The Design and Evaluation of a High Performance Ku-band Downconverter for Spaceborne Interferometric Radar

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Abstract – This paper discusses the results from the creation and testing of a high precision two-channel Ku-band downconverter development by the University of Massachusetts and the Jet Propulsion Laboratory. The Ku-band downconverter is a critical part (in terms of performance) of interferometric radar systems. The designed Ku-band downconverter is built and tested over temperature ranges and included in a rooftop deployed radar looking at snow covered ground. Lessons learned from the Ku-band development are currently being applied to a similar system operating at Ka-band.

I. Introduction

Interferometric radar works by measuring the differential phase measured by two antennas separated by a baseline. If this baseline is oriented in the direction of antenna motion (along-track interferometry), the system is primarily sensitive to the velocity of observed targets. If the baseline is oriented in the cross-track direction (Fig.1) the phase difference is proportional to the topography. In either case, the precision to which the differential phase can be measured affects the accuracy of either the velocity or the topographic measurement.

The basic equations for this treatment, and their importance to the development discussed here, are discussed in [1]. Fundamentally however, an increase in the carrier frequency allows for a proportional reduction of baseline length if all other variables are held constant. Since resolution is proportional to bandwidth, higher frequencies also have the advantage of being capable of achieving higher resolution. Hence, in order to reduce the dimension and mass of spaceborne structures for single-platform, single-pass interferometers, and achieve good spatial resolution, there is a general trend to achieving interferometry at higher frequencies (e.g. Ku- and Ka-band).

Challenges associated with working at these high frequencies are associated with the ability to measure phase accurately and thermal effects which affect the differential path length for signals within the downconversion chain. The downconverter from RF to baseband is an important component in the overall development of high frequency interferometers (Fig. 2) and is the topic of work supported at the University of Massachusetts by NASA's Earth Science Technology Office through the Advanced Component

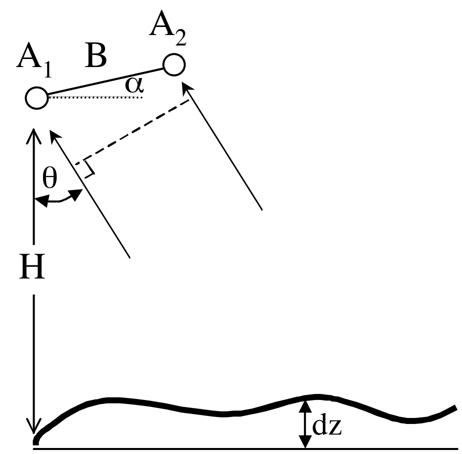

Fig 1. Observing geometry of a cross-track interferometric radar.

Technology Program. This paper summarizes progress made in building and characterizing a two-channel, two-stage downconverter, initially at Ku-band and subsequently at Ka-band.

II. Basic Developmental Components

The basic developmental components of the downconverter design, can be broken down into three parts. That is, from the carrier frequency (Ku- or Ka-band) to an intermediate frequency (L-band), downconversion from L-band to baseband, and finally, in creating a measurement system capable of characterizing the system to high precision in terms of phase and amplitude as a function of frequency and temperature. The intermediate stage at L-band is necessary for providing sufficient room for image rejection and for setting the noise bandwidth. Design performance characteristics for the Ku-band downconverter are given in Table 1, with a similar set of characteristics applying to the Ka-band system (RF from 34.985-35.015). An block diagram of the Ku-band version of the downconverter is given in Fig. 3, with an image of the completed downconverter given in Fig. 4.

A. *Downconversion for Ku- (Ka-) to L-band*

The Ku-band and Ka-band downconverter stages are implemented on Rogers 6002 laminate glued to an FR4 substrate, and kept physically separate from the L-band downconversion and filtering stage to i.) improve isolation, ii.) provide convenient checkpoints for interrupting the signal flow performing intermediate analysis, and iii.) to provide a degree of redundancy in design at the L-band and further stages which can be used to focus much of the technology development at the RF stages. Downconversion to L-band also allows a significant separation (~2.5 GHz) between the RF passband and its equivalent image band, hence providing significant margin for designing image reject filters.

Separate RF tight cavities are used to minimize the inter-channel crosstalk and to suppress the excitation of cavity modes. The integrated chassis and PWB design has also taken into account the need for mechanical and thermal symmetry between the two downconversion channels in order to minimize imbalances that may occur in the differential phase performance under conditions of moderate thermal stress.

