SOME SPECIFIC FEATURES OF SHORT OPTICAL PULSE PROPAGATION IN A RESONANTLY ABSORBING ATMOSPHERE. I. HORIZONTAL PATHS

M.V. Kabanov, Yu.V. Kistenev, and Yu.N. Ponomarev

V.D. Kuznetsov Siberian Physicotechnical Scientific–Research Institute at the State University, Tomsk
Institute of Atmospheric Optics, Siberian Branchof the Academy of Sciences of the USSR, Tomsk
Received October 23, 1990

We present some results of computations of the propagation of short optical pulses of different pulse shapes along horizontal paths under conditions of resonance absorption. The paper includes a discussion of the pulse shape and energy parameters of the propagating beams on the beam's initial parameters and the properties of the medium.

INTRODUCTION

Some characteristic features of the deformation and attenuation of short optical pulses of various shape propagating along the horizontal paths located at altitudes up to 15 km in a resonantly absorbing gaseous atmosphere are considered in this paper.

An analysis of the transformation of the shape of the pulse during its propagation was made using the Maxwell–Bloch equations in the of small pulse area approximation

$$\frac{\partial \varepsilon_c}{\partial \tau} = i\int\limits_{-\infty}^{\infty} g(\Delta - \Delta')P_c(\Delta', \tau, \eta)\mathrm{d}\Delta' , \tag{1a}$$

$$\mu\frac{\partial P_c}{\partial \eta} = -\gamma P_c + i\varepsilon_c , \tag{1b}$$

where ε_c is the complex amplitude of the field, P_c is the radiation–induced complex polarization of the resonantly absorbing gas, τ is the optical depth of the resonant medium for the monochromatic radiation, $\eta = (t - z/c)/\tau_p$, $\mu = 1/(\gamma_L \tau_p)$, $\gamma = 1 - i\Delta/\gamma_L$, τ_p is the pulse duration, Δ is the detuning of the incident radiation from resonance, γ_L is the collisional half–width of the absorption line, and g is the molecular velocity distribution function.

The exact analytical solution of Eq. (1) is well known only for some special shapes of the pulse and of the absorption lines,[1,2] therefore, the solution of Eq. (1) has been carried out numerically. The method of exponential fitting[3] was used to calculate the polarization of the light because of the "stiff" character of Eq. (1b) for $\mu < 1$. Equation (1a) was approximated using the trapezoid rule.

The optical pulse was modeled in the form of a plane coherent wave whose shape upon entering the medium has the form

$$\varepsilon_c(0, \eta) = \begin{cases} [\sin(\pi\eta)]^q, & \eta\in[0, 1] , \\ 0, & \eta > 1 . \end{cases}$$

Depending on the value of the parameter q, the pulse shape varies from quasirectangular to quasi–Gaussian.

The variation of the parameters of the absorption line as functions of altitude was taken into account through their dependence on medium temperature and pressure[4] using standard atmospheric models (Fig. 1).

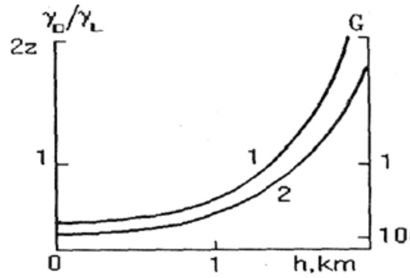

FIG. 1. Variation of the parameters of resonant absorption line broadening of water vapor in the troposphere in the visible (1) and IR (2) spectral ranges for the mid–latitudes in summer. Here γ_L and γ_D are the collisional and the Doppler half–widths of the absorption line, respectively, and $G = \ln 2(\gamma_L/\gamma_D)^2$.

RESULTS OF CALCULATIONS

Numerical calculations show that the pulse shape undergoes much greater distortions for $\mu \sim 1$. This corresponds to $\tau_p \sim 3\cdot10^{-10}$ s for the typical value of γ_L in the surface layer $\sim 0.1\ \text{cm}^{-1}$ (Ref. 5), whereas at an altitude of ~ 10 km, $\mu \sim 1$ for $\tau_p \sim 10^{-9}$ s. Under these conditions, the deformation of the pulse is caused by both the inertial response and the frequency dispersion of the medium,[6] and the contribution of these phenomena depends on the conditions of the beam–medium interaction.

In the case of adiabatic interaction, the pulse remains smooth, and its maximum shifts with the group velocity (Fig. 2). For the case of nonadiabatic interaction, the inertial response of the medium results in considerable asymmetry of the pulse shape and a rapid shift of its maximum toward the leading edge of the pulse (Fig. 3). These results are in good agreement with analytic solutions of Eq. (1) for the considered limiting cases.[2,7]

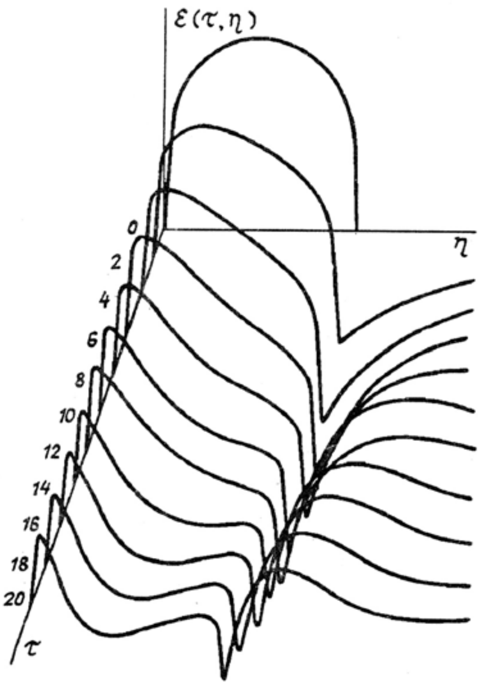

FIG. 2. Deformation of optical pulse shape in a resonantly absorbing atmosphere for $\Delta = 0$, $\mu = 1$, $G = 1$, $q = 4$, *and* $\varepsilon = \mathrm{Re}\varepsilon_c$.

