ALMA MEMO NO. 412

68.5 to 118 GHz Measurements of Possible Infrared Filter Materials: Black Polyethylene, Zitex, and Grooved and Un-Grooved Fluorogold and HDPE

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INTRODUCTION:

For the ALMA production test receivers at present being designed in the NRAO CDL, there is a need for infrared filters to reduce the thermal loading. One possibility is to use a plastic material which has reasonable absorption or scattering for the infrared wavelengths but low loss at the signal wavelengths. Black polyethylene (polyethylene with carbon filler) [1, 2], Zitex (expanded PTFE) [3], and Fluorogold (a glass-filled Teflon) [4] have been suggested as such materials. Measurements at 68.5-118 GHz with an HP8510 have been made on room temperature samples and multilayer filters (which were also measured at liquid nitrogen temperature). Measurements of grooved HDPE are also reported (which resolve an inconsistency in our earlier measurements [5]).

MEASUREMENTS:

Time-domain gated measurements were made over the 68.5-118 GHz range with the HP8510, as described in ALMA Memo #347 [5]. This frequency range is greater than the nominal range (75-110 GHz) of the 85106C with WR10 extension heads. Zitex was only measured over the frequency range 75-110 GHz.

Black Polyethylene:

Figure 1 shows the measured transmission for 90-micron thick pieces of black polyethylene (3M and Goodfellow), which shows that it has very high loss at these frequencies.

Zitex:

Figure 2 shows the transmission for a 254-micron thick piece of Zitex G110, measured at room temperature and after the sample had been immersed in liquid nitrogen. Also shown is the

MMICAD [6] calculation of the transmission for a lossless film of the same thickness with a refractive index of 1.2 [7]. Clarke and D'Addario [8] have suggested using multilayer infrared filters for reducing the heat loads in ALMA Dewars, and Figure 3 gives the transmission of 5 layers of 254-micron thick G110 with 1.575-mm gaps at 300 K and after the stack had been immersed in liquid nitrogen. At room temperature, the material is very loose in the mounting frames and not flat, so the interference effect is not seen. When cold, the material is very rigid and flat, and the interference effects can be seen. Figure 4 gives the calculated transmission of an infrared filter optimized for this frequency band (75-110 GHz), and consisting of 6 layers of 203-micron thick G108 (the same material as G110, just thinner) with gaps of 380 microns. Figure 5 shows measurements made of such an optimized filter at room temperature, where care was taken to stretch the material. Figure 6 shows measurements made after the stack was repeatedly immersed in liquid nitrogen. This shows that a low-loss filter can be designed and built to cover the band.

Fluorogold:

Figure 7 shows the measured transmission as a function of frequency, with polarization angle as parameter, for a 6.22-mm thick piece of Fluorogold. Also shown (Net1 and Net2) are MMICAD calculations for a 6.22-mm thick piece of material of refractive index of 1.61, which is well within the accepted range [7]. Net1 is calculated assuming a loss of 0.46 dB/cm and Net2 with 0.53 dB/cm, which is a good fit at 90 GHz, but the actual loss seems to rise slowly with frequency. It should be noted that it is not possible to determine any variation of the refractive index with polarization from these measurements. These measurements were difficult to make (to obtain consistent results) and highly dependent upon the alignment of the whole of the optics, whereas measurements of materials such as HDPE and Teflon are not (the reason is not understood). Figure 8 shows that linear grooving of the material (0.67-mm deep rectangular grooves 0.72-mm wide on a pitch of 1.2-mm) to reduce the reflection losses [5] works well for one polarization; the transmission of an un-grooved piece of the same thickness is shown for comparison.

HDPE:

Grooved and un-grooved HDPE measurements were reported in [5] but showed some anomalies which have been removed by a more accurate alignment of the optical system. Figure 9 shows the transmission of a grooved piece with linear grooves parallel and perpendicular to the E field. The sample was 3.16-mm thick with 0.673-mm deep rectangular grooves 0.72-mm wide on a pitch of 1.2 mm. Results for an un-grooved piece is shown for comparison.

