# AC 2007-1782: INTEGRATION OF A RESEARCH/TEACHING/ENTREPRENEURSHIP MODEL AT ELIZABETHTOWN COLLEGE

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# Integration of a Research/Teaching/Entrepreneurship Model At Elizabethtown College


## Abstract

In this paper we review an integrated research-teaching-entrepreneurship project at Elizabethtown College, where majors in engineering and business are offered in addition to liberal arts curricula.

The research component involves a continuous monitoring of the free- and bound-water rotation spectrum in hydrating portland cement over the frequency range 10 kHz to 8 GHz from initial mixing to several weeks cure, using broadband Time-Domain-Reflectometry (TDR) Dielectric Spectroscopy and an embedded capacitance sensor. The result is an improved understanding of the hydration process from a molecular dynamics standpoint, and a foundation for using TDR spectroscopy as a powerful tool for investigating the hydration process in cementitious materials.

In addition, the ability to interrogate the sensor in the time domain and extract information from the direct reflected transient can provide a novel and robust cure-monitoring method usable in the field.

The teaching component consists of integrating undergraduate students in this research through individual and team engineering projects that are offered in design and project courses from first to senior year. Some of the projects are offered to vertically integrated engineering teams (i.e., a team composed of first year students, sophomores and juniors); other projects involve interdisciplinary teams with students from engineering, applied physics, chemistry or biology.

This effort sprang from collaboration between the College and a small industrial partner, whose laboratories are located at the College and whose main technical expert offers support for teaching engineering and physics courses as a research scientist. These efforts have additional advantages such as generating collaborations and synergies among technical personnel and faculty.

Future developments may involve the integration of TDR tools with other electrical and optical methods, the TDR measurement of tissue and life science samples in collaboration with the Biology Department, and the integration of a business entrepreneurship component where business students try to market and sell the services and instrumentation generated by these efforts.


## Introduction

In this paper we describe an integrated research-teaching-entrepreneurship project at Elizabethtown College. In our institution, usually deemed a "comprehensive" college, undergraduate curricula in engineering and business are offered in addition to the traditional liberal arts setting.

The integrated project we describe here is at its infancy, with main components still under development or in the planning stage. However, it is based on recent accomplished research and has already recorded some initial meaningful interactions and achievements in the complementary educational components, reinforcing the general ideas and goals of the project and forming the basis for publication of this report.

The research component, which is central to the project, involves the use of Time-Domain-Reflectometry to study hydrating portland cement. The project provides opportunities for interdisciplinary research for students in Physics and Engineering, Biology and Chemistry. An additional important part is the integration of research and industrial aspects through the collaboration between Elizabethtown College and Material Sensing & Instrumentation (MSI), a small high-tech company. Finally, at a future stage, the inclusion of engineering and business student teams into an entrepreneurship and marketing extension of the research activities is planned.

In this paper we will briefly review each aspect of the project, describing background, past activities and achievements, present and future plans. Assessment of our project can be at this stage qualitative, with more quantitative analysis and summary reserved for a future date.

**Background**

This project originated from the drive for collaboration, expertise and resource sharing between the two authors, and from the wish to use the common research efforts to provide opportunities for undergraduate research while at the same time strengthening the capabilities of the associated high-tech venture.

One of the authors (IG) joined the institution in 2002, and set up to build a lab for electrical measurements of materials, with expertise in electrical and optical characterization of semiconductors.

The other author (NH) left a position in high-tech industry years before and joined the institution in 1994 by setting his microwave research lab (imported from industry) adjacent to other labs in the Department of Physics and Engineering. While dedicating most of his time to building the high-tech company, MSI, during many years he also taught courses at the College, whenever needed and requested. Over the years, with a number of co-workers, he developed research avenues and was funded through a number of Small Business Innovation Research (SBIR) awards from the Departments of Defense (DoD), The Department of Commerce (DoC) and the National Science Foundation (NSF). At the same time, he developed a custom-oriented business, MSI, based on design and measurement capabilities in the field of microwave materials characterization.

