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Measurements of Quasi-Optical Windows with the HP 8510

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An HP 8510 vector network analyzer was used to measure the reflection coefficient and transmission loss of a three-layer quasi-optical vacuum window and several reference samples in the frequency range 75-110 GHz. Time gating was used to reduce the effect of small reflections from waveguide flanges and optical components which otherwise seriously corrupt the measurement.

Reflection measurements

The HP 8510C [1] with WR-10 RF modules was calibrated by the TLM method using a short circuit, a through connection, and a known length of waveguide. To check the calibration in the time domain, the short was placed at the reference plane which gave a peak of amplitude 995.00 mUnits at zero time delay (0 ns).

Figure 1 shows the arrangement for measuring the reflection from flat samples. A standard 25 dB pyramidal gain horn was used with a HDPE collimating lens of focal length f = 75 mm. The lens has no matching grooves. All apertures are 4.75" diameter, and all metal surfaces are covered with AN-72 absorber to reduce reflections.

Figure 2 shows the complete time domain response with a 0.5" HDPE sample. The 8510 is set in band-pass mode with time gating off. Each peak in the response is caused by a reflection from some obstacle or interface. Peaks below 0 ns are due to discontinuities at the waveguide connections on the source side of the calibration plane. The peak at 0 ns is from the waveguide flange at the reference plane, and has a reflection of 1.25% (12.5 mUnits). The small peak at 0.65 ns is the waveguide flange of the horn, and has a reflection of 0.6%. This is followed at 0.75 ns by the transition from uniform waveguide to the pyramidal horn, which produces a reflection of 2.4%. At 1.05 ns there is the reflection from the aperture of the horn (0.4%). The peak at 1.425 ns of 3.6% is the part of the power reflected at the front (flat) face of the lens which returns to the feed (reduced due to the beam expansion). The rear (curved) face reflects 0.6% at 1.8 ns. The time difference of 0.375 ns (73.5 mm) matches well the round trip distance in the 36 mm thick HDPE lens with a relative dielectric constant of 2.34 (a typical value for HDPE). The small peak at 2.1 ns is a reflection in the system which can be reduced by placing absorber on the optical bench. The double peaks at 2.85 and 2.975 ns are due to the front and rear faces of the 0.5" thick HDPE sample. The peak amplitude, 22% when corrected for beam expansion by placing a reflecting aluminum plate at the same position as the sample, matches the expected reflection coefficient for HDPE: n-1/n+1 = 0.21. The small peaks at > 3.5 ns are caused by multiple reflections and reflections beyond the sample in the test setup.

To determine the reflection coefficient (S_{11}) of the sample under test as a function of frequency, time gating is used to exclude reflections other than those from the front and rear surfaces of the sample. The importance of time gating will be demonstrated in an example below. With gating on, the 8510 is switched to the frequency domain. A reference sweep is taken with a metal reference plate in place of the sample, and this is used to normalize the (frequency domain) S_{11} data measured on the sample under test. In these experiments, the reference data and sample measurements were stored separately and the normalization done later using MMICAD [2].

Figure 3 shows S_{11} vs frequency for the 0.5" HDPE plate measured in this way, and also the result calculated by MMICAD for a 0.5" long transmission line with $\varepsilon_r = 2.33$. An electrical delay of 1.855 ns (free space) was introduced in the 8510 to de-rotate the phase.[1] The measured results in the frequency domain are obtained with a time domain gate 1 ns wide, centered on the sample. Changing the gate width until another reflection appeared within the gate made no difference to the measurements. Moving the reference plate within the gate range made a difference of ± 0.2 dB in the calibration, and it should be carefully placed at the same position as the sample.

Figure 4 shows the (normalized) frequency response of a sample of grooved absorbing material UMass Terasorb-500 [3] which is designed for 500 GHz. The absorber is clearly better with the grooves perpendicular to the E-field. Also shown is the noise floor of -45 to -60 dB with an empty sample holder, which is very sensitive to stray reflections. If the absorber is tilted at an angle of more than a few degrees from normal incidence, S_{11} drops to -40 to -50 dB with no frequency structure.

Figure 5 shows the normalized S_{11} for a 0.850" Teflon sample, and also the results calculated with MMICAD for a relative dielectric constant 1.97 which gave the best fit to the measurements.

Finally, a three-layer PTFE/z-quartz/PTFE vacuum window was placed at the sample position. Figure 6(a) shows the (normalized) reflection and the theoretical results calculated with MMICAD. A best fit to the measurements was obtained with crystal quartz of thickness 0.221" and $\varepsilon_r = 4.66$, and PTFE of thickness 0.0224" and $\varepsilon_r = 2.10$. The glue was assumed to have a thickness of 0.0002" and $\varepsilon_r = 2.8$. For comparison, the results of the same measurement with time gating off are shown in Figure 6(b).

Transmission measurements

Figure 7 shows the arrangement for transmission measurements (S_{21}). As above, a TLM calibration was used with 801 frequencies. With no sample, in the time domain, a pulse of amplitude ~400 mUnits was seen at 2.81 ns, followed by additional peaks of amplitude < 40

[1] Without de-rotating the phase, the phase change between successive data points was too great to allow consistent data processing.

mUnits corresponding to paths with multiple reflections. Every component of the optics was aligned as accurately as possible by maximizing the transmitted signal and then further maximizing in the frequency domain with the time gate 1 ns wide.

The following measurements were made in the frequency domain with time gating on. The measured data were normalized to reference measurements taken with the sample removed. The (un-normalized) reference curve is shown in Figure 8.

Figure 9 shows the measured transmission for a 0.500" HDPE sample, and also the MMICAD fit with $\varepsilon_r = 2.33$ and no loss.

