# Measurement of the refractive index of highly turbid media: reply to comment

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Peiponen *et al.* [Opt. Lett. **35**, 4108 (2010)] have expressed concern that a theoretical model we proposed in Calhoun *et al.* [Opt. Lett. **35**, 1224 (2010)] for total internal reflection from a turbid medium may be inconsistent with the experimental data, in the sense that the model fails to take into account unexplained oscillations in our data. We show that their concern arises from misinterpretation of our data and theory, and is, therefore, unfounded. *Note:* Optics Letters *apologizes to the authors for the delay in the publication of this Reply.* 

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Recently, we proposed a Fresnel-based model for total internal reflection (TIR) from a turbid medium that incorporates angle-dependent penetration into the medium [1]. In response, Peiponen, *et al.* [2] pointed out that our data "suggests oscillation" arising from "interference of light due to the particles" and that this oscillation is "clearer" in earlier data reported by us [3]. Thus, their "main concern" is that our data is "not consistent with the theoretical model" because our model cannot account for such interferences. We wish to clarify that there actually are *two* different oscillations present in our data for the intensity ratio $I_r/I_i(\theta_i)$ [1,3], neither of which affects our model's validity.

First, there is a regular oscillation seen in Fig. 3(a) of [3], which we have previously observed and commented on [4]. Contrary to the conjecture in [2], this oscillation has nothing to do with scattering from large suspended particles: Fig. 1 shows that this particular oscillation is significant in (a) for *transparent* media, less visible in (b)–(c) for moderately turbid media, and *vanishes* in (d)–(e) for highly turbid media. Further, the period of oscillation in Figs. 1(a) and 1(b) is independent of particle size. Despite the oscillation being prominent for transparent/moderately turbid media, accurate refractive index measurement is obtained by calibrating our sensor to any of several state-of-the-art commercial refractometers. No reference refractometers exist for highly turbid media, but that is precisely the situation in which the oscillation vanishes.

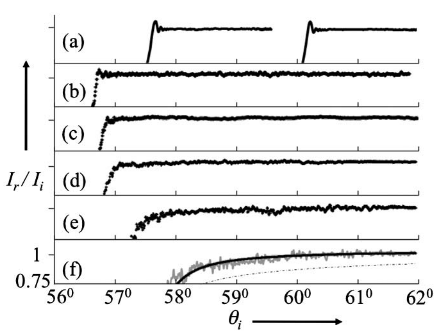


Fig. 1. Measured reflectance profiles $I_r/I_i(\theta)$ for transparent and turbid solutions [(a)–(e) have the same vertical/horizontal scale as that in (f)]. (a) Two different transparent ($n_i = 0$) water–glycerin mixtures used for sensor calibration in Refs. [1,3]. Milk with fat volume concentration of less than (b) 0.5%, (c) 1.6%, and (d) 3.3%, reproduced from Fig. 3 in [3]. Milk–cream mixtures with fat volume concentrations of (e) 10% and (f) 33%, reproduced from Fig. 2 in [1].

There is a second, completely different oscillation of the data in Figs. 1(e) and 1(f), which manifests as scatter when individual data points are displayed [as in Fig. 1(e) and in Fig. 2 of [1]), and as spiky rapid oscillations when a line is drawn between adjacent data points [Fig. 1(f), gray curve]. We agree with [2] that these oscillations likely arise from interferences in light scattered by particles, and cannot be explained by traditional Fresnel theory (i.e., Eq. 1, [1]; dashed curve in Fig. 1(f)), which fails to reproduce not just these oscillations *but also the average behavior of the reflectance profile*—this is a central point in [1]. However, a *modified* Fresnel theory, which introduces an angle-dependent penetration model of TIR (Eqs. 1 *and* 2 of [1]), produces the solid dark curve in Fig. 1(f), which *fits the data better than ever before, to the best of our knowledge, while deliberately ignoring the spiky non-Fresnel interference features*. In the absence of a reliable reference method for measuring the refractive index of highly turbid media, it seems advisable to use a physical model that fits the data best, using as few fitting parameters as possible (in our case, $n_r$ and $n_i$, the real and imaginary parts of the refractive index).

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### References

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