**Research Overview**

The authors have been active individually in diverse fields of research from semiconductor materials, to nonlinear optics, to medical signal processing, to microwave characterization and design. We look for research topics that can be the centerpiece for undergraduate involvement of

Applied Physics and Engineering students, but can also interest science majors from Chemistry and Biology, and offer diversified theoretical, analytical, design, and experimental challenges while fostering interdisciplinary collaborations. We feel that linking an academic environment with experience and opportunities in an industrial setting would provide the students with a positive enriching experience.

We converged on building the project around high-tech characterization of the cure of portland cement, widely used in the construction industry. This research explores a new method of monitoring hydration in concrete and cementitious materials including High-Performance Concrete[1] and Fiber-Reinforced Concrete.[2]

The material is embedded with an inexpensive capacitance sensor and interrogated by broadband Time-Domain-Reflectometry (TDR), providing a molecular rotation spectrum of water over an extremely wide frequency range (10 kHz - 8GHz.)

Three separate states of water participating in the hydration reaction are identified, including a free-water rotational state, a bound-water rotational state, and an ion-hopping state. The three states have been fit to appropriate models as a function of cure time, while a variation in cement chemistry revealed the nature of the processes involved.

The results are: 1) a free-water relaxation which monitors the disappearance of water into hydration and thus follows percent hydration, and 2) a bound-water relaxation which monitors water attaching to developing microstructure and thus monitors formation of this microstructure.[3]

A unique aspect of the system is that the measurement is performed in the time domain, where sensor response is separated from instrument artifacts by propagation delay. Data can be either transformed to a microwave frequency spectrum for scientific-quality analysis, or interpreted directly in the time domain for robust field-grade control.

The measurement can thus be performed in the field using an inexpensive PC-based TDR sampling unit. This initial research was supported in part by an NSF Small Business Innovation Research (SBIR) contract.

The long-term goal of the continuing research efforts is to rigorously compare the TDR signal evolution with appropriate analytical and experimental measurements of cement hydration, for the purpose of establishing potential predictive capabilities for cement cure. The focus in the first stage is to compare the 10 GHz free-water evolution with analytical measurements of cement hydration and standard ASTM compressive-strength testing.

The expressions governing TDR Dielectric Spectroscopy are described in the literature.[4] The sample permittivity $\varepsilon^*(\omega)$ is related to the Laplace Transforms of the incident and reflected pulses according to:

$$\varepsilon^*(\omega) = \frac{G_c}{\iota\omega C_o}\frac{v_o - r}{v_o + r} \qquad (1)$$

where $C_o$ is the geometric capacitance of the empty sensor and $G_c$ the characteristic line admittance. Refinements including bilinear calibration and nonuniform sampling are described in the literature.[5] The sensor used is a 3.6 mm diameter semi-rigid coaxial line with a short section of inner conductor protruding at its tip. Since the exposed tip is an effective radiator in high-permittivity liquids, it is shielded with a serrated castle nut, which provides a surrounding ground plane while allowing free-flow of material through the tip. A diagram of the sensor is shown in Figure 1.

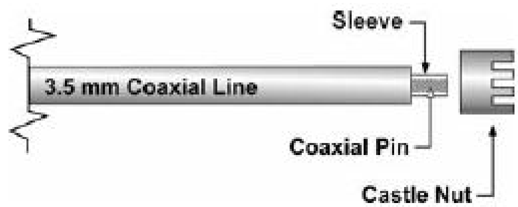


**Figure 1 – Schematic of cement sensor.**

Figure 2 shows the real and imaginary permittivity during the cure process over the frequency range 10 kHz to 8 GHz. The initial real permittivity ε' on the left shows a broad flat region above $10^7$ Hz due to free-water response and a large increase below $10^7$ Hz due to electrode polarization. During the cure process, the high-frequency permittivity near 10 GHz decreases as free water is consumed in the reaction, while a low-frequency signal grows around 1 MHz indicating reaction products forming during the process.

The initial imaginary permittivity ωε" on the right shows a large flat baseline across the frequency range representing DC conductivity. As cure proceeds the conductivity decreases, as seen by the decreasing baseline, and a medium-frequency signal, distinct from the low-frequency one, grows as a deviation from the baseline around 100 MHz, indicating reaction products forming during the process.

