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Transversal and axial gains in the confocal scanning microscope of leaky annular pupils

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The case of superresolution by positive transmitting pupil annular filters, reported in [1], has been extended to include the case of negative transmitting annular filters. The transversal and axial superresolution of confocal scanning microscope for the intensity spread function corresponding to several values of the strength c is considered.

1. Introduction and the numerical results

In the paper [1], the transversal (G_T) and axial (G_A) gains in confocal scanning microscope (CSM) with the leaky annular pupil $P(\rho) = k$ were considered, where k is a positive amplitude transmittance of the filter $(0 < k < 1)$. In the present paper, the case of transversal G_T and axial G_A gains in CSM for $P(\rho) = k(\rho < \varepsilon)$, where k is a negative amplitude transmittance of the filter $(-1 < k < 0)$ is taken into account. The negative amplitude transmittance may be realized, for instance by introducing a delay plate of π phase shift into the central circle of the annular pupil filter.

The gain G_T is expressed by the formula [1]

$$G_T = 1 + \frac{c}{1+c} \tag{1}$$

and the axial gain G_A is given by the formula [1]

$$G_A = 1 + \frac{2c(1-c)}{(1+c)^2}. \tag{2}$$

The parameter c is expressed by k and δ in the form [1]

$$c = \frac{\delta}{k}$$

where: k is the amplitude transmittance in the annulus, δ is the obstruction value of the annular pupil aperture.

In Figure 1, the runs of $G_T(c)$ and $G_A(c)$ are shown, while in Fig. 2 the case $0 < k < 1$ considered by SHEPPARD [1] is presented.

The distribution of the normed transversal $(I(v)/I_{max}(v))$ point function in the focal plane is shown in Fig. 3, for the parameter values $c = -0.1, -0.5, -0.7, -0.9$. The distribution $I(v)$ has been calculated numerically from the following dependence:

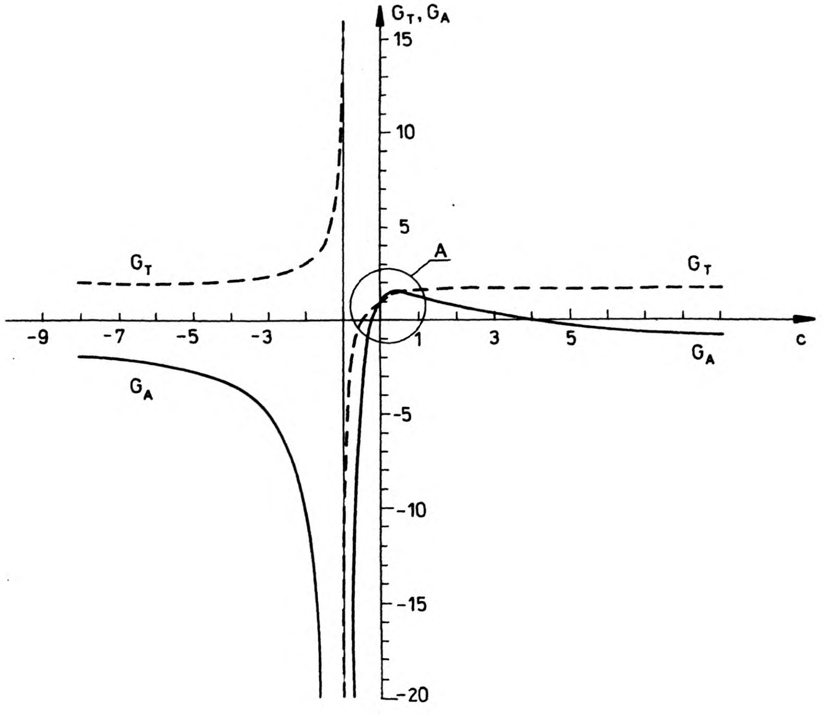

Fig. 1. Axial G_A and transversal G_T gains in the parameter c for $-1 < k < 1$

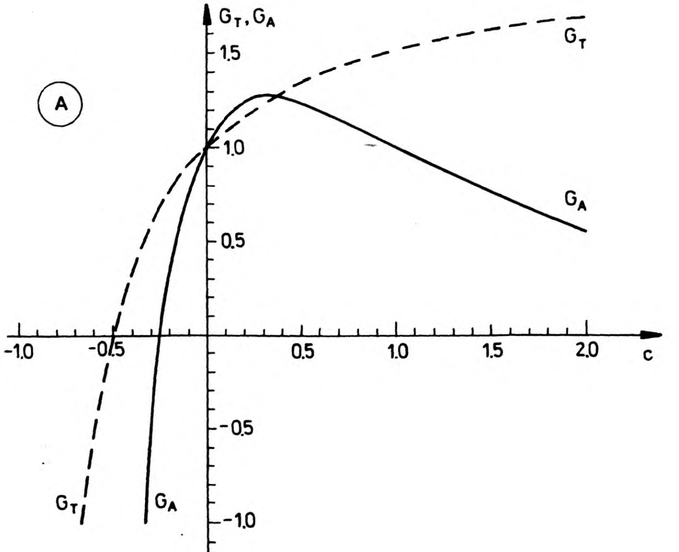

Fig. 2. Axial G_A and transversal G_T gains as a function of parameter c for $0 < k < 1$. The case described in paper [1]. Enlarged fragment (A) of Fig. 1

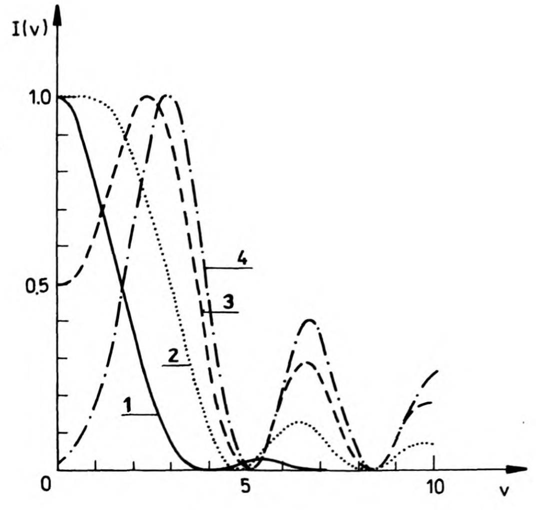

Fig. 3. Transversal $I(v)$ intensity point spread function for parameter $c = -0.1$ (curve 1), $c = -0.5$ (curve 2), $c = -0.7$ (curve 3), and $c = -0.9$ (curve 4)

$$I(v) = \left(\frac{2J_1(v)/v + cJ_0(v)}{1+c}\right)^2. \tag{3}$$

The normed axial distribution of the point spread function $I(u)/I_{max}(u)$ along the axis is shown in Fig. 4 for the parameter $c = 0.5, \ -0.3, \ -0.9, \ -3$.

For $c = -0.9$ and $u = 8.0$ unnormed $I(u)$ achieves the maximal $I_{max}(u) = 135.73$; for $c = -0.3$ and $u = 4$ $I_{max}(u) = 1.073$; for $c = -3$ and $u = 8.8$ $I_{max}(u) = 2.61$; for $c = 0.5$ and $u = 0$ $I_{max}(u) = 1$.

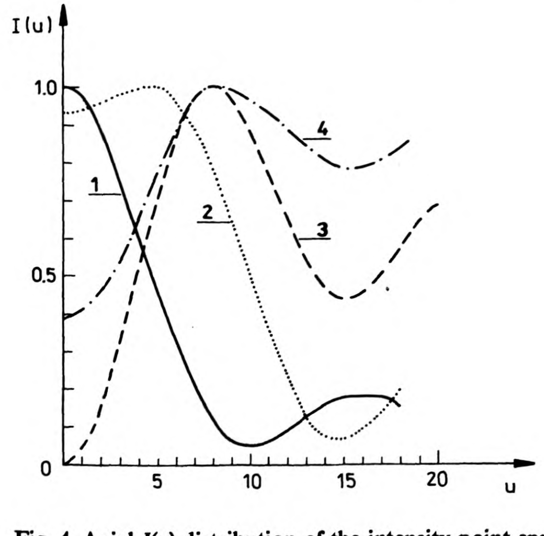

Fig. 4. Axial $I(u)$ distribution of the intensity point spread function for parameter c equal successively to $c = 0.5$ (curve 1), -0.3 (curve 2), -0.9 (curve 3), and -3 (curve 4)

The transversal distribution of the intensity spread function $I(v)$ takes the following maximal values: $I_{max}(v) = 21.17$ for $c = -0.9$ and $v = 3$; $I_{max}(v) = 2.07$ for $c = -0.7$ and $v = 2.4$; $I_{max}(v) = 1$ for $c = -0.5$ and $v = 0$; $I_{max}(v) = 1$ for $c = -0.1$ and $v = 0$.

The superresolution resulting from the annular filtering according to the Sparrow criterion for the transversal intensity spread function $I(v)$ and $c = -0.9, -0.7$ and for axial intensity spread function $I(u)$ and $c = -0.9, -3$ has been shown in Figs. 3 and 4.

Reference

[1] SHEPPARD C. J. R., Optik **99** (1995), 32.

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