# AC 2009-1763: TECHNICIAN FIRST: TEACHING HIGH FREQUENCY DESIGN AS A TECHNOLOGICAL ENABLER

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# Technician First: Teaching High Frequency Design as a Technological Enabler


## Abstract

This paper reports results of changes in student learning in a course in high frequency design. The course was revised from a traditional lecture/homework/summative examination format focusing on microwave theory to a project-based course using high frequency design techniques in the context of a realistic system design project. As wireless devices and networks continue to become more prevalent, it is more critical that electrical engineers of all sub-disciplines have a working knowledge of RF concepts and devices. Many courses on RF design require a significant prior knowledge of electromagnetics, however, limiting student access. To counter this trend a one semester course was developed designed explore ideas of teaching RF concepts as a "technological enabler" in order to give students who specialize in non-RF disciplines a basic understanding of RF system design. The participating faculty identified three critical areas that needed to be addressed sequentially to meet the goal of serving as a technological enabler: the ability to perform and understand RF measurements, a deep conceptual understanding of RF principles, and an understanding of RF system design principles. The first third of the course trained student as technicians so they were able to perform and understand RF measurements. At the conclusion of their training students were certified by measuring the performance of several RF devices using a spectrum analyzer and vector network analyzer. Conceptual understanding was addressed in the classroom by organizing the course around key RF concepts. To address system design principles during the last half of the semester the class designed a synthetic aperture radar (SAR) system. Teams of two students each designed passive components for the SAR system in an iterative approach that included simulation, testing, and then final assembly of the system. Student learning was evaluated by qualitative evaluation of videos taken during measurement tasks,and rubric based evaluation of student artifacts.


As the speed of electronic devices moves ever higher, electromagnetic radiation plays a larger role in electronic design. Wireless networking, digital pulse propagation on integrated circuits and printed circuit boards, issues of electromagnetic interference and compatibility, and the technical and ethical issues of RFID tags all require some understanding of fundamental principles of high frequency (**HF**) engineering. At the undergraduate level, however, electromagnetics and, by association, HF design are often seen as complex and arcane subjects. Students' first introduction is usually in a required electromagnetics course. Students must navigate through a conceptual maze of vector mathematics and analytic problems in which understanding of fundamental concepts is often less important than analytical tractability. While this mathematical development is vital for those students who will go on to get graduate degrees in electromagnetics, this approach does not serve the majority of students who need a working knowledge of HF devices and technology to understand how HF design impacts their own engineering sub-disciplines.

To those not "initiated into the priesthood", the principles of HF design are often seen as a "black art" [1] since analytic solutions are not tractable. However, the fundamental design principles are straightforward and based on simple principles. So much so in fact, that experts familiar with HF design can often tell a good design principle from a bad simply by looking at devices. As technology makes greater use of GHz frequencies, it is no longer acceptable for HF design to be the art of a select few "high priests". The thesis of this paper is that the burgeoning applications of HF devices and components requires a fundamental change in the way HF design and similar subjects are taught in engineering programs.

The changes needed to address the way students learn HF design that are outlined in this paper are similar to those historically faced by its sister discipline in the OSU program, optics / photonics. The National Academy of Science in *Harnessing Light: Optical Science and Engineering the 21st Century* [2] described the role of photonics in modern life: "*Although optics is pervasive in modern life, its role is that of a* ***technological enabler****: It is essential, but typically it plays a supporting role in a larger system. Central issues for this field include the following: how to support and strengthen a field such as optics whose value is primarily enabling…*" At the core of this project is the assumption that the fundamentals of HF design, similar to optics and photonics, have become so ubiquitous they now serve as a *technological enabler*. A technological enabler is any technology that impacts or enables progress in widely divergent areas such as industrial processes, medical and biological sciences, computers, communications, environmental, or military applications. Those engaged in these disparate fields need to understand and apply the enabling technology rather than have full mastery of the history and theoretical underpinnings.

Despite the broad use of HF and microwave components in many disciplines, existing courses use lecture structured around one of the many available texts to emphasize mathematical development of fundamental principles. Such teaching methods help students gain an understanding of HF principles; a <u>necessary but not sufficient</u> goal of a technologically enabling course. *Supporting and strengthening* HF design additionally requires that engineering and other students see how HF design is applied to challenges in their discipline or future career. *Ensuring future vitality* requires that HF courses both enhance students' chances HF-related employment as well as entice students to pursue graduate studies.