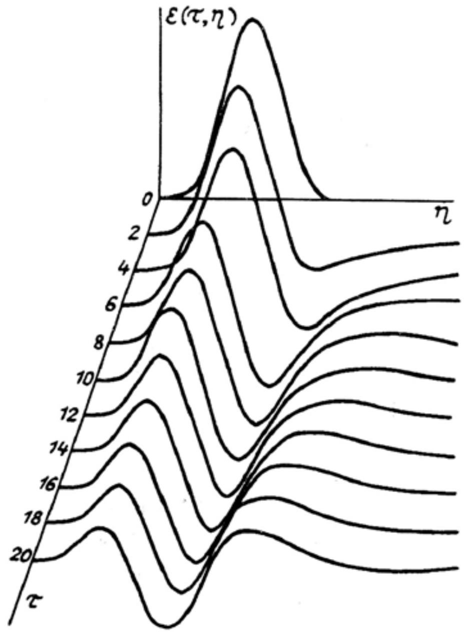

FIG. 3. Deformation of optical pulse shape in a resonantly absorbing atmosphere for $\Delta = 0$, $\mu = 1$, $G = 1$, $q = 0.25$, *and* $\varepsilon = \mathrm{Re}\varepsilon_c$.

Figure 4 shows the dependence of the transmission of the resonantly absorbing medium on pulse shape, from which it follows that short pulses with smooth shape are absorbed much more weakly. As for the analogous dependence on the pulse duration, it is trivial[2] and is not discussed here.

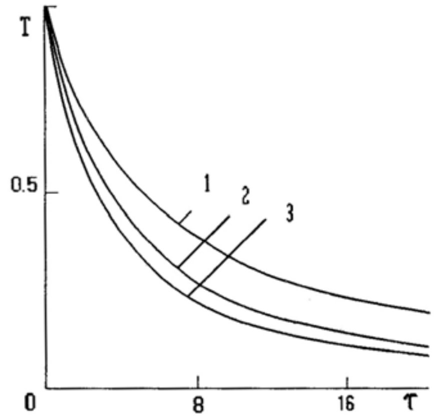

FIG. 4. Dependence of transmission of a resonantly absorbing atmosphere on pulse shape for $\Delta = 0$, $\mu = 1$, $G = 100$, $q = 4$ *(1)*, $q = 1$ *(2)*, $q = 0.25$ *(3)*.

The numerical calculations show that the tropospherical transmission of short pulses at resonance absorption lines is a function of altitude only for $\mu < 1$. In this case the medium transmission also depends on the value of the detuning of the incident radiation from resonance: in the line center a decrease of γ_L/γ_D, where γ_D is the Doppler half–width, leads to an increase in the atmospheric transmission, in the line wings the dependence is the reverse (Fig. 5).

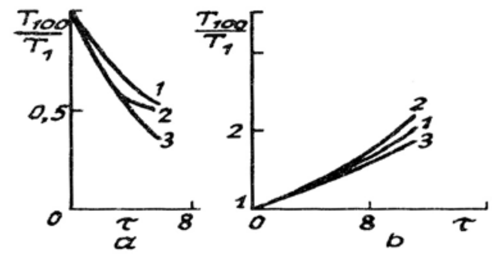

FIG. 5. Dependence of transmission of a resonantly absorbing atmosphere on the altitude of path for $\Delta = 0$ *(a)*, $\Delta = 1/\gamma_L$ *(b)*, $\mu = 0.1$, $q = 4$ *(1)*, $q = 1$ *(2)*, $q = 0.25$ *(3). Here* T_{100}/T_1 } $(G = 100)/T(G = 1)$.

REFERENCES

1. V.G. Savel'ev, Uch. Zap. Erevan Univ., Ser. Fiz. Math. Nauk **104**, 133–140 (1967).
2. M.D. Crisp, Phys. Rev. **A1**, No. 6, 1604–1611 (1970).
3. E.P. Doolan, J.J.H. Miller, and W.H.A. Schilders, *Uniform Numerical Methods for Problems with Boundary Layers* (Boole Press, Dublin, 1980).
4. V.E. Zuev and M.V. Kabanov, *Transfer of Optical Signals in the Earth's Atmosphere (Under Noisy Conditions)* (Sov. Radio, Moscow, 1977), 368 pp.
5. A.A. Mitsel' and Yu.N. Ponomarev, *Optical Models of the Molecular Atmosphere* (Nauka, Novosibirsk, 1988), 128 pp.
6. M. Schubert and B. Wilhelmi, *Introduction to Nonlinear Optics*, Pt. 2 [Russian translation] (Mir, Moscow, 1979), 512 pp.
7. Yu.V. Kistenev and Yu.N. Ponomarev, Opt. Atm. Opt. **1**, No. 4, 64–70 (1988).