Optics for the TEMPERA-C polarimetric middle atmosphere temperature sounder

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***Abstract*— This paper presents the optical design, calibration, and receiver of the new fully polarimetric temperature radiometer operating around 53 GHz (TEMPERA-C) from the University of Bern for ground-based measurement campaigns. The optical setup will allow for elevation scanning, minimises cross-polar characteristics, and is more compact than the previous iteration of the instrument. The optics have been optimised using the GRASP software and the results are presented here.**

Keywords—radiometry, polarimetric, optics, atmospheric temperature, calibration

I. Introduction

The current iteration [1] of the TEMPERA instrument is a linearly polarised radiometer at 50 GHz in a stationary configuration at the University of Bern which has been used operationally to retrieve atmospheric temperatures up to 50 km altitude. However, there is interest in extending the altitude of these retrievals and enabling campaign measurements at other locations such as the Jungfraujoch (3500 m) which is ideal for reaching higher retrieval altitudes but requires an environmentally resistant instrument. Hence, an updated version of the instrument has been developed which is fully polarimetric and is combined with a more optimised retrieval that considers the Zeeman effect [1] which is currently limiting the vertical range of the retrieval. Resolving the difference between the left- and right-hand polarised emission will make it possible to push the temperature sounding higher into the lower mesosphere. Along with redesigning the optics for polarimetry, emphasis was placed on reducing the size to create a compact and portable instrument. This optimisation has been carried out using the GRASP software by Ticra.

II. Optical Setup

The optical setup (see Fig. 1) consists of a custom designed corrugated, highly gaussian feedhorn (yellow) positioned in the horizontal with a gain of 20.13 dB illuminating a 22.5° off-axis parabolic reflector (orange) with a diameter of 190mm and an edge taper >30dB. The off-axis angle is minimised to avoid induced asymmetries in the farfield beam. The beam is reflected upwards to a circular plane reflector (green). A path length modulation mechanism is used for the mounting of this reflector to account for standing waves. The reflector alternates between two fixed positions by rotating 180°, either directing the beam to the internal calibration target (black) or to the skyward plane reflector (blue). The skyward reflector is mounted in a periscope structure (grey) which can be rotated in the elevation plane to allow for off-zenith measurements. The purpose of the periscope structure (which is not shown in its full extend in Fig. 2) is to protect the instrument during rain- and snowfall, by pointing it towards ground. Some microwave transparent material could be used to seal the periscope but would introduce unnecessary reflections or standing waves especially if the window is painted with a water-resistant coating.

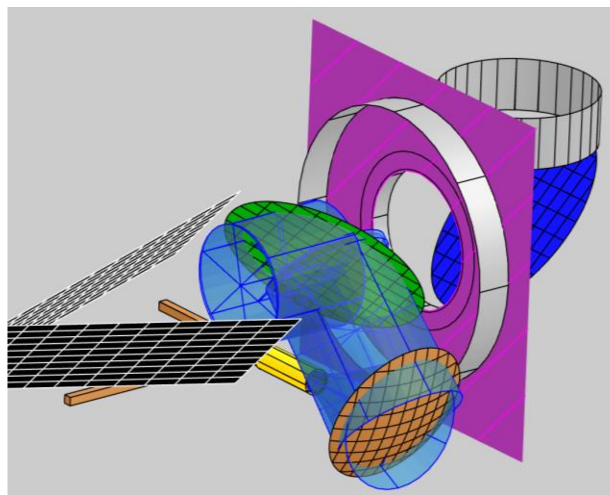

Fig. 1. GRASP model of TEMPERA-C optics in OBCT scan mode

III. Receiver

The receiver of Tempera-C is designed to simultaneously observe all four Stokes parameters. The frontend of Tempera-C splits the signal into vertical and horizontal polarisation, using an ortho-mode transducer (OMT). Both polarisation chains are identical, eliminating phase differences between the two when they are combined in the correlator. The following sentences describe a single chain for simplicity. A coupler right after the OMT facilitates adding a noise diode signal for gain calibration. After a bandpass filter, the signal is downconverted using a heterodyne mixer and then split into two. Both signals are supplied to the

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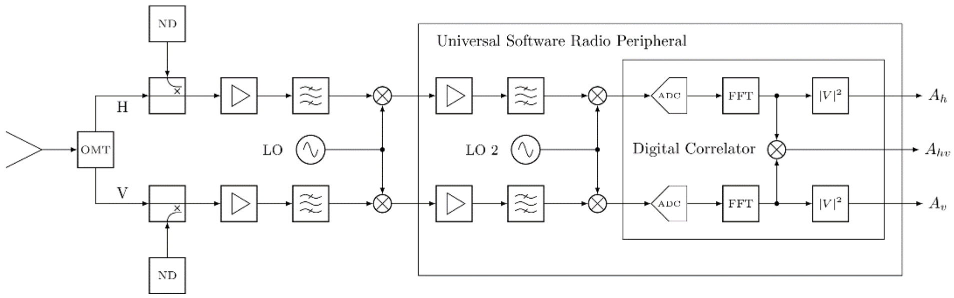

Fig. 2. Schematic of Tempera-C receiver

spectrometer (so four inputs – two per polarisation). In the spectrometer the signals are downconverted further to two different frequencies and digitised with a sampling rate of 200MHz. This allows the spectrometer to process two lines simultaneously, in this case corresponding to 53.0669 GHz and 53.596 GHz. The digital correlator inside the spectrometer then combines both polarisations to extract the third and fourth Stokes parameter. Since the correlation is done purely digitally, it removes a potential error source and is the key advantage of this setup for polarimetry. The spectrometer used for Tempera-C is based on a commercially available Universal Software Radio Peripheral and a FPGA firmware developed in-house for the real-time FFT processing and complex cross-correlation.

