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Title: FTS Measurements of Some Window Materials
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FTS Measurements of Some Window Materials

August 31, 1999

Daniel Koller[†], Geoff Ediss[†], Jeff Hesler[‡], and Charles Cunningham[#]

Summary

Fourier Transform Spectroscopy measurements are reported for various window materials over the frequency range of 300-1500 GHz. The materials include Z-cut quartz, Low Density Polyethylene, High Density Polyethylene, Epo Tek 301-2 epoxy, Goretex RA7957 expanded PTFE, a metal mesh band-pass filter and a compound PTFE-Quartz-PTFE vacuum window. The measurements were carried out, at the Herzberg Institute in Victoria, British Columbia, using a new Science Tech SPS200 Fourier transform spectrometer (FTS). The measured refractive indices of the materials were close to the expected values. However, because of instability in the source and/or detector, meaningful measurements of the attenuation coefficients were not obtained.

Spectrometer Stability

In Fourier transform spectroscopy, typically one obtains a sample spectrum which is then divided point by point by a background spectrum, taken with no sample present. In this way, the instrument response is factored out. It is then especially important that the instrument remain stable from one scan to the next (*i.e.*, lamp output, detector sensitivity, mechanical concerns...). The data shown in Figure 1 (upper traces) were simply background (BKG) scans to determine the variation from scan to scan of the instrument. Two more BKG scans, #'s 120 and 121, were taken some hours later and overlap to form the lower trace in Figure 1.

A variation of some 5-7% is immediately evident in the upper group of background scans. While this was originally attributed to the long warmup time of the lamp, it was later discovered that the detector output signal was drifting dramatically, by as much as a factor of 2 in voltage, even after the lamp had been on for an entire day. Figure 2 shows the drift in the *interferograms* for all scans 100-110, and 120, 121 (lying below the others).

The shift in the interferograms resulted in a downward shift of nearly 20% in the background scans as shown by the lower two (overlapping) traces of the first figure. The SPS200 is a slow scan system, in which acquiring a single high-resolution scan can take up to 20 minutes or more,

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so long-term drift becomes a serious concern. Such a drift makes it very difficult to utilize this system to obtain accurate information about the absolute absorption of a given material. In practice, the background noise should be reducible to less than 1% by averaging multiple scans, only if the overall system drift can be reduced to acceptable levels.

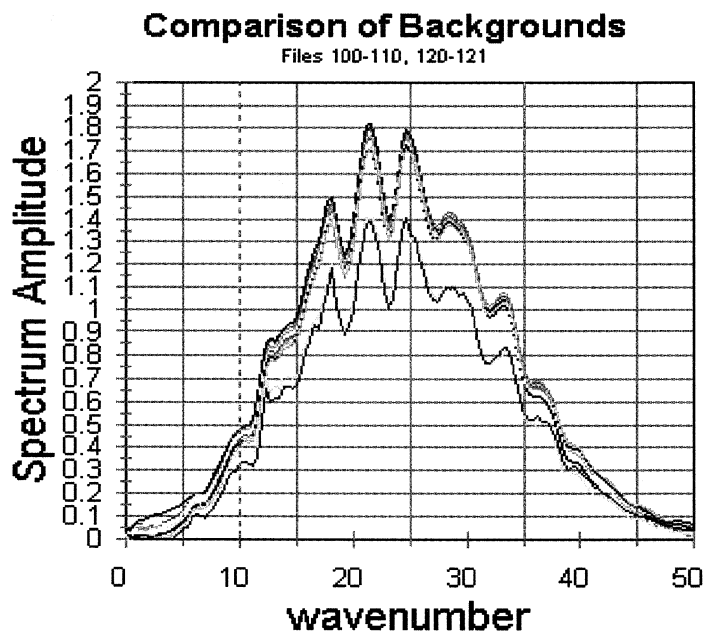


Figure 1. Background scans showing drift in the spectrometer.