<u>Discussion of Planning Meetings</u>

To create a course on high frequency design techniques that could serve as wide an audience of students as possible, the three faculty and one graduate student involved in the course met on a regular basis (primarily) during a summer intercession to discuss the key requirements for such a course. The following paragraphs summarize the discussion of these individuals and serve to outline the framework around which the course was designed.

The participants decided early in this project that keys to a course which would teach HF design as a technological enabler are *transfer*, *retention of knowledge*, and the understanding of, and relation between, different *domains*. Transfer describes the ability to take what has been learned and transfer it to new problems some time after information has been learned [3]. To enable students to transfer knowledge the faculty determined that the course needed to teach foundational knowledge and concepts, give students opportunities to monitor and measure their own understanding, and present problems in a context that is relevant.

*Retention of knowledge* is supported by a course structure that organizes knowledge around central concepts or technologies in a way that allows it to be recalled [4]. In order for students to retain what is learned and recall it for later use high frequency design content was taught the context in which it will be used, organized around core concepts or "big ideas", and organized into small units that can be fit into a student's overall framework of understanding. The *domains* of knowledge are analogous to Gardner's theory of multiple intelligences [5], but the three domains are different than those used by Gardner. Here the three domains reflect different types of skills or knowledge that each student must develop in order to actually apply what is learned and are drawn from work in developing a taxonomy of engineering skills [6]. Three separate, areas in which students need to gain competence are: 1) experimental skills that give students the ability to test what is known conceptually or analytically; 2) conceptual understanding of the overarching concepts that link seemingly unrelated problems; and 3) analytic skills to enable students to make design choices guided by analytic equations, verify their design through exact numerical simulations, and check the validity of their results by performing approximate "back of the envelope" calculations.

To implement this vision of a course that serves as a technological enabler, the HF Design course was organized into three parallel tracks as shown in Figure 1, below. The tracks, with the duration and overlap shown at left, are training as a technician in the microwave lab, learning concepts in the lecture portion of the course, and design of a microwave system performed as part of a team. These three parallel tracks are mapped to the domains of experimental skills (technical training), conceptual understanding (teaching concepts), and application of analytic skills obtained through design and characterization of a microwave system. Each of these tracks will be described in detail later in this paper.

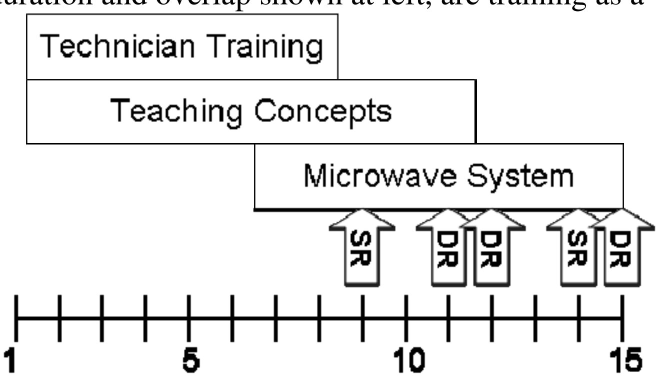



**Figure 1:** The overall organization of the high frequency design course showing components corresponding to each domain. SR = Status Report on the project and DR = Design Review.

The involved faculty felt that a key component of teaching HF design as a technological enabler was to design a microwave system made up of discrete components so that students would be able to obtain a larger, systems, viewpoint. After some discussion a synthetic aperture radar system was chosen since one faculty member had experience in the design of such systems, the system comprised both passive and active components, and uses concepts from both guided wave and free space propagation. Before the course was offered a SAR system was constructed by the graduate student using commercial, off-the-shelf components. The SAR system—and the students' role in designing and building this system—is described in detail later in the paper.

The last element discussed by faculty during preliminary development of the microwave course was how to balance the three domains through assigning course grades. There was some disagreement among participating faculty which reflected individual beliefs of teaching and learning. While some faculty felt that grades should be primarily focused on project deliverables, others thought that more traditional summative evaluations had more value. In the first iteration of the course, reported here, the project comprised approximately 40% of the grade, technician training 30%, and in-class work and examinations focused on concepts 30%.

