ALMA Memo No. 347

60 to 450 GHz Transmission and Reflection Measurements of Grooved and Un-grooved HDPE Plates

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ABSTRACT

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 the use of various plastic materials which have reasonable absorption or scattering for the infrared wavelengths but which have low loss at the signal wavelengths. One such material is HDPE, for which some sort of anti-reflection coating would be required, and because materials with the required refractive index are not available, anti-reflection grooves are a possibility. To investigate the practicality of such grooves, measurements have been made of un-grooved High Density Polyethylene (HDPE), and of samples with linear or concentric rectangular grooves and linear triangular grooves. At 75-110 GHz, measurements were made with an HP8510 and between 60 and 450 GHz with a low resolution FTS.

MEASUREMENTS

Time domain gated measurements over the range 75-110 GHz were made with the HP8510, as described in ALMA Memo No. 295 [1], but with the following differences: (i) the samples were rotated in the mounting frame about the axis of the beam, and (ii) measurements were also made with the pyramidal horns rotated (by the use of a waveguide twist) to allow vertically or horizontally polarized (with respect to the bench) or cross-polar measurements. Figures 1 and 2 show the transmission and reflection, with vertical polarization, of a 3.16 mm thick piece of HDPE rotated by 0, 90, 180 and 270 degrees in the mounting frame. The theoretical responses are also given. Figures 3 and 4 give the same for the horizontal polarization. These results show the excellent repeatability of the measurements and very good agreement with the calculated response for the thickness of HDPE with a refractive index of 2.335 (which is well within the range of values given in Lamb [2]). The apparent discrepancy between the measured and calculated values below 80 GHz and above 104 GHz is an artifact of the time domain gating.

Matching grooves, calculated using the "Scatter" software [3], were used to verify the software and as a test of the performance of such grooves and the ability of our machine shop to produce them with sufficient precision. The grooves are 0.673 mm deep, 0.72 mm wide on a pitch of 1.2 mm. Figures 5 and 6 give the predicted performance for TE and TM incidence of the grooved HDPE in the band 75 to 450 GHz and Figures 7 and 8 for the narrower 75-110 GHz range, for comparison with the measurements. For TE incidence, the E-field is parallel to the grooves, and for TM incidence, it is perpendicular to the grooves. Figures 9 to 12 show the measured transmission and reflection for various rotation angles for linearly grooved samples. These results show a small apparent gain at some frequencies (probably a focusing effect in the optical path). The differences between the two polarizations and the level for the transmission are very sharp functions of the position of the sample in the beam. Due to the mechanics of the system, rotation of the two horns leads to different positions of the beam, and this has to be optimized each time. The transmission and reflection, after optimization for the horizontal polarization, are given in Figures 13 and 14. Figures 15 to 20 give the measured results for circularly grooved samples for various rotation angles and polarizations. Finally, Figures 21 and 22 show the cross-polar performance of the circularly grooved sample, where Figure 21 gives the increase in cross-polar transmission, which was originally 35 dB's down from the co-polar level for the horns and lenses without the sample inserted (the noise floor is at -50 dB).

FTS measurements were made with the University of Virginia Bruker IFS 66V Fourier transform spectrometer using an external source [4]. The resolution is only 7 GHz which smears out the fine structure in the measured spectra. Figure 23 shows the FTS spectrum, along with the MMICAD [5] calculation averaged over 7 GHz (the resolution of the FTS), of the 3.16 mm thick piece of HDPE. Figure 24 gives the measured spectra for the unmatched and grooved HDPE with the grooves vertical or horizontal. This shows quite clearly the expected onset of diffraction modes at 7 or 8 wavenumbers (210 or 240 GHz) where the groove period is $\lambda/2$.

TRIANGULAR GROOVES

Based on simulations using "Scatter" software, triangular grooves are deeper but are expected to have wider band matching properties. Triangular grooves 100 microns wide, 200 micron spacing and 400 microns deep were machined into one face of an 11 mm thick piece of HDPE. Figure 27 gives the expected performance from "Scatter" when the grooves on the two faces are parallel and shows the wide high frequency matching. Due to machining difficulties and the time taken to machine each face, the sample had grooves on only one side. Figure 28 gives the measured FTS spectrum and Figures 29 and 30 give the 75 to 110 GHz HP8510 results for this sample. Unlike the rectangular grooves, very little change is seen if the sample is moved in the beam. The FTS measurements show good agreement over the whole frequency range, given that one surface was not matched, and therefore 0.15 dB reflection loss should be added to the calculated results. The fast ripple is smeared out due to the 7 GHz resolution of the FTS.

DISCUSSION AND CONCLUSIONS

The results given here show that matching grooves for dielectric materials used as vacuum windows and infrared blocking filters in low temperature receivers can be designed and that their performance matches expectations. Unexpected focusing and cross-polar effects are seen for our sample with rectangular grooves which were critically dependent on the lateral position of the sample in the beam. It is not clear whether those effects are intrinsic to grooves, or due to inaccuracies in machining the grooves (*e.g.*, random or periodic variation in groove depth or spacing) or due to some other cause. This was not seen with triangular grooves, suggesting they may be preferable, especially for wide pass band use. However, such grooves are difficult to machine for the high frequencies required for ALMA, and may not be practical for some materials. Further investigation of triangular versus rectangular grooves is required.

ACKNOWLEDGMENTS

We would like to thank Anthony Marshall and Michael Meek (CDL Machine Shop) for their support in machining grooves in the HDPE samples.

REFERENCES

[1] G. A. Ediss, A. R. Kerr and D. Koller, “Measurements of quasi-optical windows with the HP8510,” ALMA Memo No. 295 (3/3/2000). Http://www.alma.nrao.edu/memos/html-memos/abstracts/abs295.html

[2] J. W. Lamb, “Miscellaneous data on materials for millimetre and submillimetre optics,” *Int. J. of Infrared and Millimeter Waves*, vol. 17, no. 12, pp. 1997-2034 (1996).

[3] R. Padman, “Program scatter - a program for the calculation of plane-wave propagation in a stratified anisotropic dielectric,” CSIRO Division of Radiophysics Internal Report RPP 2031(L), 1976, as modified in N. Bailey, A. R Kerr, “Program scatter for the analysis of dielectric matching layers,” Electronics Division Technical Note No. 155, NRAO.

[4] G. A. Ediss, S-K. Pan, J. Effland and T. Globus, “Measurements of commercial vacuum windows for ALMA bands 3 and 6,” ALMA Memo No. 340 (12/5/2000). Http://www.alma.nrao.edu/memos/html-memos/abstracts/abs340.html

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

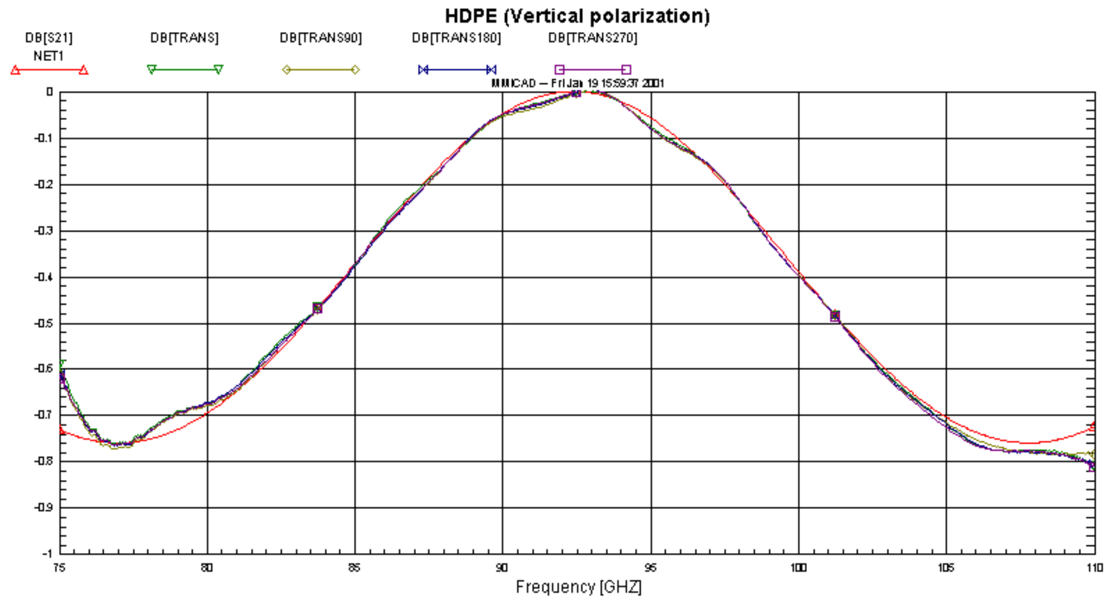

Figure 1 Transmission of a 3.16mm thick piece of HDPE for 4 rotation angles. Net1 (red) is the theoretical response.

