Ultra-thin Metal Coating to Reduce RF-Reflection Loss of CFRP Reflectors

Ultra-thin Metal Coating to Reduce RF-Reflection Loss of CFRP Reflectors

C.G.M. van ‘t Klooster(1), Carlos B. Montesano(2), V.V. Parshin(3)

(1) ESA Estec
Keplerlaan 1, Noordwijk (NL),
Kvtkloos@esa.int

(2) EADS CASA ESPACIO
Av. Aragón 404, Madrid 28022 (E)
Carlos.Montesano@casa-espacio.es

(3)Applied Physics Institute of RAS,
46 Ulyanov Street, Nizhny Novgorod, 603950, Russia
parsh@appl.sci-nnov.ru

INTRODUCTION

Reflection loss of Carbon Fibre Reinforced Plastic (CFRP) reflectors increases with increasing frequency. At Ka-band the reflection loss can be a few tenth’s of dB, with the direction of the carbon fibres in the lay-up as an additional contributing factor. Metallisation is desirable to reduce such loss.
A thin metallization would suffice to improve such reflection loss as is discussed in this paper. EADS CASA ESPACIO (ECE) has developed an alternative technology to an approach of direct metallisation of the CFRP (Carbon Fibre Reinforced Plastic) reflector surface. A process of co-curing a thin metallised film has been developed and is used for reflector antennas for telecommunication applications (e.g. Hylas, [1]) or reflectors for radio-meter antennas. Such applications require the loss contribution in the total link budget to be as low as possible with a target value preferably < 0.05 dB (1%).
A radiometer antenna observing the Earth needs high sensitivity and a low system temperature, but it is noted, that variations are measured against an object noise temperature of some 200 to 250 Kelvin. A reflector as needed in an instrument to measure the Cosmic Background radiation (a few Kelvin in temperature) needs every improvement in reduction of reflection loss, the latter being a function of temperature, bulk metal purity and thickness of the layer. The latter application would require further modifications of the technology as mentioned here.
In the paper it is shown how a very thin co-cured layer of metallised Kapton is effective and reduces reflection losses. Even although the thin layer is several times thinner than the skindepth, its effect leads to a reduction of loss <0.05 dB and can be used at even higher frequencies than Ka-band.

BACKGROUND

The radiometer instrument MADRAS was reported in [2]. The main and calibration reflectors used in the latter system have been manufactured by EADS CASA Espacio in Spain, using the mentioned process. Both reflectors have a co-cured sandwich of CFRP skins unidirectional tape, film adhesive, foam and metallic core. The overall sandwich thickness is 12 mm. In order to achieve the required reflectivity of 99.3 % between 18 and 157 GHz, the active reflectors faces have been manufactured with the mentioned process. The reflectors have demonstrated a high quality level during an environmental test campaign which included thermo-elastic distortion test. For telecommunication applications in Ku and Ka-band, EADS CASA ESPACIO (ECE) applied such techniques and has presented measured results in Ku-band for Passive Intermodulation Products (PIM). As PIM generation is strongly related with workmanship, the good results obtained [5] indicate good results for the technological approach.

REFLECTION LOSS MEASUREMENTS

Precise reflection loss measurements have been carried out on dedicated samples in a higher frequency range from 110 to 150 GHz and were in part reported in [3,4]. Accurate results have been obtained, as necessary for applications in a radiometer [2]. The reflection loss for a very thin metal layer – much thinner than the skindepth, (δ = ~0.27μ for pure Aluminum at room temperature at 100 GHz) - is effective and a strong improvement over bare CFRP.
As discussed in [3, 4] and in part repeated here, it was shown, that a thin layer of good conductive metal (like Silver, Copper, Gold and Aluminum) has a good reflectivity even if the layer is as thin as about a few ten's of nanometer. That is a value is much smaller than the skin depth and smaller than the free path of electrons in a bulk metal. For thin films much thinner than the skindepth, electrons are locked between metal surfaces, with a constant concentration. Then the reflectivity does not depend on frequency for such a thin solid metal film. For a thicker conductor the frequency dependent (and temperature dependent) skindepth plays a role. Fig.1 shows a picture of a sample typical for the technology as adopted for instance in the MADRAS reflector [2]. Also a small gap is observable between two stripes of Aluminium coated Kapton films on top, for which tests have been carried out as well, indicating that a controlled narrow or no gap is preferred.

