Coherent lidar efficiency enhancement using graded-reflectance resonator optics

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ABSTRACT

We extend previous work on the benefits of graded-reflectance unstable resonator optics in coherent lidar applications to include diffractive transverse eigenmodes. Theoretical analysis of resonator performance for several test cases incorporating super-Gaussian profiled output couplers indicates that a broad optimum exists near super-Gaussian order 6,

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1. Introduction

For a number of years the use of graded-reflectance resonator optics has been advocated as a means of improving the overall efficiency of lidar systems. Initial efforts aimed at quantifying the degree of benefit to be expected have relied on the putative ability of such optics to impose a well-defined transverse description on the lidar transmitter output[1,2]. While this approach has permitted a useful insight into the question at hand, it was nevertheless recognized that there were limits to this deterministic assumption which could only properly be addressed by means of a diffractive eigenmode treatment. The purpose of this paper is to report on the results of just such an analysis.

2. Theoretical Background

As in the previous studies, the family of functions known as *super-Gaussians* has been chosen to describe the radial variation of the coupler reflectivity *R(r):*

$$R(r) = R_0 \exp[-2(r/w_m)^n] ,$$

where R_0 is the on-axis reflectance, r the radial ordinate, and w_m is the e^{-2} radius of the reflectance profile. Also in common with the previous studies, we assume a positive branch confocal unstable resonator. The internal transverse mode structure of the resonator is computed by numerical solution of the cavity eigenfunction[3] for selected values of the cavity magnification M and equivalent Fresnel number N_{eq}. n is the so-called super-Gaussian order.

Quantitative evaluation of the overall resonator performance in a coherent lidar context is accomplished by the generation of a figure-of-merit Q given by [1]:

$$Q = \eta Q_v \quad ,$$

in which η is the far-field coherent lidar antenna efficiency and Q_v is the cavity filling factor, which represents a measure of the energy extraction efficiency. The procedure for obtaining these latter two quantities is unchanged from the description given in Ref. **2.**

3. Parametric Behavior of Figure-of-Merit

To assess the dependence of the cavity performance on the coupler reflectance profile, we track the figure-of-merit Q as a function of super-Gaussian order n and on-axis reflectance R_0 until an optimum is identified. Figure 1 shows the resulting behavior of Q for two different values of the resonator equivalent Fresnel number N_{eq}. (A cavity magnification factor of M = 2 was selected for this case study.)

The curves in Figure 1 have been adapted from Ref. 2 and represent the geometrical optics solution to the cavity mode evolution process (i.e., in the absence of diffractive effects). The geometric optics solutions yield a fundamental transverse mode profile which is a super-Gaussian of same order as the coupler (but larger in size by an amount which is dictated by the cavity magnification M)[4] while Q appears to increase asymptotically with n. However, when intracavity diffraction effects are taken into account the situation is much altered, with the mode profile determinism of the graded reflectance coupler breaking down at a finite value of n so that the existence of an optimum operating point is readily apparent. The exact position of the optimum operating point is a non-trivial function of M, R_0, and N_{eq}, but in the case of Figure 1(a), where N_{eq} = 1, the optimum can be seen to lie in the vicinity $n \sim 5$. For the case where N_{eq} = 2 - Figure 1(b) - the optimum operating point has shifted to n - 7 with a concomitant ~40% increase in optimum Q.