The RF downconversion step fundamentally consists of: amplification (LNA), image filtering, downconversion, and splitting of the RF local oscillator. The splitting of the RF LO is a critical component in that by sharing a common oscillator signal, interchannel phase accuracy is maintained at potentially the cost of reduced isolation through the common signal path. For this purpose, an RF reject filter is placed on both signal feeds from the LO, providing an additional 25 dB, to the 60 dB gained from the active components and power splitter. Indeed, a first iteration Wilkinson divider was used prior to settling on a rat-race hybrid for improved isolation performance.

TABLE I. *Ku-band dual-downconverter design constraints.*

Design Constraint	Ku-band DDC
Signal & (Noise) Bandwidth	20 MHz & 30 MHz
Input Frequency Range	13275 – 13295 MHz
Operating Temperature	-10 to 50 degrees C
Noise Figure	< 4.5 dB
Output Frequency Range	5-25 MHz
Channel to Channel Isolation	> 80 dB
Relative Channel to Channel Phase Stability	0.050 degrees RMS over BW
Receiver Phase Variation over Best Quadratic Fit	3 deg RMS over BW
Receiver Amplitude Variation	2 dB over BW
Receiver Amplitude Variation over Best Linear Fit	0.3 dB RMS over BW
Input Signal Range	-100 to –65 dBm
DDC End to End Gain	65 to 70 dB
Image Rejection	> 30 dB

B. *Downconversion from L-band to Baseband*

A four-layer FR-4 substrate is used for filtering, amplification and dowonconvesion from the L-band signal to baseband. Principal along the L-band signal path segment is the noise bandwidth filter, nominally set to 30 MHz with a 20 dB or better rejection in the stop band. At this intermediate frequency, electrical dimensions are less sensitive to temperature changes and the filter, up to 100 MHz, does not represent a significant fraction of the IF, hence simplifying the filter design. A 20 dB coupled test port is also provided at each channel of the IF, which may be terminated with a matched SMA load, or directed to a spectrum analyzer/power meter for monitoring.

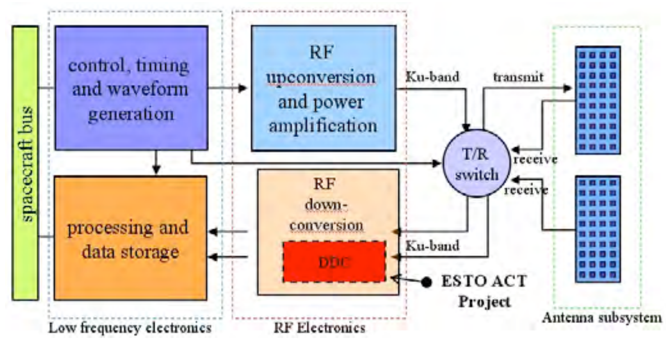

Fig 2. *Block diagram of a microwave interferometer, highlighting the downconverter development supported by ESTO.*

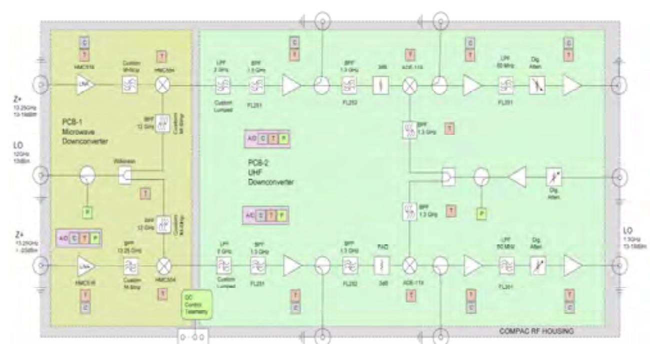

Fig 3. Block diagram of the two-stage, two-channel Ku-band downconverter.

C. *Temperature, Power and Current Sensors*

A number of simple circuits were developed for both RF and IF stages of the downconverter for sampling the power, current or temperature at various point in the PCB (Fig 3). Two, eight channel analog to digital converters operate on both the RF and IF stages, and fed out through a common serial port which may be monitored via computer. This provides a method for actively monitoring temperature, power and current at various critical stages of the downconverter; information that can later be used for determining the health of the system, or for compensating for variations which may affect overall performance.