SUMMARY AND DISCUSSION:

Table 1 gives the measured refractive indices and losses at room temperature for the materials measured above, determined at 90 GHz.

Table 1

Material	Frequency(GHz)	Refractive index	Loss (dB/cm)
Black polyethylene 3M	90	Not measurable	390 ± 20
Black polyethylene Goodfellow	90	Not measurable	280 ± 20
Zitex	90	1.2	0.2 ± 0.1
HDPE	90	1.53	Less than 0.1
Fluorogold (parallel/perp.)	90	1.61	0.53/0.46 ± 0.1
Flurogold from [7] (parallel/perp.)	150	1.625/1.602	1.71/0.87
Flurogold from [7] (parallel/perp.)	900	1.632/1.61	35.2/27.9

Fluorogold is known to be a polarization-dependent material at higher frequencies [7], but no meaningful polarization dependence could be deduced from these measurements. Lamb [7] gives tanδ values for polarization parallel and perpendicular to the grains of 0.0077 and 0.0040 at 150 GHz (loss=1.71 and 0.87 dB/cm, respectively) rising to 0.0265 and 0.0210, respectively, at 900 GHz (loss= 35.2 and 27.9 dB/cm, respectively) with dielectric constants of 2.641 and 2.566 at 150 GHz rising to 2.663 and 2.592 at 900 GHz (also shown in Table 1). The values at 150 GHz seem to overestimate the difference in loss between the two polarizations given in the original reference [9] which gives a difference of only about 20% for the two directions. HDPE, Flurogold and Zitex may be useful materials for infrared filters, especially multilayer filters, depending upon their infrared absorption and reflection properties which will determine the required thicknesses. Black polyethylene is probably not practical as it is too lossy at room temperature (~ 0.75-1 dB for 25 micron thickness).

REFERENCES

[1] Butyl-grafted polyethylene filled with carbon-black, catalog number ET331080. Goodfellow, Berwyn, PA 19312-1780.
http://www.goodfellow.com

[2] 3M Velostat 2014 carbon-impregnated EVA (ethylene/vinyl acetate) copolymer.
http://www.3m.com/ehpd

[3] Zitex G110 and G108, St. Gobain Performance Plastics, Wayne, NJ 07470-4699 (previously Norton Performance Plastics).
http://www.sgppl.com

[4] Fluorogold, St. Gobain Performance Plastics, Wayne, NJ 07470-4699 (previously Furon).
http://www.sgppl.com

[5] G. A. Ediss and T. Globus, "60 to 450 GHz Transmission and Reflection Measurements of Grooved and Un-Grooved HDPE Plates," ALMA Memo #347 (2/2/2001).
http://www.alma.nrao.edu/memos/html-memos/abstracts/abs347.html

[6] MMICAD is a microwave circuit analysis and optimization program from Optotek, Ltd., Kanata, Ontario, Canada.

[7] J. W. Lamb, "Miscellaneous Data on Materials for Millimetre and Submillimetre Optics," *International Journal of Infrared and Millimeter Waves*, vol. 17, no. 12, pp. 1997-2034 (1996).

[8] J. S. Clarke and L. R. D'Addario, "Tests of Materials for Use in Multi-Layer Infrared Filters in Cryogenic Applications," ALMA Memo #269 (7/13/1999). http://www.alma.nrao.edu/memos/html-memos/abstracts/abs269.html

[9] J. R. Birch and F. P. Kong, "Birefringence and Dichroism in Fluorogold at Near-Millimetre Wavelengths," *Infrared Physics*, vol. 26, no. 2, pp. 131-133 (1986).