As shown above in Figure 1, the three parallel components of the course had some overlap, but addressed very different learning goals. These learning goals were drawn from an engineering design taxonomy [6] used in the ECE department to evaluate curricular content. Details on each of these three tracks are outlined in the following sections.

Training as a Technician

One of the most novel aspects of the HF Design course was starting the course with formal training of each student to be a technician. Each student was expected to be able to perform accurate measurements using microwave instrumentation and software and presenting these measurements in a format used in microwave engineering. In order to be able to use the instrumentation (and continue with the course) each student has to pass in-house certification training on two instruments and a component fabrication procedure. A rubric (appendix A) was used to rate student performance. This rubric is currently undergoing revision since it did not capture the depth of student ability that was desired.

In their certification training each student was individually given formal training on microwave instrumentation by the course teaching assistant (TA). This training was provided for an RF spectrum analyzer (Agilent E4407B) and vector network analyzer (VNA) (Agilent 8722ES). For instrumentation certifications two levels were defined: measurement and calibration. Additionally students were trained to acquire data from these instruments using National Instrument's LabView® data acquisition software. Each student was shown how to calibrate the instrumentation before a test and also perform measurements on microwave components. Following formal training and individual practice the students were given a "practical examination" by the TA which was video-taped. Students were asked to verbalize what they were doing as they took the practical examination and, if necessary, were prompted by the TA. Coding is currently being developed to analyze these videos.

The second technician aspect students were trained in was analyzing and graphing acquired data. Students were shown how to upload data from the test instrumentation to LabView then export this data to Matlab. Data was presented in the form of Smith charts, and graphs of S parameters. Students were also shown how to distinguish theoretical from measured data. The measurements performed by students and data presentation assignments were designed to illustrate limitations of the measurement instrumentation. Specific data analysis tasks explored the frequency resolution limitations of the spectrum analyzer and calibration accuracy of the VNA.

Following certification to use instrumentation and acquire data, teams of two students were given commercial microwave components to characterize in a frequency band around the SAR operating frequency of 2.4 GHz.. These commercial components were an isolator, directional coupler, circulator, $90^\circ$ hybrid, power divider, and low noise amplifier. These components were those used to fabricate the synthetic aperture radar. Students measured the frequency dependent

S parameters of each component and compared measurements to the data provided from the commercial vendor to determine if the components functioned as specified.

The final step of technician training was teaching students how to fabricate passive microwave components. The commercial components that were replaced were the passive components of the microwave system including the circulator, $90^{\circ}$ hybrid, and power divider. Students were first trained in the Advanced Design System (ADS) [7] microwave design software. Following component design (discussed later) students use the software to create artwork of their component which they produced using a photo-etching procedure on Rogers® printed circuit board material. In order to pass this final step of technician training the etched components needed to meet tight dimensional tolerances. Students were also taught correct procedures for installing SMA connectors to their fabricated components to permit convenient testing and to have a modular system capable of easy component replacement.

Teaching Concepts

The instructor used an interactive lecture format focusing on elements from the project as elicited from a Q&A session at the start of the lecture. The primary focus of the lecture was to provide sufficient background to understand the theoretical aspects required to succeed at transitioning from a technician (focus on instrumentation and manufacturing) to an engineer (focus on interpretation and adapting design or measurement procedures). Example problems were also assigned to students, but were not collected or graded. Answers to these problems were given to students and part of the class discussion focused on how to solve these problems. The problems given to students were relevant to the overall microwave system design project and taught specific skills needed by students to complete the SAR design.

As mentioned previously the course was "chunked" [8] into small units to aid retention. The five major units of the course, in the order taught, are: S parameter theory, impedance matching, design of microwave components, types of transmission lines, and microwave system design. The order of topics was chosen around the needs of students as they underwent technician training and designed the SAR system rather than follow the conceptual hierarchy defined by the textbook.