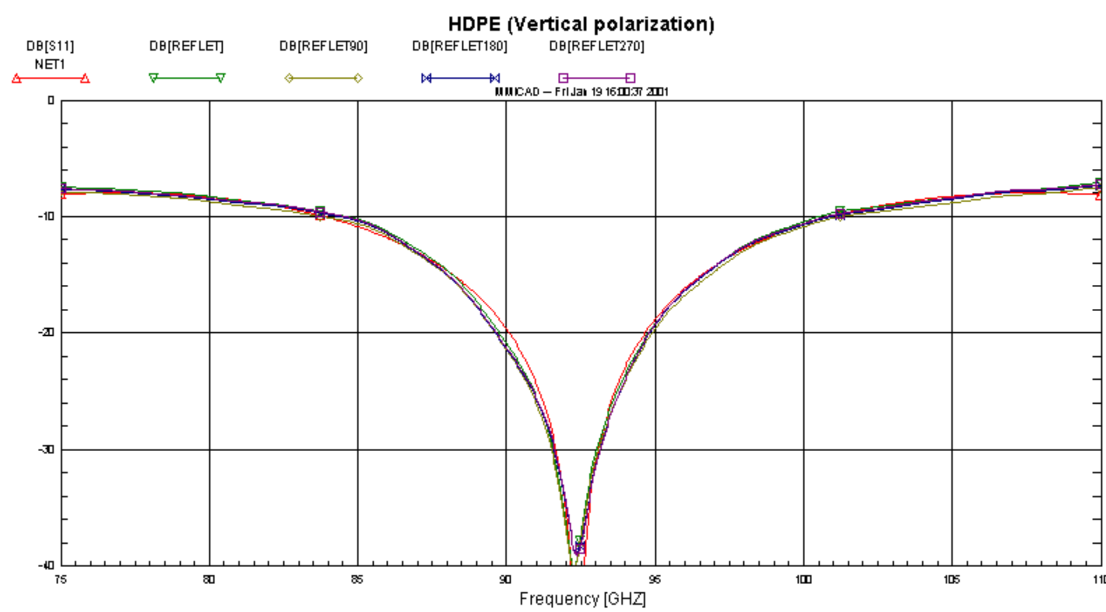

Figure 2 Reflection of a 3.16 mm thick piece of HDPE for 4 rotation angles. Net1 (red) curve is the theoretical response.

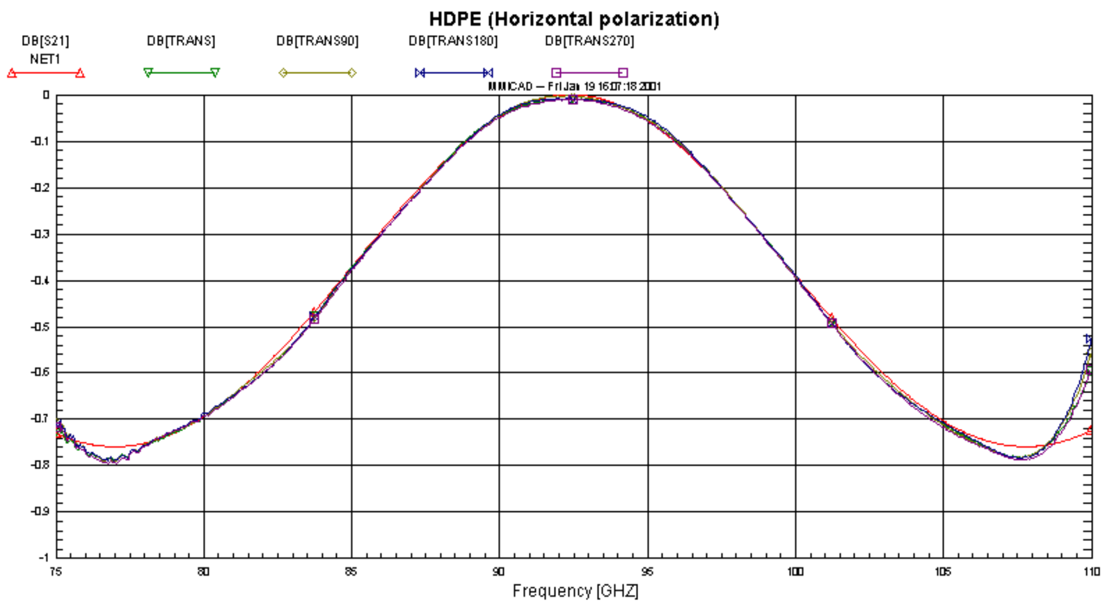

Figure 3 Transmission of a 3.16 mm thick piece of HDPE for 4 rotation angles. NET1 (red) curve is the theoretical response.

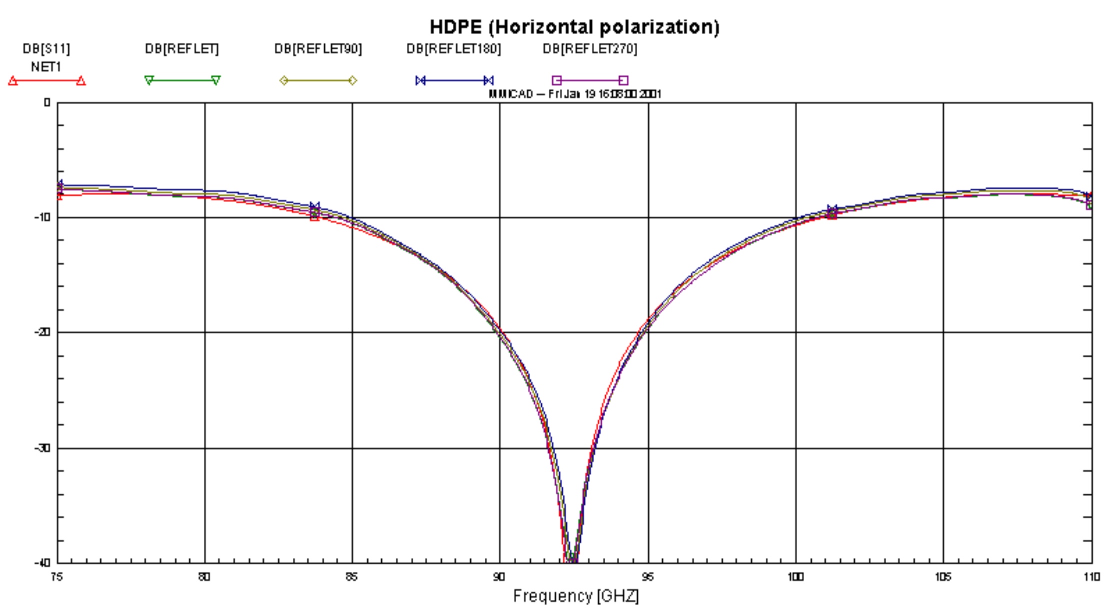

Figure 4 Reflection of a 3.16 mm thick piece of HDPE for 4 rotation angles. NET1 (red) curve is the theoretical response.

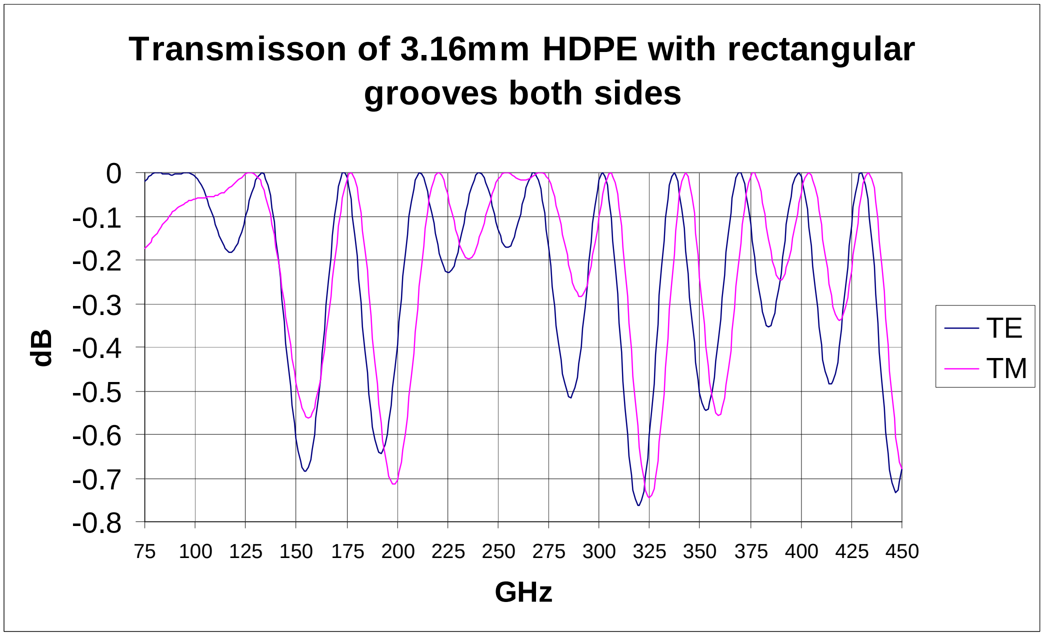

Figure 5 Calculated transmission.