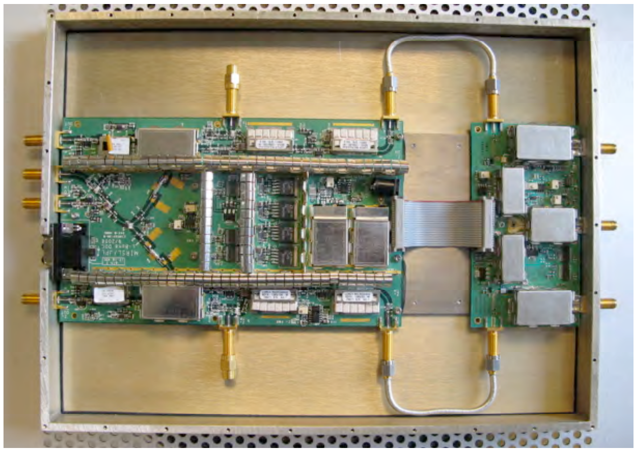

Fig 4. *Photograph of the Ku-band downconverter in its temporary housing. The dimension of the PCB is 10"x5", which can be halved by effectively folding the PCB in two.*

D. Measurement and Testing

The high degree of performance required for the dowconverter (Table 1) requires a commensurate method for testing these requirements. The presence of multiple downconversion stages which are fundamental to the device's performance, and the requirement that these performance characteristics be maintained over temperature further emphasizes the need for unique testing methods.

To achieve these goals, UMass has developed a method for measuring phase and amplitude to varying degrees of accuracy based on the number of samples collected and the overall signal to noise ratio [2]. The advantage of the approach described in [2] is that measurement accuracy can be analytically specified, thus making it possible to accept or reject various performance hypothesis based on basic signal characteristics. Using this approach, sensitivities of 4 milidegrees have been achieved, sufficient to detect one degree phase changes in the downconverter due to thermal fluctuations in the laboratory environment (Fig. 5). Isolating the downconverter in a thermal-chamber, fluctuations are shown to reduce to ~30 millidegrees.

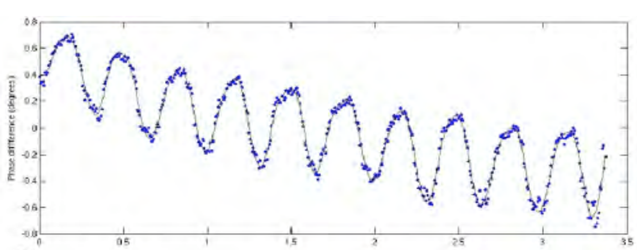

Fig 5. *Phase difference measurements for a common signal injected into two channels of the downconverter. The plot shows the phase differences (symbols) and a low frequency curve fit to the differences. After removing the slowly varying trend (line; due to temperature changes in the room), phase measurement accuracies of 3 millidegrees can be achieved.*

III. Ku-Band Downconverter Performance

Upon completing the Ku-band system design and construction, basic electrical tests were performed, among them, amplitude (Fig. 6) and phase stability over the bandwidth. Further testing of the phase and amplitude stability as a function of temperature (-10 to 50 deg. C) is now being actively carried out with the help of Temptronic corporation (www.temptronic.com), which makes programmable temperature chambers appropriate for the type of testing required for the downconverter. Analysis of these results is ongoing.

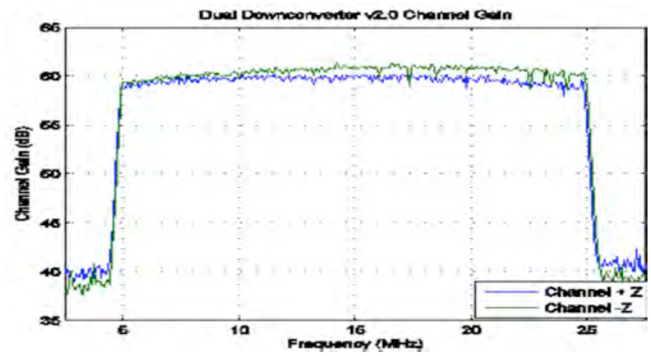

Fig 6. *Two-channel performance over a 20 MHz bandwidth. Amplitude linearity is better than 0.2 dB, and two-channel amplitude matching is better than 2 dB.*

