electrical path length variations and changes in the transmitter characteristics will have a big impact on the derived science products. The sensitivies that will have the most effect on the overall system are associated with the stability of the high power amplifier, the stability of the supply for DC power to the amplifier, and thermal pathways that will effect the electrical length of the transmit signal. For this reason, temperature, current and voltage sensors are mounted on the three basic components of the high power amplifier: the high voltage power supply (or modulator), the Extended Interaction Klystron, and on the waveguides leading into and out of the EIK.

B. Signal Routing

Signal routing takes place throughout the RF testbed. Points of primary interest are in the creation of a reference signal that can be used for comparison with signals routed through alternative pathways in the SWOT RF signal chain. At 35 GHz, this takes the form of a rat-race hybrid coupler (Figure 2), but may take other forms, depending on the frequency and the point in the system that it is applied.

A critical point for using such a reference signal is a demonstrated ability to characterize signal differences to a better degree of accuracy than the signals being measured. To achieve this goal, the most basic test setup of signal generation, splitting and reception, all occurring at baseband, has been tested and shown to be accurate to better than 3 mdeg and 0.01 dB of accuracy [Siqueira et al., 2006]. While further accuracy improvements can be made by increasing the number of samples collected [Siqueira et al., 2007], this is deemed unnecessary for this system, as it is expected that the RF components will add signal variations of at least one order of magnitude greater than these measurement errors.

Once a baseline measurement accuracy has been established, it is a straightforward matter of building outwards from a known measurement accuracy to include additional components in the transmit and receive chain and to monitor the effect that these additional components have on the overall measurement accuracy. Note that this approach is different than what might be practiced with network analyzer measurements, where it can be difficult to gain insight into the cause of various measurement errors, and therefore create a measurement strategy that minimizes them.

For tests that include the 1.5 kW high power amplifier (HPA; 61 dBm), it is important to shed energy so that the receiver can remain in its linear region (~ -60 dBm) in a way that minimizes the potential influence of the energy loss on the signal characteristics (phase and amplitude) that may be of interest. For this reason, a series of 40 dB waveguide directional couplers have been used in conjunction with an underdriven EIK, a configuration that is expected to minimize the overall sensitivity to thermal effects on the electrical path legth and bandpass characteristics, while maintaining a basic connection to the various devices under test. Once the reference signal and the signal that passes through the RF subsystem have been brought to the approporiate power levels for reception, they are fed into the two-channel Ka-band receiver.

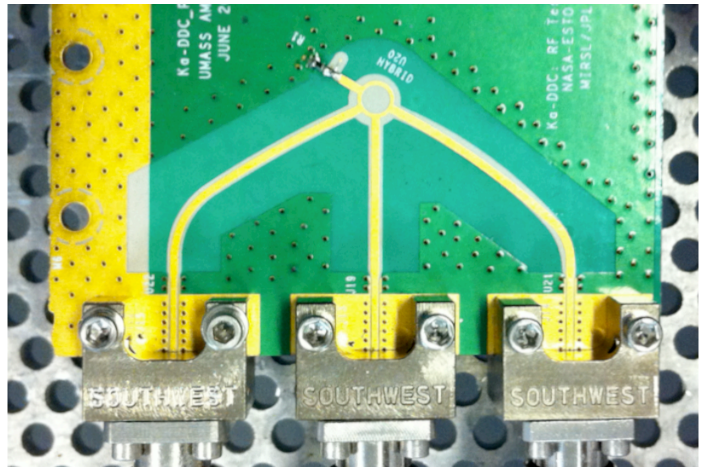

Figure 2. *A simple power splitter used for creating test and reference signals at 35 GHz. Line and cable lengths are minimized after the splitting to avoid sensitivity of the system to unintended thermal gradients. The overall width of this splitter is on the order of 5 cm.*