Figure 10 shows the measured and theoretical transmission of a 0.850" Teflon sample with $\varepsilon_r = 1.98$ and $\alpha = 39.37*(-0.13+0.0025*\text{frequency in GHz})$ dB/m as given by Afsar [4].

Figure 11 shows the transmission measurements of the three-layer window with the same fit parameters as for the reflection measurements above.

Figure 12 shows the measured transmission of the UMass Terasorb-500 absorber, with the grooves perpendicular and parallel to the E field of the horns.

Figure 13 shows the transmission of a 0.225" z-axis crystal quartz sample. The best MMICAD fit gives $\varepsilon_r = 4.42$ and negligible loss.

It is observed that all the measurements on simple dielectric samples show discrepancies below ~85 GHz and above ~105 GHz, which are probably due to diffraction and coupling changes with and without the sample. Signal levels slightly above the zero line are probably also due to same effects.

To demonstrate the effect of the time domain gating on transmission measurements, Figure 14 shows the measurements of the 0.225" sample of z-axis quartz with gating off and 6% smoothing applied (compare with Figure 13). The smooth curve shows the theoretical results.

Conclusions

It has been demonstrated that time-domain gating greatly enhances the precision of reflection and transmission measurements of quasi-optical components using a vector network analyzer. The measurement accuracy is sufficient for evaluating ALMA vacuum windows and IR filters.

References

1. HP 8510 with time domain extension from Hewlett Packard.

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

3. University of Massachusetts at Lowell, Submillimeter-Wave Technology Lab, 175 Cabot St., Lowell, MA 01854.

4. M. N. Afsar, "Dielectric Measurements of Common Polymers at Millimeter Wavelength Range," *IEEE MTT International Microwave Symposium Digest*, pp. 439-442, 1985.

