Comment on "'Aether Drag' and Moving Images"

Fresnel drag in a moving medium with refractive index n is an important prerelativity result, given by $c' = (c/n) \pm v(1 - 1/n^2)$ with the crucial $1/n^2$ dependence. The transverse Fresnel drag, when light propagates in a direction transverse to the motion of the medium, was measured carefully by Jones [1] as a spatial shift,

$$\delta x = v_d t = \frac{vL}{c}(n_g - 1/n_p), \tag{1}$$

where L is the thickness of the medium, and n_g and n_p its group and phase refractive indices. More recently, Leach *et al.* [2] considered the reciprocal situation of the light beam moving transversally in a lab-fixed static medium. They measured the "spatial shift,"

$$\delta x' = \frac{vL}{c}(n_g - 1), \tag{2}$$

instead of the Fresnel relation.

The "intriguing" discrepancy was analyzed by Leach *et al.* in terms of the difference between the Poynting vector and the wave vector, with partial reconciliation. However, a similar discrepancy in an experiment in which an optical pattern was rotated was considered puzzling.

We now show that the apparent shifts, $\delta x'$ and $\delta\theta'$, arise from the time dependence of a nonmoving pattern, unrelated to Fresnel drag and relativity. The reciprocal situation to the moving medium is when the source and the optical field move relative to the stationary frame of the medium. Instead, Leach *et al.* overlapped two beams at a small angle 2α to get parallel fringes with spacing $\Lambda = \lambda/2\alpha$. Then they introduced a frequency difference $\delta\nu$ between the beams, resulting in a time dependent phase $\phi(x, y)$ at a transverse point that gave the impression of movement with apparent velocity $v_a = \Lambda\delta\nu$. But no relative motion at any velocity is involved, as easily seen by considering larger beams of size 5 cm, with a small angle between them $\alpha \simeq 2 \times 10^{-5}$ rad, $\Lambda \simeq 2.5$ cm, and a practical $\delta\nu \simeq 20$ GHz. The "velocity" then is an unphysical and superluminal 5×10^8 m/s! One can also just magnify the fringe pattern and the velocity increases unphysically. That there is no relative motion can also be seen by considering an interference pattern with visibility less than unity.

At each point in the transverse plane, the phase changes periodically and at a nearby point it changes *similarly* after a delay $\delta t = 2\alpha(x' - x)/\lambda\delta\nu$, but there is no transverse motion. The optical field at x' is a copy of the field at x at an earlier time. (An analogous case is when a grid is moved in front of an optical beam, the shadow "moves" across at an apparent but unphysical velocity). If we compare the spatially static, time dependent intensity with itself after a time delay δt, we get the difference $\delta I(x) = \delta t \times [\partial I(x)/\partial t]$. When the time delay $\delta t = Ln/c - L/c$ is due to the two different paths to the camera through the medium of thickness L and free space, the difference in the intensity patterns is $\delta I(x) = [\partial I(x)/\partial t](L/c)(n - 1)$. The optical beam at two different times occupies exactly the same spatial region and boundary, but the intensity patterns across the beam differ by the temporal "speed" of modulation, giving the false impression of a spatial shift without genuine motion or shift. This is what Leach *et al.* saw in their experiments, both in the linear version and in the rotational version. The experiment has no relation and relevance to relativity or Fresnel drag. That there is zero spatial shift can easily be seen from the boundary of the image or the beam, which is part of the optical field and remains static. This lag could have been just an optical delay between two paths in free space without a medium, with the same result $\delta x' \propto (L_1 - L_2)/c$. An illusion of movement is not a substitute for physical motion.

In the experiment with the "rotating image," a time dependent image with apparent rotation is compared with its slightly earlier copy, with the obvious result $\delta\theta' = (\Omega L/c)(n_g - 1)$ instead of the Fresnel result $\delta\theta = (\Omega L/c)[n_g - (1/n_p)]$. There is no physical rotation, as verified from the superluminal speed that would result with a larger beam and large frequency difference.

In fact, the modulation can be in any quantity Q associated with beam, like the frequency, polarization, etc., and two measurements, one of which is delayed by a medium, will differ by the same formula $\delta Q' = \{[(dQ/dt)L]/c\}(n_g - 1)$.

This completely explains the nonrelativity results obtained by Leach *et al.*

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Received 22 December 2017; published 5 April 2019
DOI: 10.1103/PhysRevLett.122.139401

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