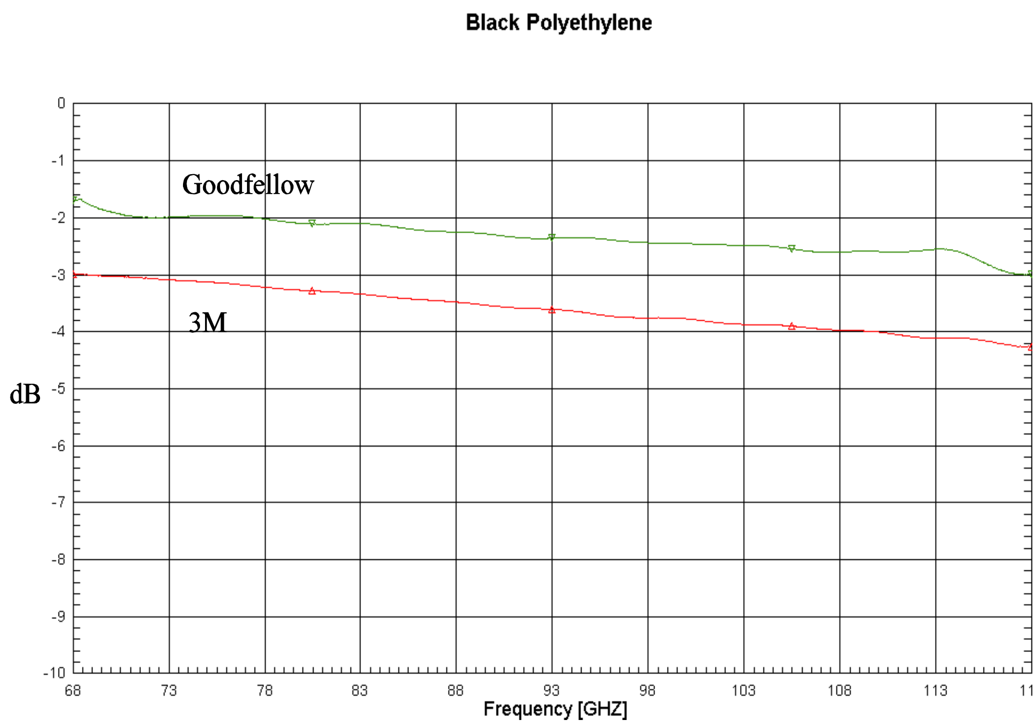

Figure 1. Transmission of 90-micron thick 3M (red) and Goodfellow (green) black polyethylene.