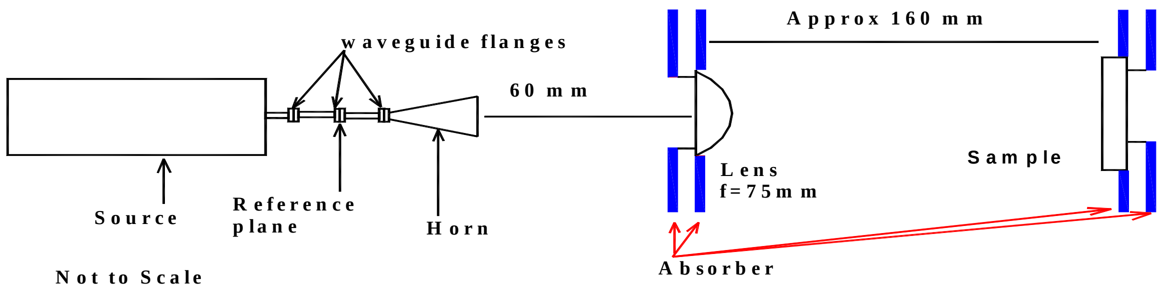


FIGURE 1

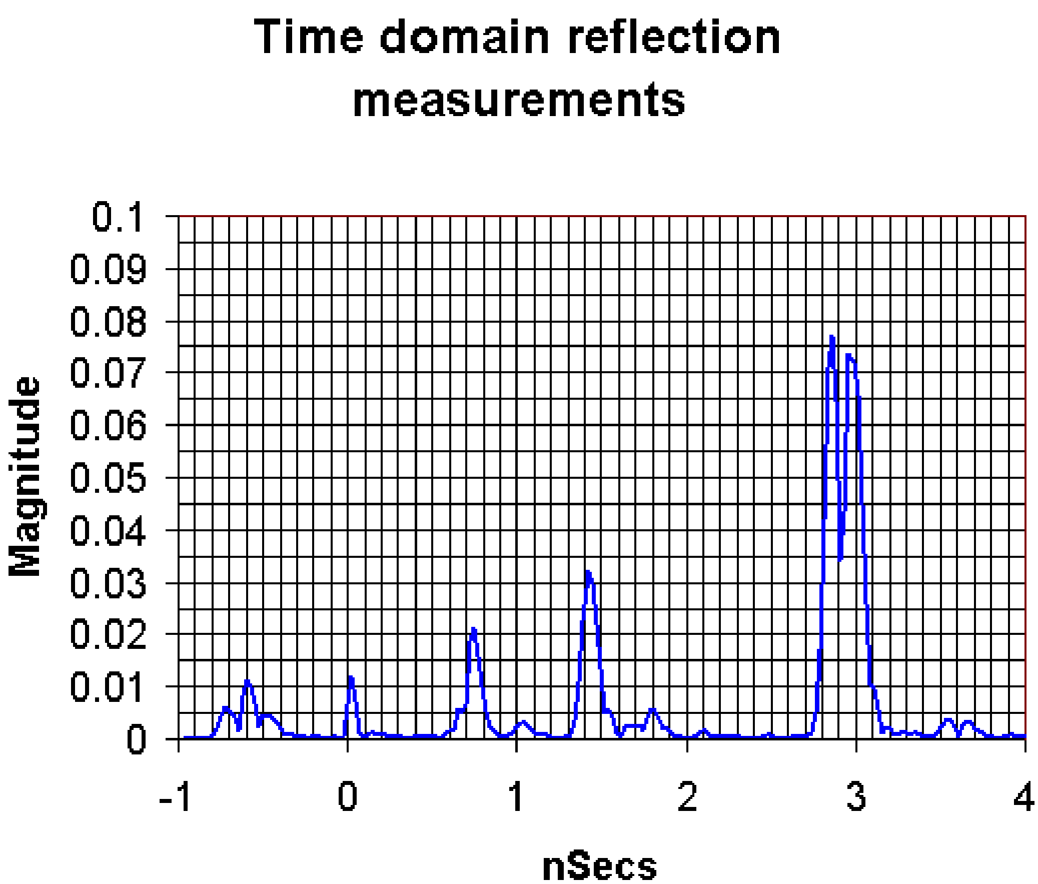


FIGURE 2

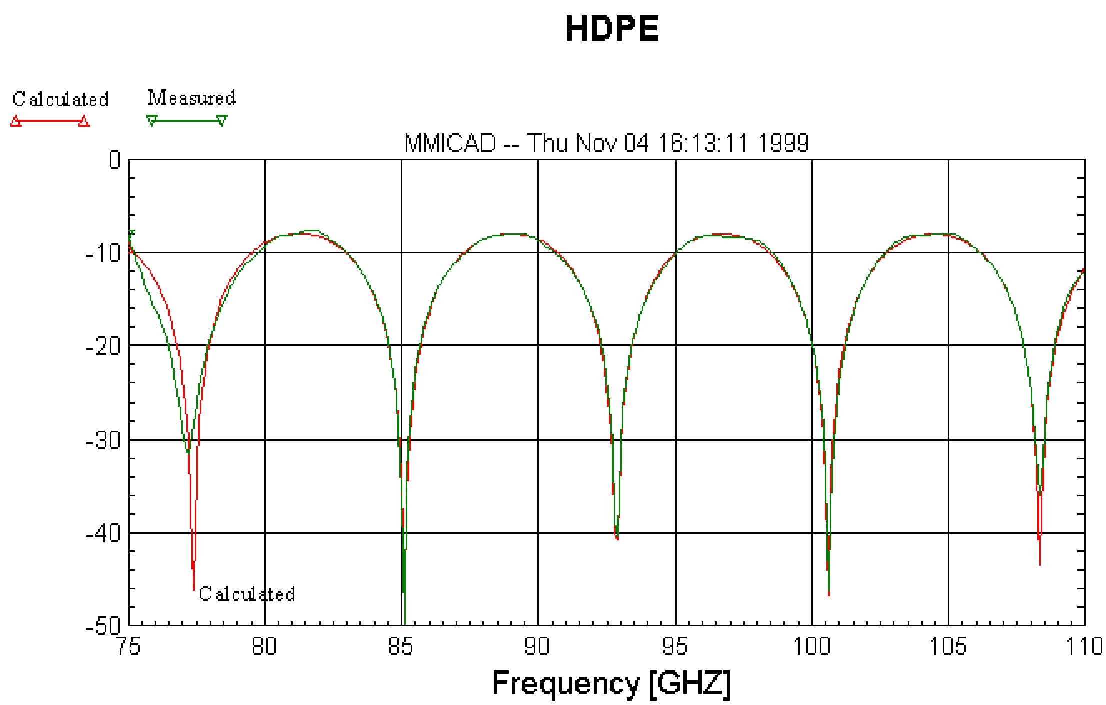


