The Need for and Development of MM-wave Radiometer Calibration Targets with Very Low Coherent Backscatter

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***Abstract* — The need for radiometer calibration targets with very low coherent backscatter (S11) is not fully appreciated in the community which designs and uses mm-wave radiometers. We discuss why very low S11 is required and our attempts to design make and test calibration target with such desired low backscatter for calibrating both ground and space-based radiometers.**

***Index Terms* — Calibration, millimeter wave measurements, measurement uncertainty, radiometers, reflectivity.**

I. Introduction

MM-wave radiometers have been used for many decades for both probing the heavens and measuring the constituents and temperature of the atmosphere [1]. They need to be calibrated and traditionally they are made to look at a cold and warm target and the observed temperature obtained by interpolation or extrapolating from these reference values. It is well understood that the targets need to be black – that is that they need to have low incoherent reflectivity. A target with low incoherent reflectivity will (via reciprocity) present to the radiometer a temperature that is derived from the target's physical temperature alone. This paper discusses an additional requirement that it has very low coherent reflectivity – that is to say reflection back into the mode defined by the radiometer's optics which is (in a time reversed view) probing the target.

II. The Problem with Coherent Backscatter

Coherent backscatter leads to standing waves between the receiver and the calibration load. This causes a periodic baseline ripple given by

$$\Delta T_B = 2\,|\Gamma_1|\,|\Gamma_2|\,(T_1 - T_2)\cos(4\pi\, d/\lambda + \varphi) \quad (1)$$

where $|\Gamma_1|$ is the amplitude reflectivity of the radiometer (determined by the match of the antenna and the front end component – mixer or amplifier – in the radiometer) and $|\Gamma_2|$ is the target's amplitude reflectivity. T_1 and T_2 are the temperatures of the receiver and the target respectively.

For example, taking an upcoming ESA Microwave Sounder: for a 57 GHz channel one could assume $|\Gamma_1|$ for the receiver as 0.32 (-10dB). Suppose the calibration target had a coherent reflectivity of 0.0056 (-45dB in power). Furthermore we assume that brightness temperature emitted by the receiver is close to the physical receiver temperature, as an isolator-protected LNA would be. Even taking T_1-T_2 to be only 20K, an optimistic assumption on the effective temperature of the receiver, the combination gives a standing wave error of the order of 72mK. While small, this is not insignificant within the error budget of current and planned instruments.

The problem is most acute when the radiometer is looking over a narrow band of frequencies and the target is close to the receiver. In such a case there is no amelioration of the problem by "washing out" – i.e. averaging of the high and low values of the ripple within a band.

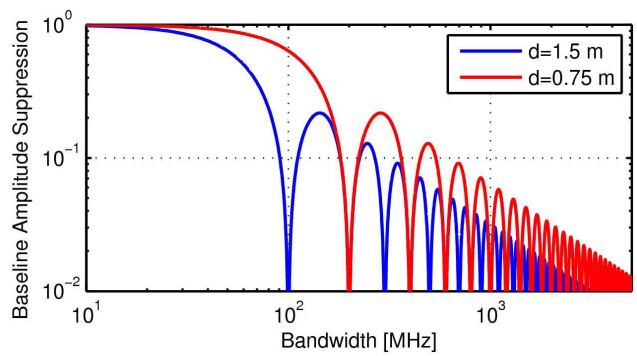

Fig. 1. Baseline amplitude suppression as a function of bandwidth for two radiometer/target distances, d.

Such "washing out" can provide some relief, which is displayed in Fig. 1 above, where suppression of the ripple is plotted against bandwidth for two radiometer/target distances of 0.75 and 1.5 m.

III. Cone and Wedge-Based Targets

Given the presence of this problem, we have, over many years developed a range of internal cone and wedge based targets, operating from 20 to 1000 GHz which aim to give very low S11 while retaining good control over the temperature of the absorbing material.

Targets built from internally-smooth cones and wedges have the advantage that rays entering the target suffer multiple specular reflections and high absorption can be achieved even though the absorption per bounce may be modest. This helps deal with the ever present engineering trade-off between the need for increasing absorption layer thickness to increase absorption to give the necessary S11 and minimizing the absorbing layer thickness to minimize temperature gradients within the absorber: it very difficult to place temperature sensors other than on the metal backing of the absorber, though the radiometric temperature is, of course, set by where the radiation is actually absorbed. If they are placed within the absorber they will scatter and impair the absorber's performance.

Such internal cones have been employed in balloon-borne atmospheric-sensing experiments (BSMILES [2], TELIS [3]) and in calibrating the ALMA telescopes [4].

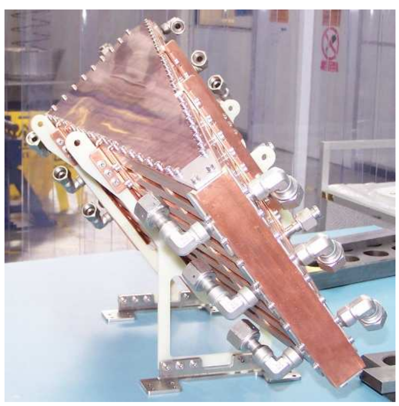

Fig. 2. Photograph of the ground based calibration target to be used to calibrate ESA's Sentinel-3 MWR radiometer.

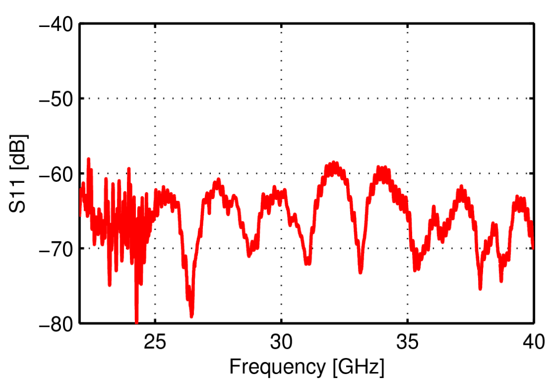

Fig. 3. S11 measurement of the target in Fig 2, showing S11 better than -60dB from 20-40 GHz

To calibrate the ESA's satellite-based Sentinel-3 Microwave Radiometer we are employing a wedge design. Being ground based the target can be large (>1m in length) and heavy (>70kg) – see Fig. 2&3 – but this gives the necessary very low S11 reflectivity. A wedged design was chosen in this case to accommodate beams from two adjacent feed horns with the same linear polarization. It was orientated so that the plane of incidence on the sloping sides coincided with the plane of polarization, in order to benefit from reduced reflection.

We prefer these designs over traditional external pyramidal array targets, both in terms of their S11 performance and because of the difficulty of maintaining temperature uniformity on pyramidal structures, especially at their tips.

IV. Conclusion

Coherent as well as incoherent reflectivity must be low to provide accurate calibration of mm-wave radiometers. Long distances between the radiometer and the target can, for wide bandwidth channels, reduce the effect of the target's coherent reflectivity. Reflectivity as good as -45dB can still contribute significant errors. Cone and wedge based internal targets can provide the necessary ultra-low S11 reflectivity.

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