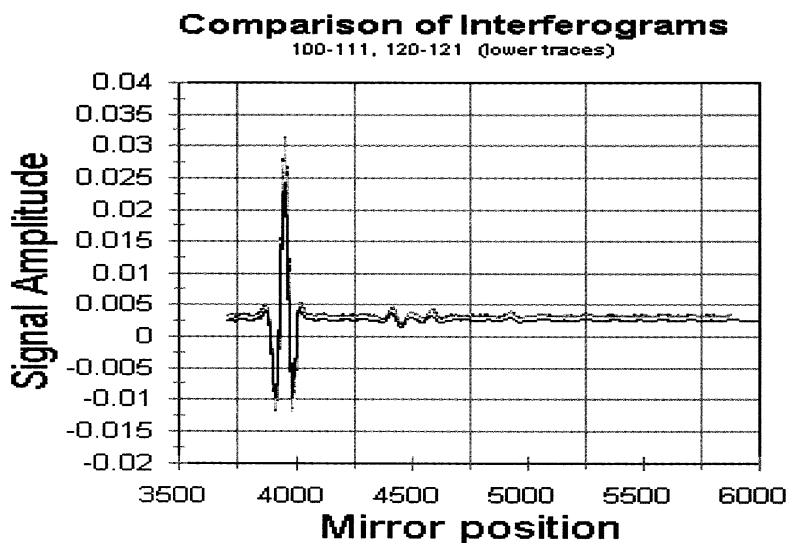


Figure 2. The interferograms corresponding to the background spectra of Figure 1.

Measurements

Filters and Windows

The Z-cut quartz crystal substrate was 12.5 mils thick and clearly shows “channeling” (interference) fringes, which were used to determine the index of refraction by counting the 6 visible interference peaks in Figure 3. The measured value is 2.1 ($\epsilon \approx 4.4$), which agrees with the value for quartz reported in [1].

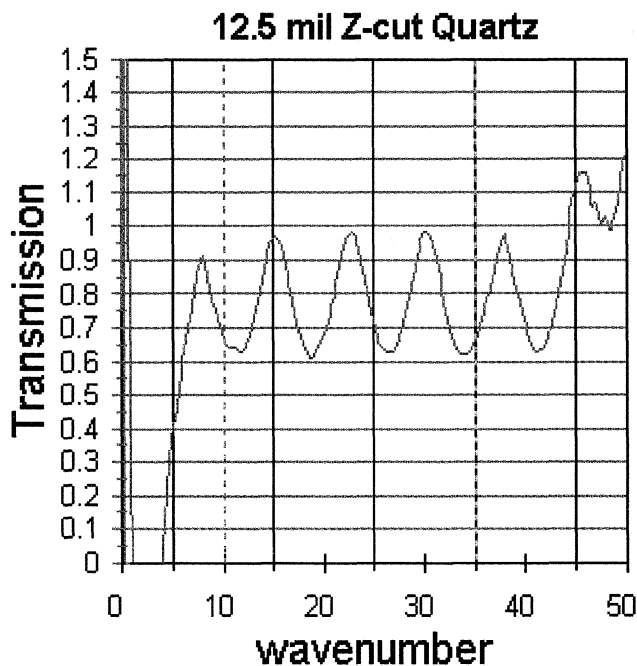


Figure 3. Interference fringes for a 12.5 mil thick Z-cut quartz substrate.

The second sample was a 600 GHz (20 wn) metal mesh band-pass filter made by Jeff Hesler (UVA) [2]. Results are shown in Figure 4. At the 20 wn pass frequency, the transmission appears to exceed unity, but remains within the accuracy of the background scans. The most significant points to notice are the artifacts occurring at about 13, 25, 35 and 45 wn. During this and subsequent measurements, it was noted that the spectra were not reproducible below about 10 wn (300 GHz) and above 35 wn (1050 GHz). The cut-offs correspond to the point at which detector signal falls to 10-20% of the maximum, as demarcated by dashed lines in several of the figures. There is still plenty of power available down to 5 wn and up to 45 wn, further indicating that system drift is adversely affecting the data.

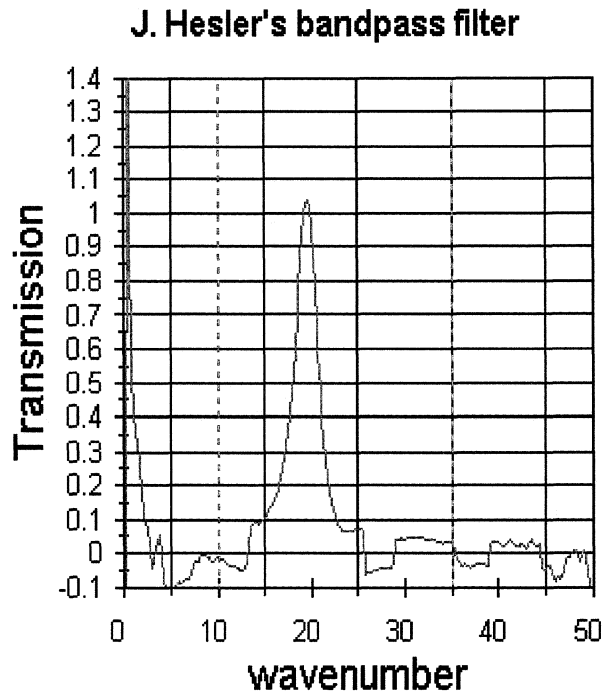


Figure 4. Spectrum of a free-standing metal cross band-pass filter.