Figure 6 Calculated reflection.

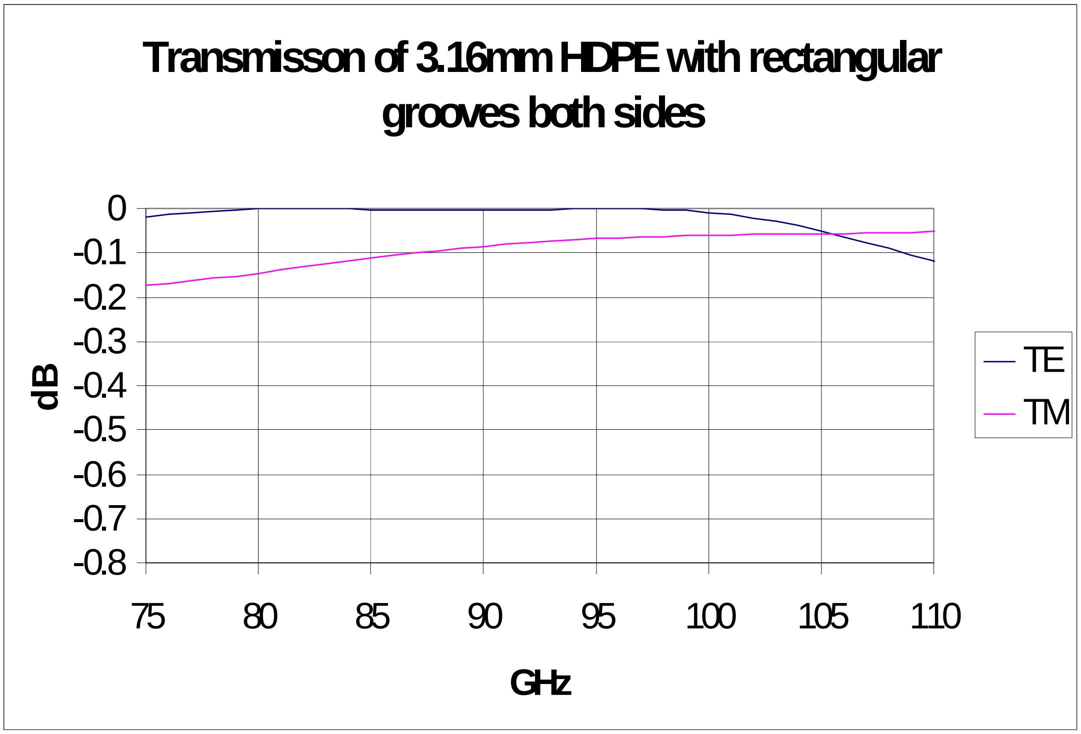

Figure 7 Calculated transmission.

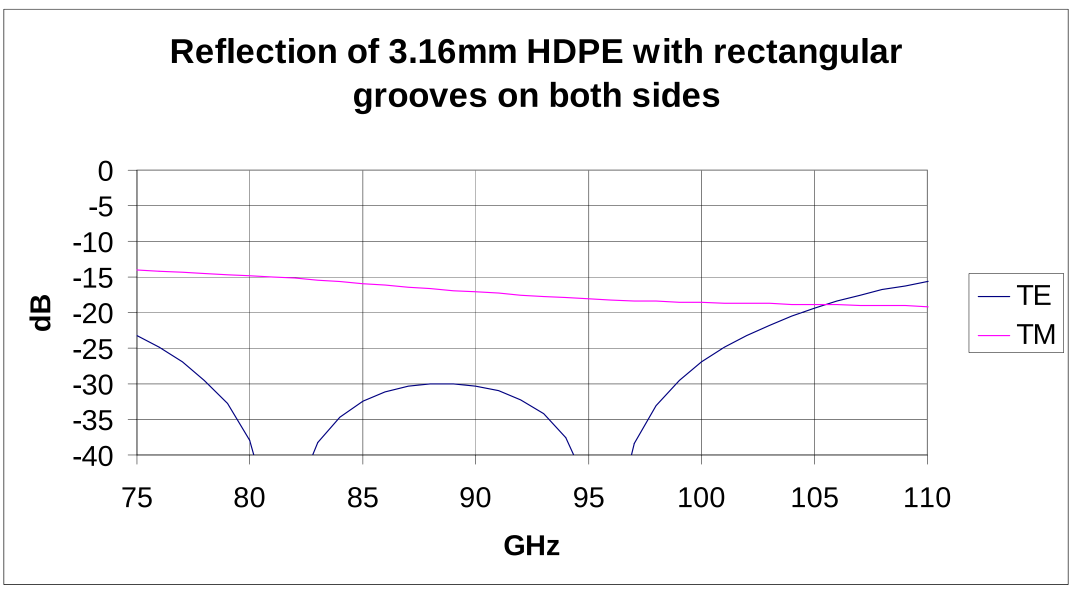

Figure 8 Calculated reflection.

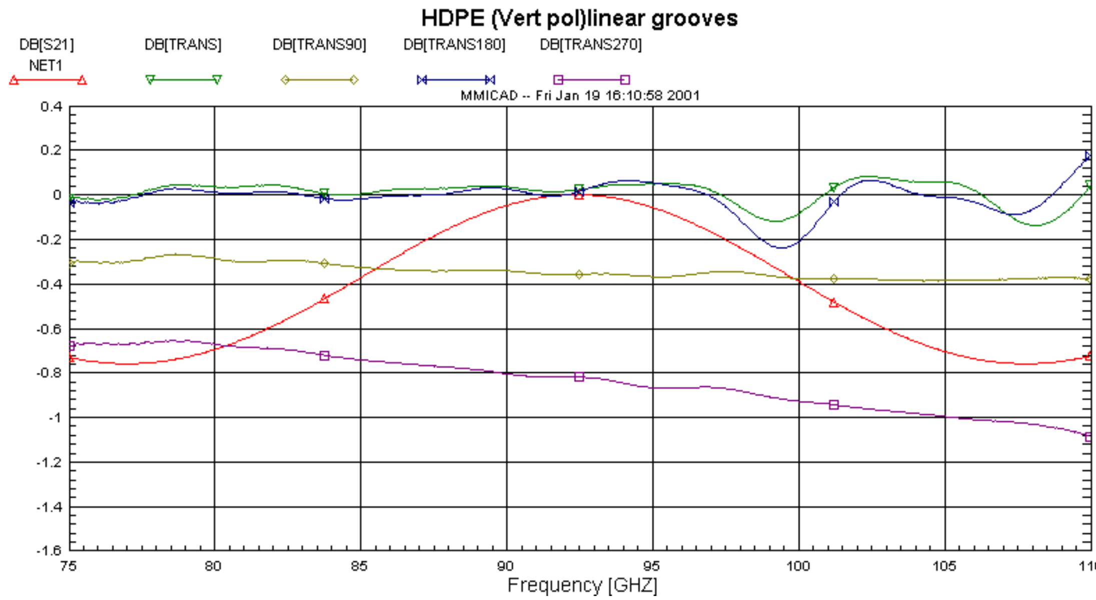

Figure 9 Measured transmission of HDPE with linear rectangular grooves on both sides for various rotation angles for vertically polarized sources. NET1 (red line) is the theoretical curve for an unmatched layer.

