



## Three-Dimensional Optical Coherence Tomography

Advantages over prior OCT systems include less bulk and greater speed.

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Three-dimensional (3D) optical coherence tomography (OCT) is an advanced method of noninvasive infrared imaging of tissues in depth. Heretofore, commercial OCT systems for 3D imaging have been designed principally for external

ophthalmological examination. As explained below, such systems have been based on a one-dimensional OCT principle, and in the operation of such a system, 3D imaging is accomplished partly by means of a combination of electronic

scanning along the optical (Z) axis and mechanical scanning along the two axes (X and Y) orthogonal to the optical axis.

In 3D OCT, 3D imaging involves a form of electronic scanning (without mechanical scanning) along all three axes. Consequently, the need for mechanical adjustment is minimal and the mechanism used to position the OCT probe can be correspondingly more compact. A 3D OCT system also includes a probe of improved design and utilizes advanced signal-processing techniques. Improvements in performance over prior OCT systems include finer resolution, greater speed, and greater depth of field.

Figure 1 includes a simplified schematic representation of the optical subsystem of a typical prior OCT system. In this system, near-infrared light from an incandescent lamp or other low-coherence source is sent through optical fibers and a fiber-optic coupler to a reference mirror. Some of the light is also sent through the fiber optics to a lens that, in turn, focuses the light to a point that lies at or near the depth of interest in a specimen. In the fiber-optic coupler, light reflected from the reference mirror is combined with light scattered from a focal point in the specimen and is then sent along another optical fiber to a photodetector. When the length of the optical path from the light source to the mirror equals or nearly equals the corresponding length to the focal point in the specimen, the photodetector puts out a

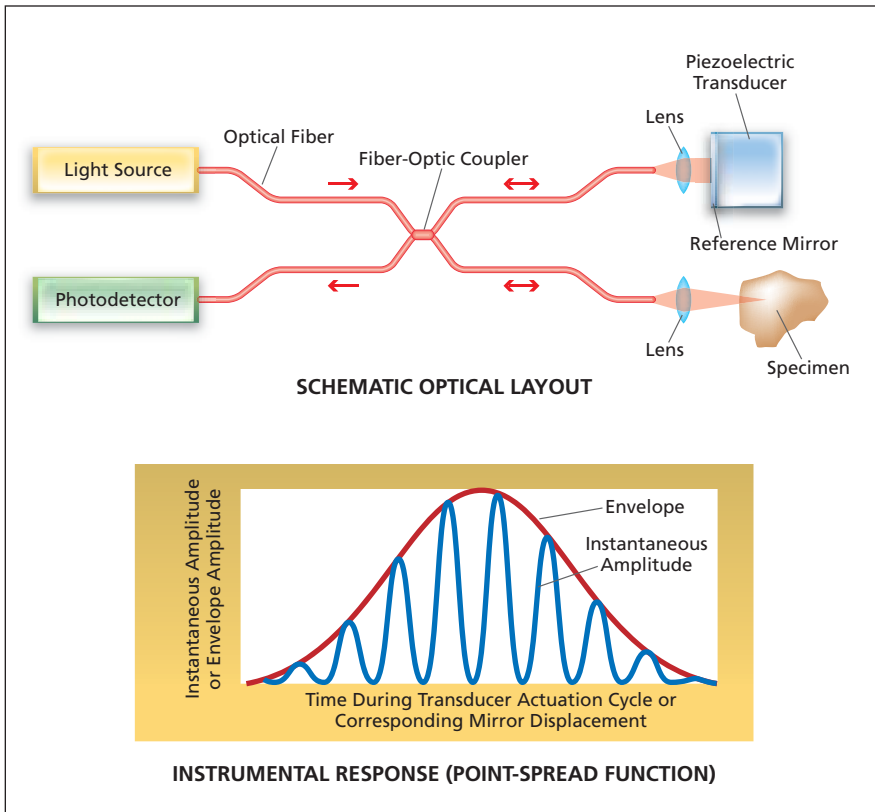


Figure 1. In a Typical Prior OCT System, scanning in Z involves piezoelectric actuation of the reference mirror, and scanning in X and Y is involves mechanical motion of the probe.

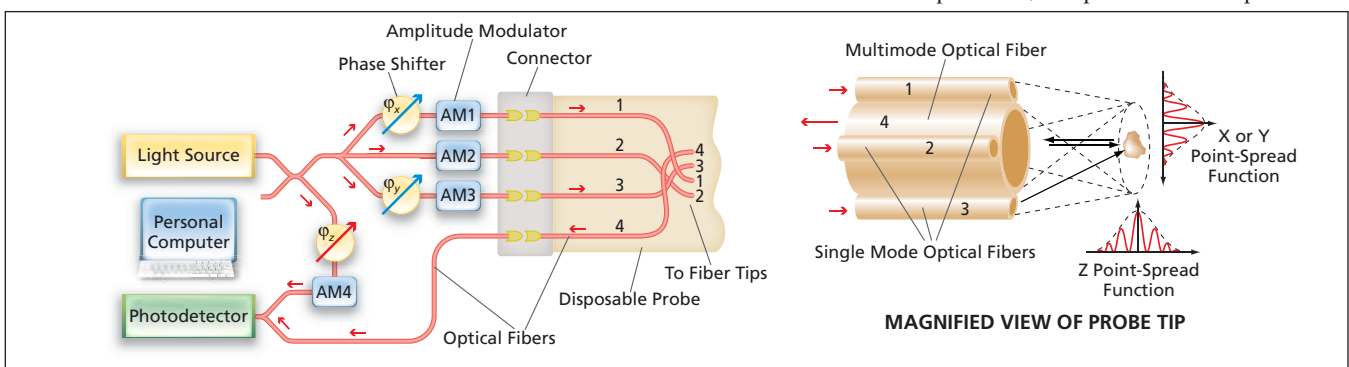


Figure 2. In a 3D OCT System, scanning in all three dimensions involves a combination of amplitude modulation, nonlinear detection, and advanced signal processing.

signal representing a pixel at the focal point in the specimen. Scanning along the depth (Z) axis is accomplished by using the piezoelectric transducer to move the reference mirror closer to, or farther from, the light source. Scanning along the X and Y axes is accomplished by mechanical motion of the probe along X and Y.