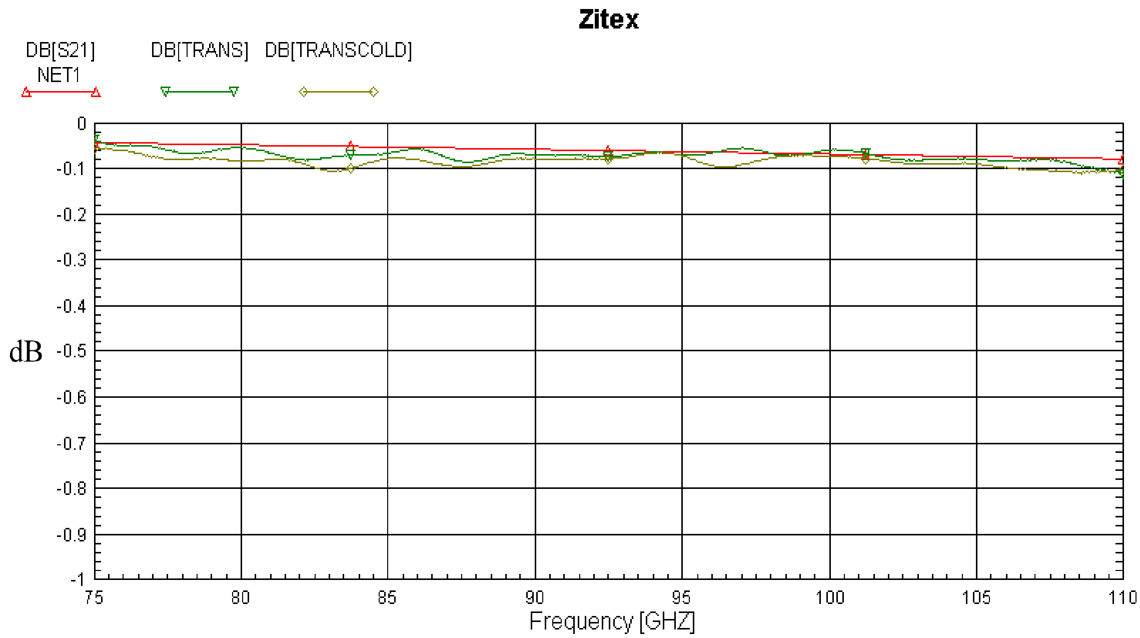

Figure 2. Transmission of free-standing Zitex G110 (254-microns thick) at 300 K (green) and 77 K (yellow). Net1 (red line) is the MMICAD curve for a material of the same thickness and refractive index.

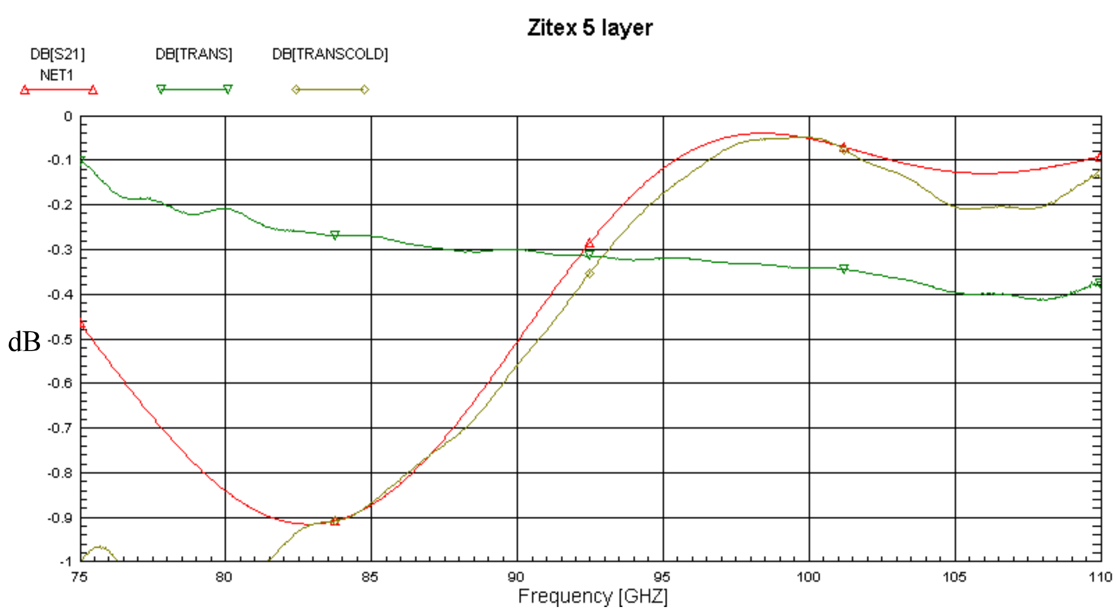

Figure 3. Measured transmission of a 5-layer Zitex IR filter (254-micron thick Zitex G110 with 1.575-mm gaps) at 300 K (green) and 77 K (yellow). Net1 (red curve) is the MMICAD prediction for the 5-layer filter of the same dimensions and loss of 0.2 dB/cm. The difference between the measured and the calculated performance below 83 GHz is probably an alignment problem.