Next, a multi-layer window consisting of a 226 mil Z-cut quartz crystal with a 23 mil teflon sheet epoxied onto each face was measured. This window is identical to the 3 layer windows now in use on the VLBA's W-band receivers. The window's pass-bands are clearly resolved in Figure 5. Note that the scan was originally obtained at a resolution of 0.05 wn, but no corresponding background was obtained. The data were instead divided by a lower resolution scan using the SPS200 operating software. Fringes from the quartz are barely resolved, appearing to fill in the troughs between the pass-bands. It should be possible to see these more clearly with a 0.01 wn resolution scan. The window was designed for the 90-116 GHz band, corresponding to the range of 3-3.8 wn. Note that only the *second* and higher passbands of the window are observed through the background noise.

Analysis of the same window using the microwave integrated circuit analysis program, MMICAD [3], is shown in Figure 6. Frequency was incremented in 1 GHz steps, corresponding to about 0.03 wn resolution. While the measured data appear to agree qualitatively with the MMICAD model, the *measured* amplitude is only accurate to within 5% (~ 0.2 dB) due to the spectrometer's instability described previously.

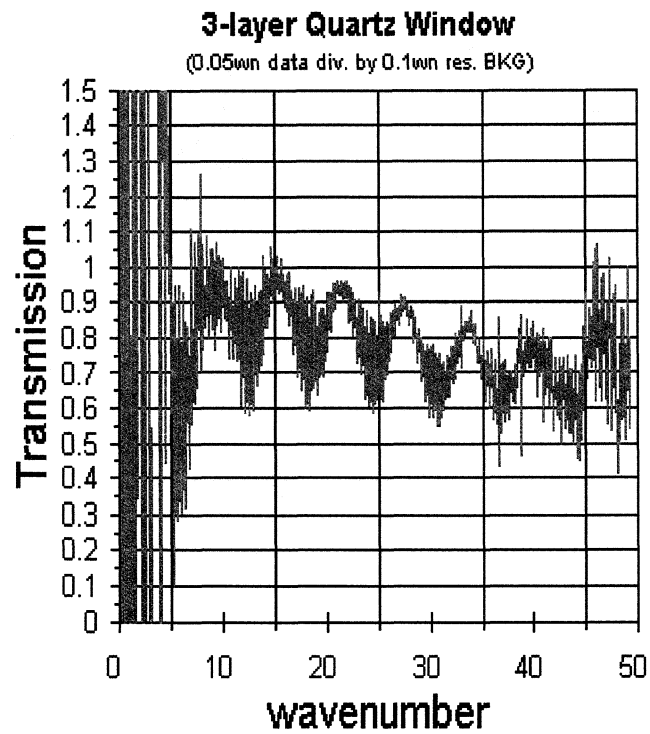


Figure 5. Spectrum of quartz/teflon 3-layer window.

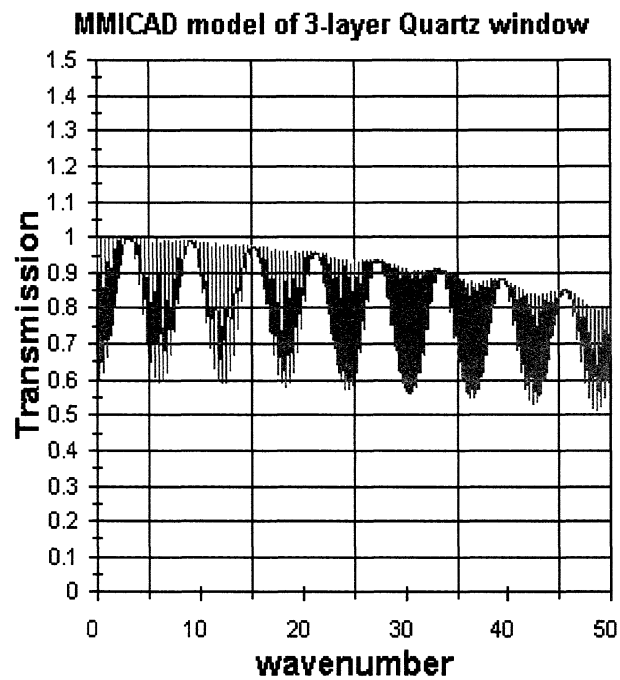


Figure 6. MMICAD model of 3-layer quartz window, corresponding to the measured spectrum of Fig. 5.

