Reflectance, Transmittance and Emittance of flat isotropic dielectric slab in microwave and sub-millimetre frequency range.

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In this brief report I review the effects introduced by a flat isotropic dielectric slab in terms of Reflectance $\langle R \rangle_\nu$, Transmittance $\langle T \rangle_\nu$ and Emittance $\langle \varepsilon \rangle_\nu$, quantities provided as in-band average. Such an analysis is linked to the design of the "optical window" for cryostats that enclose instruments working in microwave and sub-millimetre frequency range.

The central working frequencies adopted are: ν = 90 GHz (20% band) and ν = 150 GHz (30% band).

Such frequencies are interesting for instrumentation based on coherent (e.g. HEMT) and incoherent (e.g. bolometer) receivers.

The plots here presented are produced by taking into account the analysis developed to probe the systematic effects introduced, in polarization mode, by an optical window [1]. In fact, in such a paper all the used ingredients are reported.

The materials adopted are Teflon, HDPE and Polypropylene, commonly used in these frequencies.

They are dielectrics, which means that its extinction coefficient[I] is $\kappa << 1$, so that they inject very low thermal noise. Their microwave specifications are shown in Table 1.

The analysis has been performed in far field regime, and only the null incidence has been taken into account[II]. Other angles of incidence have not been considered since, as shown in Ref. [1], if the beam of the collector is narrow around 0 deg, and the window and the collector are aligned, then the signal coming from the dielectric will be collected close to 0 deg. Then, the null incidence angle is a good starting point to analyse how the presence of the window modifies the incoming radiation under study.

By means of this analysis it should be possible to optimise the design of a vacuum window for a cryostat that enclose a receiver, or several receivers, which simultaneously works in both the frequencies here adopted.

The range of thickness studied is from 0.001 cm to 1 cm.

Follow the plots.

[I] It is the imaginary part of the complex index of refraction: $\mathbf{n} = n + i\kappa$, where *i* is the imaginary unit.

[II] I assume that the axis window and the axis of the generic collectors, such as feed or Winston cone, are aligned.

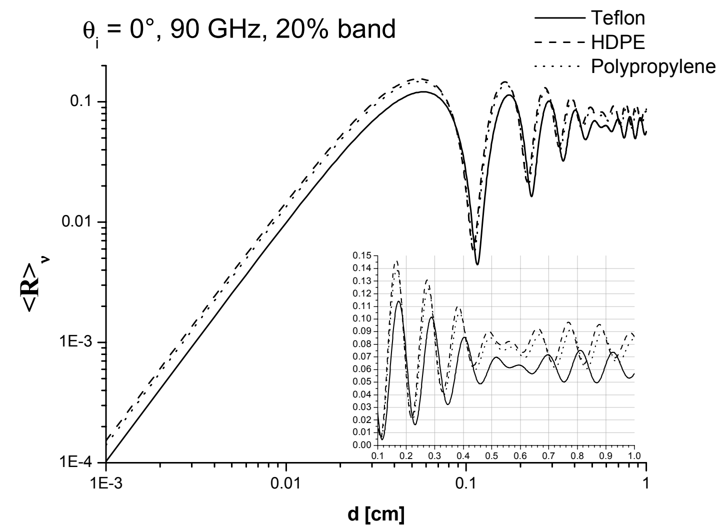

Fig. 1 – In band average Reflectance of Teflon, HDPE and Polypropylene at 90GHz@20% band.

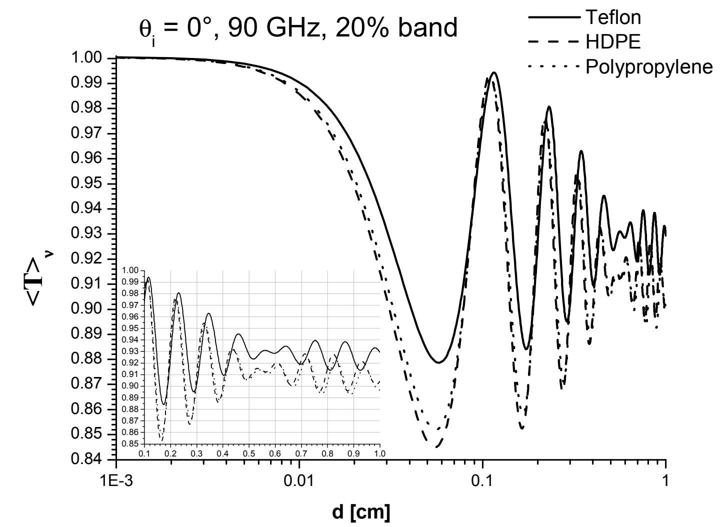

Fig. 2 – In band average Transmittance of Teflon, HDPE and Polypropylene at 90GHz@20% band.