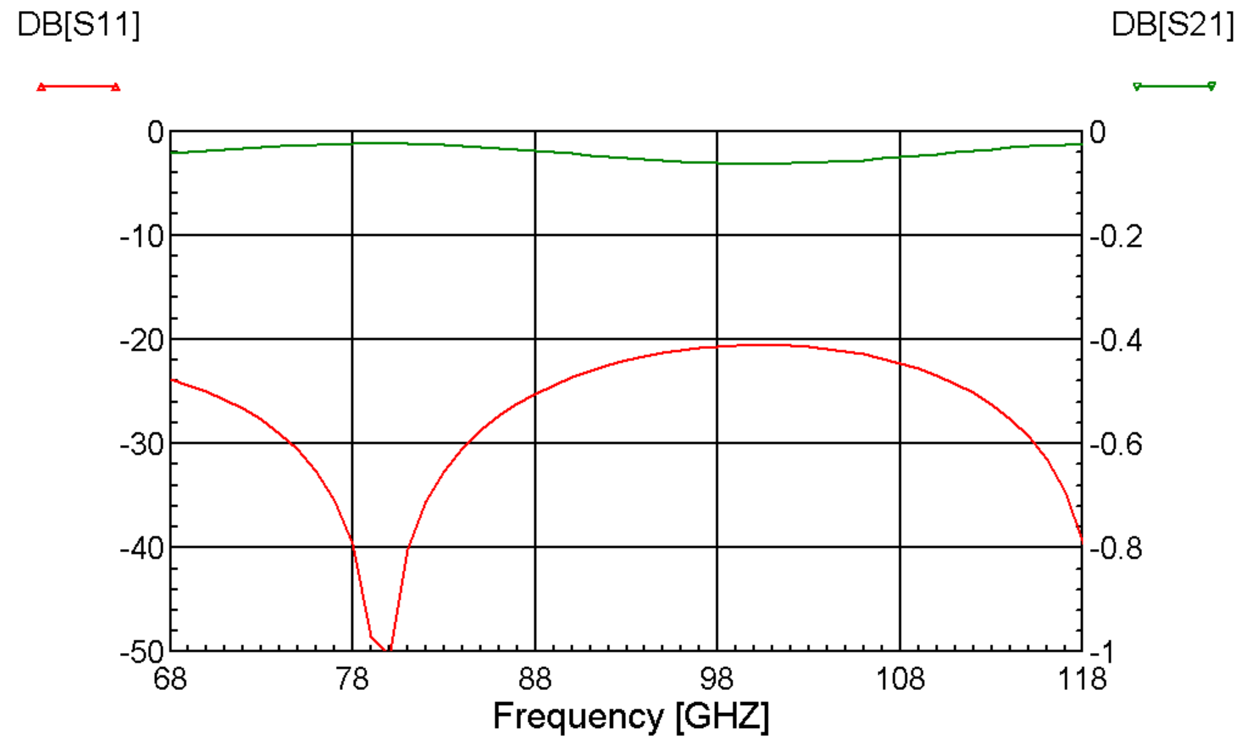

Figure 4. MMICAD calculation (transmission-green, reflection-red) for an optimized 6-layer IR filter. 203-micron thick Zitex G108 with 380-micron gaps, refractive index 1.2, loss 0.2 dB/cm.

