The Design and Characterization of a Ku- and Ka-band Downconverter for Spaceborne Interferometric Radar

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Abstract: **In this paper, we report on progress made in the construction and characterization of a two-channel, two-stage interferometric downconverter made for interferometric radar applications. The downconverters are constructed with a high-degree of symmetry between the two channels for the purpose of forming a balance between the two interferometric signal pathways, and therefore, to maximize phase tracking as a function of temperature changes. This high degree of symmetry, and closeness of proximity of the two channels however, has the potential to increase channel cross-talk, hence a balance must be found between maintaining a thermal balance between the two channels, and maximizing the channels separation from one another.**

I. Introduction

Radar Interferometry is a remote sensing technique for determining topography and target velocity that relies on the differential phase measured from a common signal received by two different antennas separated by a baseline. Generally speaking, higher frequencies lead to smaller baselines and therefore smaller deployment structures. Maintaining phase stability and measuring phase to a high degree of accuracy however becomes more difficult with increasing frequency. As such, in 2005, NASA awarded (through the Earth Science Technology Office's Advanced Technology Program; ESTO-ACT) a joint effort by the University of Massachusetts and the Jet Propulsion Laboratory to develop and characterize two interferometric downconverters, one that worked at Ku-band and the other Ka-band. In this, the project's third year, the development effort has been completed and the two downconverters have been tested from an electromagnetic/ microwave engineering point of view, and through detailed testing meant to explore the devices response to a changing thermal environment. Phase measurements accurate to within 3 millidegrees have been performed on the downconverters with results showing that the two constructed devices meet the needs of maintaining phase stability to within 50 millidegrees in a thermally stabilized environment. Current work continues on modeling the response of the system to thermal changes and for removing the effects of those changes from the device output. Further, for improving the overall instrument's Technology Readiness Level, a simple interferometric system has been constructed suitable for rooftop and airborne deployment. In this way, observables such as differential penetration and topographic measurements at the two frequencies can be made that are relevant to the spaceborne equivalent of the millimeterwave interferometric devices.

II. Current Status

Previous papers on this subject [1,2] have shown the progress of the two-frequency (Ku- and Ka-band) downconverter development from a breadboard design to a final, integrated design. For both frequencies, a common L-band to baseband section is used for noise bandwidth filtering and signal gain. Both the RF and IF boards contain considerable (24 channels) of audio A/D resources for collecting telemetry related to temperature and power monitoring of critical components along the signal path. This telemetry is read out via a serial port located on the back-end of the downconverter. In what follows is a specific update on the status of the two different downconverter systems.

A. Ku-band downconverter

The Ku-band downconverter was the first of the downconverters to be constructed. This was done in order to firstly develop a basic, 'low-frequency' design for leveraging the higher-frequency Ka-band design, and secondly to provide a platform for creating a test measurements system capable of verifying the interferometric performance of the downconveter [3]. The Ku- to L-band section of the downconverter is shown in Figure 1 below.

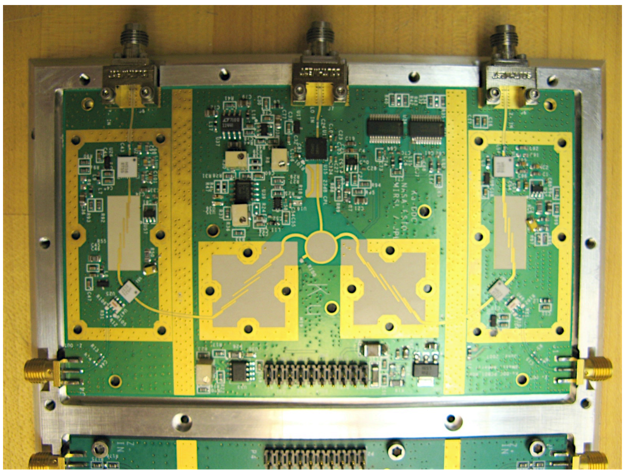

Figure 1. Ku-band to L-band downconverter section

The Ku-band part of the downconverter fundamentally consists of a an LO-distribution section (center section of Figure 1) with RF signal filtering to improve channel isolation, two channels of science data routing, complete with low-noise amplification, mixing and LO-rejection filtering, and thermal and power monitoring for use in system characterization and signal correction. The RF science data and LO inputs can be seen at the top of the Ku-band section, and output from the sides via an SMA connector which connects via a short jumper to the L-band section immediately below. The presence of these jumpers allows for insight to be gained on the RF system performance without the need of opening the overall downconverter chassis.