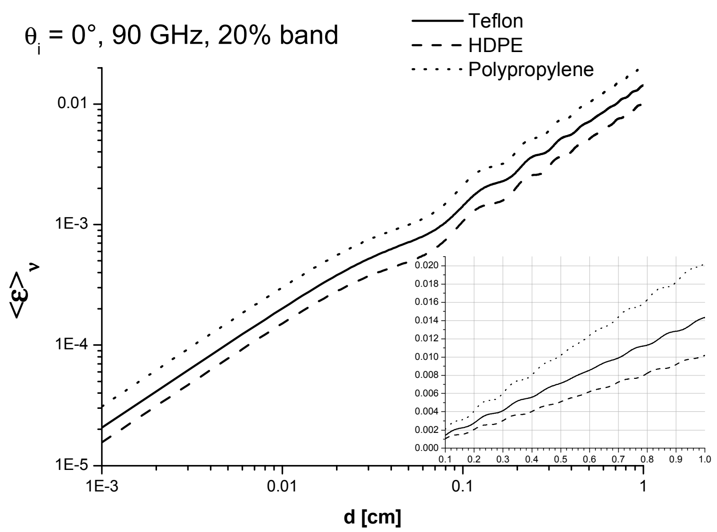

Fig. 3 – In band average Emittance of Teflon, HDPE and Polypropylene at 90GHz@20% band.

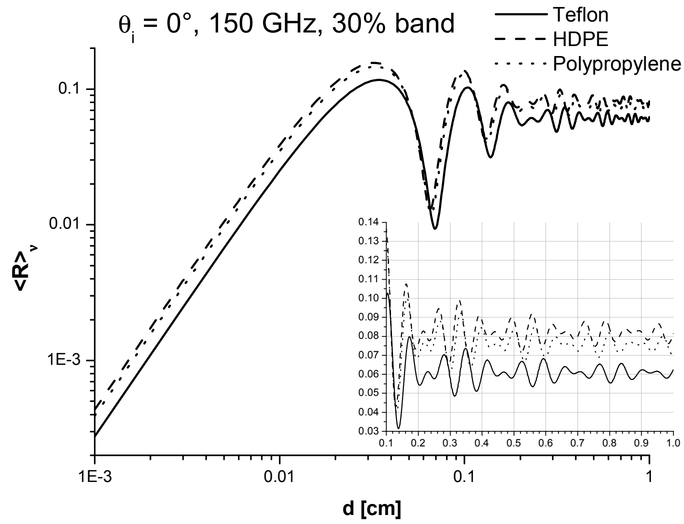

Fig. 4 – In band average Reflectance of Teflon, HDPE and Polypropylene at 150GHz@30% band.

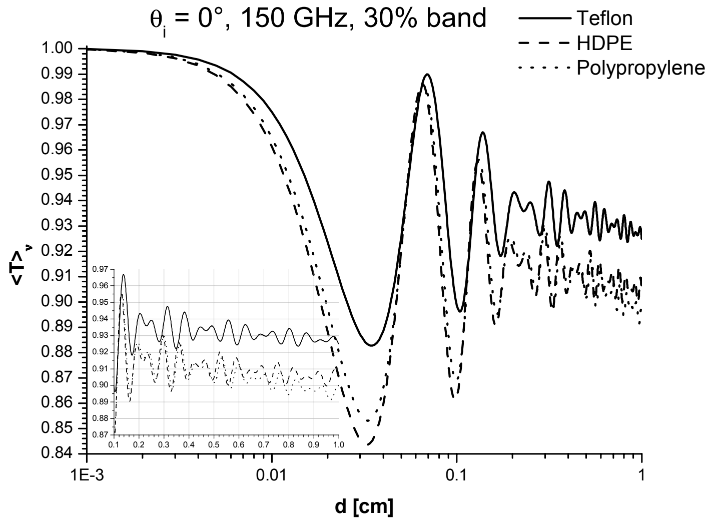

Fig. 5 – In band average Transmittance of Teflon, HDPE and Polypropylene at 150GHz@30% band.

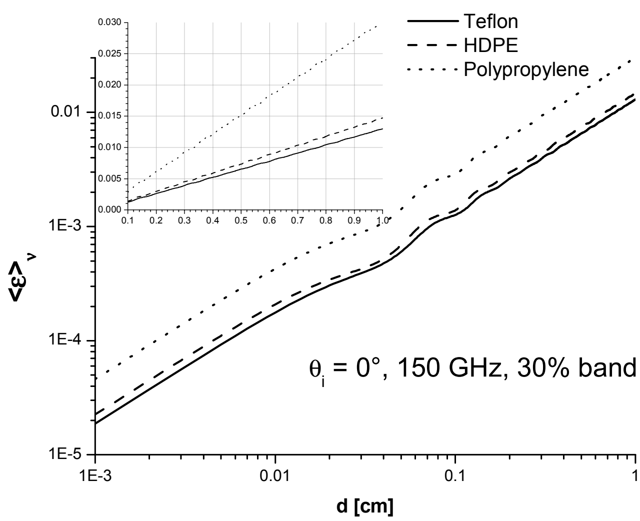

Fig. 6 – In band average Emittance of Teflon, HDPE and Polypropylene at 150GHz@30% band.

