Reflectivity Measurements of Commercial Absorbers in the 200–600 GHz Range

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Abstract

Reflection properties of several commercial absorbers measured at frequencies of 200, 300, 400, 500, and 600 GHz with different incident angles are presented in this paper. The measurements were done using a specially built test setup with a vector network analyzer and a linear scanner. The presented results show the measured peak reflectance values, i.e., the maximum reflection from the object. The reflectance requirement for absorbers used in compact antenna test ranges (CATRs) is usually –40 dB for all incident angles. According to our measurements, this is not possible with the tested absorbers over the whole frequency range.

1. Introduction

High quality radiation absorbing materials (RAM) with reflectivities below –40 dB are needed for antenna test ranges operating at submillimeter wavelengths [1]. This limit is chosen to allow low enough added fields in the quiet-zone region. If the antenna needs to be measured pointing directly to the back-wall, even lower absorber reflectivity is required. Conventional carbon-loaded convoluted and pyramidal foam absorbers do not provide the necessary absorption performance. A large-sized antenna test range, like the compact antenna test range (CATR), needs very large quantities of absorbers.

MilliLab (HUT Radio Laboratory) is developing a submillimeter wavelength CATR facility using a planar hologram in a contract for the European Space Agency (ESA) [2,3]. This CATR is planned for testing reflector antennas in the 1.5 meter class at frequencies of 300–650 GHz. It is desirable that one type of absorber can cover the whole operational frequency range. In this paper, the measured reflectances for several commercial absorber types at different incident angles and polarisations over the frequency band of 200–600 GHz are presented.

2. Tested absorbers

The tested absorbers (FIRAM-500, TERASORB-500, TK THz RAM, Eccosorb LS-22) are based on different materials. FIRAM-500 is made of iron oxide loaded silicon [4], TERASORB-500 of carbon loaded EVA (ethylene vinyl acetate) plastic [4], TK THz RAM of carbon loaded polypropylene plastic [5], and Eccosorb LS-22 of carbon loaded polyurethane foam [6]. FIRAM and TERASORB panels have a wedged-type surface design, TK THz RAM a sharp pyramidal surface, and the Eccosorb surface is flat. Eccosorb LS-22 is designed for operation below 30 GHz, but it was tested just like the others. Reflectivity results for other absorber types in the 100–200 GHz range can be found in [7].

3. Instrumentation and test procedures

The test instrumentation was built around a millimeter wave vector network analyzer AB Millimétre MVNA-8-350 equipped with submillimeter wave extensions ESA-1 and ESA-2 [2]. The source ESA-1 consists of a phase-locked Gunn oscillator and a frequency multiplier. The receiver ESA-2 has a similar phase-locked Gunn oscillator which acts as the local oscillator for a sensitive waveguide-type Schottky mixer. Fixed positions of the transmitter and receiver modules were used for precise alignment of the angle and to ensure good repeatibility.

The test setup is shown in Figure 1 for vertical E-field polarisation. A photograph of the test setup is presented in Figure 2. The used incident angles of $\theta_i = 26.5^\circ, 45^\circ, 63.4^\circ$ were chosen for easing precise alignment on the optical table. Alignment guides were mounted to the optical table and then the transmitter and receiver modules were fixed to the guides. In the $\theta_i = 63.4^\circ$ measurements, a thick absorber sheet between the transmit and receive antennas was used to reduce direct coupling due to antenna sidelobes (see Figure 2). Direct coupling between the antennas without the target was tested to be always below –70dB or the measurement noise floor (whichever higher).

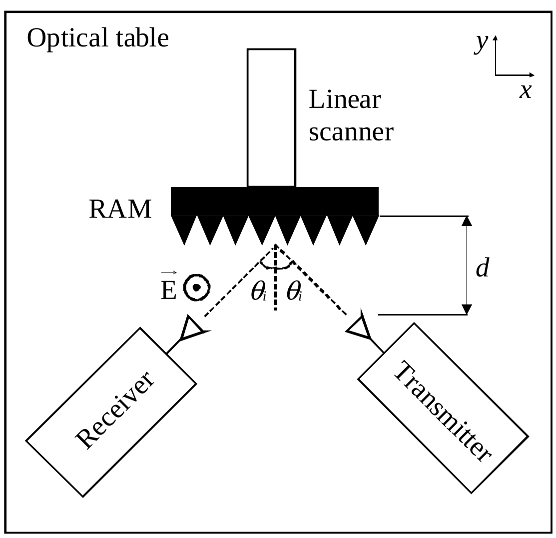

Figure 1. Schematic drawing of the test instrumentation.