The lower part of Figure 1 depicts a typical instrumental response (point-spread function) in the photodetector output obtained in scanning along the Z axis. The response includes oscillations attributable to interference between the light scattered from a point in the specimen and light scattered from the mirror. As the Z displacement increases, the contrast of the interference pattern is reduced by the loss of coherence. Usually, the envelope of the oscillations (in contradistinction to the oscillations themselves) is what is measured. In such a case, the width of the envelope and, thus, the depth resolution, is comparable to the coherence length of the light source.

Figure 2 includes a simplified schematic representation of the optical subsystem of a 3D OCT system. This system is based partly on the same principles as those of the prior system. However, there are several important differences:

- Light from the source is fed through a more-complex fiber-optic subsystem, not only to a photodiode but to three single-mode optical fibers on a probe. Light emerging from the tips of these three fibers illuminates the specimen and creates a 3D interference pattern in the specimen.
- Light scattered from the specimen is collected and sent to the photodetector by a wider, multimode optical fiber. The probe containing the illuminating single-mode fibers and the light-collecting multimode optical fibers is significantly smaller and more rugged, relative to a lens-containing probe in a prior OCT system.
- Instead of utilizing lenses and a piezoelectric actuation of a reference mirror to effect scanning in Z and focusing in conjunction with mechanical

scanning in X and Y, the system utilizes a combination of (1) amplitude modulation of the light in the three illuminating optical fibers and of a portion of the source light sent directly to the photodetector, (2) nonlinear detection, and (3) an advanced signal-processing technique that, among other things, exploits the 3D nature of the interference pattern in order to obtain (4) a 3D point-spread function that affords localization in X, Y, and Z. In principle, because mechanical scanning is no longer necessary, it is possible to achieve scanning at a video frame rate.

*This work was done by Mikhail Gutin, Xu-Ming Wang, and Olga Gutin of Applied Science Innovations, Inc. for Glenn Research Center. Further information is contained in a TSP (see page 1).*

*Inquiries concerning rights for the commercial use of this invention should be addressed to NASA Glenn Research Center, Innovative Partnerships Office, Attn: Steve Fedor, Mail Stop 4-8, 21000 Brookpark Road, Cleveland, Ohio 44135. Refer to LEW-18352-1.*

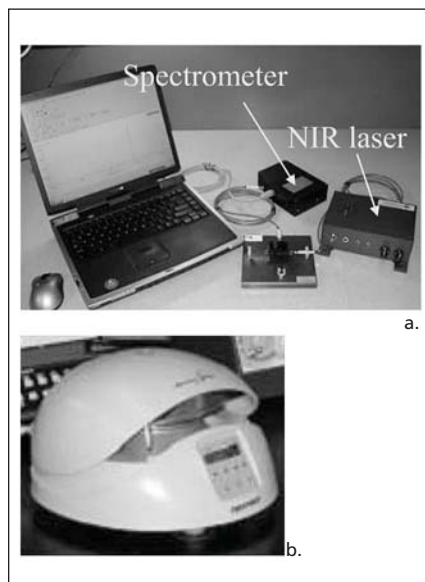
## Benchtop Antigen Detection Technique Using Nanofiltration and Fluorescent Dyes

**This technique can help to monitor the quality of water by testing for contamination at restaurants, water treatment plants, and food processing plants.**

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The designed benchtop technique is primed to detect bacteria and viruses from antigenic surface marker proteins in solutions, initially water. This inclusive bio-immunoassay uniquely combines nanofiltration and near infrared (NIR) dyes conjugated to antibodies to isolate and distinguish microbial antigens, using laser excitation and spectrometric analysis. The project goals include detecting microorganisms aboard the International Space Station, space shuttle, Crew Exploration Vehicle (CEV), and human habitats on future Moon and Mars missions, ensuring astronaut safety. The technique is intended to improve and advance water contamination testing both commercially and environmentally as well. Lastly, this streamlined technique poses to greatly simplify and expedite testing of pathogens in complex matrices, such as blood, in hospital and laboratory clinics.

The approach relies on NIR fluorescent dyes derivatized to specific anti-



The **Benchtop Analysis System** (a) consists of a medium-power, class IV laser, a four-port cuvette sampler holder, a spectrometer, laptop and software, and fiber-optic cables. (b) The microcentrifuge used in nanofiltration of the complexes.

body sets that are selected to bind and differentiate microbial surface proteins, termed antigens. In a solution containing an antigenic slurry, NIR conjugated antibodies are added to the mixture, and will bind to the respective antigens if present. To eliminate any false positives, excess antibodies, i.e., those antibodies not bound to an antigenic protein or those with no respective antigen present, are removed via the nanofiltration process using a portable, table-top centrifuge. The remaining NIR dye/antibody and antigenic protein pairs left on the nanofilter are transferred to cuvette, excited by an NIR laser, and detected by spectrometer. Using simple computer software, the results are easily interpreted as intensity peaks at the appropriate NIR offset wavelength emission.

Initial data reveal the assay sensitively identified antigens at intensity counts of 100 IC or higher (or roughly 36 pW) with an accuracy of 85 percent for 2-