In learning the conceptual basis of microwave design emphasis was placed on application rather than theory, reflecting the goals of teaching students HF design techniques to enable work in related fields. In teaching S parameters the unitary and zero properties of S matrices were covered then a series of examples were presented that illustrated, in the context of the SAR system, how S parameters were used to represent the function and performance of microwave devices. An S parameter for each component of the SAR system, Figure 2, was illustrated. Following introduction of S matrices the course reviewed impedance matching, which had been previously learned in the requisite junior electromagnetics fields course. Key ideas were using the voltage standing wave ratio (VSWR) as a measure of impedance mismatch in practical systems, the use of quarter wave and stubs to improve matching, and the relationship of mismatches to S parameters. The third conceptual module was how to design microwave components. Here students learned how to apply design equation and the foundations and limitations of computational electromagnetics. This portion of the conceptual track was given concurrently with students learning ADS and simulating components of the SAR system. The fourth conceptual element begin to move the focus from microwave devices to learning about microwave systems, specifically how to propagate microwave signals within a system using transmission lines. Here students learned various guiding structures, both TEM and quasi-TEM including coaxial, stripline, microstrip and waveguides. The final conceptual module dealt with microwave systems. Key concepts were how to specify microwave systems, the idea of and impact of signal to noise ratio, constructing signal flow diagrams, and the ways that small changes in amplitude and phase affect system performance along with determining the maximum allowable variations for amplitude and phase deviations in a system.

All of the concepts taught in the in-class portion of the course were applied by students in construction of the SAR system. To the extent possible concepts were introduced in a just-in-time format [9] so that students would apply ideas and transfer the concepts to an actual system.

Applying Concepts and Skills by Designing and Analyzing a Microwave System

The third track of the course was for student teams to design and build a microwave system, specifically a synthetic aperture radar system which would use a frequency swept source capable of acquiring range data by the Doppler shift of returned radiation. A block representation of the system is shown in Figure 2, below. A commercial microwave signal source (Agilent E8257D) was used to generate a swept sine wave near 2.4 GHz. Horn antennas were used to transmit and receive the reflected signal. Targets were foil-covered cardboard shapes fabricated by the graduate student TA. A low frequency analog to digital converter connected to LabView® was used to measure the quadrature signals from the mixers. The SAR system was built and characterized using commercial components obtained from Mini-Circuits [10]. The components shown in bold font with an asterisk in Figure 2 are those that were subsequently redesigned by student teams.

The students in the course were divided up into teams of two students each, modeled from of the pair programming approach in computer science [11]. Each team was assigned one of the passive components of the SAR system and had to redesign, fabricate, and characterize that component. Once teams had constructed replacement components, these were substituted into the microwave system and the overall system performance was characterized.

As shown in Figure 1, the design track of the course began in the sixth week of the semester, and continued for approximately nine weeks through the end of the semester. The design track was subdivided in a series of milestones with both formal and informal presentations for each milestone. For the first four weeks teams simulated the component they were assigned using ADS. Next they characterized the commercial component using the skills gained in the technician track of the course to verify performance. Informal status reports from each team allowed the instructor to verify they were making sufficiently rapid progress to complete the project in the time allotted. Following approval of the status report by the instructor, teams developed a detailed set of numerical specifications for the component they were to design. These specifications provided teams a “target” for their designs. Once component specifications were determined the teams numerically modeled their component using ADS and compared predicted performance to their design specifications.

