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Reflector Reflection Loss 110 - 350 GHz

#Cornelis van 't Klooster[1],Vladimir Parshin [2]
[1] European Space Agency, Estec, EEA
Keplerlaan 1, 2201AZ Noordwijk, kvtkloos@esa.int
[2] Institute for Applied Physics, Russian Academy of Science
46 Ulyanov St. Nizhny Novgorod, 603950 Russia, parsh@appl.sci-nnov.rul

1. Introduction

Accurate electromagnetic calculations of reflection loss for geometrically described high reflective thin single and multi-layer configurations are possible, but stay difficult. Processing parameters can give rise to variations in constitutive parameters and surface roughness can be comparable to skin-depth thickness at millimetre wavelength. But skin-depth for alloys is less accurate modelled than for pure metals and temperature dependence must be considered also. Testing is required. It is desirable to measure reflection losses with a resolution of a fraction of a 1/100 dB or "promille-type"accuracy for high performing reflector antennas in various applications. The paper refers to results of measurements of metal and metallised composite samples at ambient temperature. The new result is for a test at ~80 K, well showing reduction of the reflection loss.

2. Testing is necessary

Antenna reflectors for radiometric applications require by definition low reflection loss. New technologies are used for (sub)mm-wave reflector antennas. Testing is required as modelling fails to predict with reliable accuracy. This is needed for metals, alloys and composite materials, even when constitutive parameters are expected to be isotropic. In practice it depends on accuracy and manufacturing processes, which can involve various techniques for metallisation for composite materials, fibre orientations potentially causing some anisotropy with an influence on polarisation response. Requiring a number of skin-depths for metallisation has to be judged in equilibrium with other requirements, leading to compromises sometimes. Another reason for testing is that surface roughness involved can be comparable to the skin-depth at mm/sub-mm wavelength, with effects on reflection loss. Testing is also needed for transmission windows or frequency selective surfaces. Electromagnetic modelling may be too difficult to handle a desired precision in absolute/relative sense for reliable (low) values. Fortunately it is possible to measure accurately.

An accurate facility has been realized at Applied Physics Institute (frequency range from 60 to 380 GHz). Ultra low-loss reflector samples have been measured (reflection) for high power quasi optical networks or ultra low-loss transmission windows for gyrotron applications [4]. Comparable applications are found in ITER project. The authors of this paper collaborate for accurate reflection loss testing for terrestrial and space applications, mainly radiometry and radio-astronomy.

Several sensitive radio telescope antennas in ALMA project observe celestial sources in an interferometric configuration with high sensitivity. Reflection loss of panels in each radio telescope antenna has to satisfy special requirements. ALMA telescopes have a requirement that it should be possible to handle Sun-observation at microwave wavelength. Absorption and emission control is important. Reflection loss at RF observation frequencies has to be low [5,7]. The panels for the radio telescopes have been designed for this. Reflection loss measurements have been carried out of high reflective metal technologies (electro-formed and micro-machined, with/without particular metal coatings, different surface roughness, etc.) needed for sub-mm wave radio-telescopes (ALMA project >>www.eso.org, [9] for background). The frequency range from 100 to 200 GHz is already very indicative for assessment of sample/panel performances, using the facility as discussed.

Composite samples with different surface finishing were also measured [1,2,3]. Test results have a very good relative accuracy. Reflection loss measurements confirmed the better potential of panel technology at other (lower) temperatures. Telecommunication users might be satisfied with reflection loss requirements < 1 a 2 % (~0.1dB), but that is not good at all for reflector antennas for

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a remote sensing radiometric application. The astrophysical instrument Planck is supposed to observe the very small noise temperature variations of the cosmic background radiation with unprecedented accuracy. It is important that reflection loss of the reflectors is “low as possible” and measured over band-width and preferably temperature.

New ultra-light composite reflectors find application for space and have to be metallised to achieve low reflection loss. There can be co-existing demands to use protection coatings or thermal coatings, keeping temperature distributions (absolute level, gradients) well under control in orbital configurations with different fluxes depending on the mission scenario. Concurrent design of reflector technology is important to arrive at compromise solutions with a number of requirements to be met (RF, thermal, mechanical, environmental). The final RF performance is what is counting.

