$\alpha_{min} \approx 0.05$ dB/km or 1.2×10^{-7} cm^{-1} was realized. In the second part (Section 3), results from the laboratory experiments are applied (a) to calibrate the MPM program with an empirical continuum term, (b) to demonstrate the parametric flexibility of the code (i.e., f, v(RH), and P can be selected as variables), and (c) to conjecture on the physical basis for a water vapor continuum that is defined by the limited H_2O line base of MPM. Finally Section 4 contains examples of recently reported data from laboratory and field experiments on water vapor absorption (10-430 GHz) and their comparison with MPM predictions.

2. LABORATORY STUDIES OF MOIST AIR ABSORPTION AT 138 GHZ

Controlled experiments that simulate atmospheric conditions provide test cases for studying specific contributions to N. Assessments of basic physical principles underlying the attenuation rate α are difficult to make from measurements in the actual atmosphere. The objective of this study was to measure water vapor (continuum) absorption. A test frequency of 138 GHz was selected because of its remoteness from local H_2O lines. The expected window attenuation falls in the range 0.1 to 5 dB/km and the required detection sensitivity calls for a long (>0.1 km) effective path length, which can be attained with a resonant absorption cell.

The response curve A(f) of an isolated, high Q-value resonance is detected with a power (square-law) detector. Both, the peak value a_o at center frequency f_R and the bandwidth b_o spread over a range $f_R \pm b_o/2$ at the level $a_o/2$ might be used to detect the relative attenuation,

$$\alpha_r = 8.686(\sqrt{a_o/a} - 1) = 8.686(b/b_o - 1) \quad \text{dB}, \qquad (1)$$

of an absorbing gas that changes the corresponding quantities to a and b when introduced into the resonator. Around 138 GHz it is possible to design a compact (20 cm mirror spacing) Fabry-Perot resonator with a loaded Q-value on the order of 4×10^5, which defines ($Q = f_R/b_o$) a resonance bandwidth, $b_o = 350$ kHz.

A crucial question to be resolved is whether amplitude (a_o/a) or frequency (b/b_o) detection schemes provide the optimum sensitivity for the spectrometer. After extensive testing it was found that digital averaging of A(f), displayed over a frequency span $\Delta f_M = f_R \pm 6b_o$, was capable of resolving

$a_0/a = 1.002$ (512 pts)--but only $b/b_0 = 1.015$ even with 1024 pts. Amplitude peak-value detection provided optimum sensitivity for absorption studies. The frequency span Δf_M is needed to establish the baseline $A(f) = 0$ of the resonance response. In addition, a detection at f_R avoids corrections for dispersive distortions of A(f) [4].

Absolute calibration of absorption is accomplished by defining an equivalent path length (b_0 in kHz),

$$L_E = 47.71/b_0 \quad \text{km}, \qquad (2)$$

for the resonance spectrometer operating at f_R. From (1) and (2) follows that the absolute power attenuation rate of an absorbing gas is given by

$$\alpha = 0.1820\ b_0(\sqrt{a_0/a} - 1) \quad \text{dB/km}. \qquad (3)$$

If the estimations ($a_0/a = 1.002$, $b_0 = 350$ kHz) can be achieved, then the projected detection sensitivity, $\alpha_{min} = 0.064$ dB/km, is adequate for the planned water vapor studies.

2.1 Experimental Arrangement

The measuring system consists of the millimeter-wave resonance spectrometer and a humidity simulator. An insulated box contains a high-vacuum stainless steel vessel that houses a temperature-controlled mini-lake (10 cm across) and the resonator. Temperatures are controlled to better than 1/100 of a degree Celsius, pressure ranges over seven orders of magnitude (10^3 to 10^{-4} torr), and relative humidity is varied between 0 and 99.5 percent.

