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Smoothing by Spectral Dispersion using Random Phase Modulation for Inertial Confinement Fusion

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Abstract: Numerical simulations of beam smoothing using random phase modulation and grating dispersion are presented. Spatial spectra of the target illumination show that significantly improved smoothing at low spatial frequency is achieved while maintaining uniform intensity in the laser amplifier.

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Inertial confinement fusion (ICF) utilizing direct or indirect laser drive requires the target illumination to be uniform over a wide range of spatial frequencies. A number of approaches have been suggested to achieve the desired level of illumination uniformity.[1-5] Angular dispersion of phase modulated light (termed smoothing by spectral dispersion - SSD)[5] is attractive for ICF using glass lasers, since phase modulation preserves the uniform intensity profiles necessary for high power laser amplification. SSD with pure sinusoidal frequency modulation (FM) has been analyzed and measured,[5-8] and although the overall variance of the illumination is adequate, this method suffers from small smoothing rates at low spatial frequencies.[7,8] An alternative smoothing method is that of induced spatial incoherence (ISI)[1,3] or its extension to glass lasers,[4] where a spatially and temporally incoherent beam is propagated through the laser amplifier. The random ISI field fluctuations result in uniform smoothing even at low spatial frequencies. However, the glass amplifier efficiency is severely limited because of the large intensity variations.[4] In this paper it is shown that implementing SSD with random phase modulation (RPM) achieves the same smoothing rates at low spatial frequency as that of the ISI method.

Figure 1 shows a comparison of calculated spatial spectra of the integrated target intensity produced by the ISI smoothing method (solid curves) and that of 2D SSD using pure FM (dotted curves). In both methods an induced beam divergence of $50\lambda / D$ is assumed, where the (square) beam aperture has width D, and λ is the wavelength on target. Both methods have smoothing bound by the finite beam divergence which limits smoothing at spatial frequencies lower than that corresponding to the extent of the beam motion on target (the dashed curves in Fig. 1 show the ideal result obtained with unlimited divergence). Beyond this fundamental limit imposed by beam divergence, however, one sees that the spectral intensity produced by FM-SSD is 5-10 times larger than that of ISI for a range of low spatial frequencies.

Figure 2 shows a comparison between the spatial spectra produced by FM-SSD (dotted curves) with that of SSD using RPM (solid curves) of the same beam divergence used in the calculation of Fig. 1. One sees that the RPM method gives essentially the same results as that of the ISI method, and that the smoothing performance of RPM-SSD at low spatial frequency exceeds that of FM-SSD by almost one order of magnitude. Also, at very short integration times, FM-SSD does not smooth a broad range of low spatial frequencies at all, whereas the RPM-SSD method smoothes spatial frequencies to the fundamental lower limit imposed by beam divergence. The smoothing performance of RPM-SSD is critically dependent on the characteristics of the RPM. Most importantly, to achieve ideal smoothing at low spatial frequency, the number of color cycles across the beam must be large. That is, the temporal skew imposed by the SSD grating must be many times larger than the mean period of the phase modulation. This behavior will be discussed and quantified.

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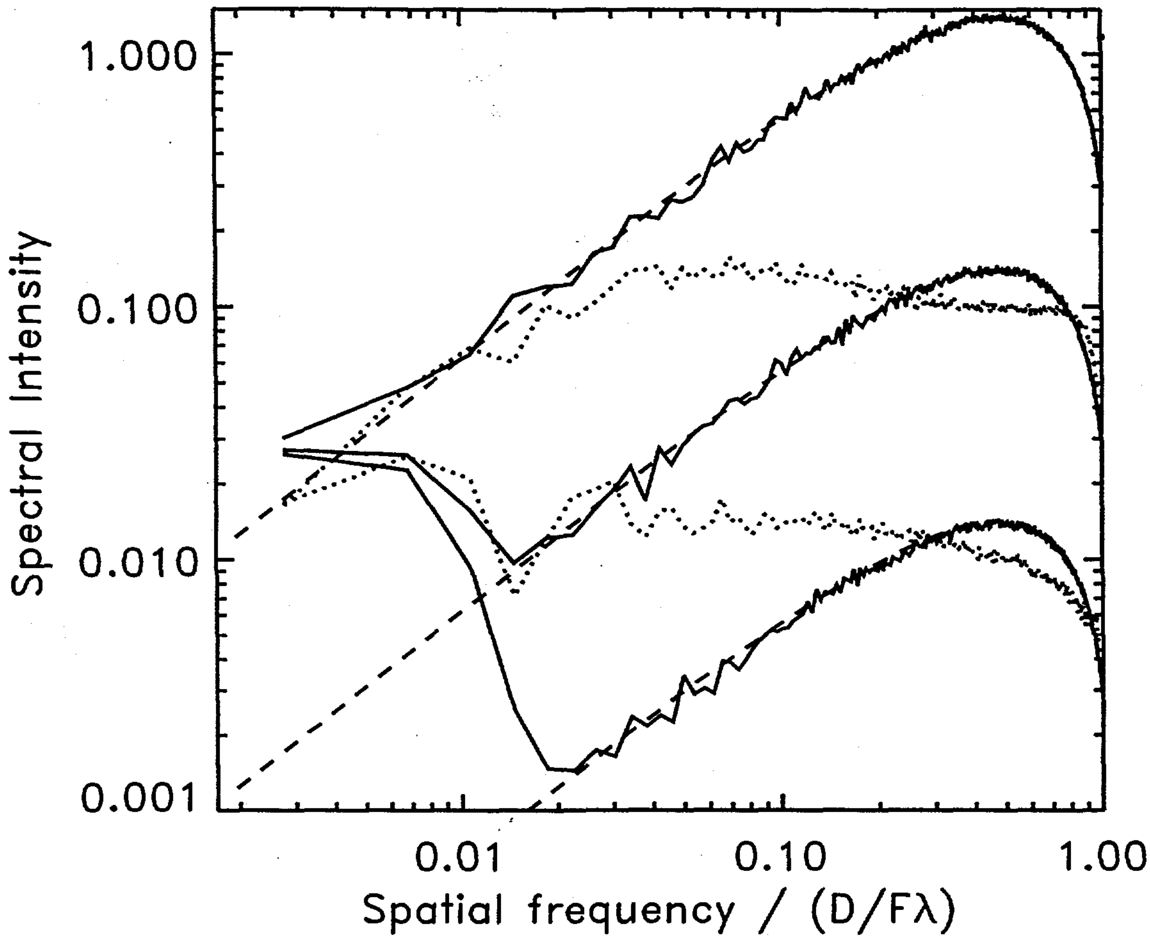
Figure Captions

