Project

WeatherCubes

Executive Summary Report

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Table of Contents

1 Introduction and Scope

1.1 Overview

This report summarizes the WeatherCubes project carried out at Omnisys Instruments. This includes its background, the most relevant test results and findings, and future recommendations.

1.2 Background

Recently, we have seen a number of factors in the space sector that are changing in a disruptive pace: the launch cost is coming down with a factor of 5-10 and the development using commercial components and techniques reduce system cost with an order of magnitude. We now seem to be able to develop "faster, better and cheaper" and as such new applications become profitable.

Earth Observation is looking for concepts that can open up new or enhance existing capabilities in terms of spatial or temporal resolution. In that respect a new weather forecasting concept has been proposed that would enable to:

- Improve forecasting of 0.5-24 hours with high accuracy;
- Improve forecasting of 24-48 hours significantly;
- Improve forecasting of 48+ hours;
- Improve in special areas, such as on the oceans.

Today a conventional weather forecasting system consists of three segments; the Sensor network, Numerical Weather Prediction (NWP) analyses and the End user segment.

NWP modelling is making vast improvements using state of the art algorithms and increased computing power and are capable of handling significantly more input data into the models. The End user segment covers a wide range of technologies from Smartphone apps to dedicated evaluation of risk and cost for sea transportation.

Although microwave satellite instruments dominate the sensor segment in numbers, they still under-sample the atmosphere by a factor >10 in time. With an order of magnitude higher temporal sampling rate, the accuracy of the predictions will improve significantly which will have a high impact on society, commercial and private interests. The reason for this activity was therefore to address this issue and propose a way of increasing temporal sampling density with an order of magnitude and provide extremely reliable now casting and short term forecasting.

1.3 Objectives

The objectives of the WeatherCubes project was to demonstrate the feasibility of implementing a state of the art microwave sounder on a 12/16 U CubeSat.

A receiver with channels at 166 and 183 GHz was implemented together with a 160 mm effective diameter reflector in a format that would be compatible with a 16U format and maybe even the 12U. This is the most important receiver channels foreseen for the next decade and more for microwave sounding satellites and may motivate a satellite as by itself.

2 Project Overview

2.1 Design Concept

One of the main original ideas behind this project was that multiple receivers could fit in a single 12/16 U CubeSat with a shared main reflector and thermal calibrating load. The reflector's optical beam would be split into four different receivers by a shared prism, as conceptually drawn in Figure 1. This idea would be demonstrated by manufacturing and testing one of these four receivers.

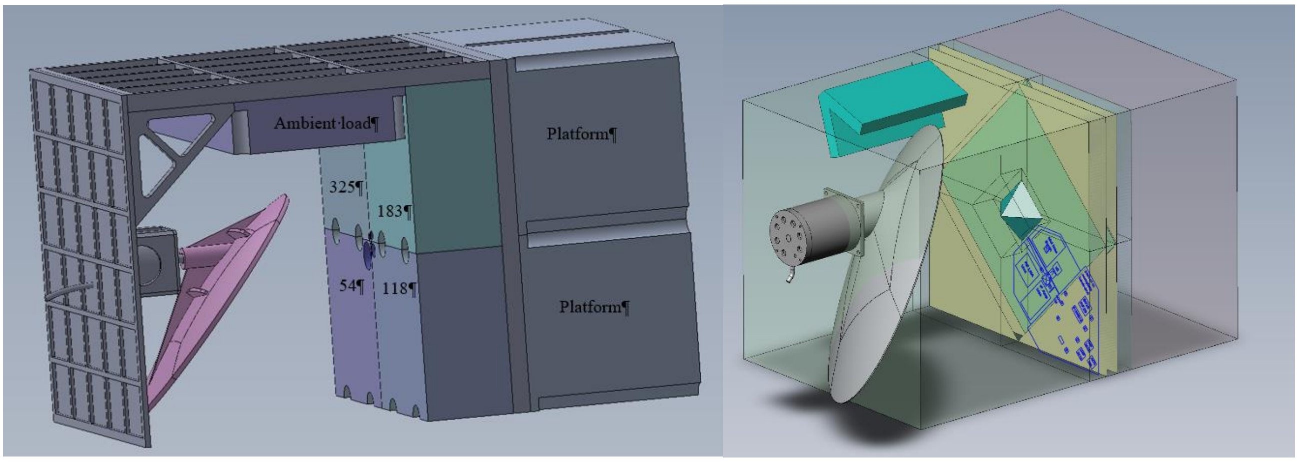

Figure 1 Two concept drawings of the same original 12U concept. The realized structure can be seen in Figure 3.

