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LABORATORY STUDIES OF WATER VAPOR ABSORPTION IN ATMOSPHERIC EHF WINDOWS

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Abstract

A measuring system, comprising a millimeter wave resonance spectrometer and a humidity simulator (RH = 0-101%), for determining absolute absorption by moist air in the 30 to 300 GHz range is described. Performance data and first results obtained at 138 GHz are discussed.

Introduction

The performance of communication, radar, and remote sensing systems in the EHF range (30 to 300 GHz) depends strongly on atmospheric attenuation and delay effects which, in turn, are weather sensitive -- that is sensitive to the amount of water, both vapor and liquid, along the radio path (see Fig. 1). Laboratory measurements play an important role in verifying modeling schemes for EHF properties of moist air [1],[2]. Especially, an explanation is needed as to the physical origin of water vapor-related excess absorption that is most apparent in the 90-140-220 GHz window ranges [3],[4],[1]. Water uptake by aerosol [5],[6] and forming of $(H_2O)_n$ clusters [7] are among the considered additional absorbers. To gain insight into the true nature of the excess, an "EHF weather" simulator was built, which is capable of accurately reproducing combinations of pressure, temperature, humidity, and visibility occurring in any climate between sea level and 100 km altitude.

Moist Air Mm-Wave Spectrometer

A compact, insulated box (Fig. 2) contains a stainless steel vessel which houses a radio test path and a mini-lake (10 cm across). Signals at frequencies between 30 and 300 GHz can be operated over an equivalent free-space path of 0.5 to 0.05 km; temperatures are controlled to better than 1/100 of a degree Celsius; pressure ranges over seven orders of magnitude (10^3 to 10^{-4} mb), and relative humidity is varied between 0 and 101%.

Water Vapor Behavior

Water vapor is difficult to control, even in the laboratory, due to its attractive force toward surfaces. Water molecules do not ordinarily aggregate spontaneously, but become liquid water when wettable surfaces are present to retain the impinging molecules. A threshold of $> 2 \times 10^{-5} \text{ cm}^{-1}$ in the surface-to-volume ratio is sufficient to form a continuous interface between vapor and liquid. This value is always exceeded in atmospheric air as well as in a laboratory test chamber.

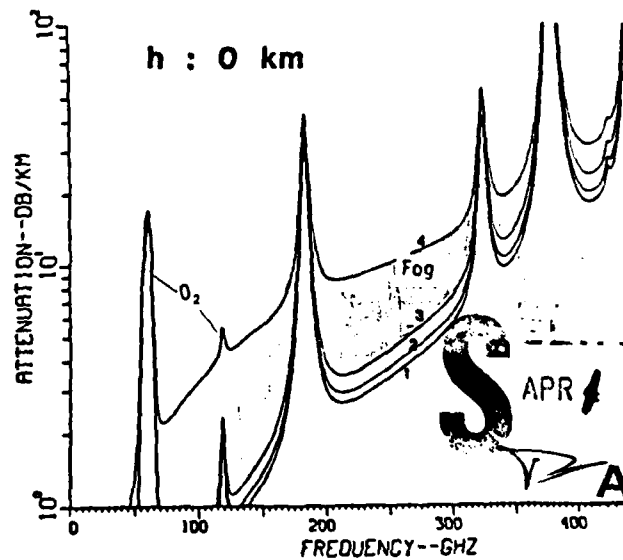
One can select surface materials that, to a certain extent, passivate the attraction for water vapor. A systematic study was made of various surface coatings applied inside a stainless steel cavity (3440 cm^2), which was evacuated for > 24 hours to 10^{-4} torr and subjected to pure water vapor. Results on the relative water-uptake by the walls and the time response of adsorption and desorption are summarized in Table 2.

Results

An example of a first series of absorption measurements at 138 GHz is given in Fig. 3. A distinct discrepancy from model predictions is apparent. The hysteresis between increasing and decreasing RH supports condensation effects [5], and future studies will clarify if they are caused by the instrument or if they are, indeed, medium-related.

Conclusions

The anomalies shown in Fig. 3 emphasize the importance of making accurate laboratory measurements under the widest possible ranges for absolute and relative humidities (i.e., temperature). At present, describing water vapor absorption mechanisms and relating them to measurable quantities is partly an empirical matter and lacks credibility in a general sense.



