Quantum Electronics **35**(10) 971–972 (2005)

PACS numbers: 42.68.Bz; 42.68.Wt
DOI: 10.1070/QE2005v035n10ABEH013012

Effect of aperture losses on the accuracy of hitting a remote object by radiation reflected from a PC mirror

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Abstract. **It is shown experimentally that when phase conjugation (PC) methods are used for self-directing laser radiation to remote objects, the fraction of laser radiation hitting the object amounts to 80 % ± 10 % of the total energy reflected from a PC mirror, and in most cases depends weakly on the degree of atmosphere turbulence and the path length despite considerable aperture losses.**

Keywords: *turbulent atmosphere, input aperture, PC mirror.*

It is well known that in the case of the phase conjugation (PC) effect, a wave reflected from a PC mirror propagates successively through intermediate states, returning finally to the initial state. The discovery of this effect in 1972 stimulated numerous theoretical and experimental studies devoted to the possibility of self-directing radiation on a target by using PC. One of the variants of such a self-directing is shown in Fig. 1.

A laser illuminates a target, the light reflected from the target is collected with a telescope, amplified, reflected from a PC mirror, amplified again, and is directed exactly to the target. This was demonstrated in many laboratory experiments where the optical elements of schemes were *a priori* arranged so that almost all radiation reflected from the target or its simulator fall within the PC mirror aperture. It is obvious that a limited aperture of the PC mirror even in the absence of atmospheric distortions in natural experiments should reduce the fraction of energy falling exactly on the target. This occurs due to a decrease in the so-called conjugation parameter – the normalised overlap integral

$$\chi = \frac{\left|\int E_{\mathrm{d}} E_{\mathrm{b}} \mathrm{d}S\right|^2}{\int |E_{\mathrm{d}}|^2 \mathrm{d}S \int |E_{\mathrm{b}}|^2 \mathrm{d}S},$$

where E_{d} and E_{b} are the amplitudes of the direct and conjugate radiation waves and $\mathrm{d}S$ is the area element in the beam cross section. By using this expression, it is easy to show that in the presence of aperture losses and the 100 % PC in the mirror, the value of χ is equal to the relative fraction of the signal beam energy captured by the PC mirror aperture. If the initial beam is diffraction-limited, the value of χ directly determines the fraction of the reflected energy within the diffraction angle.

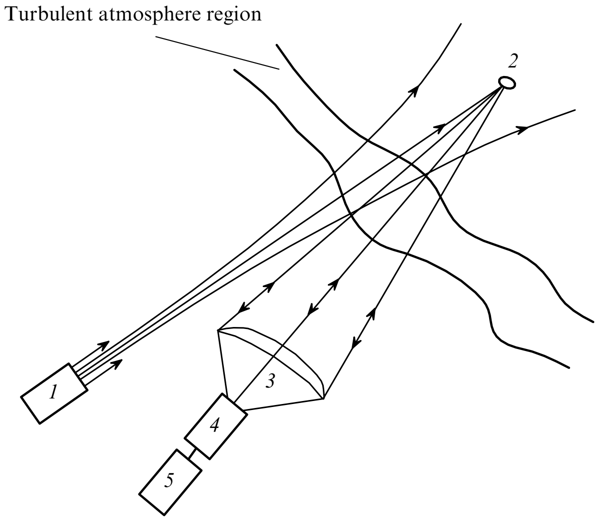

Figure 1. Scheme of the use of self-directing in real atmosphere: (*1*) illuminating laser; (*2*) remote target; (*3*) telescope; (*4*) laser amplifier; (*5*) PC mirror.

Depending on the relation between the Fresnel length Z_{F}, the path length L, the divergence of the initial radiation, and the view angle in a phase-distorting medium (in our case, turbulent atmosphere), different variants of the incomplete compensation for phase distortions and, hence, of the decrease in the fraction of energy hitting the target are realised. It is important to note that two-dimensional phase plates were used in model experiments. Not considering all the possible variants [1], we will discuss the one that is most favourable for the problem under study: for $Z_{\mathrm{F}} \geqslant L$, the geometrical optics approximation is valid and distortions introduced by a phase plate are compensated; however, the divergence of the compensated radiation will be determined by diffraction for the receiving aperture of the PC mirror. Now we should find the conditions under which the turbulent atmosphere can be replaced by the equivalent phase plate providing the fulfilment the condition $Z_{\mathrm{F}} \geqslant L$. By using the data from monograph [2], we can find the dependences of the correlation radius of a light beam on the path length and the structural constant C_n^2 for the neodymium laser wavelength 1.06 μm (Fig. 2).