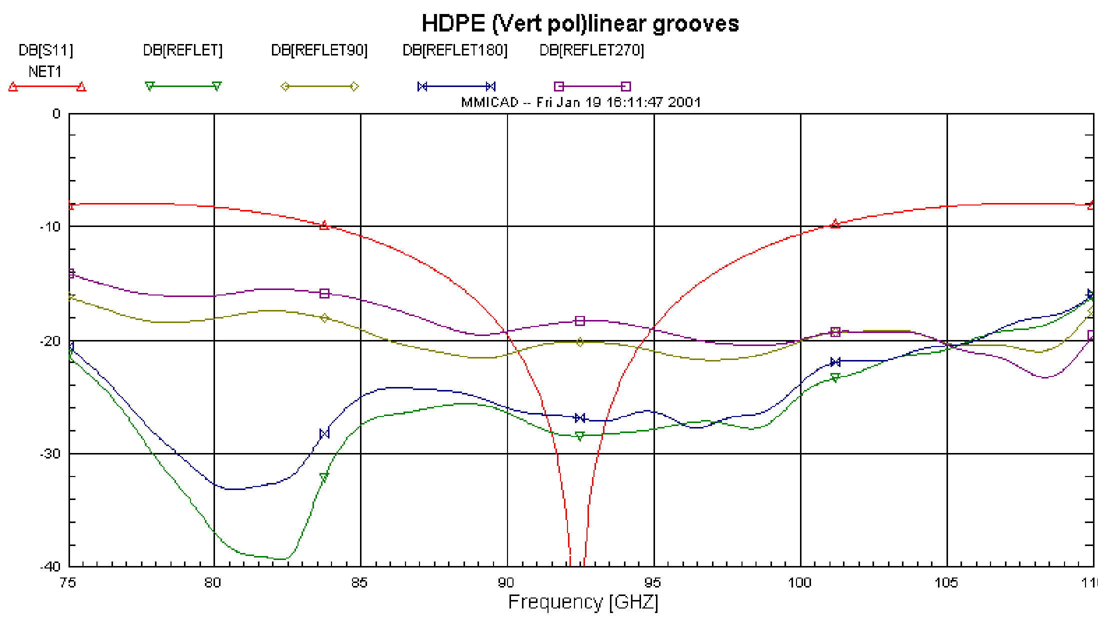

Figure 10 Measured reflection of HDPE with linear rectangular grooves on both sides for various rotation angles for vertically polarized sources. NET1 (red line) is the theoretical curve for an unmatched layer.

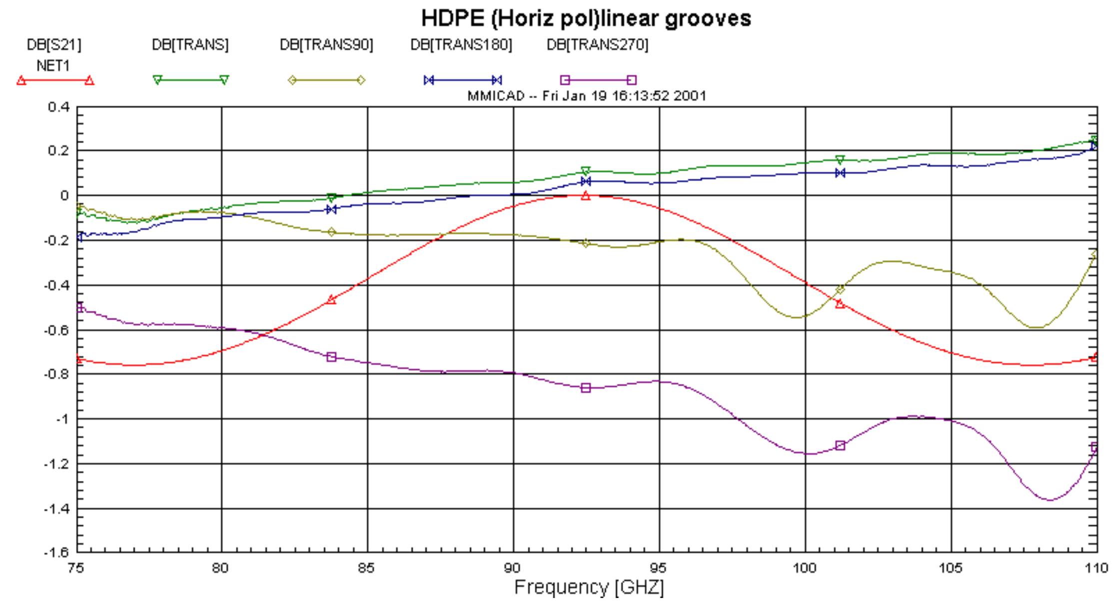

Figure 11 Measured transmission of HDPE with linear rectangular grooves on both sides for various rotation angles for horizontally polarized sources. NET1 (red line) is the theoretical curve for an unmatched layer.

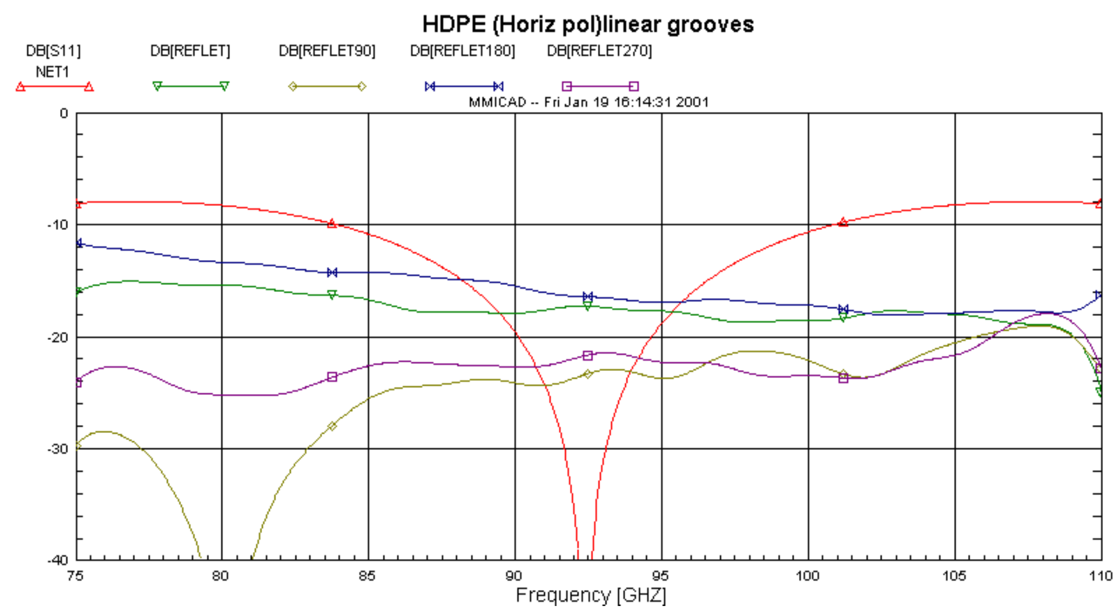

Figure 12 Measured reflection of HDPE with linear rectangular grooves on both sides for various rotation angles for horizontally polarized sources. NET1 (red line) is the theoretical curve for an unmatched layer.

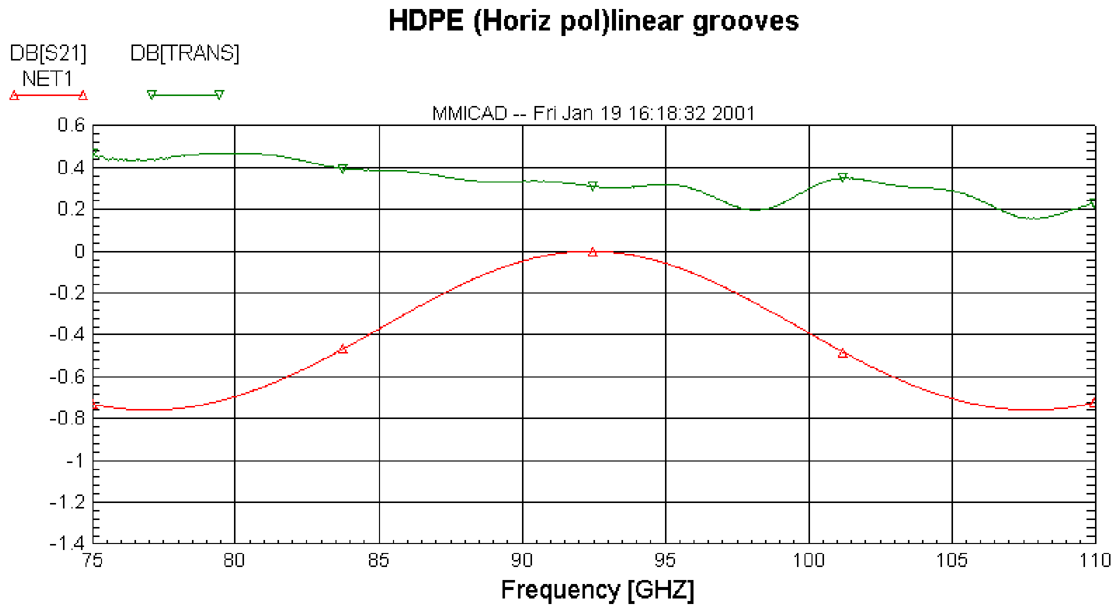

Figure 13 "Optimized" transmission of HDPE with linear rectangular grooves on both sides. NET1 (red line) is the theoretical curve for an unmatched layer.