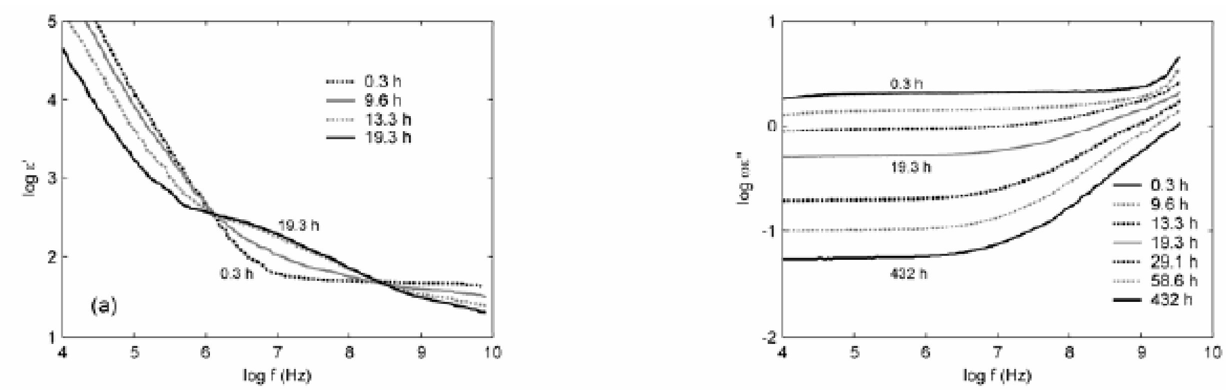


**Figure 2 – Real and Imaginary Permittivity evolution during OPC cure**

The low and medium frequency signals are not present in the initial cement paste but only appear after several hours cure, monitoring some additional states forming with developing microstructure. The real and imaginary components fit separate relaxation frequencies, around 1 MHz and 100 MHz, indicating that two reaction-product signals (low and medium frequency) are present in both permittivity and loss.

Figure 3 shows a typical model fit in which a broad molecular relaxation and two narrow relaxations are fit to both real and imaginary components. Their evolution can now be monitored continuously during the cure process by fitting the model continuously as a function of cure time. Variations in chemistry are used to elucidate the nature of the processes involved, and the three relaxations are now attributed to free-water relaxation at 10 GHz, bound-water relaxation at 100 MHz, and ion-hopping processes at 1 MHz.[3]

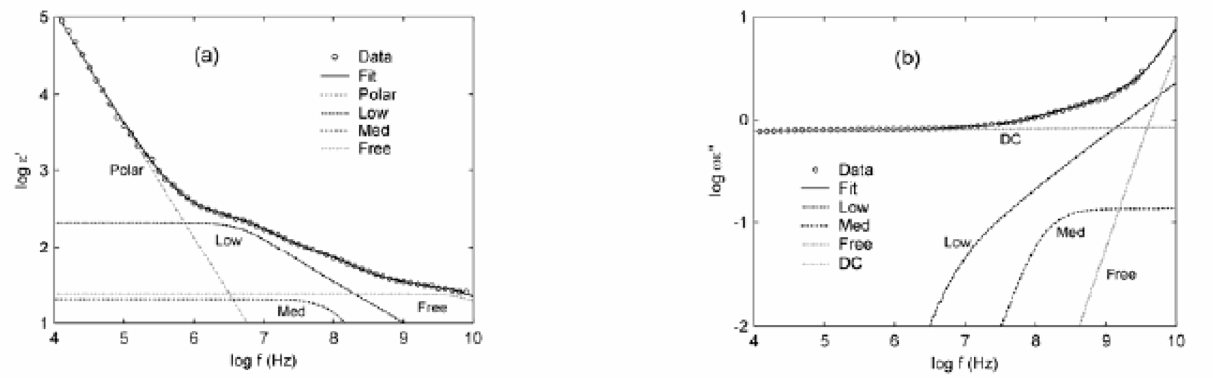


**Figure 3 – Model fitting to real and imaginary permittivity at 15 h cure**

## Undergraduate Research Opportunities

An important associated goal of these research efforts is to offer a variety of opportunities for undergraduate research and development.