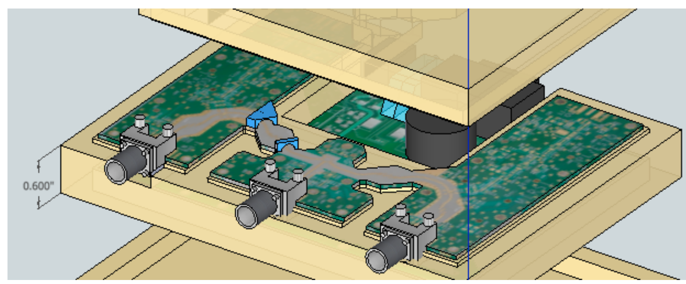

Figure 3. *Closeup of the current Ka-band to L-band downconverter design. The RF board connects to the DC telemetry and power board through a set of Tusonix feed-through connectors. Different functional blocks of the downconverter (two channels and LO distribution) are isolated from one another by a set of drop down walls that mates with the lower part of the chassis.*

C. Signal Reception, Storage and Analysis

The two-channel Ka-band receiver used in the SWOT RF testbed has been developed as part of our group's ESTO (Earth Science Technology Office) funded ACT (ACT-08-0048) [Siqueira et al., 2010]. The most recent instantiation of this receiver consists of a single-stage downconversion from Ka-band to L-band followed by digital sampling that takes place on a custom-built, two-channel 3 GSamp/sec analog-to-digital conversion board, complemented by a Xilinx-4 FPGA and supporting hardware. The inclusion of a powerful FPGA with high-speed A/D converters creates a digital subsystem that is also capable of receiving thermal and electrical status (power, current and voltage) telemetry from the analog portion of the downconversion process. Thus, the two interferometric data streams can be blended with the telemetry data, to characterize and ultimately compensate for thermally and electrically sensitive components of the analog downconversion process.

The Ka-band to L-band downconverter has been updated from a previous design [Siqueira et al., 2007] which includes a separate board for low-frequency power and telemetry as well as a set of isolation cavities on the RF side which separate the two channels of downconversion, filters, and LO distribution from one another. The newer design also has increased the number of telemetry sensors and includes a method for actively influencing the temperature of the two down-conversion channels (Figure 3).

The L-band output of the two-channel downconverter is then input into the A/D converters and subsequently processed by algorithms implemented in the Xilinx-4 FPGA. Here, the data can take one of three paths. In the first, two channels of raw, 8-bit data collected at 3 GSamp/sec is windowed using an on-board trigger, and then formatted and sent to a hard disk via a standard SATA interface capable of storing data at 3GB/sec. In this way, data can be monitored for bit conversion errors and anomalies that are expected to occur rarely. A second path for data analysis is via a set of on-board algorithms designed to measure frequency, phase (absolute and differential) and amplitude in real-time, as well as to report telemetric observations of temperature, voltage and current read from external sensors, or those located on-board the RF downconverter [Vijayendra et al., 2011]. Results are output through a serial interface and may be monitored over periods extending from seconds to days.

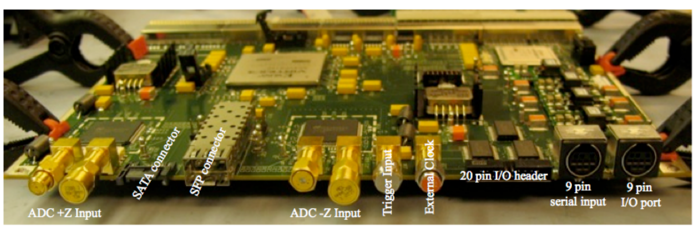

Figure 4. *Front-end image of the two-channel 2 x 3 GSamp/sec board built with space-qualifiable parts. It is designed to interface to the UMass Ka-band to L-band downconverter. The dimensions of the A/D and FPGA board are 24 cm x 16 cm.*

The third path that data input to the A/D board can take is through the standard processing that is expected for SWOT science data. This path includes digital filtering of the two channels of 200 MHz bandwidth data and compensation for temperature effects that may affect the phase and amplitude performance of the downconverter. Two-channel output from the digital filters implemented on the FPGA are then sent for further processing or storage through a standard PCI bus that is intended to be the standard SWOT interface to the downconverter.