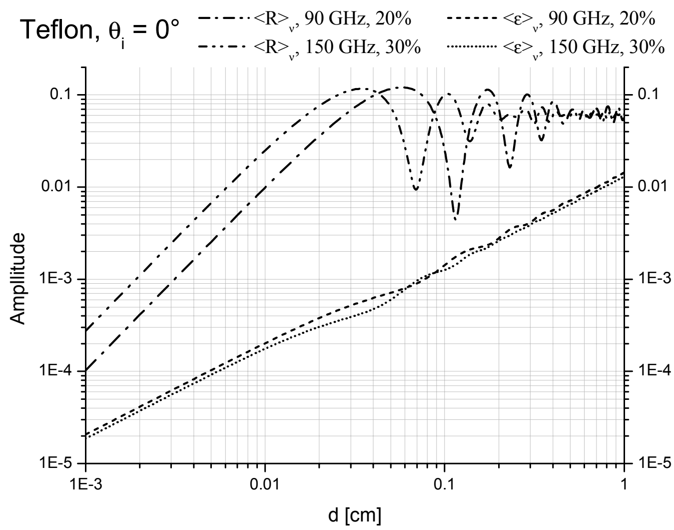

Fig. 7 – In band average Reflectance and Emittance of Teflon at 90GHz@20% band and 150GHz@30% band.

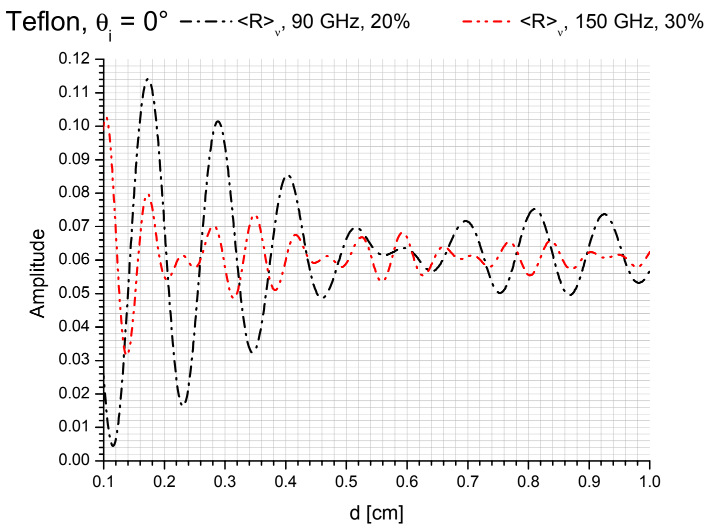

Fig. 8 – In band average Reflectance of Teflon at 90GHz@20% band and 150GHz@30% band.

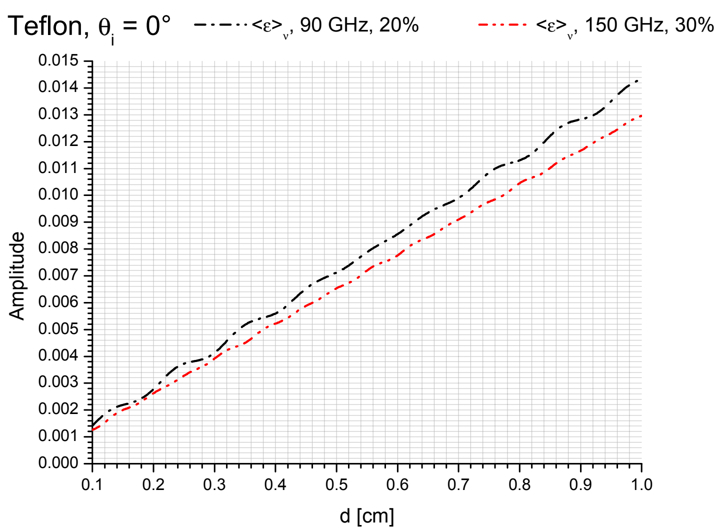

Fig. 9 – In band average Emittance of Teflon at 90GHz@20% band and 150GHz@30% band.

Discussion

The plots show the typical interference trend, and they highlight the polypropylene as the material featured by the worst in-band average Reflectance, Transmittance and Emittance, with respect to Teflon and HDPE.