In addition, the receiver that was built (one of the four 1x1 dm quarters in Figure 1) was designed to cover both a window channel at 165 GHz, and multiple lower sideband channels of the water vapour line at 183 GHz. The combination of these channels in one receiver, as well as the compact size, is the innovating concept behind this.

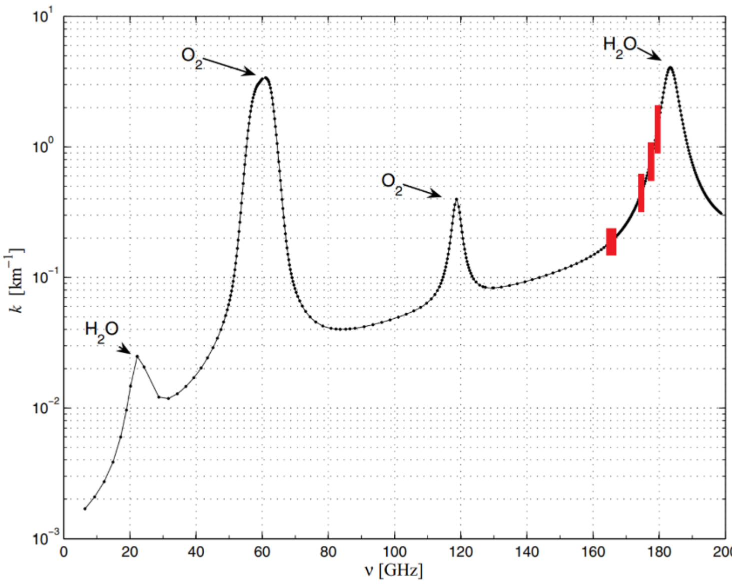

Figure 2 Frequency bands covered by the manufactured receiver. This is one out of a total of four possible receivers to fit in the concept shown in Figure 1.

2.2 Assembled Receiver

The completed optical structure together with the front-end of the built receiver can be seen in Figure 3. This structure partly represent the CubeSat enclosure from Figure 1, but holds two thermal test loads instead of one that will be used for a flight instrument. This was to enable testing in the lab, but would in flight be replaced with cold sky.

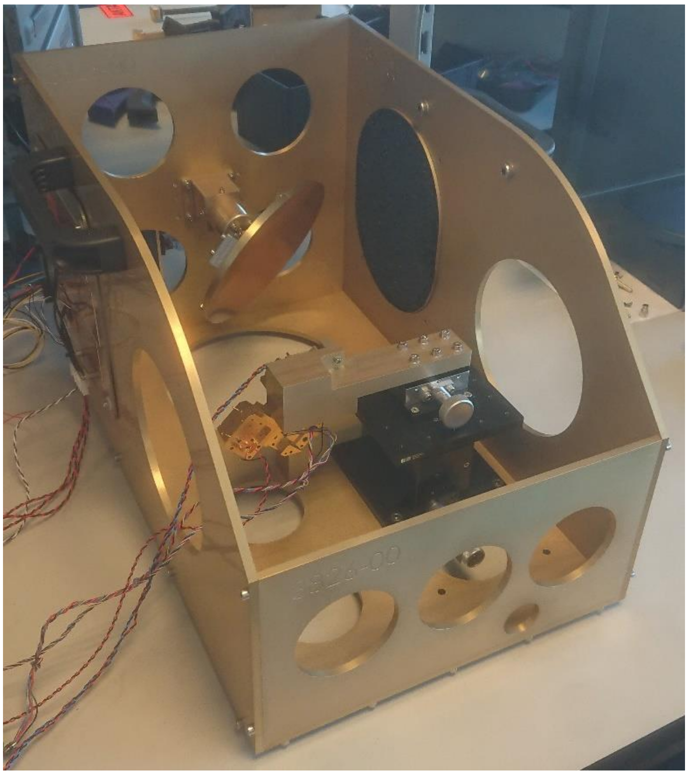

Figure 3 The front-end mounted in the optical test setup.

The entire WeatherCubes system together with the back-end can be seen in Figure 4. The purpose of the back-end was to demonstrate function, rather than trying to make it as compact as possible. Therefore, it is not mounted in the test structure, but in a separate shielded box. For flight purposes, it is suggested to put on a level below the front-end together with controller functions.

For this project, a board with both DC amplification as well as controller functions for LO, ADC, and motor was implemented. Similarly to the back-end, it is placed in the shielding box in Figure 4 and it was not prioritized to reduce its size. However, that is not expected to be a problem since it is already small, and could provide functionality for the other three potential receivers suggested in Figure 1 as well.