Materials

Several materials were measured, including Low Density Polyethylene (LDPE) [4], High Density Polyethylene (HDPE) [4], Ultra High Molecular Weight Polyethylene (UHMW PE) [4], 1/4" Goretex RA7957 expanded PTFE [5], 0.041" Goretex RA7957 [5], and Epo Tek 301-2 Epoxy [6]. RA7957, HDPE and Epo Tek epoxy are used in an experimental 5-layer quartz window and it is desirable to measure the mm-wave properties of these materials. The polyethylene samples were cut from sheet stock, with known orientation, so that any polarization effects resulting from the manufacturing process could be determined.

Data for the Goretex samples remain inconclusive as only low resolution scans were obtained, and the drift in the detector signal did not allow accurate attenuation measurements, so they are not shown.

LDPE samples were measured with sufficient resolution (0.1 wavenumbers) to obtain the index of refraction by counting channeling fringes. The index of refraction was found to be 1.48 ($\epsilon \approx 2.19$) and 1.51 ($\epsilon \approx 2.28$) for polarizations A (chosen arbitrarily) and B (rotated 90° with respect to A), respectively (Figures 7 and 8). 0.5 wavenumber resolution scans were also obtained, and yield an index of 1.49 ($\epsilon \approx 2.2$) for both polarizations. It also seems there is a difference between polarizations in the sample as shown in Figures 7 and 8. Note the downward curvature of the spectrum for the "A" polarization, and the more flat response of the "B" orientation.

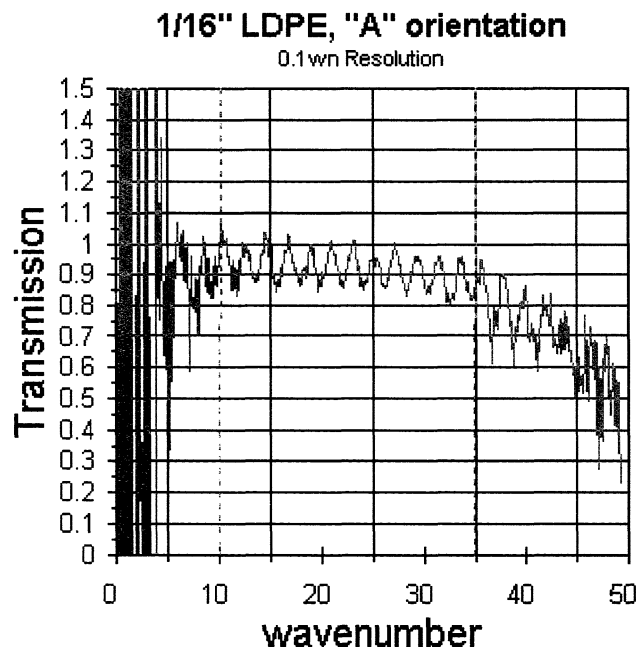


Figure 7. Spectrum of low density polyethylene sheet.

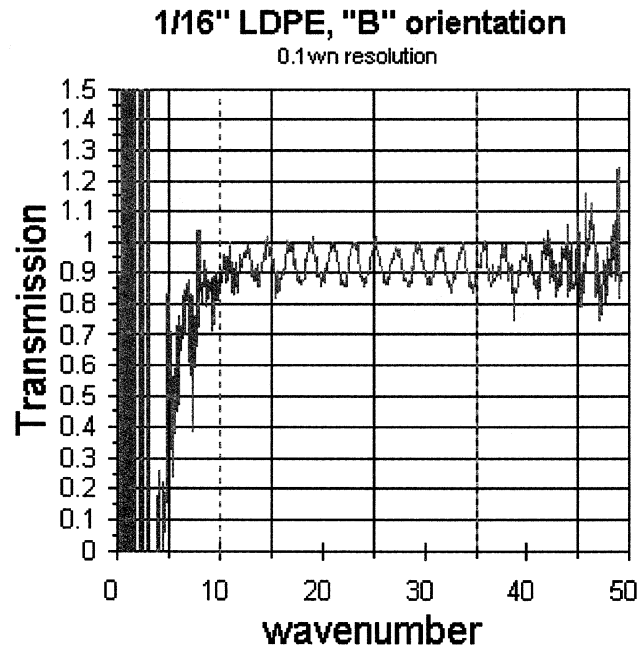


Figure 8. Spectrum of low density polyethylene sheet, rotated by 90 degrees.