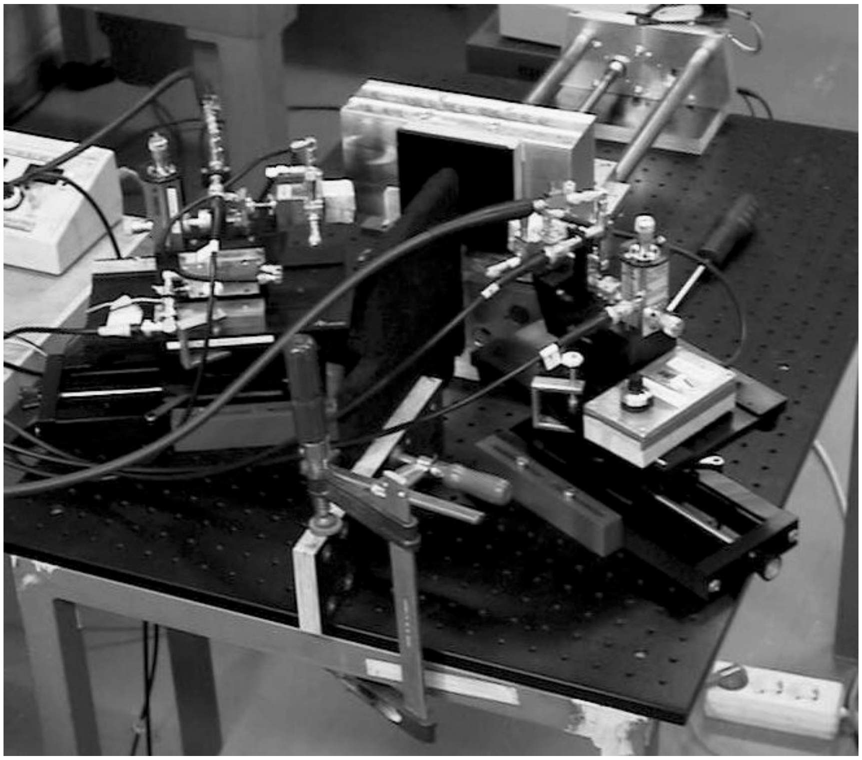

Figure 2. Photograph of the test setup.

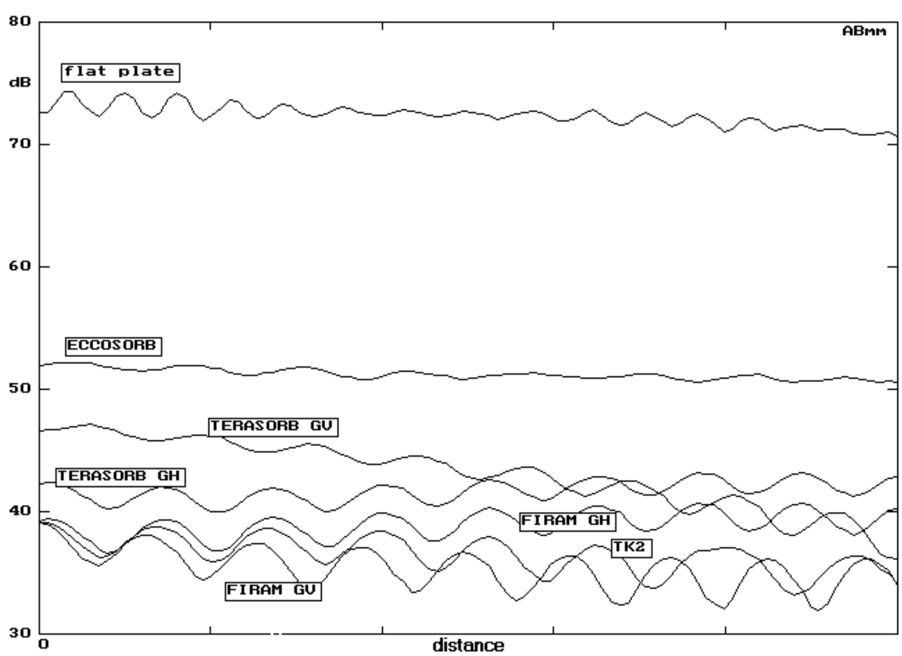

Figure 3. Amplitude data from the network analyzer (300 GHz, 45 degrees and H-H pol).