FIGURE 3

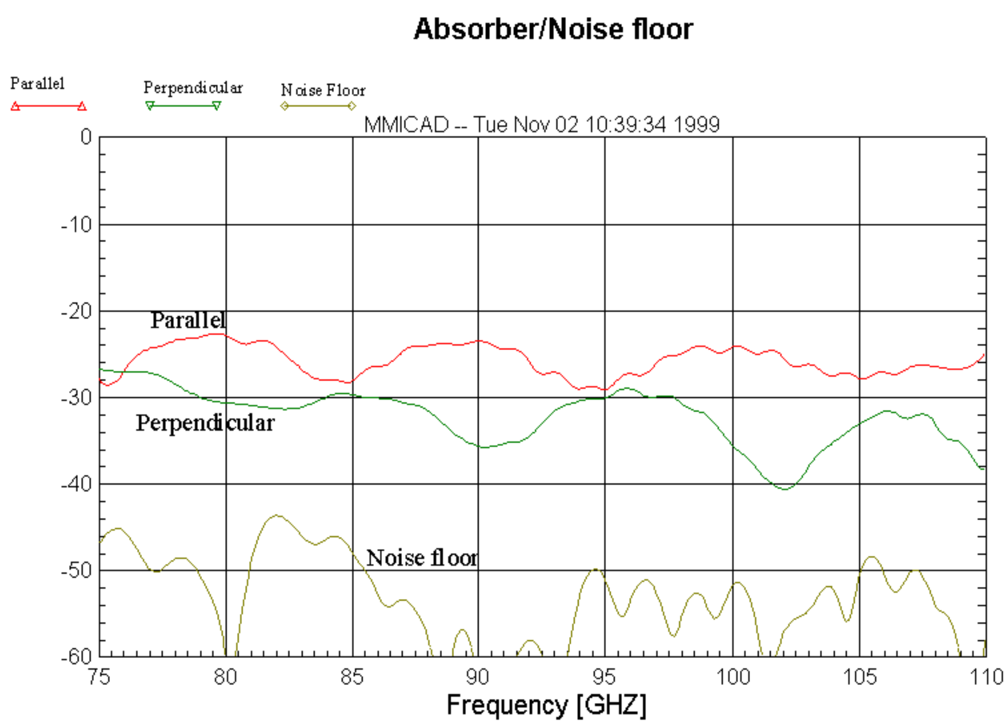


FIGURE 4

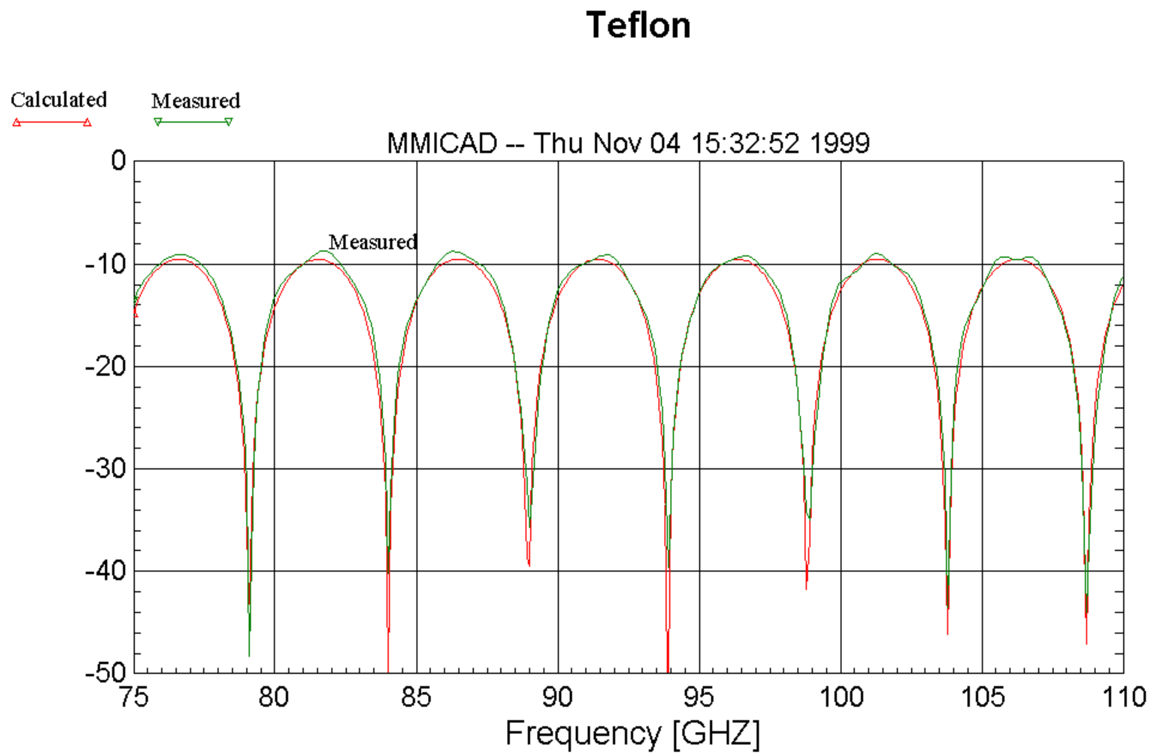


FIGURE 5

