THz Hydration Sensitivity: Dielectric Substrate Window Considerations

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Variations in water volume fraction have been investigated as a possible source of contrast in several reflective THz medical imaging applications including corneal hydration sensing and burn wound severity diagnosis. Due to surface roughness and non-planar geometry most reflective systems employ low loss windows such as quartz or sapphire to minimize the effects of the specimen's topology. This creates a multilayer system consisting of the dielectric substrate window between the tissue medium and free space. Multilayer systems have interference effects due to internal reflections that vary periodically with frequency. To investigate the effects of interference on THz hydration sensing, we implemented an electromagnetic model that computes sensitivity metrics given a window index, window thickness, and incidence angle.

We model the dielectric constant of biological tissue as a function of tissue hydration using effective media theory and the double Debye model of water. We examined the spectrum from 100 GHz to 1 THz for windows ranging in thickness from 0 mm (no window) to 4 mm, and indexes from 1 to index 5.

We found that the variation in the reflected field's magnitude and phase due to the window is greater than the variation from physiologically relevant changes in tissue hydration. This resulted in both increases and decreases in hydration sensitivity depending on center frequency, bandwidth, window thickness, and widow index. Furthermore the reflectivity as a function of hydration is non-invertible for systems that employ windows.

We conclude that the window methodology that maximizes hydration sensitivity depends on the expected tissue system hydration range. For tissue that spans large hydration ranges, such as burn wound imaging, windowless systems have superior sensitivity. Conversely for imaging applications involving tissue systems that span small hydration ranges, such as biobanking, the presence of a dielectric substrate window may enhance hydration sensitivity.