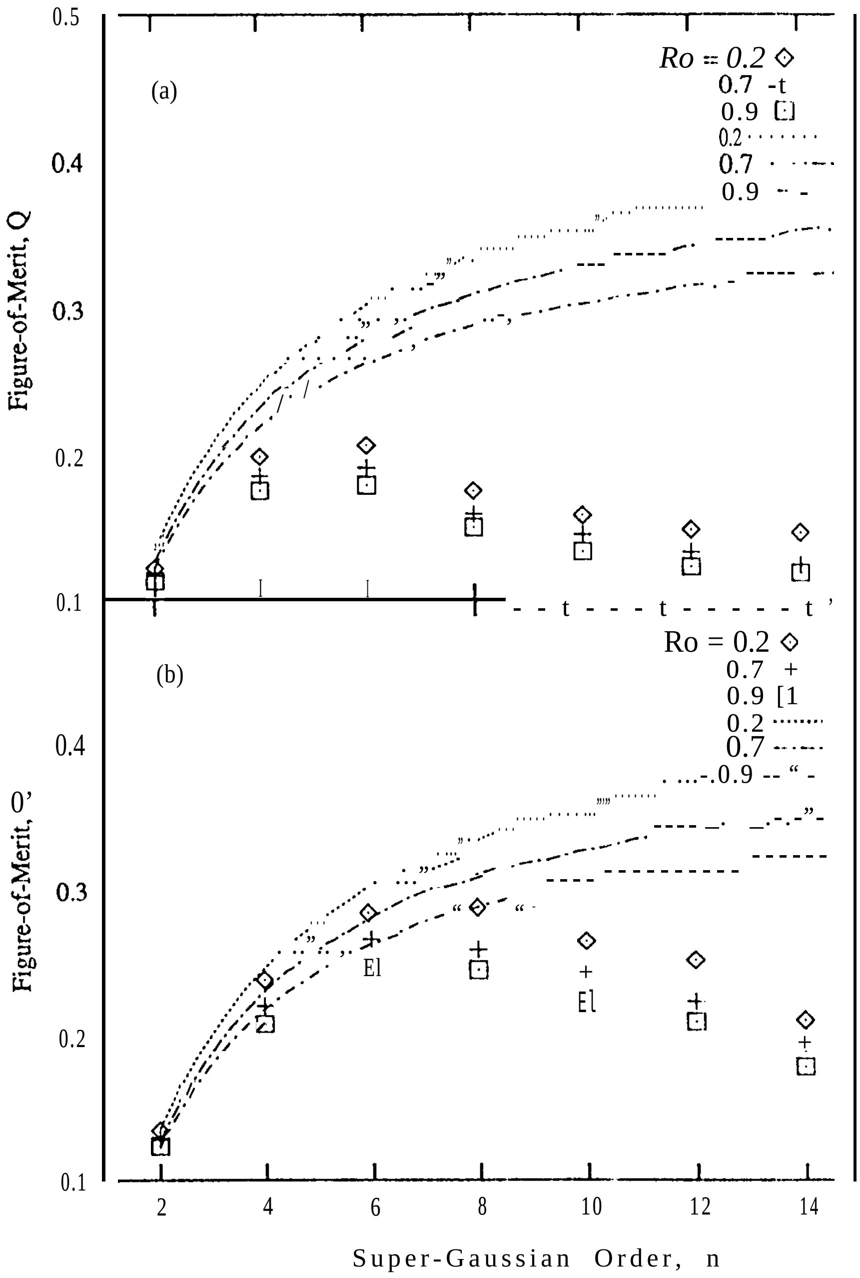

Figure 1. Dependence of coherent lidar figure-of-merit Q as a function of unstable resonator coupler super-Gaussian order n for a cavity magnification M = 2. The curves represent geodetical optics mode solutions and the points represent the equivalent diffractive optics solutions for the values of R_0 indicated. (a) N_{eq} = 1; (b) N_{eq} = 2.

4. Discussion

This work has provided further evidence that a judicious] y tailored graded-reflectance output coupler can be employed to optimally enhance the performance of unstable resonator laser transmitters in coherent lidar applications. The empty-cavity (therefore wavelength-independent) results presented here show significant dependence of the optimum operating point on the salient unstable resonator parameters: n, M, R_0, and N_{eq}. However, while these findings are useful as a general guide, the performance envelope of a given resonator structure should ultimately incorporate a knowledge of the laser medium itself, since the dynamics of the gain medium must also be taken into account when computing the resonator eigenmodes[5].

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