TABLE I
Ku-band Electrical & RF Performance

Electrical Characteristics	
Voltage	10 to 16 V
Current	1.3 to 0.8 A
Power	13 W
RF Characteristics	
Gain	62 dB
P1dB	-44 dBm
Input Return Loss	17 dB
Isolation	61 dB
Noise Floor	-115 dBm
Estimated Noise Figure	3 dB

B. Ka-band downconverter

After the completion of the Ku-band downconverter, the Ka-band was the next step in the development. The completed downconverter consisting of both the Ka- to L-band and L-band to baseband sections is shown below in Figure 2. Shown also in the Ka-band section are some of individual filter shields (gold plated metallic covers) bolted to the PCB and chassis below. A larger cover, with drop drop down walls that bond electrically to the gold plated via strips seen on the PCB, is later secured after testing is completed.

Because of the short wavelengths involved, packaged parts such as amplifiers are not practical (and don't exist) because of the inductance associated with the leads. Hence, gold filaments are used to transition from the microstrip feed to the amplifier die, making a hybrid design, as shown in Figure 3. In this image, note too the chip capacitor used to provide a clean power source for the amplifier. The dimension of the chip capacitor is approximately 1mm on a side.

The L-band section in this figure has facilities for additional noise bandwidth filtering and on-board power regulation and a switching power supply. Telemetry data is read out via the serial port seen to the right of the image and the L-band board.

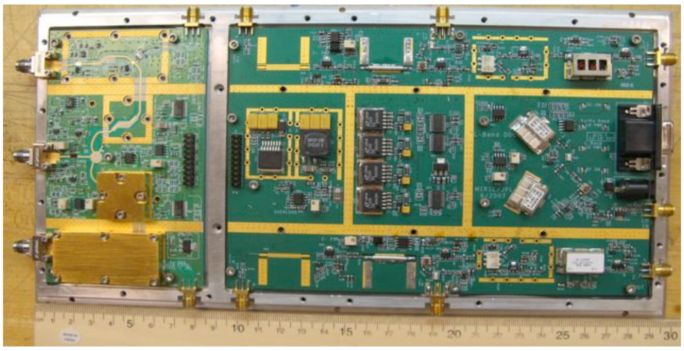

Figure 2. The complete Ka-band downconverter

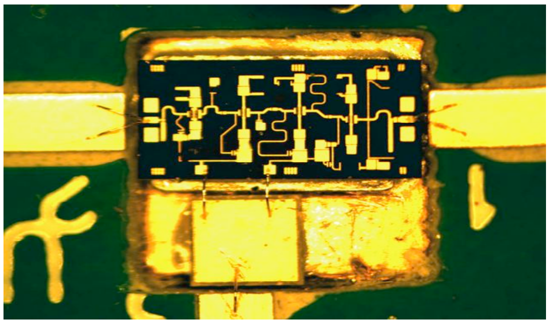

Figure 3. The Ka-band LO power amplifier.

III. Detailed Testing

The construction of RF to baseband downconverters has been a well practiced art since the inception of RF wave propagation for communications. In that context, higher frequencies have been attractive because of the larger bandwidths available for a given fractional bandwidth. For the application that this downconverter was constructed for, radar interferometry, precision of relative phase and gain between the two channels if of paramount importance. Figure 4 shows the location of the two-stage downconverter (labeled DDC) in a spaceborne interferometric system. It can be seen that this forms the heart of the instrument. Characteristics that influence the measurement of relative phase between the two channels of downconversion directly affects the science deliverable, in this case topographic height, which is derived from the phase via a linear relationship.

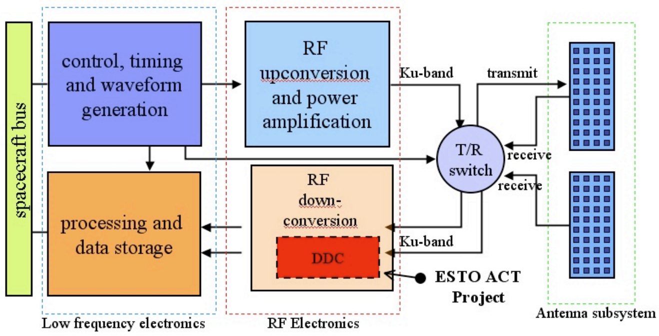

Figure 4. Block diagram of a spaceborne interferometer. The two-stage RF downconverter is specifically highlighted.

The gain pattern for each channel, as a function of bandwidth, is a first, and fairly straightforward measurement to make. Gain flatness with respect to a linear fit becomes important for interferometry because of a slight shift in the target's spectrum for the two different antennas that make up the interferometric pair. This is corrected for by shifting the spectra relative to one another, and causes a slight loss in range resolution. The results of this for the Ka-band system is shown in Figure 5 below, where it can be seen that over a 100 MHz bandwidth, the flatness with respect to a linear fit is better than two dB relative, and better than 4 dB absolute. Over shorter bandwidths (likely for a spaceborne case) this performance is even better. In both cases, the flatness is deemed to be sufficient, but perhaps not extraordinary, for interferometric applications.