The Physics and Engineering program at Elizabethtown College has grown rapidly during the last 10 years, going from 3 full-time professors and 40 undergraduate students in 1996 to 7 full-time professors and 85 undergraduates in 2006. Other departments with whom we collaborate, such as Biology and Chemistry, have also been growing. Such growth has prompted the need for the new Science, Mathematics, and Engineering Center now under construction.

The nature of this research project can provide undergraduate students with a taste of interdisciplinary collaboration with students from other disciplines; it also gives them the possibility to choose applied subprojects relevant to an important national industry.

Students can join this project through formal courses or specific summer internships. The following formal courses are part of the Applied Physics and/or Engineering curricula:

• EGR 110 - (Introduction to Engineering II, 2 credits) – spring semester, freshman year. Includes a project where first-year students are teamed up with sophomores from EGR 291 and juniors from EGR 391 for "vertical integration and peer mentoring."

• EGR 291 (Sophomore Project, 1 credit) – spring semester, sophomore year. A project course where second-year students are teamed up with freshmen and juniors.

• EGR 391 (Junior Project, 2 credits) – spring semester, junior year. A project course where third-year students are teamed up with freshmen and sophomores.

• EGR 280 (Elective Research, 0-3 credits) – individual elective

• EGR 380 (Independent Study, 1-4 credits) – individual elective

• EGR 491 and EGR 492 (Senior Research and Design Project, 2 credits) - fall and spring semesters, senior year. Administered in teams of up to three-four students, emphasizes research and/or design.

Chemistry and Biology students (including pre-med students) usually take introductory physics for non-physics majors. Through these courses we start interactions that eventually lead some of them to be interested in participating in interdisciplinary teams, especially through summer research/internship opportunities.

In summer 2006 two students worked on topics related to this project: one Computer Engineering major, whose project consisted in upgrading part of the software for the experimental apparatus; and one Biology major, who worked on setting and performing analytical measurements, using differential scanning calorimetry available in the Chemistry Department.

This part of the ongoing research was funded during summer 2006 by a Keystone Innovation Zone seed grant, with a final report submitted on October 2006.

In the Table 1 below we describe some of the tasks planned for continuing research during the next three years as well as projects offered to students in that context. The table also indicates the preferred research/design courses or activities (such as summer internships) for the various projects.

From Table 1, one can see that students in Physics and Engineering will integrate into research task 1, addressing upgrading and optimization of sensors for the TDR measurements of cement cure. Their specific project will consist of building and testing 3.5 mm pin sensors and a large-size 7 mm sensor on our available CNC machine.

Additional interdisciplinary teams of engineering and biology/chemistry majors will be integrated into research task 2, the extension of free-water analysis; their specific projects will consist of performing differential scanning calorimetric measurements of cement samples on-campus, as well as coordinating and/or performing thermogravimetric analysis and compressive strength testing in external labs.

Similarly, additional students and teams of students will be offered opportunities to help with specific projects in other research tasks, such as bound-water analysis or analysis of hydration.

A number of projects involve designing and building set-ups for new desired experiment, such as a large cylinder measurement to collect moisture gradient data and a station for freezing experiments, needed to determine freezing points of the various free- and bound-water components. This last type of projects fit very much the interests of engineering majors.

Students in biology and chemistry programs can sign-on to perform analytical chemistry and other lab work, especially assisting in research tasks 2 and 3, based on their analytical chemistry course work and general lab experience. Specific measurements that fit their expertise include Differential Scanning Calorimetry, Thermogravitmetric Analysis, Thermoporometry, and Scanning Electron Microscopy.

