The Attenuation of 3.392μ He-Ne Laser Radiation by Methane in the Atmosphere

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Measurements of the propagation of infrared waves at 3.392μ and 3.508μ in clear weather have been carried out over a 2.6-km path of atmosphere at Holmdel, New Jersey. The measuring system employed antennas and detectors common to the two wavelengths. The excess attenuation at 3.392μ, after considering various corrections, is interpreted as absorption by methane in the atmosphere and has been found to be 5.5 ($\pm$0.5) db/km.

I. INTRODUCTION

The proximity of the 3.392μ He-Ne laser emission to one of the absorption lines of methane[1,2] predicts that this laser radiation may be somewhat attenuated by the earth's atmosphere. The characteristics of this attenuation are interesting not only in evaluating the potential use of the 3.392μ line for communications, but also because of possible application in measurement of the methane content in the atmosphere. An estimate of the absorption of 3.392μ laser emission by methane in the atmosphere has appeared in the literature.[1] The purpose here is to present a measurement which compares propagation of infrared waves at 3.392μ and 3.508μ over an atmospheric path length of 2.6 km. The differential transmittance at these two wavelengths, after accounting for the effect of water vapor, is used to determine the attenuation of the 3.392μ wave by methane in the atmosphere.

II. EXPERIMENTAL EQUIPMENT

The profile and terrain of the 2.6-km propagation path are illustrated in Fig. 1. The experimental site at Holmdel, N.J. is about 5 km south of the shore of Raritan Bay on the Atlantic Coast.

The transmitting and receiving equipment, located 150 feet and 370 feet above sea level, respectively, are sketched in the block diagram of Fig. 2. The transmitters consist of a 3.392μ He-Ne laser and a 3.508μ He-Xe laser; the laser outputs are chopped simultaneously at 330 cps. The two laser beams are aligned into a common path by means of a reflecting mirror and a beam splitter which in turn feeds a bisected near-field Cassegrainian telescope. This telescope consists of two bisected confocal paraboloids as shown in Fig. 2. The main reflector is one half of a 15-inch diameter spin-cast paraboloid of 12-inch focal length while the parabolic subreflector has a diameter of 0.5 inch and a focal length of 0.4 inch. In addition to desirable properties, such as good preservation of mode composition (a consequence of negligible aperture blocking), short focal length, and mechanical simplicity, this particular telescope design offers good impedance match which is especially important in receivers using high-gain laser amplifiers as described below. The concentrated beams from the subreflector of the receiving telescope pass through a He-Ne tube, which is a 3.392μ amplifier, in tandem with a He-Xe tube, which is a 3.508μ

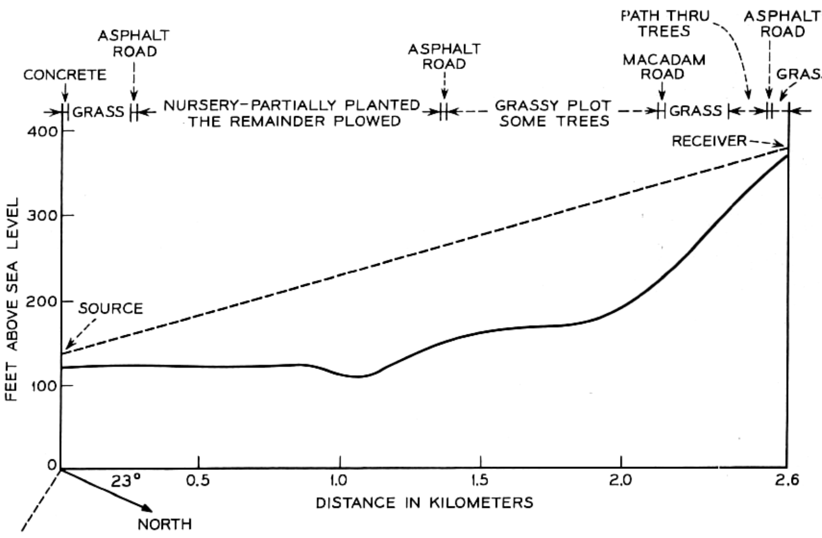

Fig. 1 — Profile of transmission path.