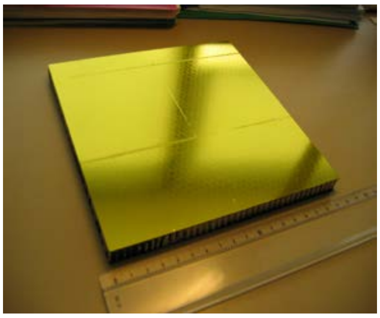
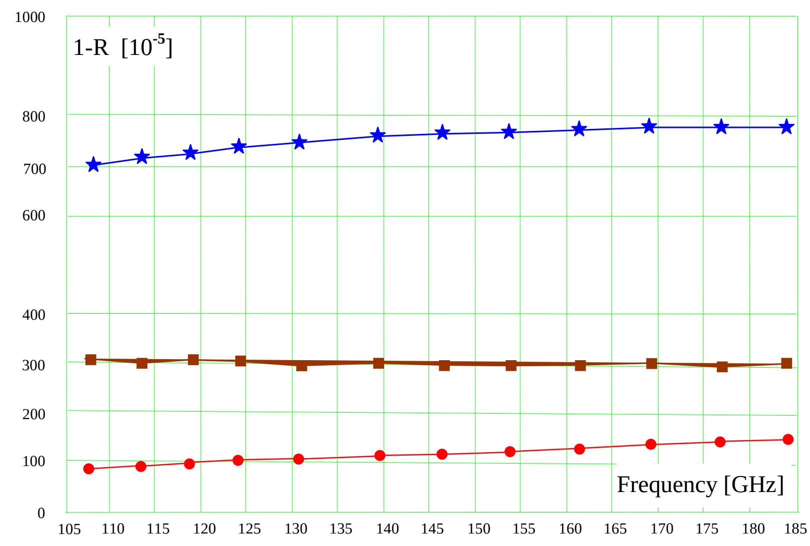


Fig. 1. CFRP Sample with co-cured Aluminised Kapton film.



Reflection losses frequency dependencies of CAS-MARFEQ-OT-09-3
E-polarization along fibers.
★ - Spot #10 at 295K . ● - Silver coated mirror at 295K.
■ - Spot #10 at 78 and 88 K (difference =2.7 %)

Fig. 2 As indicated, measurement results for a particular position of the beam waist on the sample at room temperature (blue), at a low temperature (brown - cooled with liquid N_2) and for Silver at room temperature (red).

MODEL DERIVED USING MAXWELL

Assume a two layer model, consisting of a thick carrying conductive material (2) and a thin layer with thickness 'd' on top. It could be, that 'd' is much thinner than the skindepth of the material of the top layer. An incident field on top causes a current to flow in both layers. The current distribution in the bottom layer decays wit distance. The current distribution in the top layer is represented by a decaying rxponential in positive and negative direction. With the schematic configuration indicated in fig.3 with constitutive parameters for medium '1' and '2' respectively as μ_1 , σ_1 and μ_2 , σ_2, we can write:

$$i_{z2} = Ce^{-\tau 2x}, \quad \tau_2 = \frac{(1+j)}{\delta_2} = (1+j)\sqrt{\pi f \mu_2 \sigma_2} \tag{1}$$

$$i_{z1} = A\sinh\tau_1 x + B\cosh\tau_1 x, \quad \tau_1 = \frac{(1+j)}{\delta_1} = (1+j)\sqrt{\pi f \mu_1 \sigma 1} \tag{2}$$

With the tangential field components derived from Maxwell, matched over the interface (glue or resin variations not modelled), we get an impedance Z per square:

$$Z = R_{s1}\cdot(1+j)\cdot\left[\frac{\sinh\tau_1 d + \frac{R_{s2}}{R_{s1}}\cosh\tau_1 d}{\cosh\tau_1 d + \frac{R_{s2}}{R_{s1}}\sinh\tau_1 d}\right] \tag{3}$$