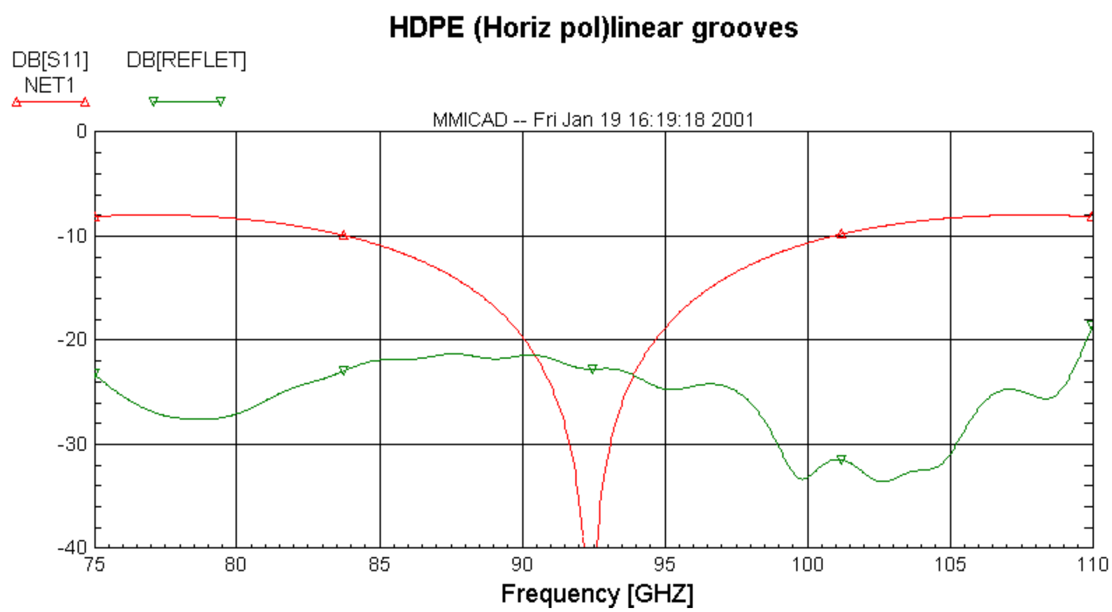

Figure 14 "Optimized" reflection of HDPE with linear rectangular grooves on both sides. NET1 (red line) is the theoretical curve for an unmatched layer.

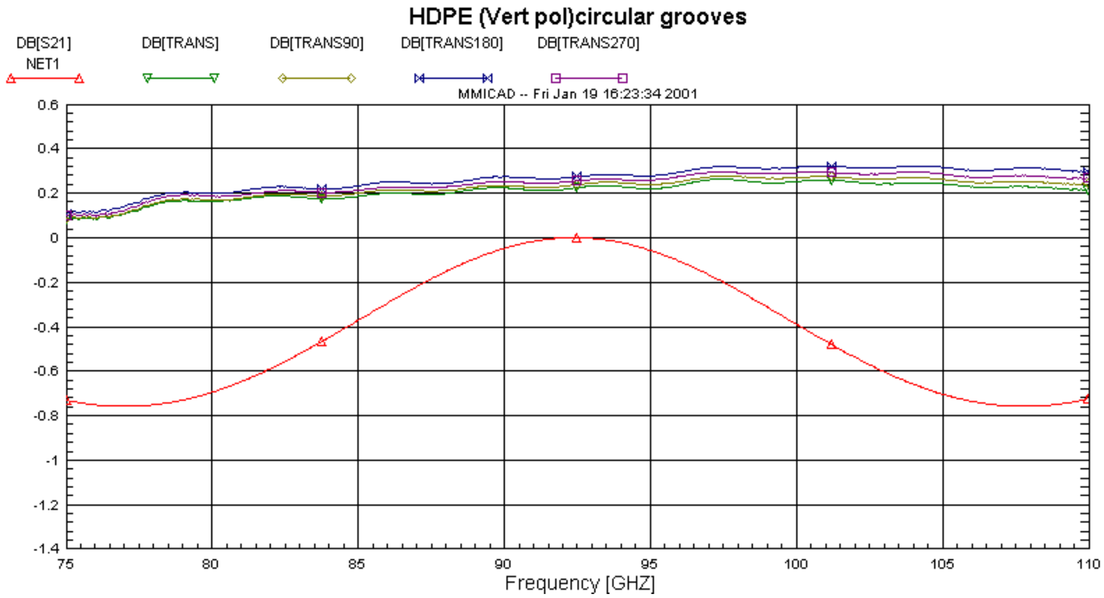

Figure 15 Transmission of HDPE with circular rectangular grooves on both sides at rotation angles 0, 90, 180, and 270 degrees. NET1 (red line) is the theoretical curve for an unmatched layer.

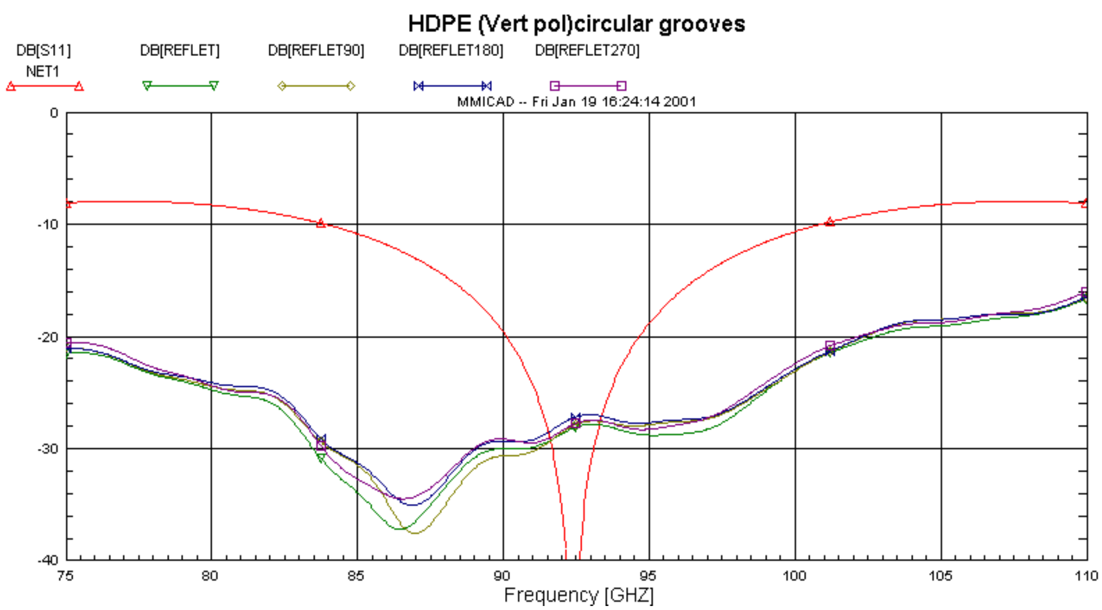

Figure 16 Reflection of HDPE with circular rectangular grooves on both sides at rotation angles 0, 90, 180, and 270 degrees. NET1 (red line) is the theoretical curve for an unmatched layer.

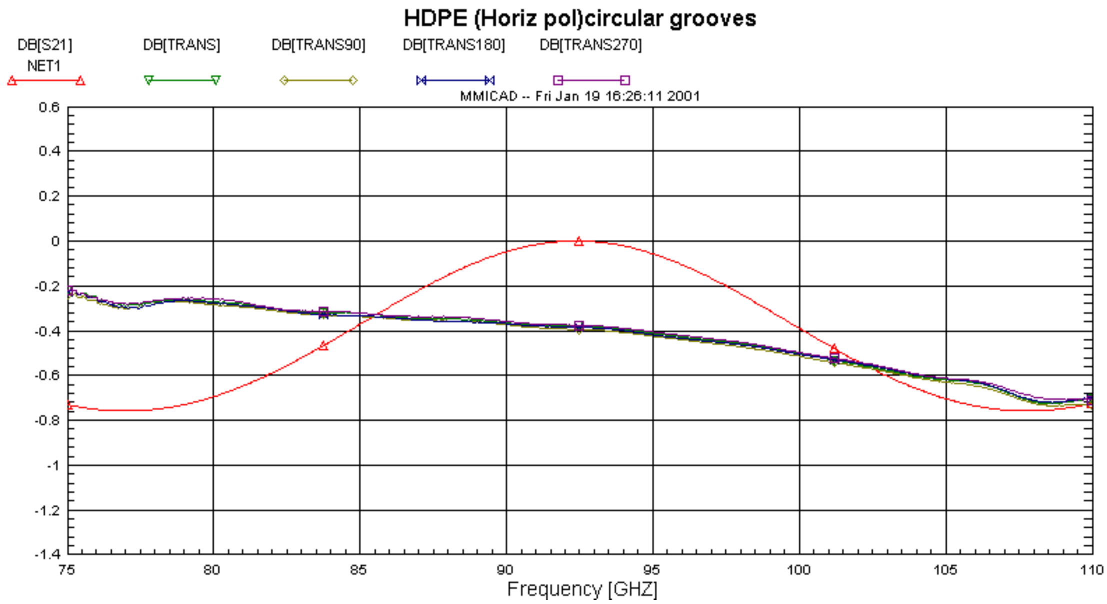

Figure 17 Transmission of HDPE with circular rectangular grooves on both sides at rotation angles 0, 90, 180 and 270 degrees. NET1 (red line) is the theoretical curve for an unmatched layer.