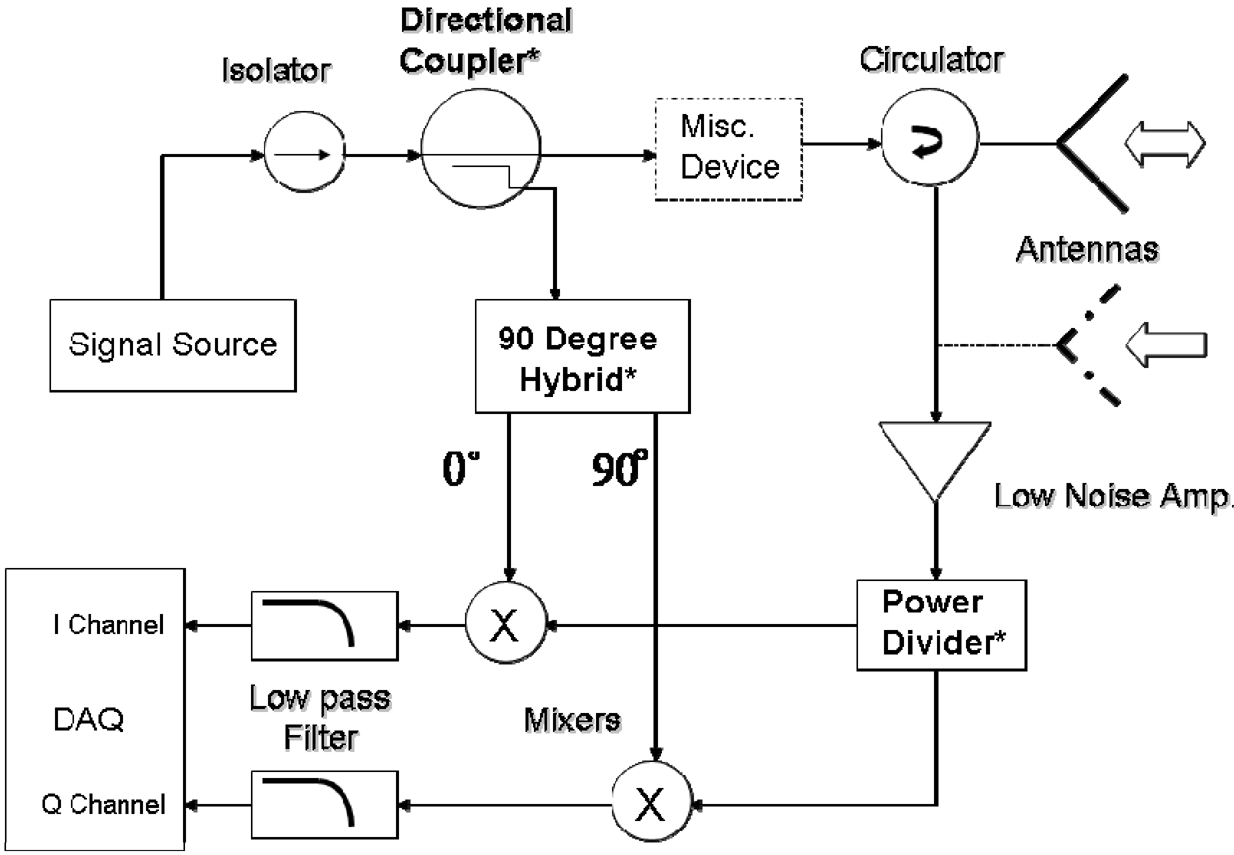



**Figure 2:** Functional decomposition of the synthetic aperture radar (SAR) system used to contextualize learning in the HF design course. Components in **bold** with an * are those which were redesigned by student teams.

Teams presented their simulated design and compared simulation to specification in a formal, public design review. For the design review each team created a PowerPoint presentation as a narrated slide show. The choice to have teams produce a narrated presentation rather than give a "live" talk was to separate effects of performance anxiety, not having English as the students primary language, and public speaking skills from the technical content of the presentation. Pre-recorded presentations also prevented the common phenomena of running over the allotted class time. The presentations were played during class on a computer projector and were followed by an open question-and-answer session. All three participating faculty evaluated design review using a rubric (appendix B). Verbal feedback was provided to teams about weaknesses and strengths of their design.

Once teams' designs were approved—by obtaining a passing score on their presentation—they fabricated the microwave devices and then characterized their performance. A second design review, again using recorded presentations, was used to score how well teams succeeded in designing replacement components for the SAR system.

The final phase of the design track of the course was to replace commercial components with those fabricated by student teams and determine the impact of these changes on the overall SAR system performance. Students characterized signal to noise and amplitude and phase changes at each point of the SAR system as well as determined the range and range accuracy with both commercial and self-designed components. The final design review occurred in a public forum as part of the Engineering College's "Design Day". Design Day is an open house in which students from multiple engineering departments display their projects to visitors that include high school students, parents, and industry representatives.

One unique aspect of the SAR design is that the low pass filters (see Figure 2) that were used for the SAR system had been previously designed by students in the introductory EM course. The use of devices designed by students in previous courses was thought to support integration of concepts.