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Received 21 June 2005
Kvantovaya Elektronika **35** (10) 971–972 (2005)
Translated by M.N. Sapozhnikov

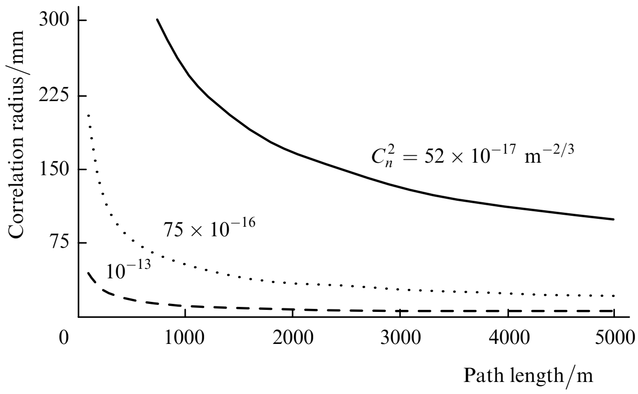

Figure 2. Dependences of the correlation radius on the path length and the structural constant C_n^2 for $\lambda \simeq 1$ μm in the case of weak (solid curve), moderate (dotted curve), and strong (dashed curve) turbulence.

The calculations were performed by the known formula $\rho_0 = (0.54 C_n^2 \kappa L)^{-3/5}$ for a ground path [2].

One can easily see that, by calculating the Fresnel length $Z_F = \kappa \rho_0^2 / 2$ in the case of a weak and moderate turbulence, we obtain the value obviously exceeding 5000 m. This means that the atmosphere can be almost always treated as a phase plate 'pressed down' to the input aperture of the PC mirror, and distortions introduced by the atmosphere will be almost completely compensated. In this case, the fraction of light falling exactly on the target will weakly depend on the value of aperture losses if the aperture of the PC mirror makes it possible to resolve the target size, i.e., when $\lambda L / D < d$, where D is the PC mirror aperture and d is the characteristic size of the target. If this inequality is violated, the faction of energy hitting the target is drastically reduced.

The experimental study was performed on a natural stand with the path length ~ 600 m. The scheme of the experiments is shown in Fig. 3. Radiation from a passively Q-switched single-mode Nd^{3+} : YAG laser amplified in two stages propagated through the target simulator representing an aperture of diameter ~ 1 cm, was directed to a plane fold mirror located at a distance of ~ 300 m from the target and then, after reflection from the plane mirror, it entered the aperture of the PC mirror consisting of a lens of diameter 50 cm. A SBS cell filled with titanium tetrachloride was placed in the lens focus. First calorimeters were balanced, the transmission coefficient of the path was determined, etc. In operation with the full aperture, almost 90 % ± 5 % of the energy coming from the SBS mirror propagated through the aperture simulator. Depending on the weather conditions, the pump beam size on the PC mirror aperture varied from 10 to 35 cm.

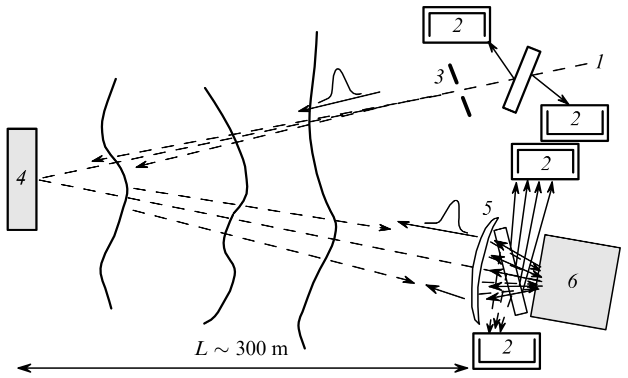

Figure 3. Scheme of the experiment: (*1*) single-mode laser beam; (*2*) calorimeters; (*3*) target simulator; (*4*) plane 50 × 50-cm mirror; (*5*) lens of diameter 50 cm; (*6*) SBS cell.

Aperture losses were introduced by using ring apertures placed directly in front of the focusing lens. In this case, calorimeters located in the forward direction measured the value of aperture losses and in the backward direction – the quality of target hitting. We have failed to study the entire range (from the 100 % beam capture to the case when the capture is absent) because of the quasi-threshold nature of the SBS mirror and the insufficient accuracy of calorimeters. Nevertheless, when the pump energy was reduced by a factor of 2 – 3 due to introduced aperture losses, the energy propagating through the target simulator changed rather weakly and was 80 % ± 10 %, which confirms the above qualitative considerations.

Thus, we have shown that in a rather broad range the turbulent atmosphere can be treated as a phase screen 'pressed down' to the receiving aperture of the PC mirror. This makes it possible to introduce into the target from 90 % to 80 % of the light field energy formed by the PC mirror.

References

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