NDnano
Notre Dame Nanoscience and Technology

NDnano Undergraduate Research
2020-21 Winter Session Project Summary

1. Student name: Alex Beck

2. ND faculty name & department: Dr. Thomas O'Sullivan, Department of Electrical Engineering

3. Winter Session project title:

Frequency Domain Diffuse Optical Spectroscopy (FD-DOS) on a Chip

4. Briefly describe new skills you acquired during your Winter Session research:

I gained the skill of using lasers, photodetectors, and other optical components and characterization equipment. I also acquired the knowledge to use SPI and I2C protocol to communicate between devices while increasing my proficiency in programming, 3D modeling, soldering, and technical communication.

5. Briefly share a practical application/end use of your research:

A practical application of this research is to improve the accessibility of low-cost, effective breast cancer screening and treatment monitoring devices.

6. 50- to 75-word abstract of your project:

In this project we investigated the use of an application specific integrated circuit (ASIC) for frequency domain diffuse optical spectroscopy (fd-DOS) to reduce the size, power consumption, and cost of noninvasive quantitative tissue optical characterization. We conducted experiments that simulate signals received from diffuse optical imaging of breast tissue in order for the device to measure changes in amplitude and phase needed for fd-DOS imaging.

One-page project summary that describes problem, project goal and your activities / results:

Noninvasive diffuse optical imaging of tissue has shown promise in several biomedical fields including breast cancer treatment and functional brain imaging. Frequency-Domain Diffuse Optical Spectroscopy (fd-DOS) is a sensing and imaging technique that can provide increased sensing depth, resolution, and accuracy of tissue optical characterization. Due to the different optical absorption exhibited by components of tissue, such as deoxygenated and oxygenated hemoglobin, water, lipids, etc., it is possible to estimate the concentration of these molecules by using DOS. fd-DOS accomplishes this task by modulating the intensity of light, typically at near-infrared wavelengths and measuring the phase delay and amplitude attenuation caused by absorption and scattering of photons in the tissue. Light from the source can then be detected in either a transmission or reflection geometry. The relative differences in the laser diode's output and the photodetector's received signal can be used to quantify tissue composition.

Emerging applications of DOS are in oncology for the detection and monitoring of tumors, neurological monitoring of brain injury, and image guided surgery, among others. However, a primary challenge is to reduce the cost, size, and complexity of current fd-DOS devices. A potential candidate to address this challenge and progress toward widespread implementation of DOI technology is the use of custom-designed Frequency-Domain Application Specific Integrated Circuits (fd-ASIC) that can perform fd-DOS. Because of the ultrasmall size and efficiency of the fd-ASIC, it allows for ultra-high density spatial and multi-frequency interrogation of different tissues. This versatility also creates the opportunities for real-time imaging and selectable imaging modes. The long-term objective of this research is to produce a low-cost fd-ASIC with high spatial and density resolution which will further the applications of fd-DOS in the clinical setting; however, the goal of this immediate project was to prove that fd-ASICs can be used to decrease the size, power consumption, and complexity of current systems.

In this project, we evaluate a fd-ASIC developed by collaborators at the University of California, Irvine that can produce modulated outputs with a frequency range of ~0.05-1GHz, de-modulate the detected optical signal and determine the phase delay and amplitude attenuation between the two. All of the data processing is done on the integrated circuit on its evaluation board, typically these functions are accomplished by bulky and relatively expensive equipment.

Through this research it has been shown that the board produces a RF signal that, after amplification, can sufficiently modulate a laser diode. The fd-ASIC captures optical signals collected by an avalanche photodiode (APD) and detects changes in amplitude and phase when the light is scattered and absorbed in a phantom. We created a test system to automate amplitude and phase measurements and used it to characterize tissue-simulating phantoms.