The HDPE showed a polarization behavior identical to that of the LDPE, within the accuracy allowed by the system drift, suggesting the behavior is real (Figures 9 and 10). The downward curvature of the "A" spectrum is more pronounced than that of the "B" orientation. Note that even between 35 and 45 wn, where the accuracy of the spectrum is suspect, the results are still similar. The lower resolution (1 wn) of these scans made it difficult to obtain any more than qualitative information about the material.

Between 10 and 35 wn, the UHMW PE spectra were relatively flat, and so are not shown.

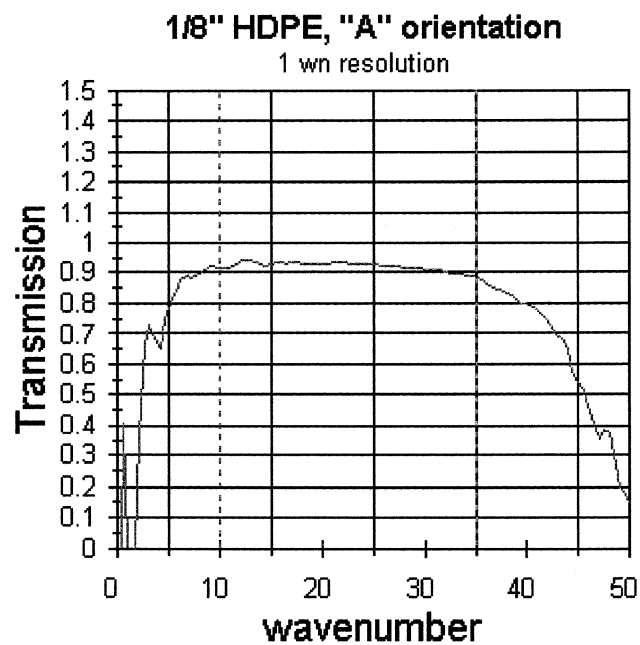


Figure 9. Spectrum of high density polyethylene sheet.

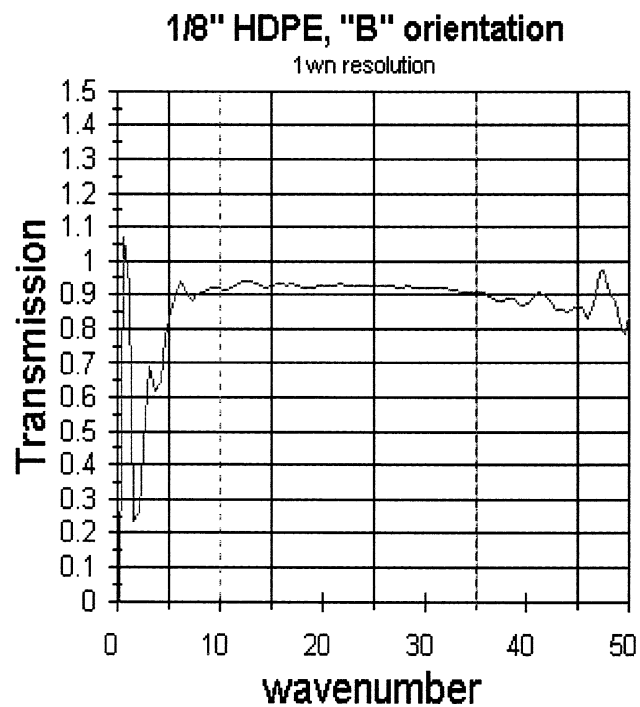


Figure 10. Spectrum of high density polyethylene sheet, rotated by 90 degrees.

Finally, a 59.5 mil thick sample of Epo Tek 301-2 optical epoxy was measured, and the results are shown in Figure 11. The fringes were carefully counted to determine the index of refraction, $n = 1.67$ ($\epsilon \approx 2.8$), more or less constant over the range from 7 to 25 wn . The solid line is a MMICAD fit to the data over the frequency range of 300-900 GHz (10-30 wn). The model included a frequency dependent absorption coefficient of the form $\alpha = A + Bf + Cf^2$. The best fit was found for $A = 0.0 \text{ dB/m}$, $B = 2.1 \text{ dB/m}$, $C = 5.7 \times 10^{-3} \text{ dB/m}$, and is plotted versus frequency in Figure 12.

