MEASUREMENT OF THE ATMOSPHERIC ABSORPTION OF RADIO WAVES IN THE RANGE 0.76–1.15 mm

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ABSTRACT: Experimental results are given for the absorption coefficient of atmospheric water vapor in the longwave region of the submillimeter range. The measurements were made under natural conditions by the varying humidity and varying distance methods, with a monochromatic source of radiation. The smallest values of absorption occurred in the range \( \lambda = 1 - 1.15 \text{ mm} \); here under normal atmospheric conditions \((p = 760 \text{ mm Hg}, T = 298^\circ \text{ K}, \rho_v = 7.5 \text{ g/m}^3)\), \( \gamma \) varied from 5.5–3.5 dB/km. In the other relative transparency window, \( \lambda = 0.87 \text{ mm} \), the absorption coefficient was equal to 10.8 dB/km. The experimental results are compared with theoretical calculations.

Previous papers [1–3] have presented the results of experimental investigations of the absorption of submillimeter waves in the atmosphere over the spectral band 0.06–0.87 mm. Measurements were made both under laboratory conditions (by means of a vacuum spectrometer) and also in the field over large distances (up to 250 km). The large measure of agreement between these results, obtained under different conditions and with different equipment, is evidence that the data presented [1–3] are free from any serious systematic errors. In the longer wave region of the submillimeter range \((\lambda > 0.87 \text{ mm})\) there have not yet been any reliable measurements of absorption. (As has been pointed out in [3, 6], the data in [4, 5] cannot be considered as reliable.) In the region of \( \lambda \sim 1 \text{ mm} \) the absorption (according to theory [6]) should be considerably smaller than in any other relative window in the submillimeter range. It is therefore of interest to obtain absorption measurements in this part of the spectrum.

In the present paper an account is given of measurements of the absorption coefficient in the range 0.76–1.15 mm.

APPARATUS

Transmitting equipment. The oscillator used was a backward-wave tube having a maximum output power of the order of a few milliwatts. The transmitting antenna was a parabolic mirror \( M_1 \) (Fig. 1) of diameter 900 mm and focal length 365 mm. This was fed from an elliptical reflector \( M_2 \) of 100 mm diameter and focal lengths 40 and 840 mm.

The rf signal from the BWT was fed to the antenna system through a waveguide consisting of a smooth transition from a cross section of 3.6 \( \times \) 1.8 mm\(^2\) (at the output of the BWT) to one of 0.7 \( \times \) 0.35 mm\(^2\); a short length of waveguide of 0.7 \( \times \) 0.35 mm\(^2\) ensured operation in the principal mode. The line was terminated in a pyramidal horn, the aperture of which was calculated to suit the dimensions of the reflector. In the optical setting up of the antenna system, one of the radiator loci was placed at the phase center of the horn, and the other at the focus of the parabolic reflector. The antenna system was adjusted to any required direction using an optical viewfinder.

When taking measurements over an extended period of time, it is important to monitor the transmitted power level continuously. In the present work, monitoring was made more necessary by the fact that the output of the BWT varied markedly with anode potential; the variation was in the form of a series of very sharp peaks differing in intensity (oscillation zone), and intermediate nulls. Since the width of the peaks was only 5–10 V (i.e., 0.15–0.3% of the anode voltage) and the voltage difference between neighbouring peaks was also small, it was extremely difficult to locate a particular peak and maintain operation on it over an extended period (operation at a fixed wavelength) without monitoring facilities.

A relative power-level meter was therefore used to enable the level to be continuously monitored and a constant radiated power to be maintained. The radiation indicator was a nonselective pneumatic detector type OAP–1. A spherical mirror \( M_3 \) of diameter 80 mm and focal length 500 mm was used to divert about 1% of the radiated power to the receiver.

To avoid errors in the measurement of the power level caused by changes in the sensitivity of the OAP and of the amplifier, a standard source was provided for calibration purposes. The calibration signal was infra-red radiation from a bulb; filters were used to extract the range of wavelengths 1–2.5 \( \mu \). The current in the bulb was monitored on a pointer instrument to an accuracy which enabled the level of the calibration signal to be maintained to within 1.5%.
In order to prevent slow changes in the radiating power of the standard source due to destruction of the filament, the operating current was held to one third of the nominal value. The calibration signal (and the radiation from the BWT) was modulated at a frequency of 10 cps by a mechanical resonance vibrator. The power meter was firmly attached to the transmitter and so the setting of the entire system was maintained even when the orientation of the antenna was altered.

In order to illustrate the operation of the meter, we show in Fig. 2 a recording of the transmitter power at different anode voltages (different wavelengths), and also a recording of the signals from the standard source. In order to test the linearity of the meter, signals were recorded both at the input and at the output of the meter circuit for different transmitter levels. A linear relation was found. It should be noted that the control measurements might not allow for the changes in the signal level caused by such phenomena as corrosion of the reflecting surfaces of the mirrors, or deposits of dust or dew. In order to prevent these effects, a protective polythene cover was used, and this was periodically cleaned or replaced.

The wavelength of the transmitter was measured by means of a Boltzmann interferometer. The plane mirrors of the instrument were set up on a comparator IZA-2 and, in this way, it was possible to measure the path difference to at least 1 μ. The error in measuring the wavelength was less than ±0.2%.

A device in the high tension supply to the BWT enabled the anode voltage to be varied at the required rate to sweep through the frequency band. A fine control of the anode voltage (over 30 V) made it possible to carry out extended measurements on a fixed wavelength.

For the varying humidity method, the baseline distance was 1.35 km. The signal path lay over water. The height of the antennas above the surface was 12.5 m. Since the width of the polar diagram of the transmitting antenna was about 5°, there was no possibility of the receiving antenna accepting radiation reflected from the water surface.

The experimental procedure was as follows. The received signal level was recorded as the frequency of the transmitter was automatically varied; thus spectrograms, similar to Fig. 2 were obtained. Each spectrogram covered about 15 minutes in time so the humidity was practically constant while information was obtained over a wide spectrum. For certain points in the range (in particular for λ = 0.87 mm, corresponding to the atmospheric transparency window), control measurements were also taken by recording the signal level at a fixed wavelength on individual oscillator and is negligibly small in the submillimeter region. The other atmospheric mixtures do not make any important contribution even at millimeter wavelengths [8]. Thus the investigation of the atmospheric absorption of submillimeter waves can be carried out by either of the well-known methods; the received signal level can be recorded for different values of humidity, or the distance between the source and receiver can be varied. In the present case, measurements were taken by both methods so that the magnitude of systematic errors could be evaluated.

For the varying humidity method, the base line distance was 1.35 km. The signal path lay over water. The height of the antennas above the surface was 12.5 m. Since the width of the polar diagram of the transmitting antenna was about 5°, there was no possibility of the receiving antenna accepting radiation reflected from the water surface.

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