**Table 1: Research tasks and projects offered to students**

| | Research/Design Activity Details | Time span in months | Students / Courses | Students' tasks |
|---|---|---|---|---|
| 1 | (a) Design/fabricate pin sensors.<br>(b) Optimize cement/sensor.<br>(c) Upgrade calibration.<br>(d) Upgrade 15 ps stimulus<br>(e) Design/fabricate large sensor | 1-8 | (a and e) 3 students from EGR 110, EGR 291, EGR 391<br>(d) Junior electrical engineering student. | (a, e) Design, fabricate and test sensors, using CNC/lathe<br>(d) Integrate 15 ps generator into TDR station and test. |
| 2 | (a) Free-water analysis<br>(b) Thermogravimetric analysis<br>(c) Differential scanning<br>(d) Precast field testing<br>(d) Compressive strength testing | 4-24 | (b, c, and d) 3 teams interdisciplinary from applied physics and junior/senior chem. / bio student | (b) Coordinate TGA with external lab<br>(c) Perform DSC in-house<br>(d) Coordinate compressive testing with external lab |
| 3 | (a) Bound-water analysis<br>(b) Pore size or imaging analysis<br>(c) (QENS)<br>(d) Grain-polarization analysis | 6-24 | (b) One student in senior project (EGR 491/492) or self-study (EGR 380) | (c) Literature search; modeling; compare with other techniques. Coordinate with external labs. |
| 4 | (a) Instrument large cylinder<br>(b) Moisture gradient data | 6-24 | (a and b) 3 students from EGR 110, EGR 291, EGR 391 | (a) Design and instrument cylinder with TDR and thermocouple sensors. |
| 5 | (a) Analysis of Hydration Kinetics and effect of additives | 18-36 | (a) One team of junior/senior chem./ bio student | (a) Analyze hydration kinetics and samples with specified additives. |
| 6 | (a) Setup test station for freezing experiment<br>(b) Acquire freezing data | 12-36 | b) One senior project (EGR 491/492) or from (EGR 380) | (a) Design and instrument freezing chamber with TDR and temperature sensors |

## Integration of business and entrepreneurship component

The last stage of the integrated project, still in the planning stage, is the business-entrepreneurship component. For this part we will offer specific business tasks associated with the research project and pertinent also to the activity of the partner company, MSI. These tasks could range from marketing a product or a line of service, to building interest in our research and its spin-off potential products in potential customers; or from approaching customers and evaluating their needs to proposing possible customer-specific variations in the products and the services available.

This business-entrepreneurship component will offer opportunities to students majoring in Engineering, and especially in Industrial and Management Engineering, together with Business majors. Once again interdisciplinary teams will be formed, and projects will be integrated within formal courses in both departments.

**Assessment**

At this stage our assessment can be only qualitative. We are very pleased with the synergy introduced by this collaboration and by the opportunities that are being generated for undergraduate research.

As mentioned above, last summer two students started to work on this project and the first flavor of interdisciplinary interactions were felt in our labs. New offerings are ongoing in the present academic year.

This project has already attracted a Keystone Innovation Zone seed grant. There is interest from adjacent Biology and Business Departments to go along with this interdisciplinary experience.

As part of the project details, a more engulfing assessment plan is also being prepared, to be applied after two years of activity. This assessment plan will include evaluation by graduating students who participated in the project, as well as other traditional estimates in term of the quality and volume of the projects and of the amount of funding assembled.

**Conclusions**

We have described our efforts to expand some collaborative research efforts into a full educational project that integrates research, teaching and business/entrepreneurship aspects.

The research topics chosen to be at the centerpiece of this project addresses the characterization of cement cure using broadband Time-Domain-Reflectometry and additional techniques from a variety of disciplines.

Projects are offered to Applied Physics/Engineering students through formal research/design courses as well as through summer internships. Some of these research/design courses are structured to team up upper-classmen with freshmen and sophomores, an arrangement that is usually called peer mentoring.

Students from additional science departments (Chemistry, Biology) can also join (and have joined) this project. We attract their interest and advertise available opportunities through their first physics courses; upon joining they are assigned research topics and measurements that fit their knowledge and expertise.

By the nature of the research topics and of the departments involved, these projects carry a strong interdisciplinary activity and flavor, offering students the possibility to interact with students and technical staff from other disciplines and possibly to be exposed to techniques and measurements beyond their major fields.

An additional aspect of this project is the integration of components from an academic environment with elements from high-tech industry, rendered possible by the historic presence on campus of the research and development labs of Material Sensing & Instrumentation (MSI), a small high-tech venture, whose senior personnel also supports teaching when needed. This particular set-up, joined with the quest for synergy and mutual benefits, allows us to plan also a business-entrepreneurship component, to be enacted in the near future in conjunction with the institution's Business Department.

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