# Using Microfluidic Channels to Determine the Electromagnetic Response of Nanoliter Fluid Volumes from 100 Hz to 40 GHz

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The interactions between electromagnetic radiation and fluid samples are the subject of much active research. Dielectric permittivity measurements provide important information regarding fluid properties, and microwave heating techniques can be used to control fluid temperature and catalyze chemical reactions, for example. Traditional microwave fluid permittivity measurements employ open-ended coaxial techniques or carefully fabricated fixtures, which require relatively large sample volumes, are difficult to implement as a function of temperature, not amenable to integration, and can be slow. These factors have severely limited the application of electromagnetic techniques to interesting biological systems, as many relevant samples are difficult to produce in large quantities, such as proteins. We describe the integration of lithographically-defined, planar high-frequency microelectronic structures with microfluidic channels to produce on-chip experimental structures where the active fluid volumes interrogated by the electromagnetic fields are on the order of nanoliters or smaller. Such devices allow us to probe the interactions between electromagnetic fields and fluids on faster time scales and with greatly improved sensitivity for small sample volumes. We have developed finite element electromagnetic simulations of our microfluidic-microelectronic structures in order to extract quantitative dielectric permittivity values from electronic measurements over the broad frequency range from 100 Hz to 40 GHz, and have also performed measurements as a function of temperature. We have verified our measurement system with extensive measurements of de-ionized water, methanol, and isopropanol, and have applied it to measure the dielectric response of latex beads and protein solutions, for example. We have also used our integrated devices to explore rapid electromagnetic heating of fluids, and have demonstrated dielectric-based temperature measurements, both on millisecond time scales. The microfluidic nature of these electromagnetic measurement and manipulation techniques allows for the exciting possibility of integration with other fluid property measurements in future mutlifunctional micro-total analysis systems.