CURVE: T | Vapor, Water | RH

	°C	g/m3	%
1	21	7.79	0
2	12	8.00	0
3	10	9.28	0
4	10	9.28	0.5

Fig. 1. Modeling moist air attenuation for conditions reported in Ref. [3] using the spectroscopic data base given in [2].

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Table 1. Water vapor adsorption test of 3.4 l beaker (SS304, electropolished, surface/volume = 0.37 cm^{-1}) treated with various surface coatings. The initial water vapor pressure was $e_0 = 25 \text{ mb}$ at 23°C (i.e., $\text{RH} = 90\%$).

COATING	e/e_0 %	Adsorption time constant τ_{Ad} (sec)	Desorption time constant τ_{De} (sec)	Monomolec. layers (cube 1.0 l)
1	1.05	175	1000	23
2	1.2	310	260	28
3	1.35	225	1390	29
4	1.5	310	1270	35
5	1.5	270	3700 (1 h)	35
6	1.6	180 (Reference)	510	37
7	1.6	130	580	37
8	1.8	260	800	42
9	1.9	200	540	48
10	2.3	270	>530	53
11	2.9	230	5500 (1.53 h)	67
12	4.0	240	(>2 h)	115

COATING

- | | |
|---|---|
| 1 Teflon FEP 120 (DuPont)
1 coat, SS 304 ($\approx 0.1 \text{ mil}$) | 7 Parylene "C" (Union Carbide)
0.75 mil, polished SS 304 |
| 2 Hexamethyldisilazane (.5 cc/coat)
1 coat, gold-plated SS 304 | 8 Parylene "C"
1.0 mil, acid-etched SS 304 |
| 3 HMDS [(CH ₃) ₃ Si] ₂ OH
1 coat, SS 304 | 9 Silicon SR 240 (G. E.)
SS 304 |
| 4 HMDS
1 coat on 1 | 10 Gold-electroplated
SS 304 |
| 5 HMDS
2 coats, SS 304 | 11 Teflon FEP 120
2 coats ($\approx 1.0 \text{ mil}$) |
| 6 Electropolished SS 304 | 12 Clear Lacquer (N.A.P.)
2 coats (2nd coat unbaked) |

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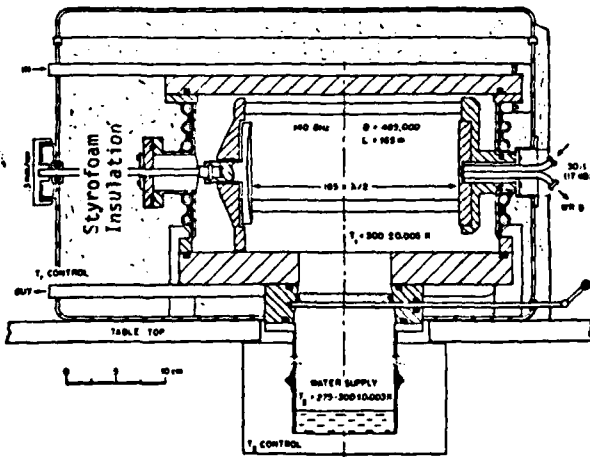


Fig. 2. Cross-section of measuring system comprising a millimeter wave high-Q resonator in a humidity simulator. The equivalent one-way propagation path is 165 m at 140 GHz.

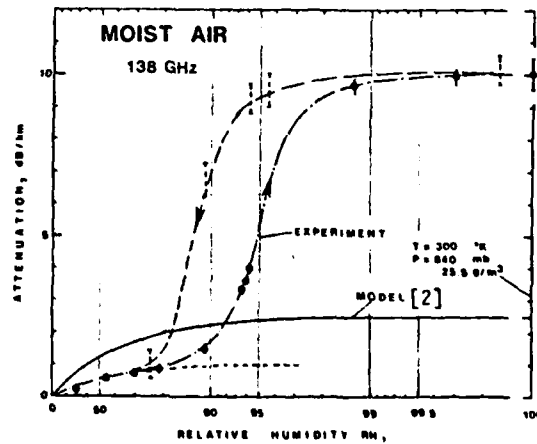


Fig. 3. Measured attenuation in moist air at atmospheric pressure and 300°K as a function of relative humidity RH. The data were taken with the apparatus sketched in Fig.2.

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