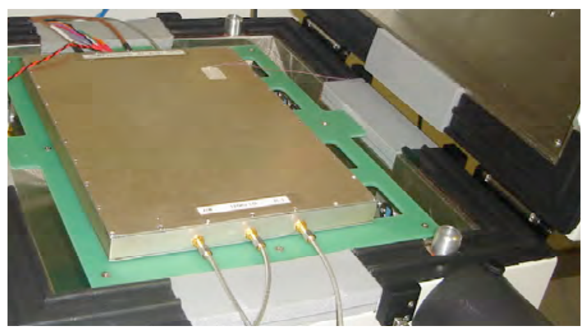

Fig 7. *The Ku-band DDC mounted in its thermal test setup provided by the Temptronic Corp, in Sharon, MA.*

Once it had been verified that the system performance would meet specification, it was desired to combine the downconverter with a transmit front end (2W), and antenna (Fig 8) so that it could be tested in the field and therefore augment the technology readiness level of the overall device. During January 2007, an opportunity arose to deploy this system in Canada, at the Center for Atmospheric Research Experiments (CARE; Fig 9) north of Toronto, so that simple measurements of the local topography with snow cover could be collected. Because of the instrument's close proximity to the ground, it was difficult to convert the measurements into topography (Fig. 10), yet the measurements provided sufficient evidence of overall stability and operation to further pursue these types of experiments.

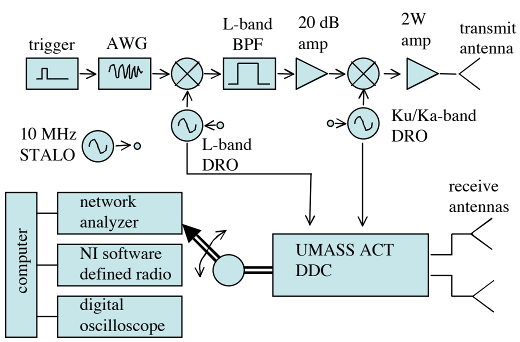

Fig 8. *Block diagram of the full Ku-band interferometer.*

Fig 9. *Photograph of the Ku-band interferometer deployed in Canada. Shown at left is a network analyzer data system, power supply and DDC housing, and antenna positioner control. To the right are three slot fed patch arrays, one foro transmit and two for receive.*

IV. KA-BAND DOWNCONVERTER DEVELOPMENT

The Ka-band downconverter development is currently well underway. Initial designs of the bandpass filters and power dividers (Fig. 11) have been completed. In order to compensate for manufacturing differences and effects on the performance of the RF substrate, banks of filters were designed and constructed for the RF and LO (Fig 12) reject filters necessary for achieving image rejection and sufficient interchannel isolation.

To achieve minimal losses due to radiation or dielectric losses, much of the signal transmission will take place via co-

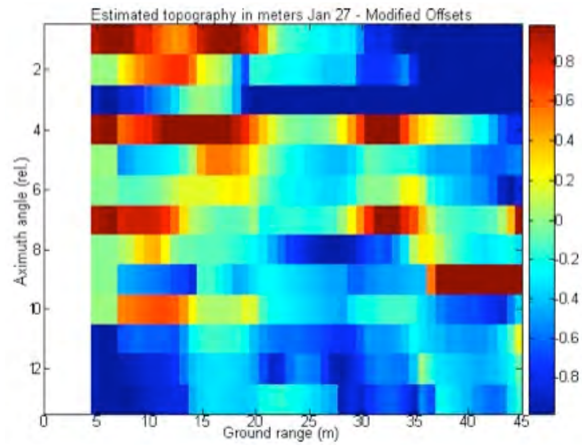

Fig 10. *Derived topography of a snow field in Canada (2007) using the Ku-band downonverter. The horizontal axis is the ground range, and the vertical axis the azumuth position. Topographic discontinuities in the above are likely due to phase wrapping occurring in single resolution elements, an effect also known as geometric decorrelation.*

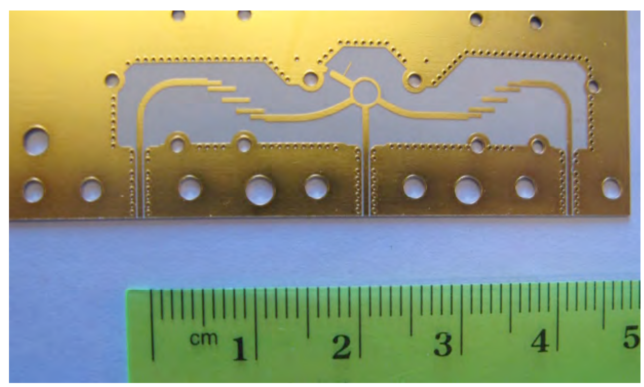

Fig 11. *A rat-race power divider used for providing the LO signal to the two channels of downconversion. A tuning stub is provided at the difference port of the hybrid.*