III. Results

While there are multiple tests that are ongoing with this test setup, and development continues with respect to making a dedicated system (i.e. system components are regularly used for a variety of test configurations), a number of results using this system have been generated.

The accuracy of the test setup was analyzed first. To achieve this goal, a 10 MHz STALO was split and used as the test and reference signal and as an input into a 4 GSamp/sec digital oscilloscope (Agilent DSO6102A). Recorded samples from the two channels were then used to estimate the differential phase and amplitude characteristics of the two channels [Siqueira et al., 2007] with the result showing that the amplitude is stable to within 0.01 dB and the phase to within 3 mdeg (Figure 5). Larger measurement variations of signals that have gone through further analog processing (e.g. amplification, filtering, upconversion, and downconversion) represent error characteristics of the additional components in the signal path.

Results using this method that show the effect of temperature on the differential phase have been demonstrated several times [Siqueira et al., 2007; Siqueira et al., 2010]. Current plans call for the technique to be used for a thermal compensation algorithm to be implemented on the A/D-FPGA board mentioned in Section II.C. To show both the effects associated with the generation of high power at Ka-band through the Extended Interaction Klystron, a test was performed using a setup similar to the configuration shown in Figure 1. In this case, a sinusoidal signal was generated over time, upconverted and then split into a test and reference signal. The test signal was then amplified by the EIK and subsequently attenuated and sampled by one of the two channels of the downconverter (the other channel being used for the reference signal). The result of this test yielded a biomodal distribution for the phase difference between the two signals (Figure 6), a result that has been traced to instabilities in the signal path induced in the power availability from the High Voltage Power Supply (HVPS). Additional measurements such as the ones described above will be used to improve the design of the HVPS so that phase deviations do not adversely affect the overall performance of the SWOT mission.

IV. Conclusions

In this short paper, an RF and digital subsystem testbed for the SWOT mission has been demonstrated. This testbed incorporates a 35 GHz High Power EIK amplifier and a two-channel 3 GSamp/sec Analog-to-Digital converter system. Additional upconverter, downconverter, and telemetry components can be used to monitor the effects of temperature, voltage and current on the overall performance of the RF subsystem. The testbed has been constructed so that various components can be inserted or removed from the testbed to monitor and test overall system behavior and to improve the system design.

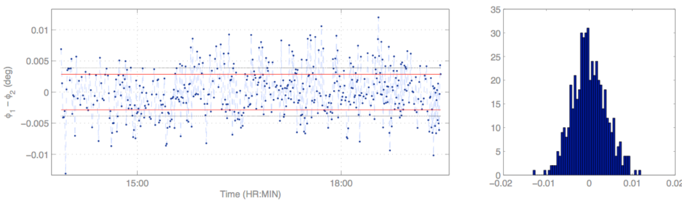

Figure 5. *Demonstration of the system measurement accuracy in terms of differential phase using a split 10 MHz STALO as the test and reference signal. As can be seen in the above time (5 hours) and histogram plots, the standard deviation of the phase estimates is on the order of 3 mdeg.*

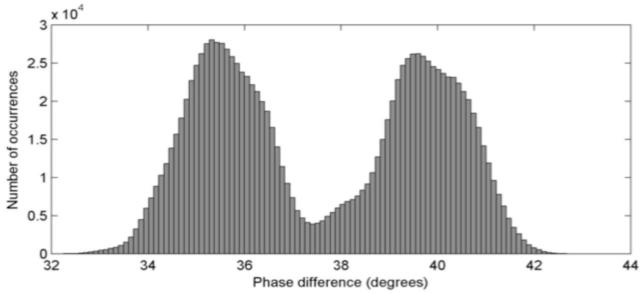

Figure 6. *A histogram of the phase difference between a reference signal and a signal that is amplified by a 35 GHz EIK. The bimodal distribution apparent in the above is "real" (see Figure 5) and has been traced back to deficiencies in the HVPS used to supply the EIK.*

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