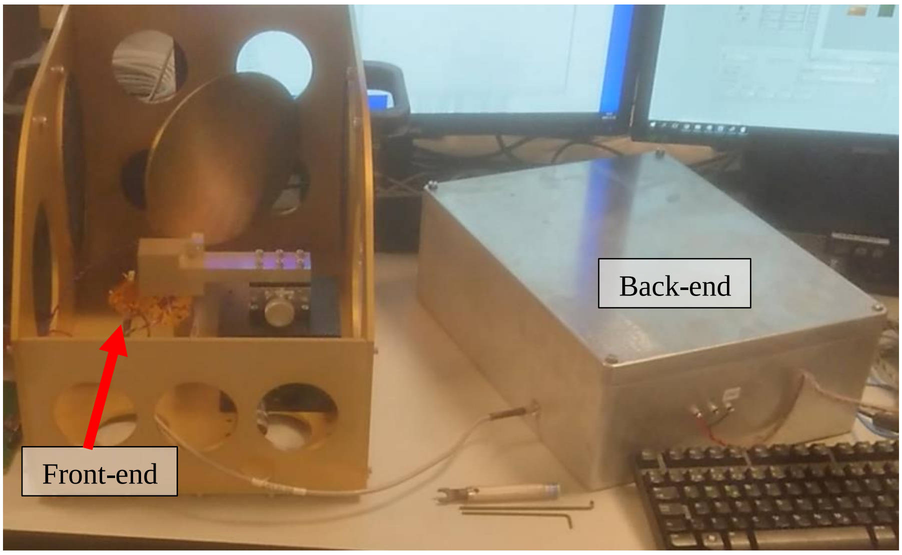

Figure 4 Front-end and back-end with rotating reflector.

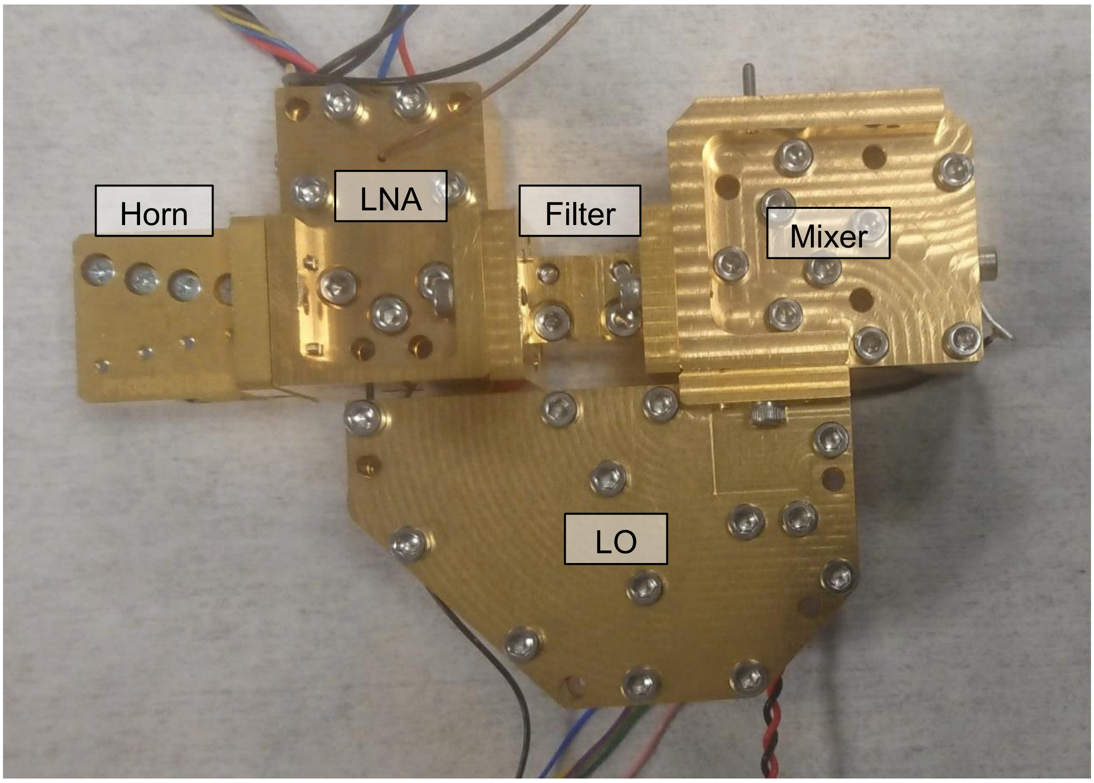

Figure 5 WeatherCubes front-end.