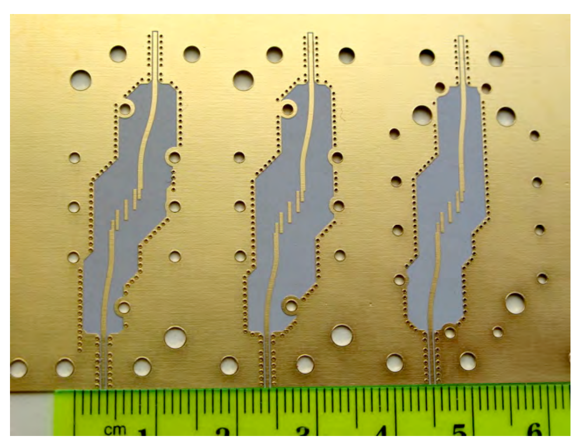

Fig 12. *A bank of RF rejection filters constructed with small, 2.5 micron manufacturing variations meant to determine the best design for the final manufactured product.*

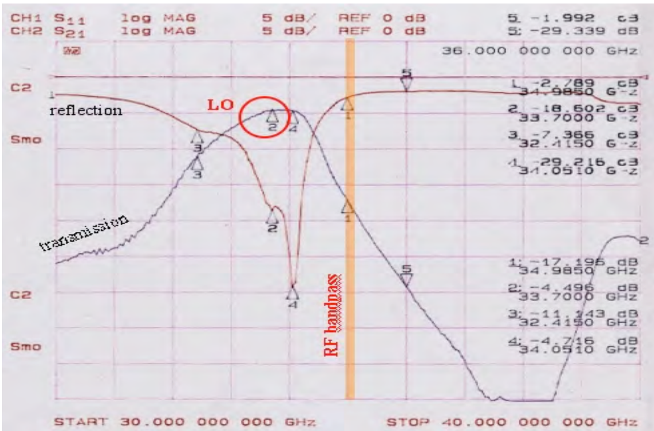

Fig 13. *Transmission and reflection characteristics of the RF rejection filters shown in Fig 12. The plot demonstrates a 12.5 dB or better rejection in the stopband.*

planer waveguide (CPW). Given that, coupled line filters are best designed utilizing microstrip. Hence, care has been taken in utilizing iterative design methods for the CPW to microstrip transition to minimize reflection and radiation losses.

V. Conclusion

In this paper, the motivation behind creating a high performance two-stage, two channel downconversion system was discussed in the context of cross-track interferometry. Given that motivation, and a table of design goals (Table I), the design philosophy for a PCB version of the downconverter was given. The Ku-band version of the downconverter has been implemented and characterized in a laboratory environment.

To achieve the accuracies required by the downconverter, it was necessary to implement a custom test environment whereby signal to noise ratio and the number of samples could be adjusted to achieve the desired measurement accuracies. The performance of the test setup is capable of measurement accuracies of better than 4 millidegrees, an order of magnitude smaller than the downconverter's performance requirements. This test setup has then utilized to characterize the downconverter when it was exposed to the open laboratory environment and under a more thermally isolated environment. Under the thermally isolated environment, it has been shown that the Ku-band version of the downconverter achieves differential phase accuracies to better than 20 millidegrees, a fair margin below the overall devices' accuracy goal of 50 millidgrees.

Because of the Ku-band downconverter's encouraging performance as a stand-alone device, it has been incorporated into an operable interferometer, and deployed in a field experiment in January 2007, to look at a snow target. Early results show that the system is operable, but perhaps was too close (~16m) to the ground to provide useful results. This is due to the large look angle variation per resolution cell, an effect also known as geometric decorrelation.

The Ka-band version of the system is currently under design and preliminary tests. This has been shown to provide sufficient RF band rejection to provide the requisite 80 dB or more of isolation between receive channels.

Acknowledgements

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References

[1] Siqueira, P., and Tope, M., "A High Performance Ku-band Two Channel Downconverter for Interferometric Radar Applications," NASA ESTC, Baltimore, MD, 2006.

[2] Siqueira, P., Wirth, J., Bachmann, A., " Variable Precision Two-Channel Phase, Amplitude and Timing Measurements for Radar Interferometry and Polarimetry," submitted to IEEE Microwave Theory and Techniques.