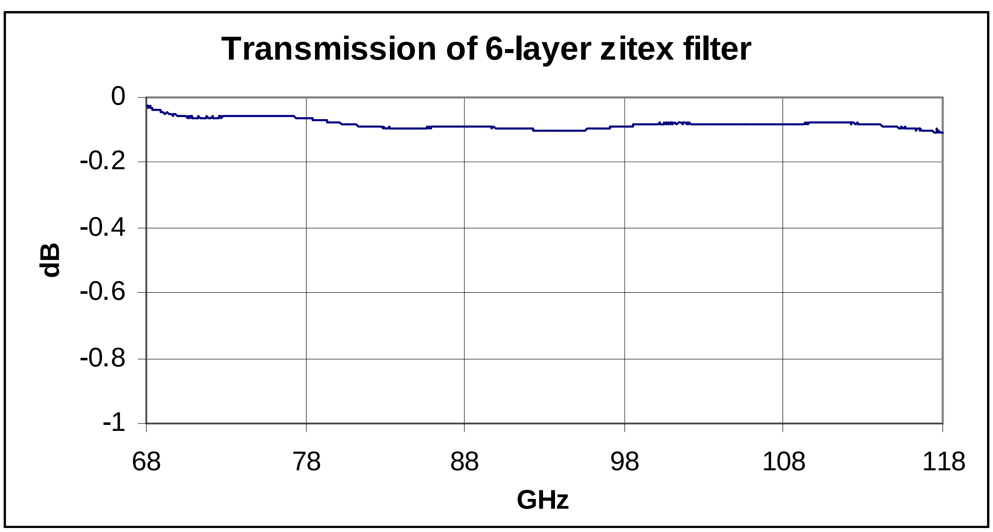

Figure 5. Measured transmission of 6-layer filter at room temperature.

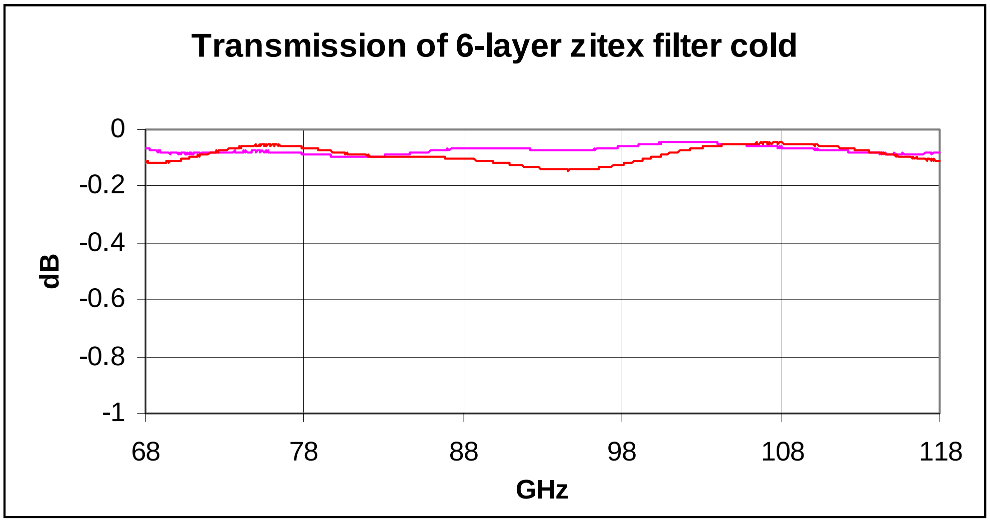

Figure 6. Measurement of transmission of 6-layer filter after repeated immersion in liquid nitrogen.