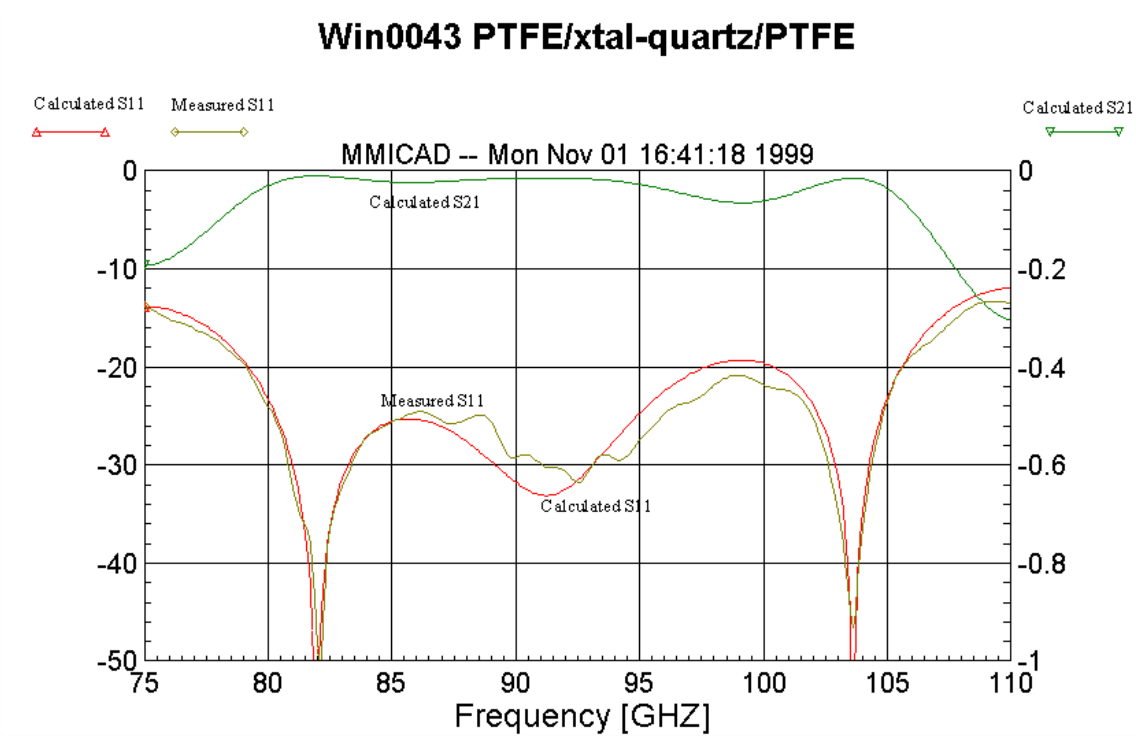


FIGURE 6a

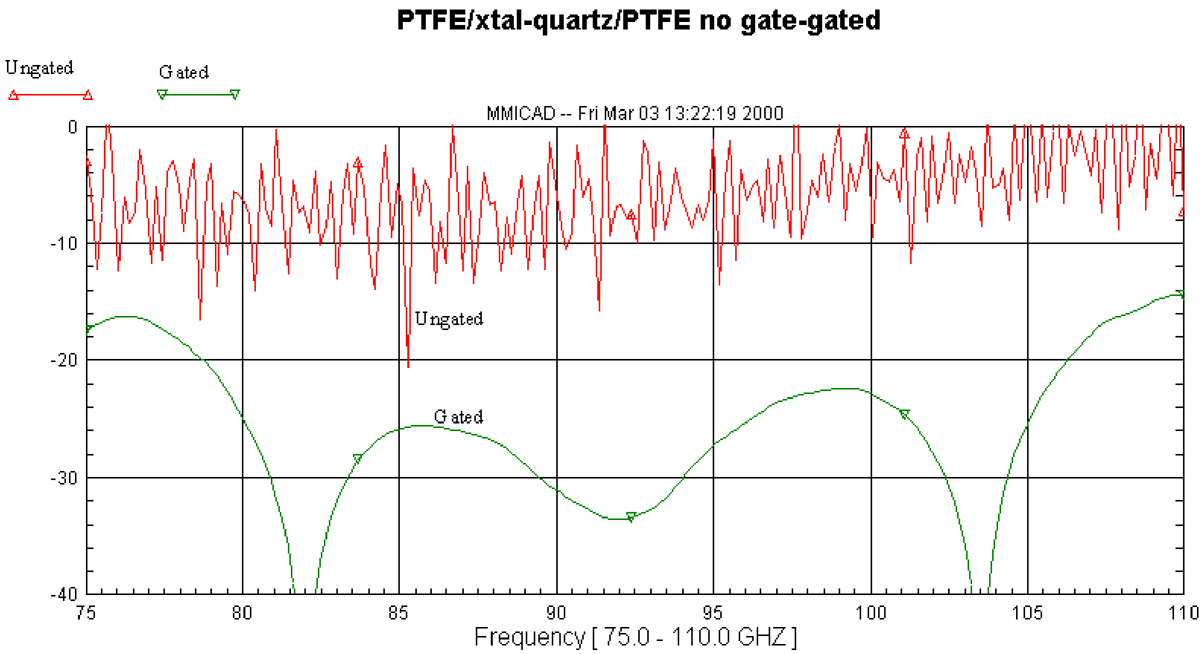
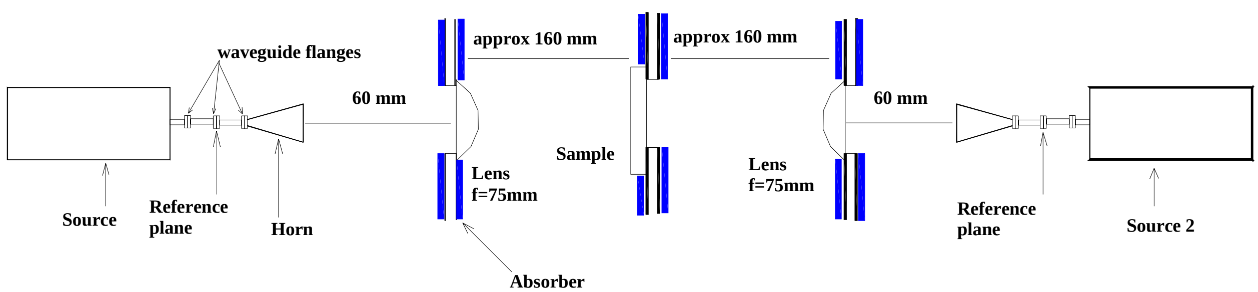