About the analysis of Reflectance in both the bands studied, as the plots in Fig. 1 and Fig. 4 show, thickness from 0.1 cm to 1 cm produces about the Teflon a mean value of ~ 0.06 (Return Loss ~ –12 dB) and about HDPE and Polypropylene ~ 0.08 (Return Loss ~ –11 dB). Thickness $d \leq 0.1\,\mathrm{cm}$, which can produce lowest Reflectance, can be adopted but it must be taken into account the surface size of the slab to avoid any possible rupture due to the gradient pressure over the window (1 atm = 1Kg/cm^2). The HDPE produces the lowest Emittance in the band around 90 GHz (see Fig. 3), and the Teflon in the 150 GHz band (see Fig. 6), definitively. While around 90 GHz the materials show emittances close to each other (see Fig. 3), around 150 GHz the polypropylene produce values decoupled from HDPE and Teflon (see Fig. 6).

In spite of the slight greater Emittance of the Teflon with respect to HDPE around 90 GHz, in the two bands here investigated the Teflon can be considered the dielectric that introduces the lowest effects as disturbance over the incoming signal under study.

The Teflon Reflectance plot in Fig. 8 shows that in 90 GHz and 150 GHz band the curves are out of phase, so highlighting that it is not simple to choice the optimal thickness at a visual inspection of the plots itself.

Then, a possible procedure to optimise the design of the window, that is the choice of the thickness *d*, is linked to the physical quantity that the receiver has to measure.

For example, in the Cosmic Microwave Background radiation, the 90 GHz frequency is inside the so-called "cosmological window" which defines the frequency band where the presence of Foreground is minimized. In the 150 GHz band, the dust (thermal-component) contaminates the CMB data, although a CMB signal is yet present. Then a possible choice for the thickness could be linked to the minimization of the Reflectance in the 90 GHz band, but around a zone where in the 150 GHz band the reflection can be considered acceptable.

Conclusion

Some aspects about the effects due to the presence of vacuum widow in cryostat have been presented in total intensity analysis, by performing in-band average estimation of Reflectance, Transmittance and Emittance, by placing the slab in far field regime. The band probed was 90GHz@20% and 150GHz@30%, due to our interest for coherent and incoherent receivers.

Teflon, in both bands, can be considered the best material with respect to HDPE and Polypropylene by performing the analysis with values of the complex index of refraction taken from bibliography. For thickness from 0.1 cm to 1 cm the mean value of $\langle R \rangle_\nu$ is $\langle \langle R \rangle_\nu \rangle_{\mathrm{d}} \approx 0.06$. Values lower than 0.06 can be achieved by thickness $d \leq 0.1\,\mathrm{cm}$, but such a choice depends on mechanical reason: the window must sustain, over its surface, a pressure of ~1Kg/cm^2.

Finally, from the electromagnetic point of view, the choice of the optimal thickness can depend on the signal that the receiver has to measure.

This work is inserted in the BaR-SPOrt program [4], an experiment aimed at detecting the CMB Polarization both at 32 and 90 GHz.

	n					κ [10^{-4}]					ε_r					tg(δ_e) [10^{-4}]				
ν [GHz]	**90**	**100**	**150**	**156**	**160**	**90**	**100**	**150**	**156**	**160**	**90**	**100**	**150**	**156**	**160**	**90**	**100**	**150**	**156**	**160**
Polypropylene	/	1.5017	/	1.5017*	/	/	5.48	/	4.88	/	/	2.255	/	2.255*	/	/	7.3	/	6.5	/
Teflon	/	1.44	1.433	/	/	/	3.81	2.08	/	/	/	2.074	2.053	/	/	/	5.3	2.9	/	/
HDPE	1.519	/	/	/	1.5246	2.73	/	/	/	2.36	2.307	/	/	/	2.324	3.6	/	/	/	3.1

Table 1 - Microwave characteristiques of the materials adopted. The value signed by "*" has been assumed due to lacking of data. Data taken from Refs. [2, 3].

* assunto

References:

1) Macculi C., Zannoni M., Peverini O., Carretti E., Tascone R., Cortiglioni S., "*Systematic effects induced by isotropic dielectric vacuum windows*", 2005, in submission.

2) Lamb James W., "*Miscellaneous data on materials for millimetre and submillimetre optics*", Institut de Radio Astronomie Millimétrique, France.

3) Marfuta Phil, "*The design of an adaptive Microwave Lens at 90 GHz*", Project supervisor: Prof. Suzanne Staggs, Experimental Project Writeup, 7/10/2002.

4) S. Cortiglioni et al., "*BaR-SPOrt: an experiment to measure the linearly polarized sky emission from both the cosmic microwave background and foregrounds*", in 16th ESA Symposium on European Rocket and Balloon Programmes and Related Research. Edited by Barbara Warmbein, ESA SP-530, 271-277, (2003).