Schematical diagrams of physical and electronic (Figure 1) arrangements and a photograph of the equipment (Figure 2) convey an overview of the experiment. A temperature-controlled water reservoir serves as the vapor source. Electropolished stainless steel was used exclusively as construction material. Various hydrophobic coatings were studied as possible means for neutralizing the absorption/desorption cycle of surfaces exposed to water vapor [5], but were abandoned in favor of slightly heating the mirrors of the resonator. Four fast-responding ($\tau < 1$s) temperature sensors inside the cell signaled any disturbance of isothermal conditions. Data acquisition was computer controlled.

The resonator inside a vacuum chamber (Figure 1b) is the heart of the absorption spectrometer. A key-word summary of its specifications reads as follows: Fabry-Pérot reflection-type, semiconfocal arrangement, 10 cm mirror diameter, 40 cm curvature radius, mirror heating: 1°C/0.3 W, Fresnel number: 6; pinhole coupling: circular, 0.65 mm diameter, 0.075 mm double Mylar vacuum/pressure seal, coupling factor k = 0.0550; resonance frequency, selected for optimum performance of the available klystron, f_R = 137.80 GHz, temperature compensated ($\Delta f/f_R = 0.9 \times 10^{-6}/°C$) and insensitive to pressure loads from 0 to 2 atm; resonance bandwidth: b_0 = 334 kHz yielding an effective path length, L_E = 0.141 km (Eq. 2), mirror spacing: $x_R = 182\ \lambda/2$ = 198.0 mm; micrometer tuning: 0.3175 mm/rev ≡ 2500 SU/rev (SU = scale unit on micrometer) with a resolution, Δx_R = 0.127 μm/SU, which converts into a frequency change,

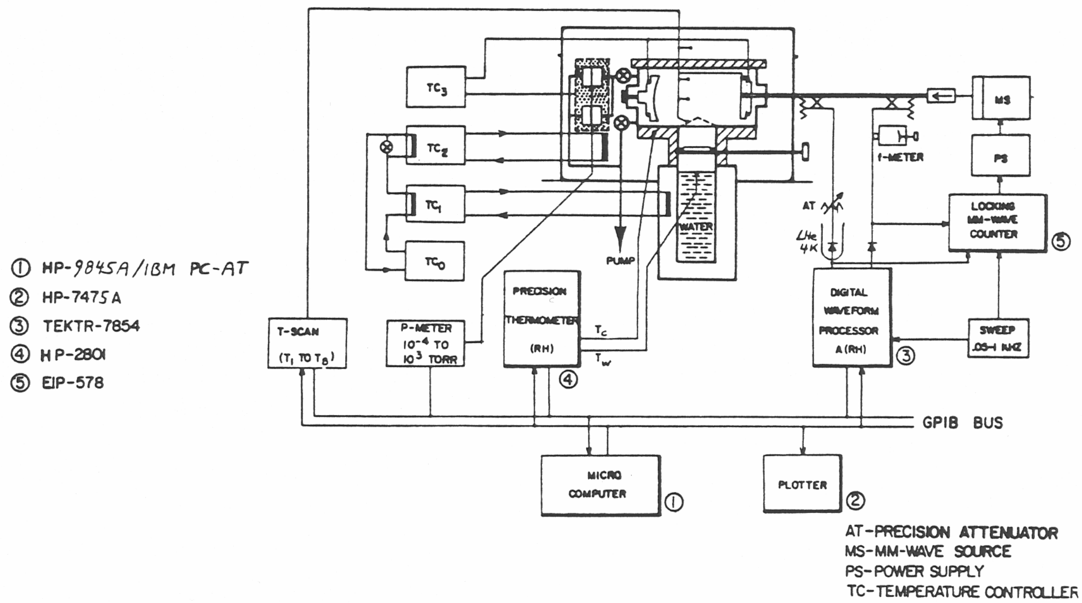
$$\Delta f_R = -f_R(\Delta x/x)_R = -88.4 \text{ kHz/SU}. \qquad (4)$$

Over a 2.5 cm tuning range of the micrometer, the resonance at x_R was the "best" out of 52 choices with respect to other-mode interferences and Q-values.