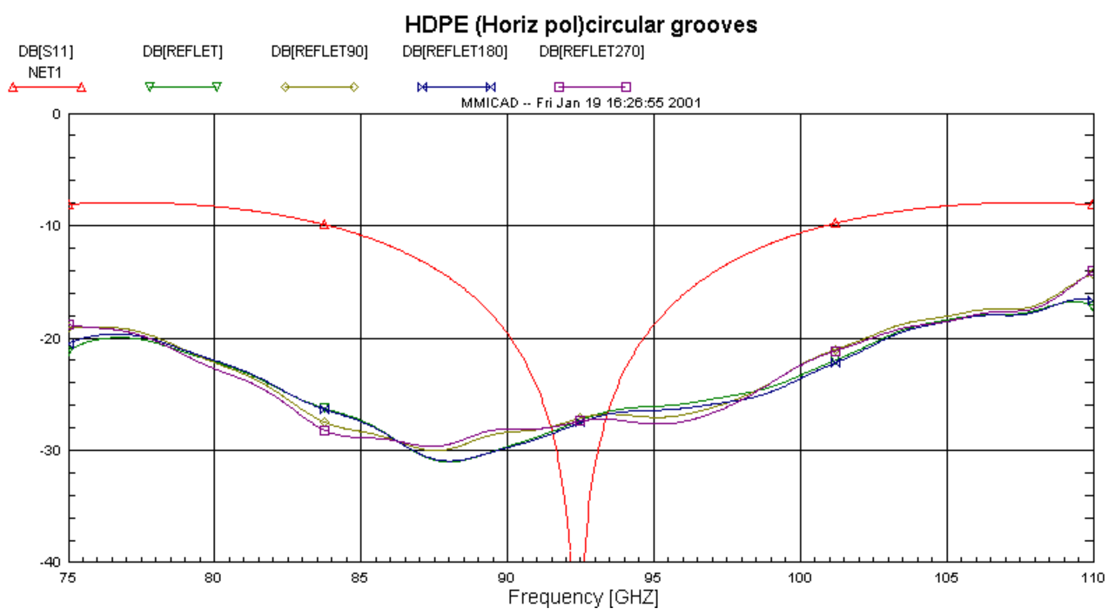

Figure 18 Reflection of HDPE with circular rectangular grooves on both sides at rotation angles 0, 90, 180, and 270 degrees. NET1 (red line) is the theoretical curve for an unmatched layer.

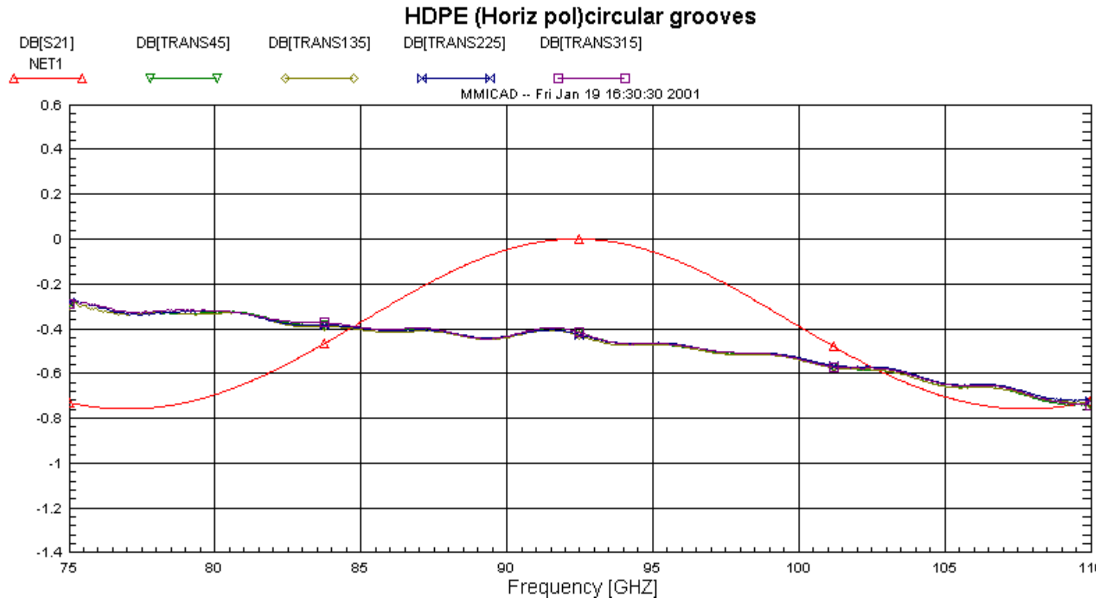

Figure 19 Transmission of HDPE with circular rectangular grooves on both sides at rotation angles 45, 135, 225 and 315 degrees. NET1 (red line) is the theoretical curve for an unmatched layer.

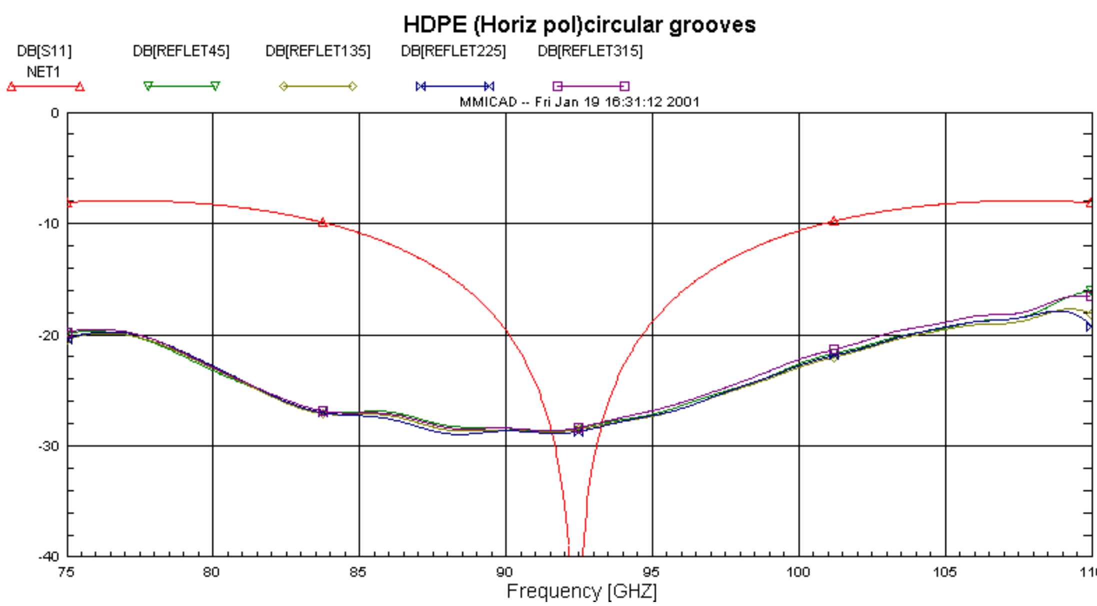

Figure 20 Reflection of HDPE with circular rectangular grooves on both sides at rotation angles 45, 135, 225, and 315 degrees. NET1 (red line) is the theoretical curve for an unmatched layer.