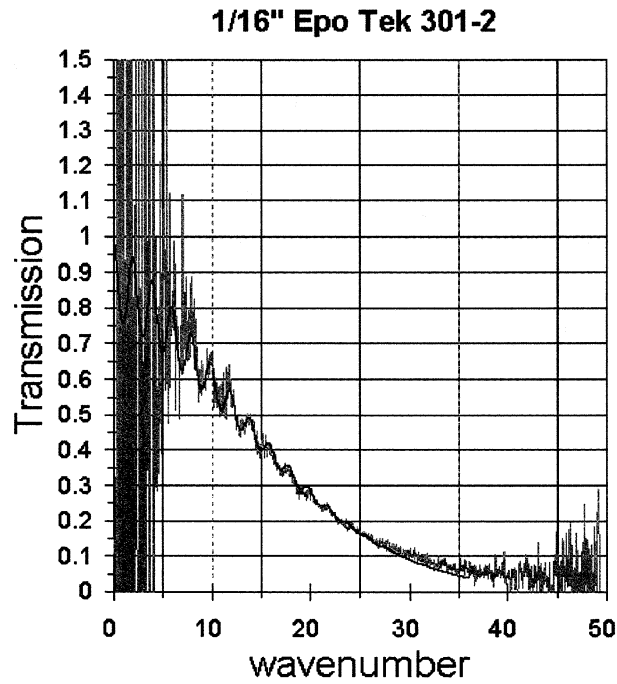


Figure 11. 1/16" disk of Epo Tek 301-2 Epoxy. Solid line is a fit, modeled to the data.

Attenuation Coefficient Vs. Frequency

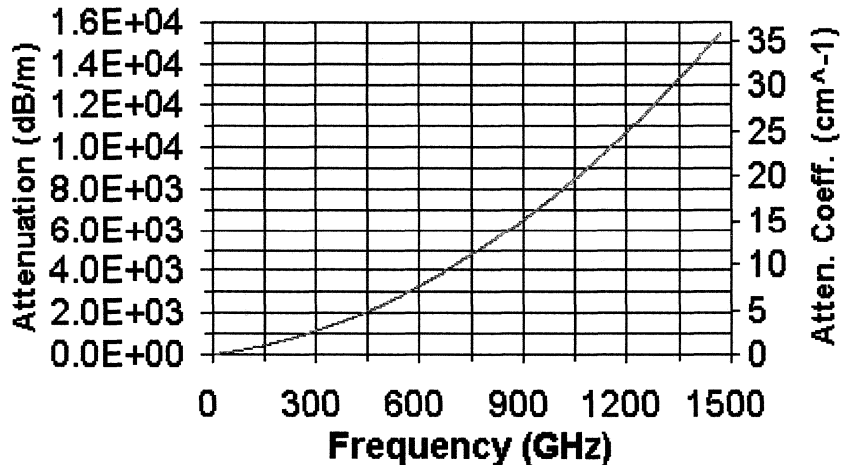


Figure 12. Modeled attenuation coefficient of Epo-Tek 301-2.

References

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- [2] D. W. Porterfield, J. L. Hesler, R. Densung, E. R. Mueller, T. W. Crowe and R. M. Weikle II, "Resonant Metal-Mesh Band Pass Filter for the Far Infrared," *Applied Optics*, vol. 33(25) 194, pp. 6046-6052.
- [3] Optotek, Ltd., 62 Steacie Drive, Kanata, Ontario, Canada K2K 2A9.
[Http://www.optotek.com/](http://www.optotek.com/).
- [4] Obtained from McMaster-Carr, P. O. Box 440, New Brunswick, NJ 08903-0440.
Njsales@mcmaster.com All three polyethylene samples are from sheet stock, natural white color, oil free. LDPE is catalog #8657K111. HDPE is catalog #8619K321, UHMW PE is catalog #8752K111.
- [5] W. L. Gore and Associates, Inc., 1901 Barksdale Rd., P. O. Box 9236, Newark, DE, 19714-9236. RA7957 is currently designated RA7956 in thicknesses less than 0.1".
- [6] Epoxy Technology, Inc., 14 Fortune Dr., Billerica, MA 01821-3972. 301-2 is a two-part, slow curing optical epoxy.