FIGURE 6b



Not to Scale

FIGURE 7

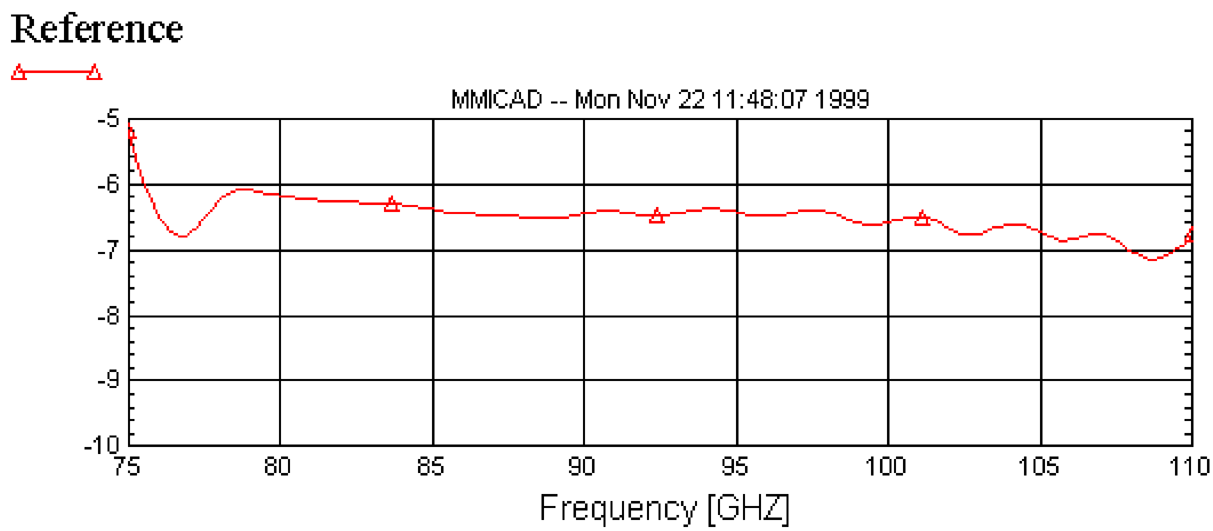


FIGURE 8

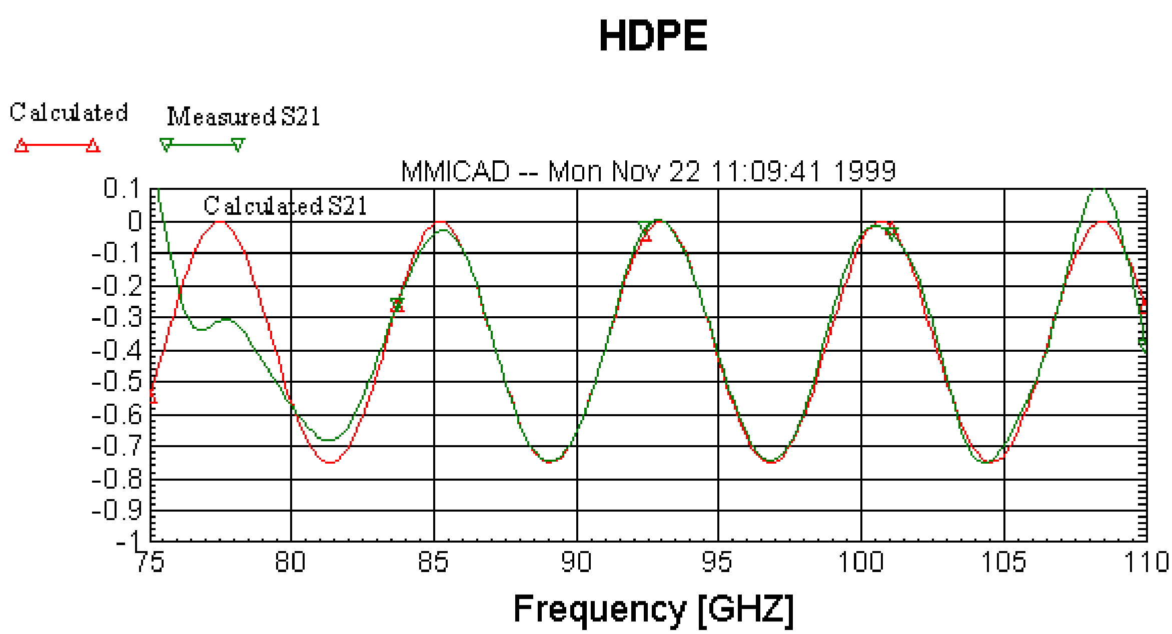


FIGURE 9

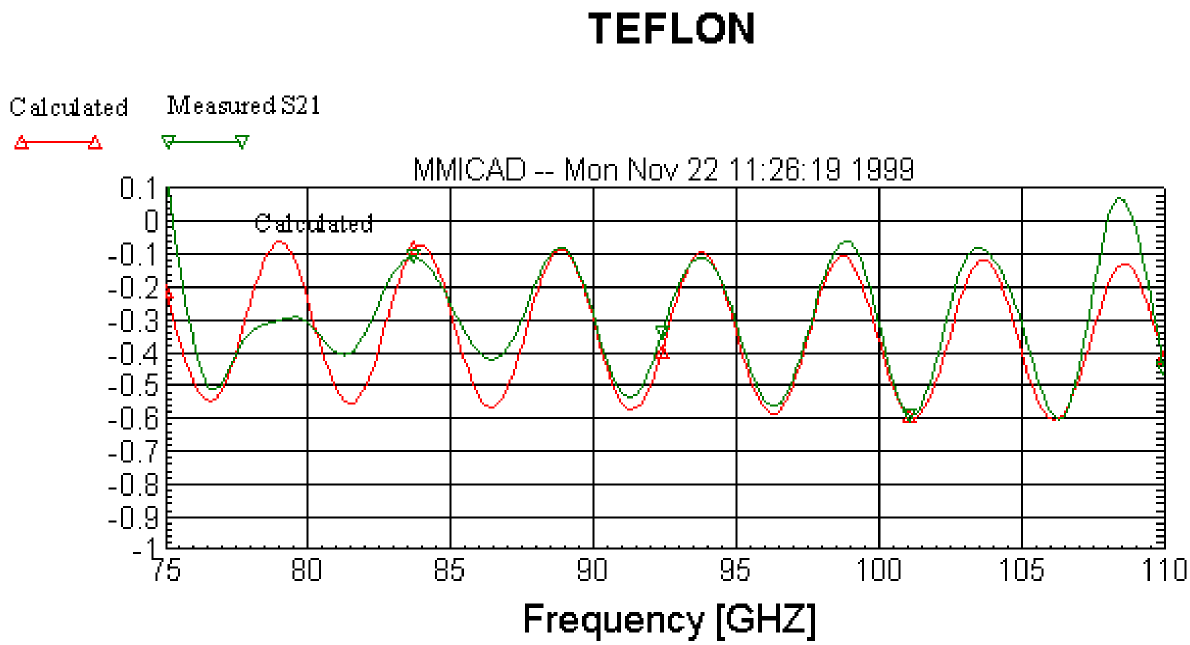


FIGURE 10