The detector of the resonance pulse A(t) was an InSb bolometer, cooled to 4.2 K-LHe, and connected by a WR-12 waveguide mount. The maximum voltage output of the preamplifier was 10 V. A power-linear response of 4.2 V/mW was measured up to 1.0 V. With a 50-kHz detection bandwidth, the noise power was about 5 nW. The bolometer bias (92 mV) served as cryogenic thermometer (T_D).

The power source was a 138 GHz klystron (20 mW) that was frequency-modulated by a sawtooth voltage generator to provide frequency-to-time domain conversion. The modulation frequency was exactly 500 Hz derived from a 10 MHz frequency standard. The linear sawtooth ramp was gated at exactly 1925 μs, the fly-back time took only 2 μs, which eliminated A(t) from the retrace. The modulation sensitivity of the klystron was determined to be 12.56(13) MHz/V by using the resonance peak a_0 as frequency marker, tuned with the resonator micrometer to the end points of the ramp and checked for linearity over a modulation voltage range from 0.500 to 3.000 V. A tuning uncertainty of 1 SU introduced about 1 percent error in determining the frequency-to-voltage conversion factor.

(a)



(b)

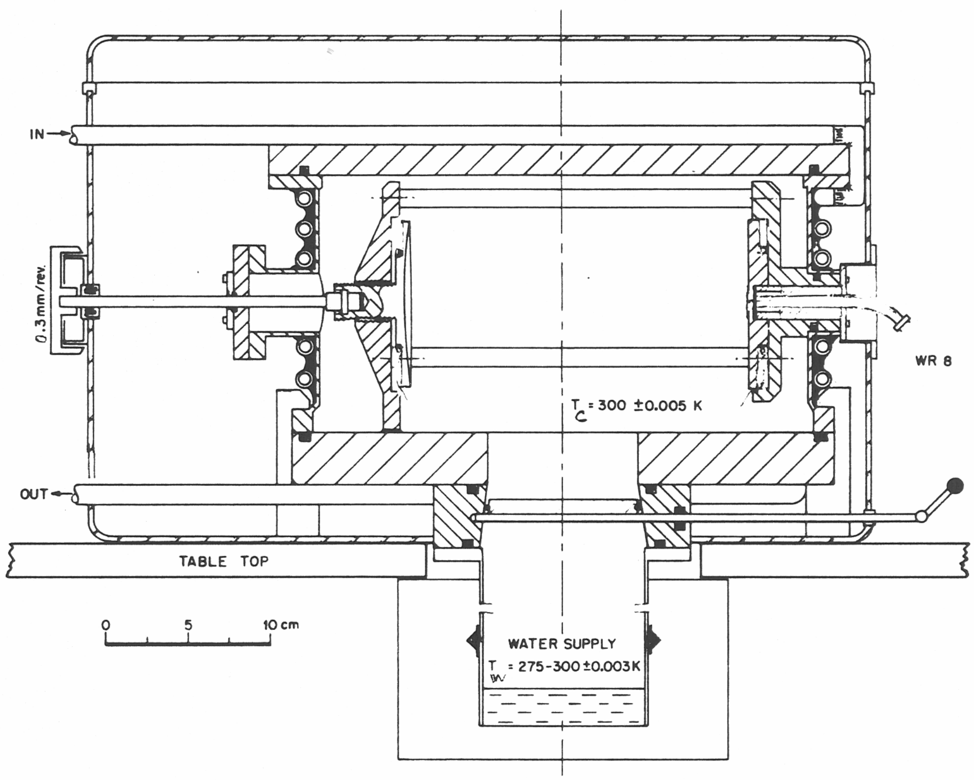


Figure 1. Millimeter-wave spectrometer for controlled moist air studies: (a) schematic and (b) cell design.