IV. Simulated Instrument Performance

The optics of Tempera-C were designed using an ideal gaussian beam approximation and consequently optimised and simulated with the simulated pattern of the actual feedhorn using the GRASP package from Ticra. The horn was selected based on its very low crosspolar levels. A comparison of the simulated pattern against measurements can be found below in Fig. 3. Key performance criteria for the instrument are a full width half maximum of <4°, minimised spillover and

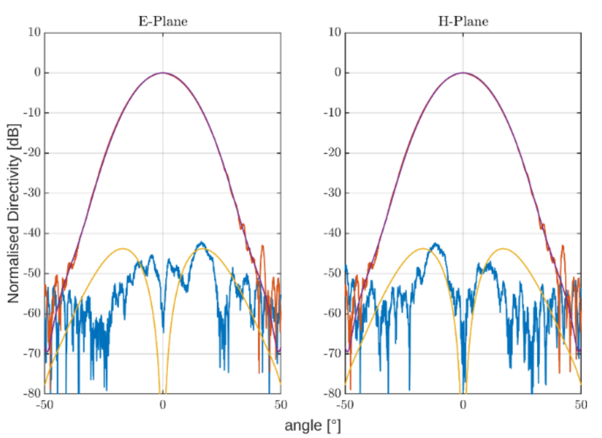

Fig. 3. Tempera-C horn measurements in comparison to simulation. Co- and Cross-polar simulation in violet and yellow. Measurements in red and blue.

low cross-polar component. Fig. 4 shows the farfield beams in zenith for two orthogonal polarisations as simulated in GRASP on a Phi, Theta grid. At low power levels (< -20dB), some small aberrations can be seen, due to the off-axis reflector. The total spillover of the instrument is less than 0.2%, including consideration of the periscope tube.

To check the bias introduced by the optics the product of the co-polar pattern of one plane and the cross-polar pattern of the orthogonal plane is calculated. In Fig. 4 it is the product of the two fields forming a column. The sum of these two products is the bias seen in the third stokes by the digital correlator. Assuming the horn pattern is symmetrical, the bias of the horn farfield using this methodology would be zero, as any bias in the individual chain would be identical to the other chain, but with a flipped sign and cancel out. This was verified in GRASP with the real pattern and a gaussian pattern to verify the approach. In the farfield of the instrument (including the optics) at zenith pointing the bias is the equivalent of –2.6mK, for a homogenous scene of 300K.

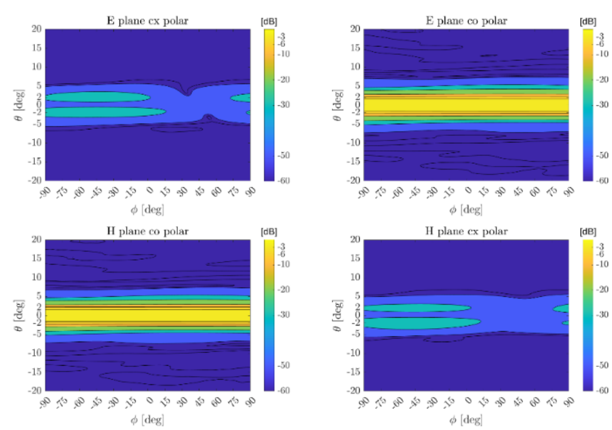

Fig. 4. Farfield patterns of Tempera-C for two orthogonal polarisations

V. Calibration

The instrument includes a wedge-shaped ambient load for calibration. In addition to the ambient load, the noise diodes in both frontend chains allow calibration without the constant use of a cold load. Periodically, this calibration methodology is validated using a liquid nitrogen cold load positioned below the skyward reflector, which can be rotated to point to ground. The ambient wedge is rotated 45° to both the horizontal and vertical polarisation for consistent performance across both polarisations. The ambient load is based on an existing design developed by University of Bern for the Arctic Weather Satellite [3], including an absorber mixture which was developed inhouse. Test data of the Arctic Weather Satellite wedge load show a return loss of 55 to 65 dB across the Tempera-C band. A cone would be a preferable shape since it is polarisation independent geometry but is harder to manufacture.

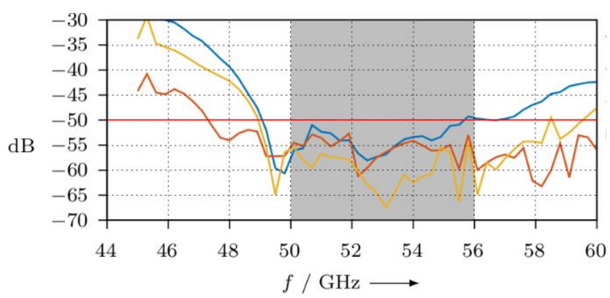

Fig. 5. Comparison of TE, TM and 45° rotation (blue, red and yellow respectively) return loss of OBCT.

VI. Conclusion

The Institute of Applied Physics is building a new fully polarimetric radiometer called TEMPERA-C, which allows to measure the for Stokes parameters simultaneously and to resolve the circular polarization which is caused by the Zeeman splitting of the oxygen emission lines. The new design raises the retrieval altitude into the lower mesosphere and the instrument will also be capable of measurement campaigns. As part of the optics redesign, an ultra-gaussian feedhorn was optimised along with more compact optics. The radiometer includes two identical receiver chains and a digital correlator which will eliminate error sources for the correlation. However, the optics could introduce a bias, which was investigated and found 2.6mK for a 300K homogenous scene in zenith. Further work is required to investigate this bias for other scan angles and inhomogeneous scenes.

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References

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