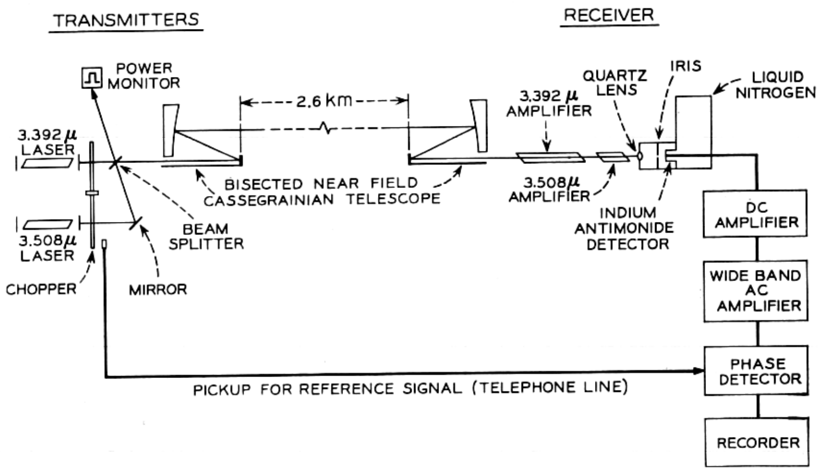

Fig. 2 — Experimental equipment block diagram.

amplifier.* After these two amplifier tubes, the signal passes through a calcite polarizer, a quartz lens, and an iris, to a liquid nitrogen-cooled indium-antimonide photovoltaic infrared detector whose output is fed into a synchronous detection system. The comparison measurement is carried out by blocking one of the two laser outputs every other five minutes. The signal-to-noise ratios using a detector time constant of 2 sec are about 38 db for 3.508μ, at a laser amplifier gain of 15 db, and 23 db for 3.392μ, at a laser amplifier gain of 25 db.

III. MEASURED RESULTS

The measured data are summarized in Table I.

Having taken into account all conceivable correction factors, the unexplained excess attenuation of the 3.392μ signal over the 3.508μ signal is interpreted as the absorption by methane in the atmosphere. These factors, given in Table I, are determined as follows.

The difference in the laser outputs is obtained by a monitoring detector which is a biased lead-selenide photoconductor. The beam splitter (Fig. 2) transmits 20 per cent of the 3.392μ power while it reflects 60 per cent of the 3.508μ power into the telescope. The measured half-power widths of the transmitting beams are about 50 sec of arc. How-

* The He-Ne plasma introduces negligible loss to the 3.508μ wave; the same is true of the effect of the He-Xe plasma on the 3.392μ wave.

TABLE I — THE COMPARISON DATA

Wavelength	3.392μ	3.508μ Amplifier off	3.508μ Amplifier on
Laser output	+4 dbm	+7 dbm	+7dbm
Beam splitter loss	−7 db	−2.2 db	2.2 db
Diffraction loss	−(D + 1) db	−D db	−D db
Water vapor attenuation	−3 db	−1 db	−1 db
Amplifier gain used	25 db	0 db	15 db
Expected signal level	(18 − D) dbm	(3.8 − D) dbm	(18.8 − D) dbm
Expected signal ratio	$p_{3.39}/p_{3.5}=$	14.2 db	−0.8 db
Measured signal ratio	$p_{3.39}/p_{3.5}=$	0 db	−15 db

ever, the 3.508μ measured transmitting beamwidth is slightly narrower than at 3.392μ such that one expects about one db higher signal level at 3.508μ, this small difference in transmitting beamwidths being attributed to a slight difference in the laser beams and to imperfection in the laser-telescope alignment at 3.392μ. The diffraction loss, D, includes beam spread, telescope imperfections, and any insertion loss introduced by the amplifier tubes. The diffraction loss for the two wavelengths should differ only by the aforesaid one db; its absolute magnitude has not yet been determined with sufficient accuracy thus no numerical value is indicated for this item in the table. Of course, since the measurement is one of comparison, the absolute value is of no great significance here.

For the measurements under discussion, the water vapor density in the atmosphere was 10 gm/m^3 (from the measured temperature and relative humidity, 68°F and 50°RH). Then the attenuation due to the water vapor content of the atmosphere, taken from standard tables[3], is 3 db and 1 db (total path) for 3.392μ and 3.508μ, respectively.