R_{s1} and R_{s2} are given as $1/\ \sigma_{Al}\delta_{Al}$ and $1/\ \sigma_{cfrp}\delta_{cfrp}$ respectively with assumption for values as indicated below (for CFRP it is depending on materials, but its effect is not too high)

With the loss due to reflection derived from (4), we find, with the real part of (3) as R_s and Z_0=377 Ohm for perpendicular incidence (representative for the test configuration with the resonator):

$$R_{loss} = \frac{4\cdot R_s}{Z_0} \tag{4}$$

(where (4) is an approximation - not elaborated here and found in textbooks- on a basis of still good conductivity in comparison to displacement currents).
The loss due to reflection results as example. It is calculated for a thin layer of thickness of 35 nanometer of Aluminium (σ_{Al}=3.7*10^7) on top of CFRP (σ_{CFRP} =2500) and μ_1=μ_2=μ_0 =4.π.10^{-7}, we get a loss of 0.0079.

RESULTS OF REFLECTION LOSS MEASUREMENTS

A low value of reflection loss was obtained in the testing of these samples. A small dependence on the position of the beamwaist was observed, which could possibly be correlated with small sub micron fluctuations resin between the thin metal and CFRP. (within ~15% of the absolute value being below 0.9% or <0.04dBfor both **E** vector polarizations).
The reflection losses difference between **E** polarization along and normal the direction of lower placed fibers is ~ 10%, but note that 10% is a variation in the absolute value as measured and always below 0.9% at room temperature.
The result in Fig.2 is for a typical case and a just a particular position of the beam waist on the sample. The minimum and maximum values for the reflection loss were reported in [3]. The frequency dependence of the measured curve is rather flat over the frequency range.
The reflection loss has been measured at a cold temperature and this result is shown in fig. 2 as well (0.3% reflection loss or ~0.01dB). This result at cold temperature is about ~2 to 3 times higher *at these high frequencies* than for a silver coated mirror at room temperature). Note that reflection loss is very flat as a function of frequency at low temperature.
In comparison, the technology applied for Planck reflector has a lower loss, but clearly the technology discussed here with the thin film is of interest for radiometer and telecommunication applications.

CONCLUSION

A very thin metal layer, much less than the skindepth on top of CFRP is of interest to obtain good reflection characteristics at higher frequency bands. When cooled to lower temperature, the reflection loss decreases. The developed accurate and precise reflector technology is of interest for radiometer applications, but has slightly higher reflection loss than the thicker VDA coated CFRP reflector applied for Planck. With results obtained already for PIM testing [5] and expected for such tests in Ka-band, it is of high interest for applications in telecommunication in such frequency bands and possibly higher.

REFERENCES

[1] O. Castro, C. Palacios, A. Yarza, C. Limiñana “Industrialisation Process in High Stability Large Reflectors”, 30th ESA Antenna Workshop WPP-283, 27-30 May2008 Noordwijk, Netherlands.

[2] L. Costes, C. Bredin, J.L. Tajan, C. Goldstein, “The 18 to 157 GHz Antenna of MADRAS Radiometer Instrument”, 30th ESA Antenna Workshop, WPP-283, 27-30 May 2008, Noordwijk, The Netherlands.

[3] V. Parshin, C.G.M. van ’t Klooster, E.A.Serov, “Antenna Reflectors Reflectivity at 100 – 350 GHz and 80 Kelvin”, 30th ESA Antenna Workshop, WPP-283, 27-30 May2008, Noordwijk, The Netherlands.

[4] V. Parshin, S. Myasnikova, C.G.M. van ‘t Klooster, L. Costes, C.E. Montesano, “Reflectivity of Antenna Reflectors at a Frequency Range of 110 to 350 GHz, EUCAP Conf., Nice, France 2006.

[5] C.Palacios, O.Castro, B.Portillo, D.Marote,“Reflector Metallisation-Technology tested for Passive Intermodu-lation”, MULCOPIM ESA Workshop, University of Valencia, 24-26 Sept 2008.