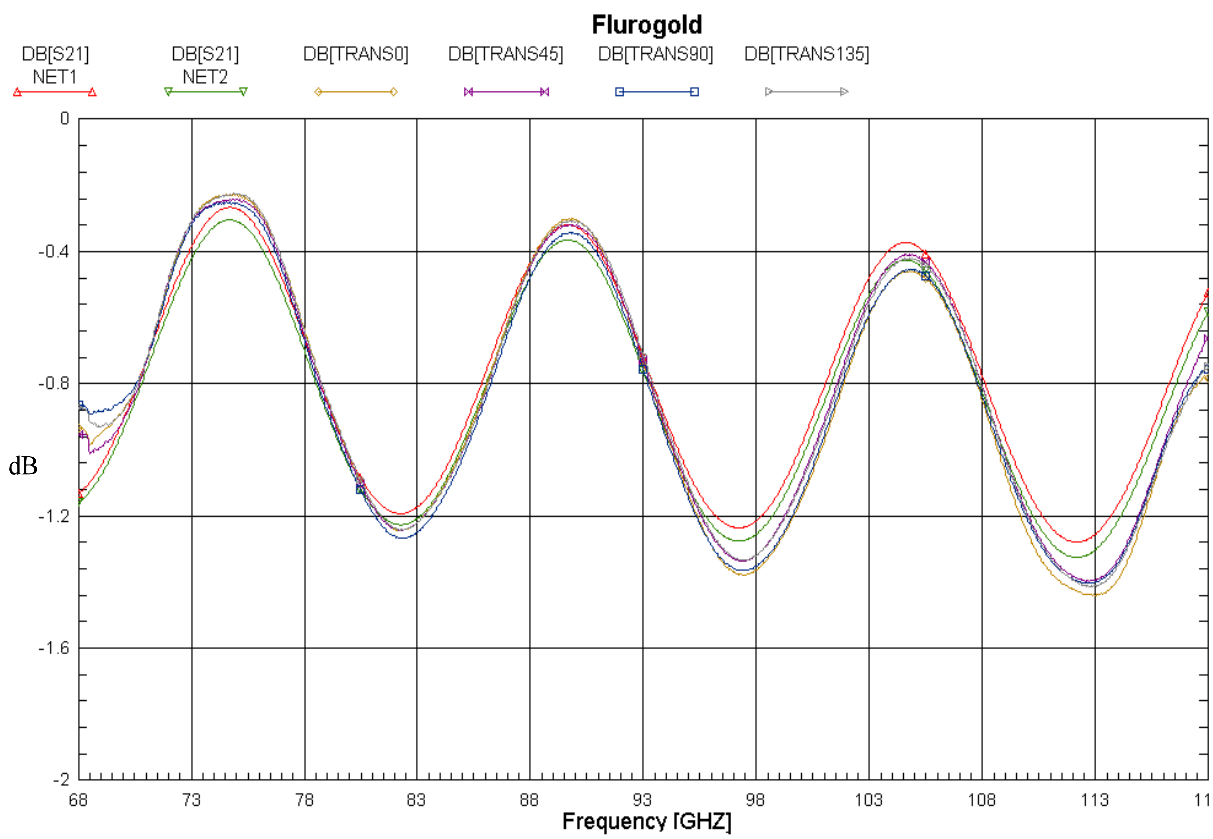

Figure 7. Transmission of a 6.22-mm thick piece of un-grooved Flurogold for rotation angles 0 (yellow), 45 (blue), 90 (purple), 135 (grey) degrees. Net1 (red) and Net2 (green) are MMICAD calculations for losses of 0.46 and 0.53 dB/cm, respectively.