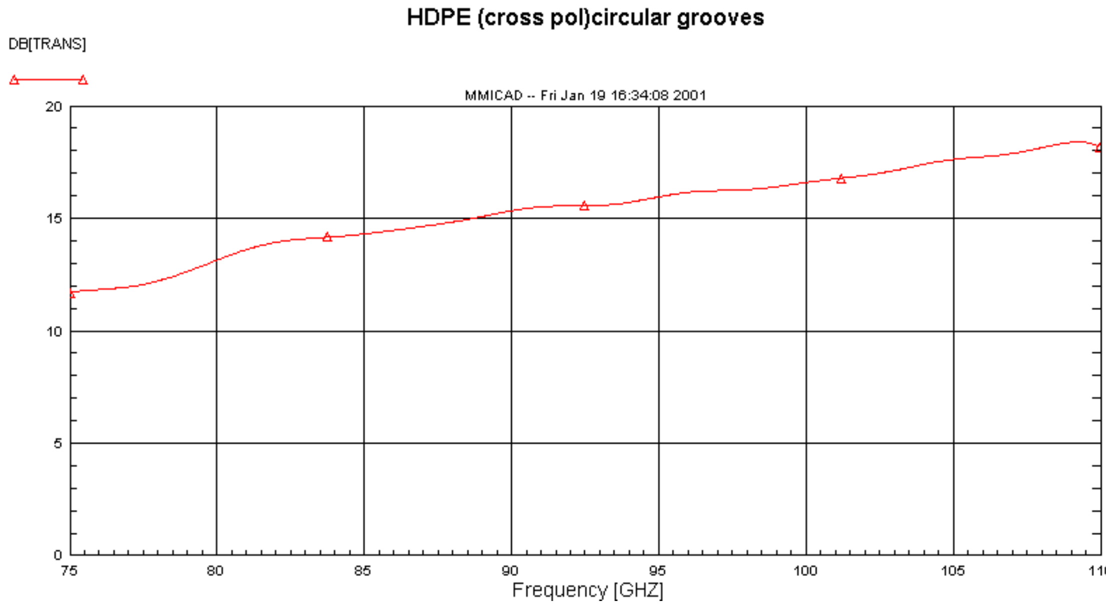

Figure 21 Cross polar increase with circular rectangular grooves on both sides.

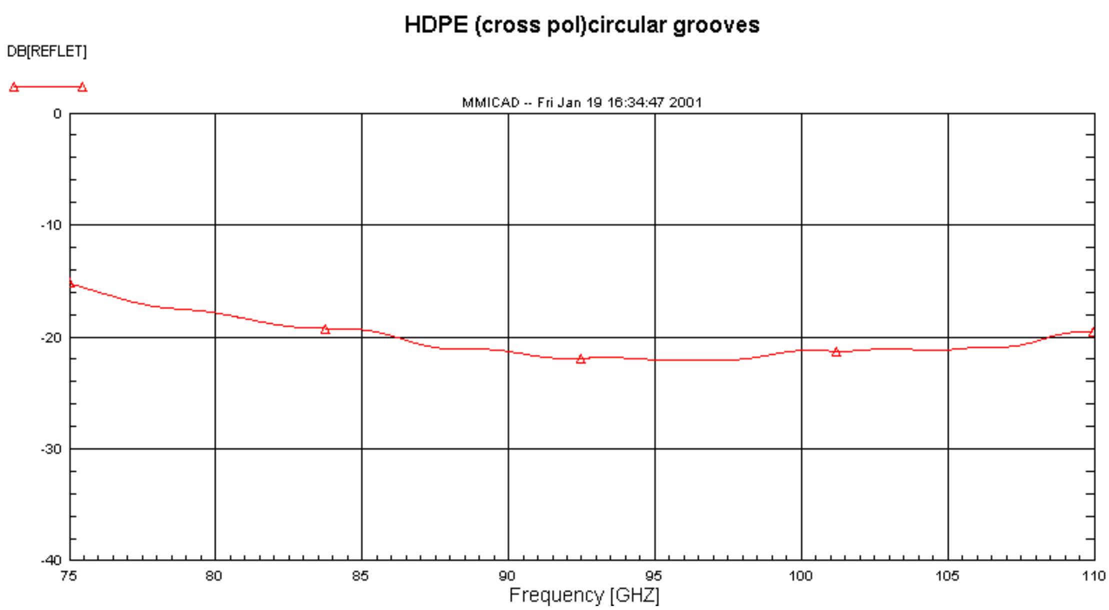

Figure 22 Cross-polar reflection for circular rectangular grooves on both sides.

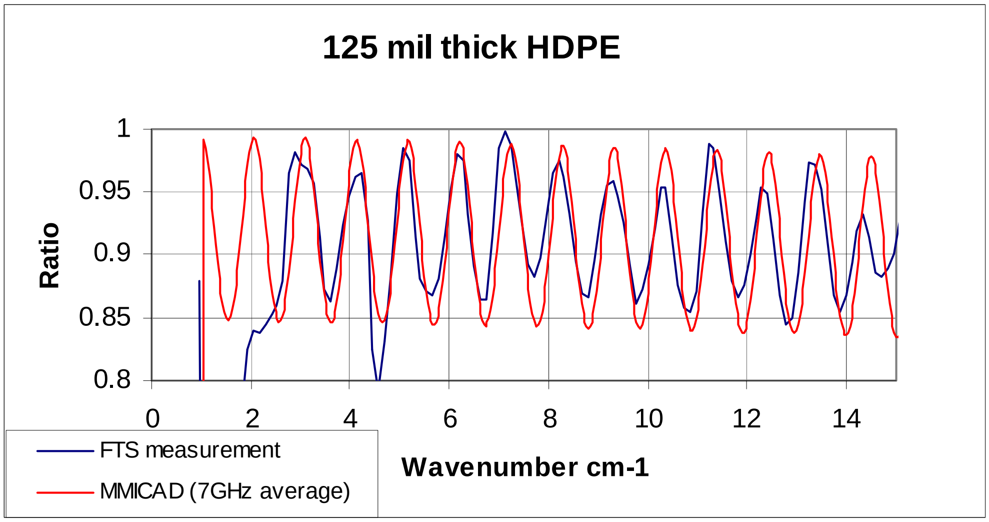

Figure 23 FTS and MMICAD calculations (averaged over 7 GHz) including loss of a 125 mil thick piece of HDPE (1 wavenumber = 30 GHz).

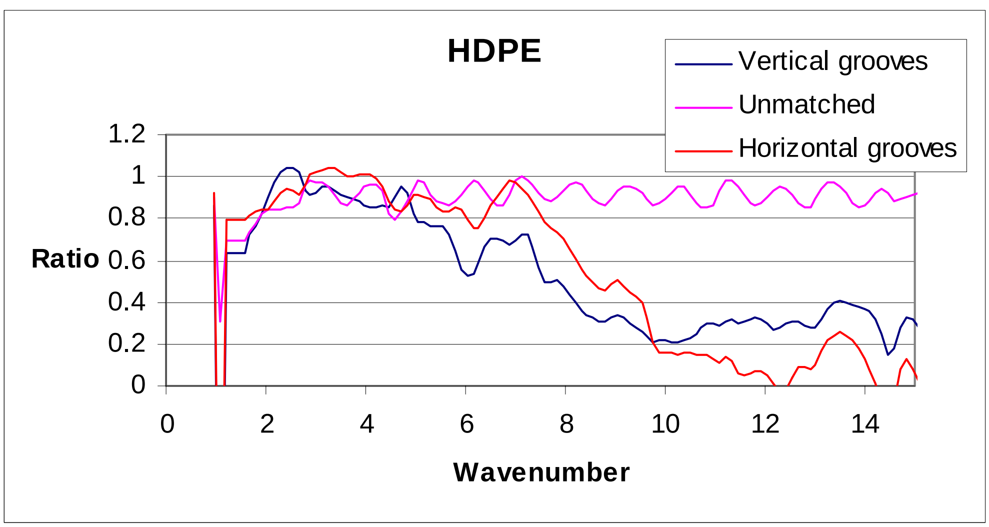

Figure 24 FTS spectra of grooved (linear rectangular both sides) and un-grooved HDPE, resolution 7 GHz (1 wavenumber = 30 GHz).