The flat metal plate used for calibration and the tested absorbers were mounted to a linear scanner. The distance of the test object (*d* in Figure 1) was varied a few wavelengths around its center value determined by geometry. The measured reflected powers have clearly periodical patterns, as can be seen from Figure 3, due to field scattering from the target. At least ten averaged amplitude and phase values were taken for each wavelength in the reflectance measurements.

The surface area illuminated by the incident beam is relatively small and the reflectance results depend on the position of the absorber. To find out the effect of this, the absorbers were tested in three different mounting positions along the x-axis.

Accuracy of the reflection measurement depends on the analyzer dynamic range, which degrades with increasing frequency (from about 100–60 dB at 200–600 GHz). The amplitude measurement accuracy for both vertical and horizontal polarizations at 200–400 GHz is estimated to be ± 0.1 dB, and about ± 0.5 dB at 500–600 GHz.

4. Measurement results

The reflected power from a flat aluminium plate was measured first for each incident angle. After that, the reflected powers from different absorbers were measured. The presented absorber reflectivity dB-values in this paper are all relative to the reflectivity of the flat plate. They show the highest measured reflectivity, i.e., the worst performance over three subsequent linear scans with the absorber mounted in different position. For the wedged-type absorbers FIRAM-500 and TERASORB-500 the results are given for both vertical (gv) and horizontal (gh) groove directions.

The measured and calibrated absorber reflectivities for $\theta_i = 26.5^o, 45^o, 63.4^o$ using vertical and horizontal polarizations are shown in Tables 1 and 2, and also presented in Figures 4–6. The lowest measured reflectivities for each test are printed in bold in Tables 1 and 2. Reflectivities of even the best absorbers are always higher than –40 dB. The measured reflectivity values increase with larger incidence angles. The frequency dependence, however, is not so clear. FIRAM-500 and TERASORB-500 materials are specifically optimized for 500 GHz, and they clearly have better performance in the 400–600 GHz range than in the 200–300 GHz range. In the lower frequencies TERASORB has somewhat lower reflectivities than FIRAM, but in the 400–600 GHz range the results are quite similar with both groove directions. TK THz RAM has the lowest reflectivity in almost all angles and frequencies. Eccosorb LS-22 has the worst performance, as can be expected for a standard microwave absorber intended for frequencies well below 30 GHz.

5. Conclusions

The reflectivities of several commercially available absorbers have been measured at 200–600 GHz. The measurements were carried out with incident angles of

$\theta_i = 26.5^o, 45^o, 63.4^o$. The results presented in this paper show the measured peak reflectivity values taken over three different positions of the absorbers. The reflectivity requirement for high performance compact ranges is usually –40 dB in all angles of incidence. This is clearly not yet possible at submm-waves with commercially available materials. TK THz RAM manufactured by Thomas Keating Engineering Physics, Inc., was found to have the best overall performance in the tests.

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References

[1] Foster, P.R., Martin, D., Parini, C., Räisänen, A., Ala-Laurinaho, J., Hirvonen, T., Lehto, A., Sehm, T., Tuovinen, J., Jensen, F., Pontoppidan, K., "Mmwave antenna testing techniques - Phase 2", 1996, *MAAS Report 304*

[2] Säily, J., Ala-Laurinaho, J., Häkli, J., Tuovinen, J., Lehto, A., Räisänen, A.V., "Instrumentation and testing of submillimeter wave compact antenna test ranges", *11th International Symposium on Space Terahertz Technology*, Ann Arbor, MI., USA, May 1-3, 2000, pp. 590–597

[3] Säily, J., Ala-Laurinaho, J., Häkli, J., Tuovinen, J., Lehto, A., Räisänen, A.V., "Test results of a 310 GHz hologram compact antenna test range", *Electronics Letters*, Vol. 36, No. 2, 2000, pp. 111–112

[4] University of Massachusetts Lowell Submillimeter Technology Laboratory, "Design and manufacture of submillimeter-wave anechoic structure", Product sheet, http://stl.uml.edu/stlweb/stl_firam.html

[5] Thomas Keating Engineering Physics, Inc., "Space qualified tessalating THz RAM for the 100 to 1000 GHz region and beyond", Product sheet, http://qmciworks.ph.qmw.ac.uk/TKI/RAM/ram.html

[6] Emerson&Cuming Microwave Products, Inc., "Eccosorb LS lossy flexible microwave absorber", http://www.emersoncumingmp.com/catalog/ECCOSORB/LS.htm

[7] Lehto, A., Tuovinen, J., Räisänen, A.V., "Reflectivity of absorbers in 100–200 GHz range", *Electronics Letters*, Vol. 27, No. 19, 1991, pp. 1699-1700

Table 1. Reflectivity measurement results for vertical-vertical polarization (values in dB relative to the flat-plate reference).