2.3 Main Results

From the entire optical system, an FWHM beamwidth smaller than 1.0° was shown, corresponding to a spatial resolution < 10 km from a foreseen 600 km altitude.

Two different LNAs were tested with the front-end; one that covered bands at 166, 183, and 200 GHz, and one narrower that only covered 166 and 183 GHz. It was clear that the narrower LNA performed significantly better in terms of sensitivity, showing receiver temperature below 650 K.

The receiver have therefore demonstrated both considerably better sensitivity as well as spatial resolution than specified for the METOP 2G MWS.

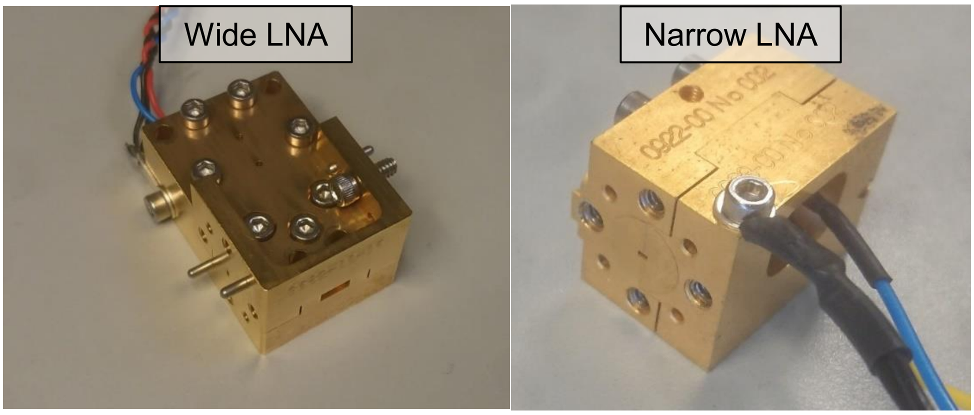

Figure 6 Two different LNAs tested with the front-end.

As for the rest of the front-end, the filter, the LO, and the mixer all performed as expected, showing S-parameters, phase stability, and noise figure as simulated. The front-end also showed stability well enough to cover an entire calibration cycle.

Some experiments were also made with another configuration for the mixer, where a double sided mixer was used before an LNA and the rest of the WeatherCubes receiver. The results were very good receiver noise temperatures at world record levels for that type of configuration, with possible band at 183 ± 12 GHz. That setup would also be a good candidate for a future CubeSat solution, but as for the rest of this project, the main focus was on the original 162 GHz upper sideband solution.

During the initial tests on the back-end, some ripple could be seen during tests on frequency response. Certain interfaces were suspected to be the case, and on an iterated version where these had been adressed, all ripple was gretly reduced to be well within acceptable levels. Linearity was also measured, revealing a 20 dB margin to compression.

Some more work would need to be put into the back-end before it could be considered ready for flight. Its stability would need to be looked into, but there are ideas that it could be improved by eliminating anouther invterface. A breadboard of the same principal design, but opimized for smaller space should also be manufactured.

As for the front-end, by using a narrower LNA with a lower noise figure, as have been demonstrated possible, the front-end seen in Figure 5 can be considered flight ready.

3 Summary

3.1 Future Recommendations

It has been shown that a great improvement of receiver noise temperature can be made by using an LNA that omits the 200 GHz window channel. This is strongly recommended for future uses, as it would also allow for a more compact back-end.

The back-end size could also be reduced to fit a 12U format by using the previously mentioned 183 GHz DSB mixer, which has shown very good performance in terms of noise. That would, however, mean that the back-end channels and the LO module design needs to be re-breadboarded.

The back-end showed good performance in terms of frequency response, but some work would need to be put into improving its stability. It is suggested to put at least the first DC-amplifier on the same PCB as the diode, to eliminate having a very faint DC-signal travel through straps between PCBs where it is more susceptible to disturbances. This could likely improve sensitivity and long term drifts as well, although these are already at acceptable levels.

3.2 Conclusion

This project has shown that it is possible to combine a two band receiver in a very small volume, with both a window channel at 165 GHz, and multiple detection channels at the lower side of the 183 GHz water vapour line. It has demonstrated function with thermal loads, and with an optical path that allows for 3 additional receivers to be implemented with the same loads.

For the back-end, some work remains before being flight ready. However, component choice, layout, and design have been demonstrated successfully. As for the front-end, by simply switching to the more narrow-band LNA which has demonstrated good performance, the front-end can be considered flight ready.