3. Test set-up for the measurement at Applied Physics Institute

The principle of the test facility is based on a high-quality open Fabry-Perot resonator [4] with accurate handling of resonant quasi-optical modes, control of coupling parameters, frequency stability, environment and influence of the latter. Comparable resonators are commercially available, but not that accurate and wide band as the one in API. The resonator set-up with 2 equal spherical mirrors separated by ‘L’ provides a determination of the loss of the high quality spherical mirrors. One of such mirrors is then used in a test configuration with a sample under test measured at the beam waist of a resonator at distance L/2 from a spherical mirror. The method of testing is self-contained, requiring of course dedicated steps to calibrate the facility and no need for external standards. Measurement of reflection properties at mm-wave frequencies requires careful handling of environmental aspects. Atmospheric absorption of RF signals must be accounted for. Pressure, humidity, temperature are therefore measured and stabilised or other gasses like N_2 are used. Such a type of resonator set-up can be used also as high resolving spectrometer to measure atmospheric properties and can be made in a plastic foam box with dry nitrogen to avoid absorption in all frequency range by H_2O vapour and O_2, especially near absorption lines (50-60 GHz, 118 Hz for O_2; 183 GHz, 325 GHz; 380 GHz for H_2O). A recent step forward at Applied Physics Institute permitted testing above 200 GHz up to 380 GHz with high accuracy. Early results have been reported in the 28th ESA Antenna Workshop [2].

3.1 SENSITIVITY AND ACCURACY.

The line-widths **Δf** of resonator curves are measured for a loaded and non-loaded resonator**.** The rms of the **Δf** measurements is ~100 Hz (frequencies ~150 GHz), a result of averaging 128 measurements. It appears to be enough for reflectivity measurements. Such measurements have a mean width of ~150 kHz (for best mirrors) corresponding to a reflectivity value ~10^{-3} (**P/P_o**). The sensitivity for reflectivity is then ~10^{-6}. A **relative accuracy** for the best reflectors (Ag, Cu, and Au) is **~ 0.1%** of the actual derived (low) reflection loss value**.** It applies for good performing samples.

Estimation of **absolute** accuracy is more difficult for loss measurements. Uncertainties are present in any resonator configuration due to coupling and diffraction losses, reducing the **absolute** accuracy. Scattering in reflectivity calculations is higher for higher frequencies and impacts on the sensitivity as function of frequency. Unknown variation in coupling coefficients is a function of the frequency. For precise absolute measurements one must take a set of measurement points over a wider frequency band and compare it with predicted scattering. The resonator can be used for line observations (spectrometry). The **absolute** accuracy can be ~$5\cdot10^{-5}$ for high frequencies (300-400GHz) in such a configuration and ~ $2\cdot10^{-5}$ for lower frequencies (40-50 GHz). We have at least **10^{-5}** of **absolute** accuracy for reflectivity tests. Scattering of reflectivity values grows with increased losses (values >$5\cdot10^{-3}$) due a reduced signal to noise. Intrinsic properties of samples have to be understood in relation to field scattering, size, surface roughness and planarity, as function of frequency [1,2,3]. The facility in API can measure reflection loss over a very wide frequency range.

4. RESULTS FOR DIFFERENT SAMPLES

Various metal samples were tested. Different surface roughness and coating have been considered before [1,2,5,6,7]. The tests assisted the development of an important space technology spin-off from ESA’s XMM-Newton project for the ALMA project (www.eso.org).

Results have been measured, depending on fibre directions, leading to different results for the polarisation along or perpendicular to fibre directions, causing some influence on polarisation. Also bare CFRP samples have been tested. A clear dependence on fibre direction was observed. Losses up to 30 % were reported. Metal coating is necessary to improve the reflectivity. Dependence on the fibre direction is virtually not present for accurately metallised reflector samples (Planck, EADS Astrium GmbH). Fig.1 shows measurement results. One (early) sample had a yellow appearance and had higher loss [1,2]. The metallisation of Planck samples was demonstrated to be very good.

A metallisation technique has been applied by CASA EADS and the samples have been tested with good results. The reflectivity of the sample material can be applied for RF functionality in microwave radiometers. Details on manufacturing technology are with EADS CASA Espacio. The low reflection loss varies somewhat as function of the location on a 170×170 mm sample as a result of the implementation approach. A slightly higher reflection loss as measured depends also on the constitutive parameters of the carrying CFRP material below the metal top layer. The sensitive test facility can provide useful and sensitive information about the samples under test.

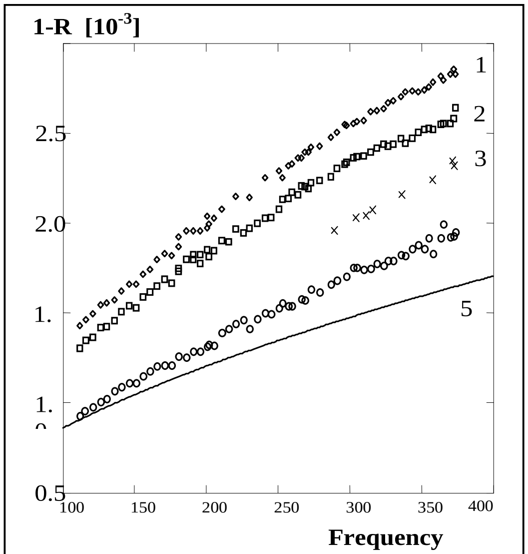

Fig.1. Reflectivity of Carbon fiber Planck reflectors (1,2) covered by Aluminium.