26.5 deg vertical-vertical

f (GHz)	**firam gv**	**firam gh**	**terasorb gv**	**terasorb gh**	**tk thz ram**	**eccosorb**
200	-21.7	-26.2	-21.3	-29.5	**-34.6**	-13.2
300	-25.2	-27.7	-23.5	-32.6	**-33.4**	-14.6
400	-23.5	**-32.4**	-27.9	-27.9	**-32.4**	-18.8
500	-21.4	-27.6	-25.3	-24.8	**-28.5**	-10.7
600	-25.2	-25.7	-25.3	-25.7	**-29.5**	-22.7

45 deg vertical-vertical

f (GHz)	**firam gv**	**firam gh**	**terasorb gv**	**terasorb gh**	**tk thz ram**	**eccosorb**
200	-17.8	-24.7	-17	-27.3	**-35.5**	-12.4
300	-19.5	-27	-16.3	-30	**-31.1**	-14.4
400	-19.7	-29.7	-21.8	-26.3	**-31.9**	-18.8
500	-20.7	-24.7	**-28.3**	-23.8	-27.8	-9.9
600	-22.8	-24.6	-24.2	-21.9	**-28.1**	-16.5

63.4 deg vertical-vertical

f (GHz)	**firam gv**	**firam gh**	**terasorb gv**	**terasorb gh**	**tk thz ram**	**eccosorb**
200	-14.2	-18.2	-12.7	**-22.3**	-20.1	-9
300	-12	-16.7	-9.55	-19.9	**-20.1**	-7.3
400	-10.6	**-20.5**	-12.7	-22.3	**-20.5**	-11.7
500	-9.7	**-19**	-12.7	-17.7	-18	-12.6
600	-14.4	-18.5	-15.4	-16.9	**-24.9**	-13.7

Table 2. Reflectivity measurement results for horizontal-horizontal polarization (values in dB relative to the flat-plate reference).

26.5 deg horizontal-horizontal

f (GHz)	**firam gv**	**firam gh**	**terasorb gv**	**terasorb gh**	**tk thz ram**	**eccosorb**
200	-31.5	-27.1	-30.4	-25.3	**-33.1**	-17
300	-31.5	-28.6	-37.4	-28.5	**-39.1**	-19.3
400	-33.1	-30	-30.7	-28.5	**-35**	-25.9
500	-28.3	-25.4	**-30.6**	-24.6	-25.3	-17.3
600	-24.9	-23.5	-25.7	-24.5	**-26.9**	-17.2

45 deg horizontal-horizontal

f (GHz)	**firam gv**	**firam gh**	**terasorb gv**	**terasorb gh**	**tk thz ram**	**eccosorb**
200	-23.5	-23.9	**-24.5**	-23.7	-18.5	-19.6
300	**-33.6**	-30.4	-25.4	-27.9	-33.4	-20
400	-34.7	-28.2	-30.6	-30.9	**-35.6**	-24.5
500	-29.5	-25.3	-30.1	-28.5	**-30.4**	-20
600	-25.8	-28.1	-28.8	**-33.2**	-30.4	-21.8

63.4 deg horizontal-horizontal

f (GHz)	**firam gv**	**firam gh**	**terasorb gv**	**terasorb gh**	**tk thz ram**	**eccosorb**
200	-16.8	-18.7	-15.4	-18.7	-12.4	**-20.4**
300	-15.4	-16.3	-12.8	-15.9	**-22**	-16.3
400	-12	**-21.3**	-15.6	-18.1	-16.2	-15
500	-14.6	-20.8	-17.6	**-21.6**	-19.4	-14.4
600	-19.8	-23.4	-19.4	-24	**-25.7**	-18.7