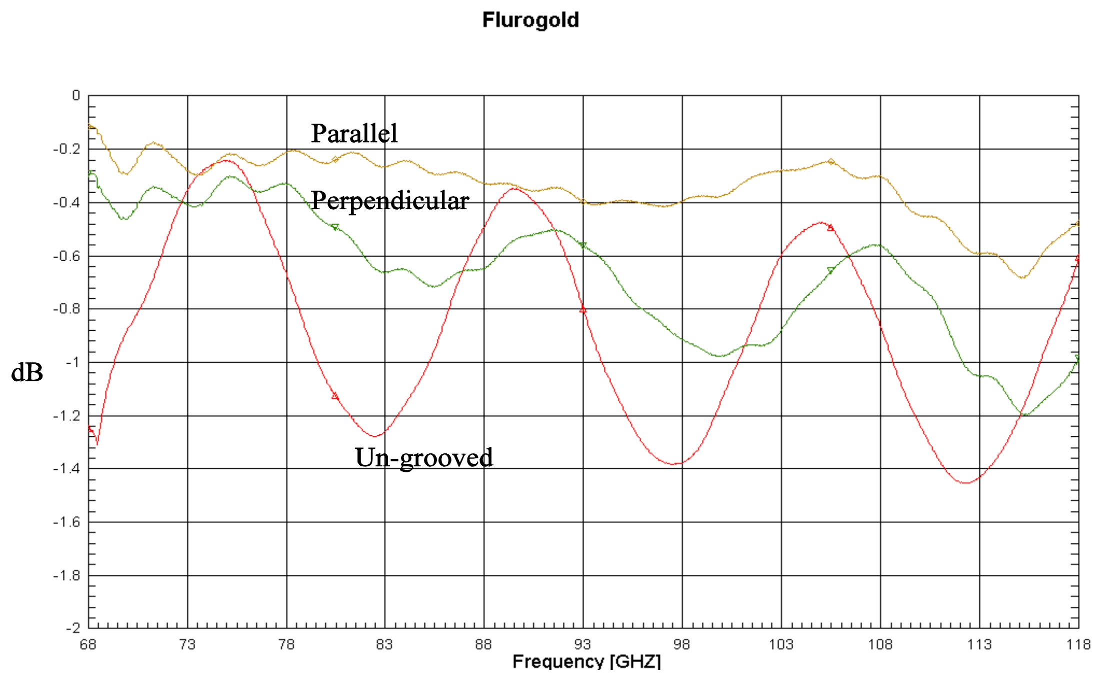

Figure 8. Transmission of linearly-grooved Flurogold (6.22 mm thick) for grooves parallel to the E-field (yellow) and perpendicular to the E-field (green). The red curve is for an un-grooved piece of Flurogold (6.22 mm thick).

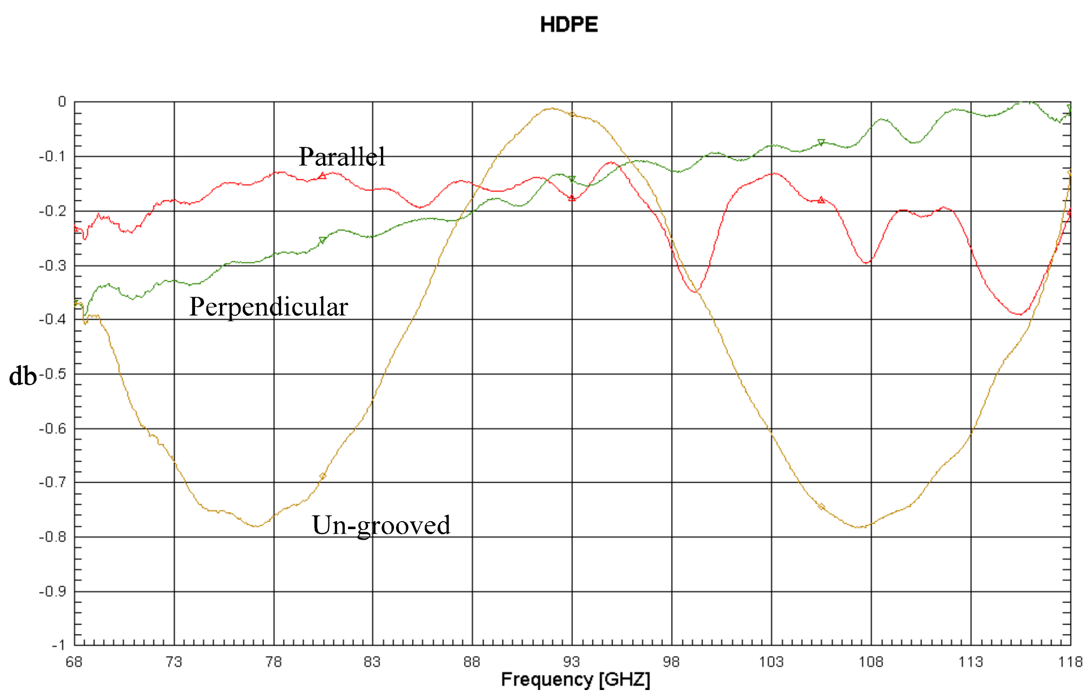

Figure 9. Transmission of un-grooved (yellow) and linearly-grooved HDPE (both 3.16 mm thick) parallel (red) and perpendicular (green) to the E-plane.