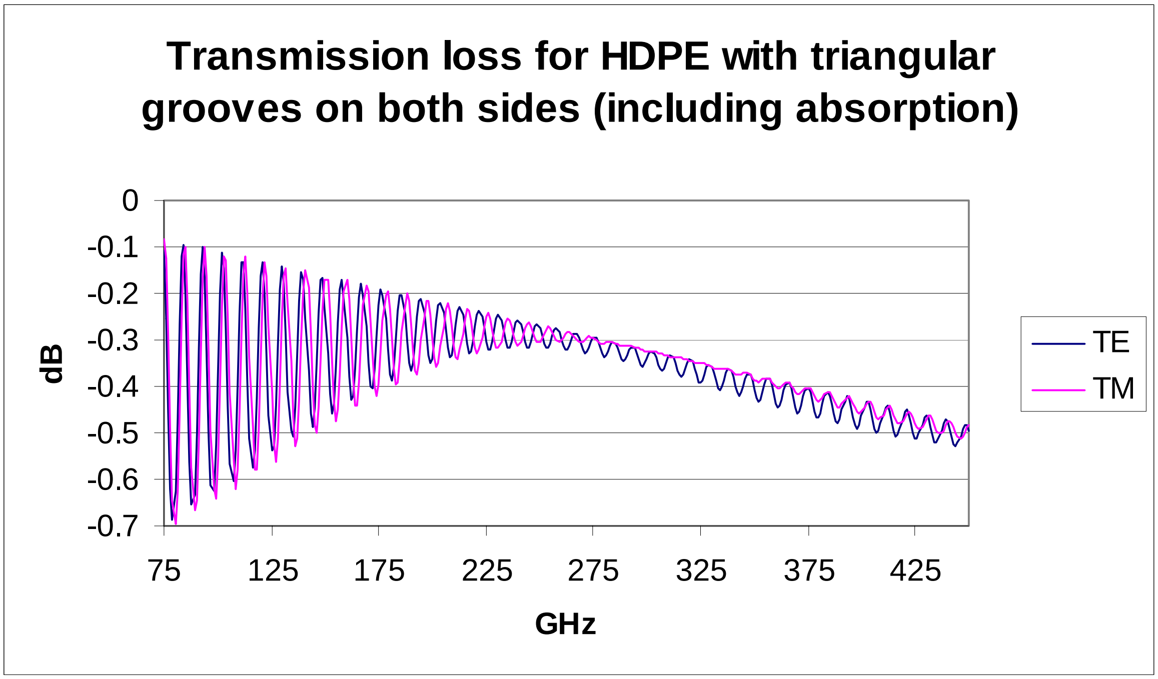

Figure 25 Scatter calculation for the transmission loss of a 11mm thick piece of HDPE with triangular grooves on both sides (including absorption loss tanδ=0.0007, which over estimates loss at low frequency end [2]).

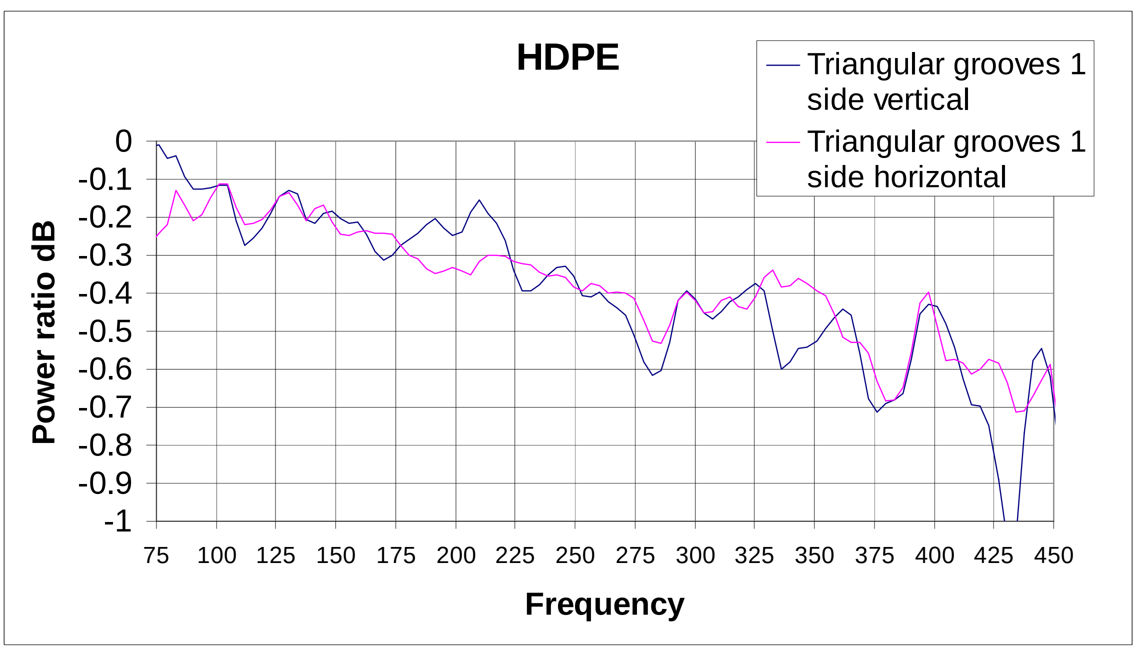

Figure 26 FTS spectra of HDPE with triangular grooves on one face.

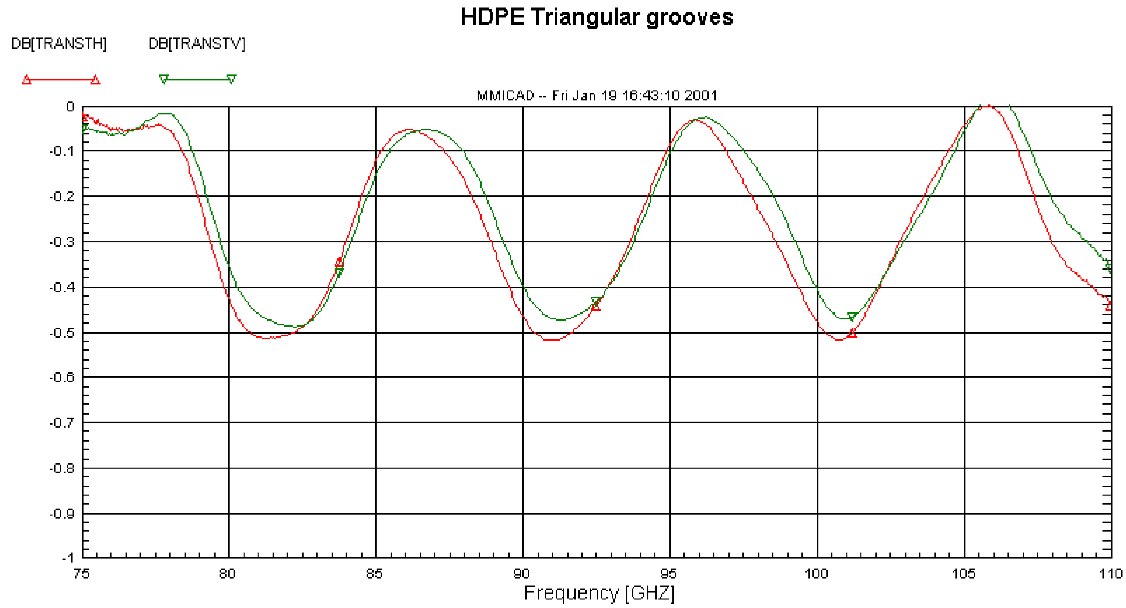

Figure 27 Transmission of HDPE with triangular grooves on one face. Red line horizontal, green line vertical.

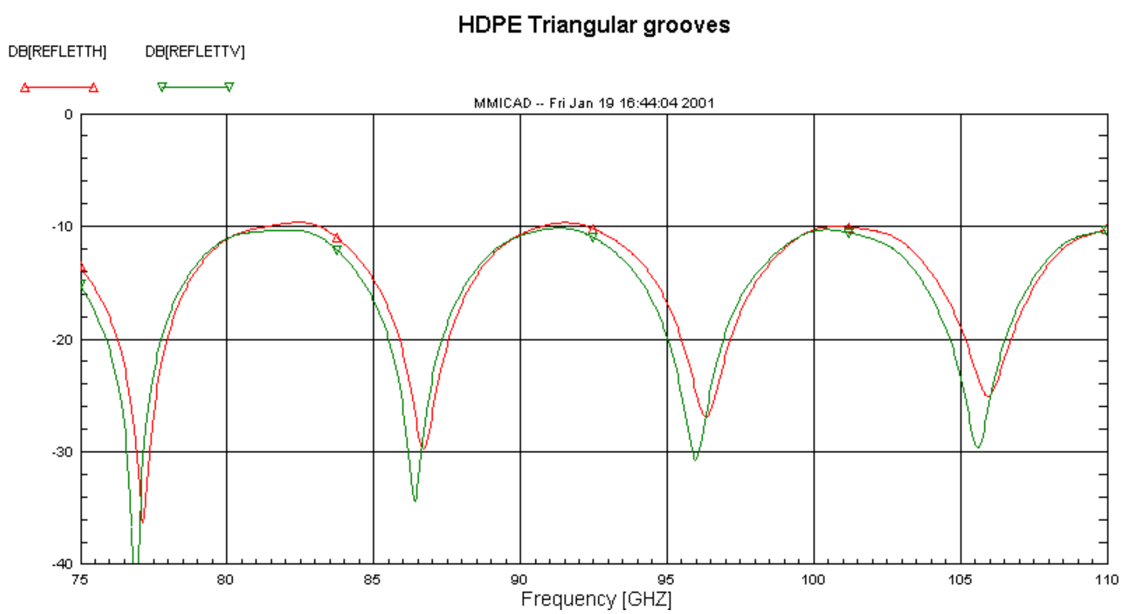

Figure 28 Reflection of HDPE with triangular grooves on one face. Red line horizontal, green line vertical.