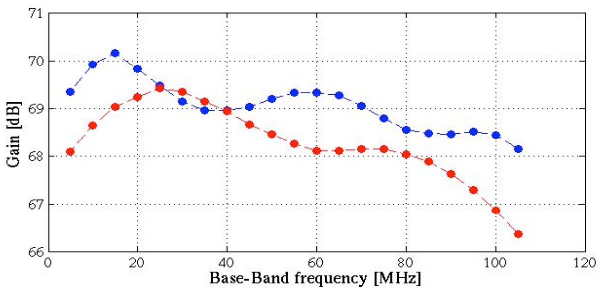

Figure 5. Gain curves for the two channels of the Ka-band downconverter.

A second performance measure of considerable importance is the phase stability of the two-channels relative to one another. This stability, and the channel isolation, can dictate the distance that the two antennas of the interferometer are separated by; hence, having a strong impact on the overall satellite structure. Similarly, by bringing the two antennas of the interferometer closer together reduces the overall path length that the RF signals have to transverse, making the signals less susceptible to thermal differences and therefore having a doubly favorable effect on the overall system performance.

To measure the phase difference to a high degree of accuracy (better than 3 millidegrees), a maximum likelihood technique was developed [3]. Results of the phase difference, as a function of time (one measurment taken every 10 seconds over five hours), is shown in Figure 6. Here, a steady phase difference drift can be seen due to the differential heating between the two channels, and a slow drift toward a higher operating temperature. Because of the slowly changing behavior of the phase due to the thermal drifts, these effects can be accounted for by the on-board thermal sensors. The fast varying phase variations however are more problematic and represent a fundamental performance limit for the system. A limit, which has also been shown to be temperature sensitive (not shown here). As shown i the figure, leaving the phase trend in the data gives a phase variation of 115 millidegrees. After removing the trend, the variation is 44 millidegrees. These measurements were taken inside of a thermally isolated chamber where the ambient temperature was allowed to reach the operating temperature of the downconverter (approximately 45 degrees Centigrade).

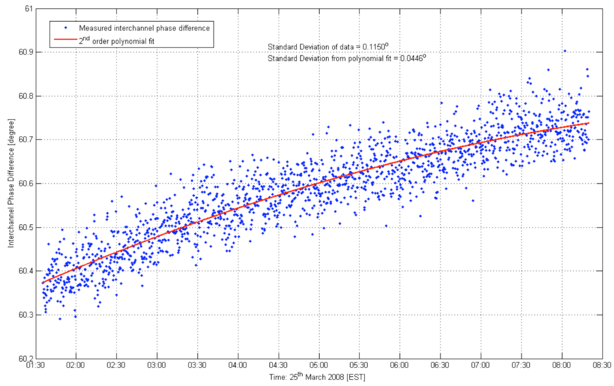

Figure 6. Differential phase measured as a function of time

III. Increasing the TRL

To increase the overall Technology Readiness Level (TRL) of the system, the downconverter is being placed within a working interferoemter. This consists of a transmit section, antennas, and a digital system composed of either a combination of an arbitrary waveform generator and a digital oscilloscope, or a combined system created out of parts available off of the shelf from National Instruments.

The engineering design of antenna system, using a slotted waveguide architecture is shown in Figure 7. Here, a flange is added to the elevation direction of the waveguide to broaden the effective size of the antenna and increase the gain. The presence of the flange also aids in the isolation between the receive channels and forms a smoother impedance transition to free space. This design has been implemented, and tested in a near-field range, using standard WR-62 (Ku-band) and WR-28 (Ka-band) waveguide. After finalizing the implementation of the interferometer digital and mechanical subsystems, it will be tested from a building top on the UMass campus, and eventually on an airborne platform (currently being investigated).

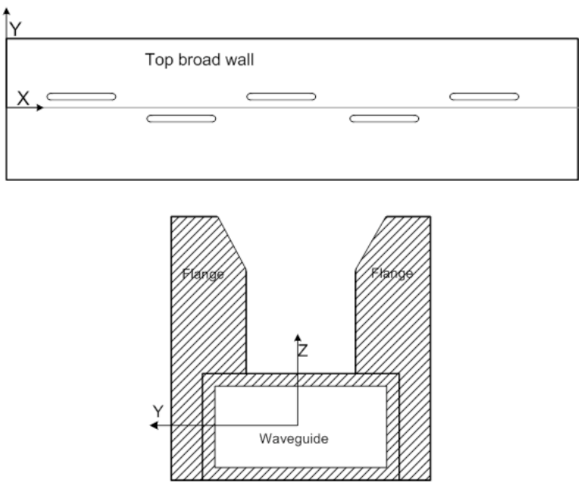

Figure 7. Design of the slotted waveguide antenna

IV. CONCLUSIONS

The Ku- and Ka-band downconverters have been built and tested as part of this Earth Science Technology Office's Advanced Component Technology program. Results have shown that the system is performing well and that it can be characterized, at both frequencies, to the level of accuracy required to show performance. In addition to continuing with thermal and performance testing, the downconverter is being integrated into the larger system to demonstrate its overall application and to further its TRL rating.

ACKNOWLEDGMENT

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