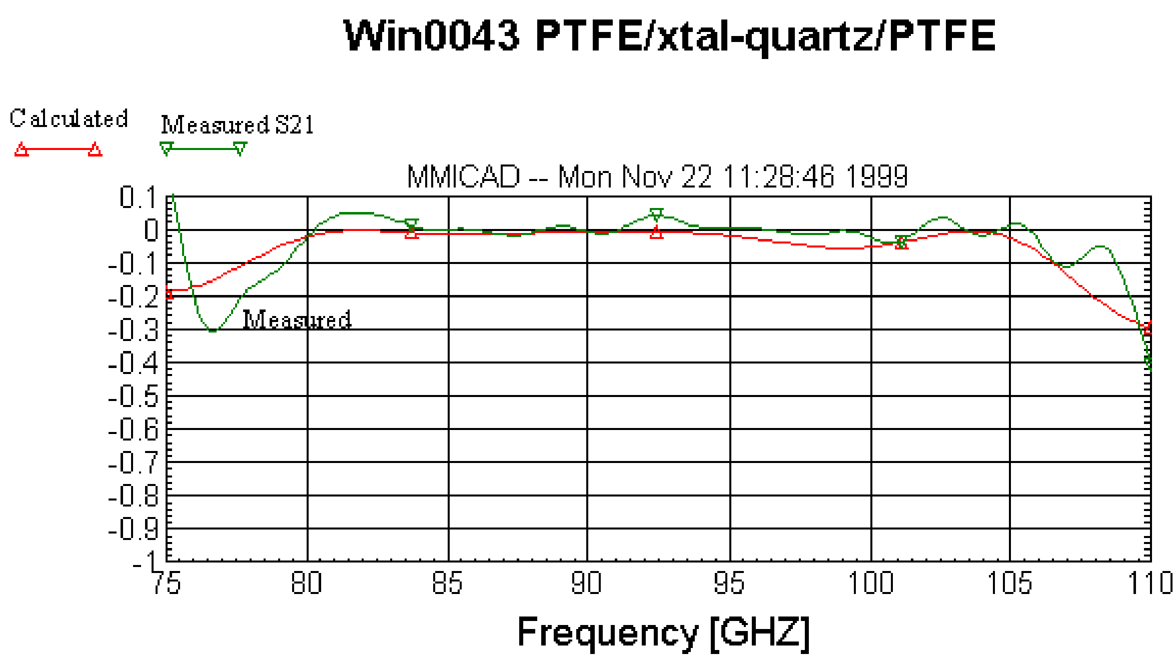


FIGURE 11

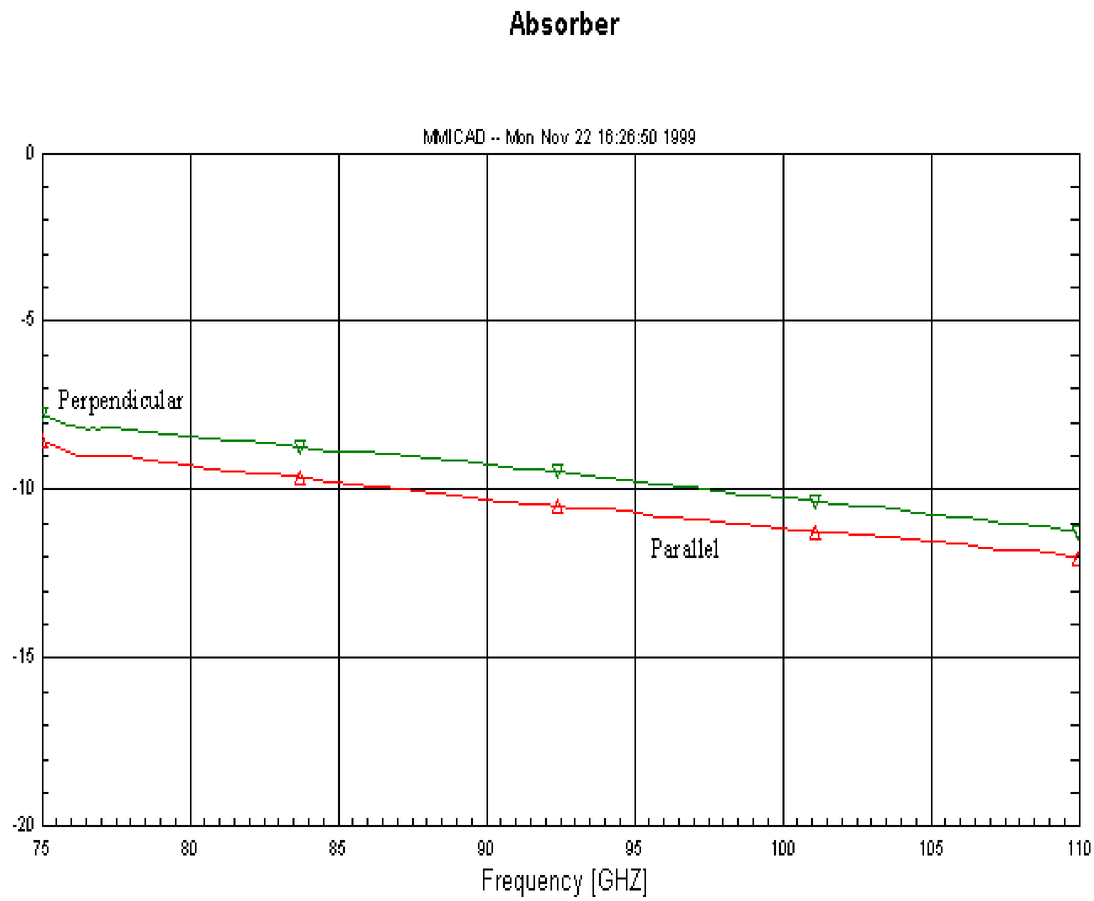


FIGURE 12

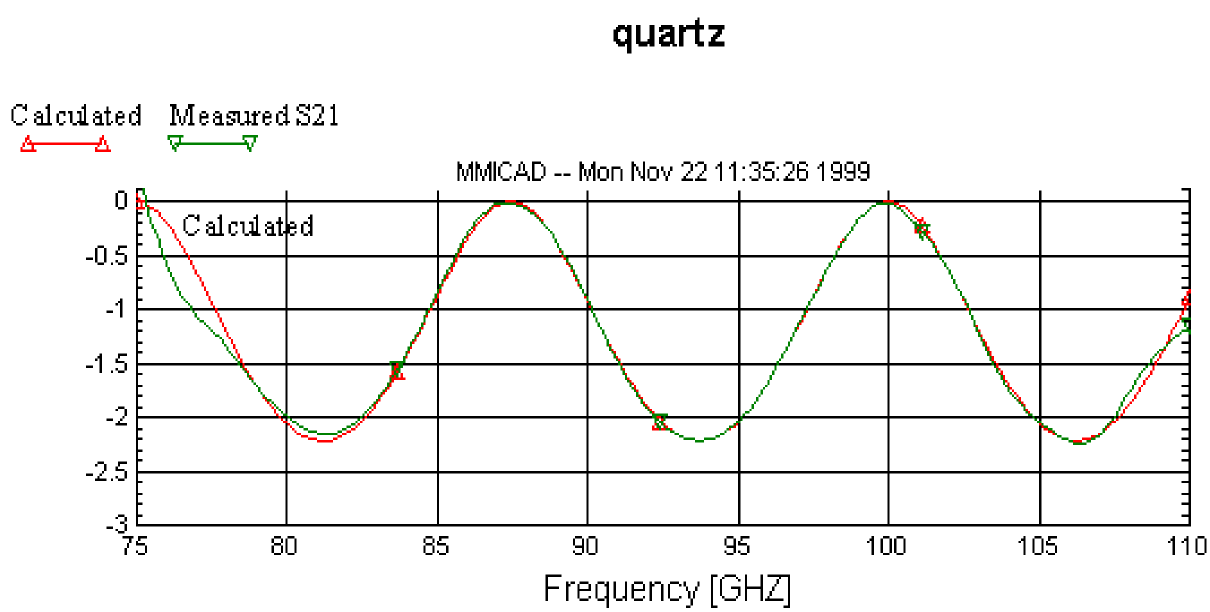


FIGURE 13

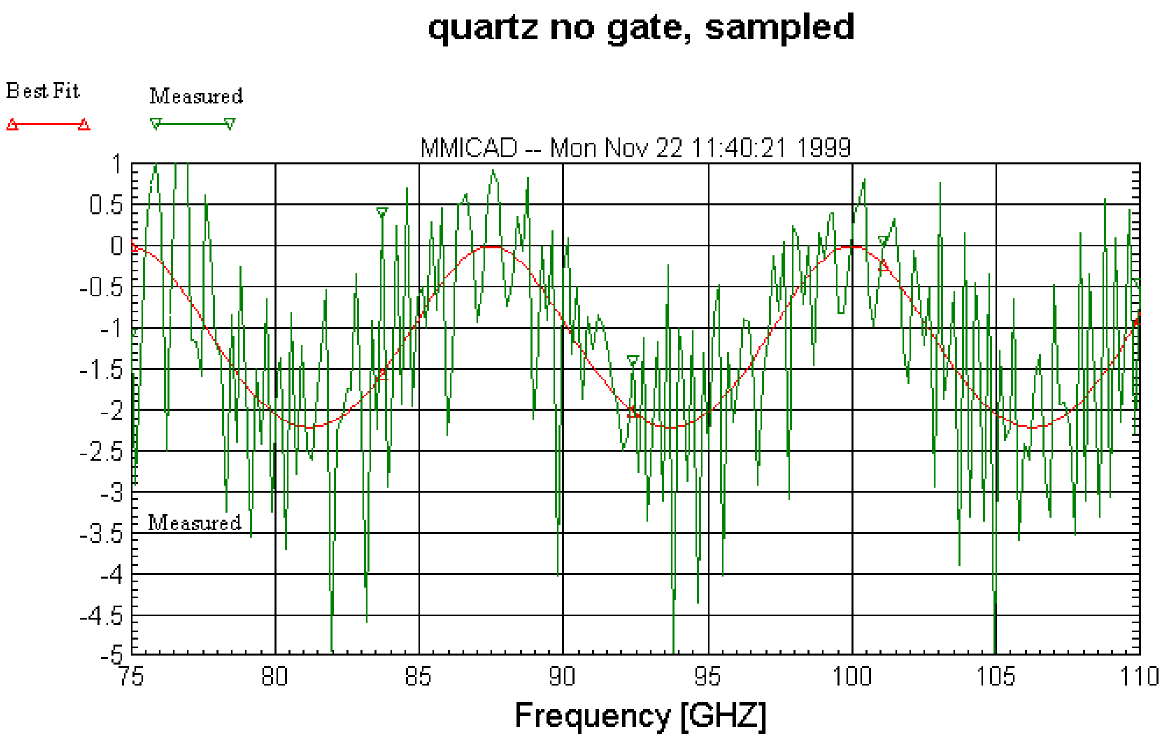

quartz no gate, sampled
Best Fit
Measured
MMICAD -- Mon Nov 22 11:40:21 1999
1
0.5
0
-0.5
-1
-1.5
-2
-2.5
-3
-3.5
-4
-4.5
-5
Measured
75
80
85
90
95
100
105
110
Frequency [GHZ]

FIGURE 14