Figure 1: Comparison of calculated spatial spectra using smoothing by an ISI type method of divergence FWHM 50 λ / D (solid curves) with that of standard FM 2D SSD of similar divergence (dotted curves) for (top to bottom) the initial static speckle pattern (solid) and after an integration time equivalent to 10 and 100 coherence times. The spatial frequency is normalized to the F# limited value of $D / \lambda F$, where F is the final lens focal length. The dashed lines show the ideal smoothing result for the case of ISI with large beam divergence.

Figure 2: Comparison of calculated spatial spectra using 2D SSD with random phase modulation of divergence FWHM 50 λ / D (solid curves) and standard FM (dotted curves) of similar beam divergence for (top to bottom) the initial static speckle pattern (solid) and after an integration time equivalent to 3, 10, and 100 coherence times. The dashed curves show the ideal smoothing result for the case of ISI with large beam divergence.



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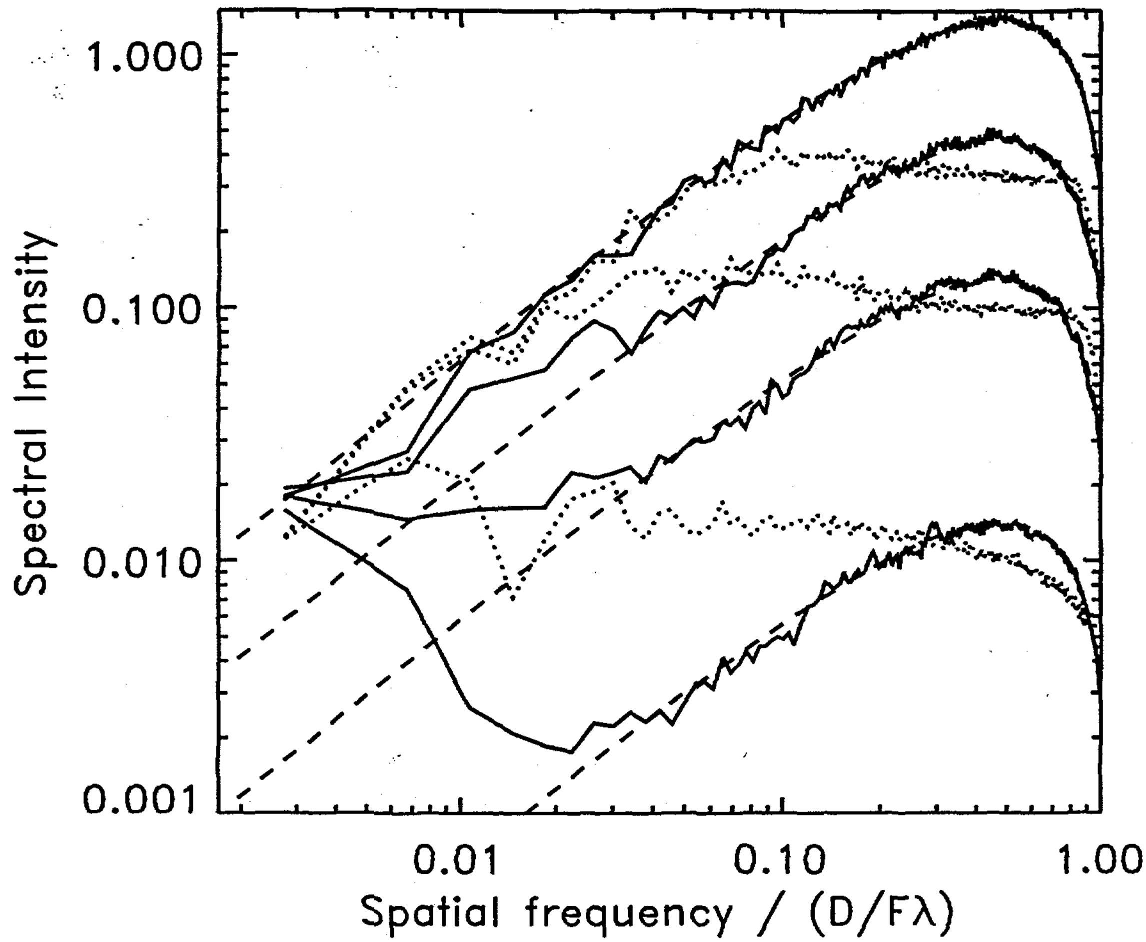

Figure 2: Comparison of calculated spatial spectra using 2D SSD with random phase modulation of divergence FWHM 50 λ / D (solid curves) and standard FM (dotted curves) of similar beam divergence for (top to bottom) the initial static speckle pattern (solid) and after an integration time equivalent to 3, 10, and 100 coherence times. The dashed curves show the ideal smoothing result for the case of ISI with large beam divergence.

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