The measured gain of the 3.392μ amplifier tube is 25 db. However, it turned out, as shown by the second column in Table I, that the measured average signal level of 3.392μ with its amplifier tube operating was very closely equal to that of 3.508μ with its amplifier tube turned off. It follows that the over-all measured attenuation difference attributed to methane absorption is 14.2 db for the 2.6-km propagation path; this value, obtained on June 3 and 4, 1965, is typical of the measured data. The data distribution from several comparison tests and error estimates of the experimental equipment lead to the conclusion that the absorption of 3.392μ by methane in the atmosphere is 14.2/2.6 = 5.5 (±0.5) db/km.

IV. DISCUSSION

The above measured attenuation of 5.5 db/km agrees fairly well with the estimated transmittance $T = \exp(-1.1L)$ given by Edwards and Burch,[1] where L is the path length in kilometers. Their transmittance prediction was arrived at by laboratory measurements of the transmission of the 3.392μ He-Ne laser emission through different mixtures of methane and nitrogen in a cell, and by estimating the amount of methane (about 1 part in 10^6) in the atmosphere.[4] Edwards and Burch conclude from their measurements that the collision-broadened width of the absorption line of methane in the atmosphere is 3.9 ($\pm$1.2) kmc and the separation of the 3.392μ emission line from the center of the closest methane absorption line is 0.09 ($\pm$0.06) kmc. In Ref. 2, the methane absorption line closest to 3.392μ (2947.903 cm^{-1} or 88437.09 kmc) is given as 2947.888 ($\pm$0.015) cm^{-1} or 88436.64 ($\pm$0.45) kmc. It should be pointed out that Edwards and Burch only determined the separation between the 3.392μ emission line and the closest methane absorption line but not the absolute position of the 3.392μ emission line.

The Doppler-broadened width (0.27 kmc) of the 3.392μ emission

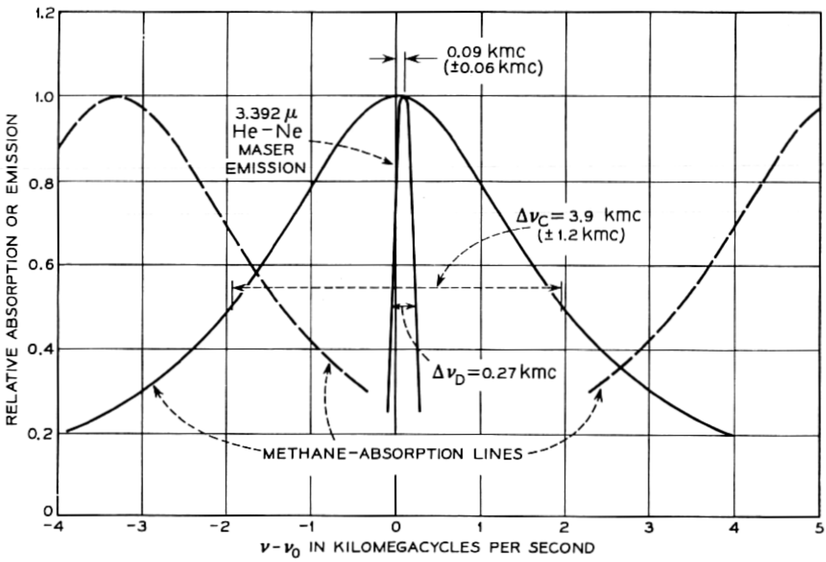

Fig. 3 — Doppler broadening of the 3.392μ (88437.09 kmc) He-Ne Laser emission and collision broadening of the absorption lines of methane in the atmosphere.

line is small compared with the collision-broadened width of the absorption line of methane in the atmosphere and lies close to the center of the 2947.888 cm^{-1} methane absorption line as illustrated in Fig. 3. Therefore, the uncertainty of the cavity resonance within the Doppler broadening of the laser emission should not contribute significant error to the measurement of absorption of 3.392μ laser emission by methane in the atmosphere.

Consideration has also been given to magnetic field tuning of the laser oscillator as a possible scheme for investigating the profile of the methane absorption line. Fork and Patel[5] reported a maximum splitting of 11.84 kmc for 3.392μ emission using a magnetic field of 4 kilogauss. A frequency shift of 11.84 kmc should pull the 3.392μ laser line out of the collision-broadened width of the closest absorption line of methane in the atmosphere; however, one will run into the neighboring lines of the $P(7)$ branch of the methane absorption spectrum which are shown as dashed lines in Fig. 3.

V. ACKNOWLEDGMENT

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