Simple experimental arrangement for observing spectral shifts due to source correlation

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A filter-lens combination in conjunction with partially coherent light is used to produce a secondary source that violates a certain scaling law. The spectral shifts observed have been found to be dependent on the complex degree of spectral coherence, filter peak transmission wavelength, and half-band-width of the filter.

INTRODUCTION

Recently Wolf[1] has shown theoretically that the spectral density of radiation in the far zone of an extended source may be different from the spectral density of a radiating source if there exists some spatial coherence between the fluctuations in the source. If the source is planar, secondary, and quasihomogeneous and if the degree of spectral coherence at the source satisfies a certain scaling law, the normalized spectrum of the field is the same throughout the far zone and is equal to the normalized spectrum at the source. The source is said to obey the scaling law if the complex degree of spectral coherence depends on the wavelength only through the variable $k(\mathbf{r}_2-\mathbf{r}_1)$ where $\mathbf{r}_2-\mathbf{r}_1$ denotes the distance between two points on the source and $k=2\pi/\lambda$, λ being the wavelength of light. If the degree of spectral coherence does not satisfy the scaling law, the spectrum of the emitted radiation that is detected some distance away from the source will be different from that measured at the source. Experiments showing the influence of source correlation on the spectrum of light detected in the far zone have been reported by a few workers.[2–6] Influenced by the novelty of the work and also giving due consideration to the complexities of the experimental setup used earlier, we have set up a very simple experiment for observing such an important phenomenon.

This communication reports the frequency shift in the optical spectrum detected in the far field of a planar secondary source. A specially designed filter-lens (FL) combination system has been used that produces a secondary source with a certain degree of spectral coherence which is independent of the wavelength and thus violates the scaling law. The experimental arrangement is shown in Fig. 1.

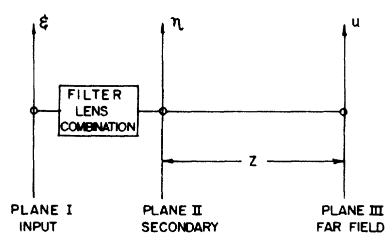

FIG. 1. Experimental arrangement for realizing a secondary source with varying degree of spectral coherence.

EXPERIMENTAL RESULTS

In our experimental setup a 450-W tungsten halogen lamp was used as a primary source. In the close proximity of this source a circular aperture a_1 of radius 1.5 mm was placed. The aperture plane is defined as source plane I. A Gaussian filter having a peak transmission at 540 nm and half-band-width$\simeq$200 nm was used along with a lens of 20 cm focal length. The coherence interval at the secondary source plane was $\simeq 35\ \mu$m at 540 nm. The image of the aperture at source plane I was obtained at the focal plane of the lens which is defined as secondary source plane II. The spectrum at plane II was detected by means of a 0.5-m Jarrell-Ash grating monochromator and was found to be independent of the spatial location of the filter-lens combination. Curve A in Fig. 2 shows the spectral intensity at the source plane II at various locations in the far field. It was found that the normalized

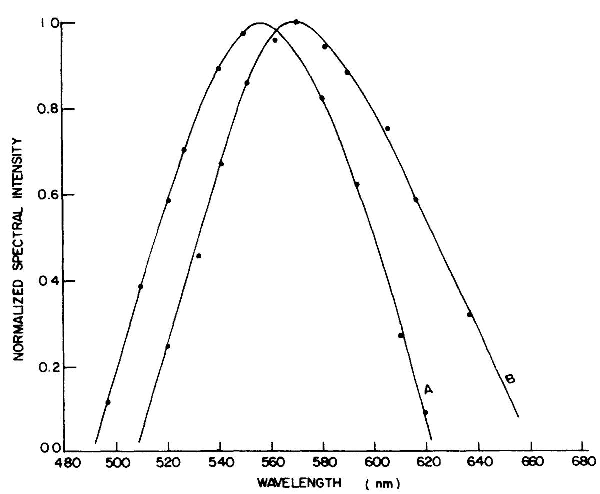

FIG. 2. Source spectrum in plane III (curve A) without an aperture at plane II and (curve B) with an aperture at plane II.

TABLE I. Wavelength shift due to source correlation.

Peak transmission wavelength (nm)	Half-band-width (nm)	Shifted peak transmission wavelength (nm)	Nature of shift
420.5	9	421.0	red
484.5	9	485.1	red
515.0	5	515.5	red
566.6	13	564.9	blue
609.2	8	608.8	blue
652.0	8	651.6	blue

spectrum was independent of the location of the detection plane.

By introducing a circular aperture of radius a_2 equal to 400 μm in the secondary source plane II and satisfying the far-field conditions by choosing $Z \gg a_2^2/\lambda$ (where Z is the distance in the far field and λ is the peak transmitted wavelength of the filter), the spectrum was again recorded. The off-axis spectral intensity was measured in the far field (plane III). It was found that the spectrum broadens and the peak shifts by almost 10 nm towards the red end of the spectrum, as shown by curve B in Fig. 2. It may be noted that the observed shift and the broadening of the spectrum could not be explained on the basis of the theoretical explanation given by Morris and Faklis[2] because the theory has been derived under the assumption that the source spectrum and the spectral degree of coherence are Gaussian. These assumption are not exactly met in our case. No comparison between our experimental results and the theoretical explanation given by Morris and Faklis has, therefore, been made.

It is necessary that the effect of source correlation and diffraction should be identified separately. In order to distinguish the two, an aperture $a_3=20$ μm was put in plane III and the spectrum of the source plane II was measured in the far field. The coherence interval in plane III being 10 μm, any diffraction effect caused in plane II was expected to be modified by the aperture present in plane III. It was, however, found that no detectable change in the spectrum occurred.

DISCUSSION

Our experimental results show that the correlation properties of light at the source plane modify the spectrum in the far zone. This is consistent with the theoretical predictions made by Wolf.[1] The spectrum is invariant if the optical field follows a certain scaling law. On the other hand, violation of the scaling law produces change in the spectrum.

In the present experiment the circular aperture inserted in source plane I produced a secondary source at plane II which is a Bessel-function-correlated source. The filter-lens combination was used to produce a spectral correlation in plane II. The illumination thus produced in plane II violated the scaling law. Introduction of a circular aperture in plane II helped in modifying the spectrum in the far zone.

Using a Bessel-function-correlated source to produce any functional form for the complex degree of spectral coherence through the application of the van Cittert–Zernike theorem and to eliminate the wavelength dependence of the complex degree of spectral coherence, various filter-lens combinations were used. The filter peak transmission wavelength, half-band-width, and the corresponding shifts are presented in Table I. The table shows that for a filter-lens combination having filter peak transmission wavelength $\lambda < 560$ nm, the peak shifts towards the red end of the optical spectrum, while for $\lambda > 560$ nm, a blue shift is observed. The shifts are of the order of 1 nm and have a prominent dependence on the half-band-width of the filter. The broader the filter, the more the spectral shift. This shift is attributed to the degree of spectral coherence introduced due to source correlation.

The practical utility of the experimental setup described in this Brief Report is its simplicity and resemblance to the setups used for spectroradiometoric and spectroscopic measurements. The effect of the spectral shifts observed in such experiments have been reported elsewhere.[6]

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