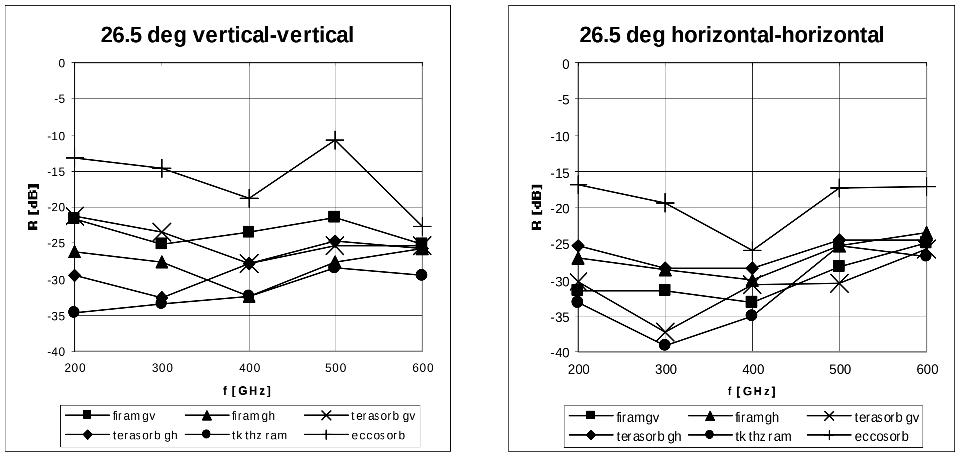

Figure 4. Measured reflectivities for θ_I = 26.5 degrees.

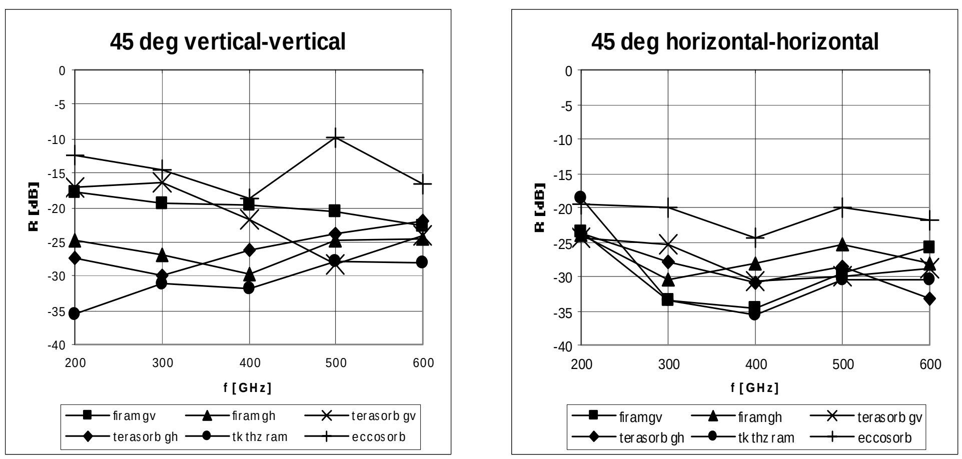

Figure 5. Measured reflectivities for θ_I = 45 degrees.

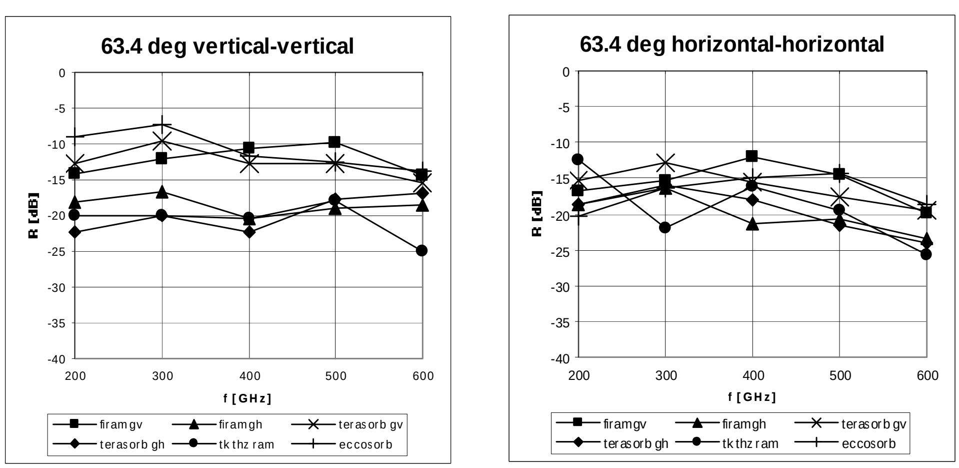

Figure 6. Measured reflectivities for θ_I = 63.4 degrees.