1. Sample SR3D (“yellow”).
2. Sample SR2D (“Silver”).
3. Stainless steel with galvanic covering by Silver (5microns).

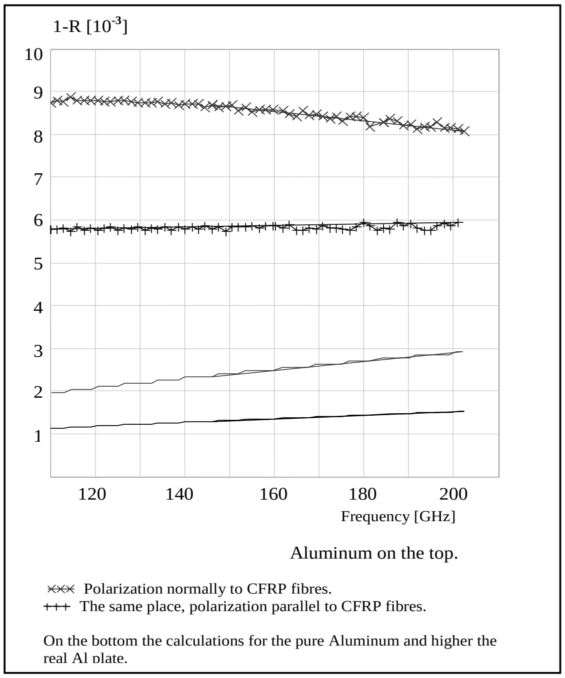

Fig.2 CFRP sample EADS CASA at ambient temp.

Fig.2 above shows results for a sample with thin Aluminum. The curve on the top is for polarization perpendicular to a fiber direction. The curve near to $6\cdot10^{-3}$ is for a polarization direction parallel to the fiber direction. The curve running from $2\cdot10^{-3}$ at 110 GHz to $3\cdot10^{-3}$ at 200 GHz is for a real Aluminum test sample for comparison. The lowest curve is for calculated (theoretical) Aluminum. The reflection loss is about 4 to 5 times worse than for a realistic Aluminum sample and a function of frequency, not following the model predictions. The difference in loss for different polarizations is due to the very thin dimension of the Aluminum layer on top, combined with top-layer fiber directions. The material below (CFRP) influences the test results with its (composite) constitutive parameters. Measurements have been repeated at a low temperature (~70 to 80 Kelvin) for a comparable sample and very interesting results have been obtained (Fig.3). Clearly the reflection loss for this material is reduced by more than a factor 2 to about $300\cdot10^{-5}$. For pure metals, the loss depends from the temperature approximately following a square root law, thus for a four times lower temperature, one obtains about two times lower loss value. Fig.3 shows a larger reduction of the reflection loss, compared to the result at ambient temperature (the curve running from $7\cdot10^{-3}$ to $8\cdot10^{-3}$ (Note, the vertical scale indicates $700\cdot10^{-5}$). The composite technology with metallization has to be measured and its result is of high interest, showing good performances for a cooled reflector and of course for processing/quality control. The curve below shows data for a silver coated mirror for comparison (at ambient temperature: further improvements are possible..).

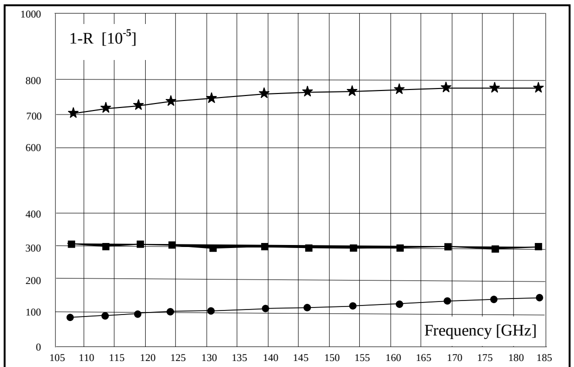

Fig. 3 Reflectivity loss CASA sample at ambient and cold temperature (liquid N_2.
(vertical to $1000 \cdot 10^{-5}$ or 1%, horizontal = GHz)
E- polarization along the fibers.
★ - at 295K, ■ – at 78 and 88 K difference =2.7 %
-● - Silver coated mirror at 295K

5. CONCLUSION

Reflectivity of reflector surfaces depend on the quality of thin reflecting metal layers and their coating as is shown in test results in examples here and in the references. The influence is of course relatively larger for high reflective metals because of the smaller skin-depth. Results presented in this paper show low reflection loss for Planck reflector technology and very reasonable reflection losses for a metallised CFRP technology. The latter technology has been measured at low temperature (liquid N_2) and it is of interest to observe more than an expected factor ‘2’ reduction in reflection loss. The importance of measurement of reflection loss has been discussed and results presented or referred to in this paper confirm such a need. More results will be shown during a presentation.

Acknowledgments

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