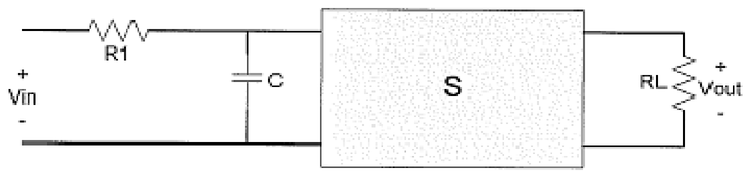
**Course Outcomes and Evaluation**

In the first iteration of the course reported here, six senior electrical engineering students enrolled. One student was female, one non-native English speaker, and one student represented themself as American Indian. Different metrics were implemented to assess student learning for three parallel tracks of experimental skills (technician), conceptual understanding (class work), and analytic skills in system design (building the SAR).

Two separate metrics were used to assess how well students were able to fulfill the role of a technician to characterize, graph, and fabricate microwave components. Submitted student work was scored using a rubric (Appendix A) developed for this course. Students were also asked to demonstrate a measurement of a microwave component to the TA. The demonstration was video-taped for later analysis. Students were asked to verbalize what they were doing as they took the practical examination and, if necessary, were prompted by the TA. Videos of students performing characterization measurements were recorded both early in the course immediately following technician training as well as near the end of the course to determine changes in ability. For the first iteration of this course, reported here, it was found on subsequent analysis of the tapes that an interview schedule needed to be developed to ensure prompting was appropriate and consistent. The authors are in the process of developing a coding scheme based on an engineering design taxonomy [6] and the coding scheme and preliminary analysis will be presented at the conference

To determine the depth of students' conceptual understanding, a summative final examination was used. The final exam asked open-ended questions that asked students to describe how microwave components or systems would behave when parameters or geometry were changed. Rather than perform analytic calculations, students sketched S parameter curves or wrote explanatory paragraphs. Questions were chosen to reflect the concepts taught during the course. The examinations are currently being analyzed to identify student misconceptions. Once sufficient data is collected the authors will develop a concept inventory that can be given in a pre-post format to measure changes in understanding of HF design concepts. An example question from the final examination is shown in Figure 3, below. Conceptually this problem probes if students understand how discrete components are represented as S matrices and how matrices can be represented as discrete components.

Consider the problem below:




Outline a procedure that details how you would determine Vout given Vin and S.

**Figure 3:** Example question from final examination used to measure student misconceptions.

The results of the summative examination are still being analyzed, and will be presented at the conference. Preliminary analysis shows that students had a fundamentally sound grasp of HF design concepts. The major misunderstandings arose in how to apply the concepts to problems that they had not been exposed to in the course; i.e. transfer. The performance of students was closely grouped- no student showed significantly worse conceptual grasp than others in the course. The class also tended to have misconceptions about similar concepts indicating that these misconceptions were likely due to the course rather than differences between individuals.

Student understanding of microwave systems and the system design process were measured by rubric-based scores on the design presentations discussed earlier. Presentations were ranked on overall understanding, simulation results, prototype fabrication, using a valid technical approach, understanding system integration, and the organization and delivery of the presentation. Three faculty evaluators scored each presentation; the correlation between scores of two of the evaluators was high ($r = 0.74$, $p < 0.001$) evaluators; scores of the third evaluator are not reported in the presentation Overall these scores were high, and all components designed by team functioned within specification. The presentations indicated that overall students understood most aspects of the design process although several tasks seemed to be done by rote rather than with a deep understanding, as expected for the structure of this course. Rubric scores reflected this analysis since students were rated significantly lower on the "Understanding" portion of the rubric in appendix B (73 v.s. 83-96 on other aspects).

Another issue that became clear from analysis of design presentations was that the students did not really understand how the ADS simulation software was characterizing their components, and took a somewhat *deux ex machina* view of the software. In a discussion following the second design review the students felt that they should have simulated a simple 50 Ohm transmission line and then manufactured it. After characterizing the S parameters with a VNA they could then rethink what they "knew" about its performance. This step of starting with a well-understood canonical problem to help think through what they were doing was an important maturation for the students in their development as thinking engineers. Another issue students seemed to have difficulty with was how many iterations of their design should be performed. This seemed to be due to lack of expertise in what characteristics could be achieved and difficulty in assessing the point at which iteration of the design gave minimal returns. Some teams performed a large number of iterations while other seemed to do the bare minimum necessary.

An unexpected outcome was that the SAR system continued to function when commercial components were replaced by those fabricated by student teams. The participating faculty expected that student components would not be able to match the performance of commercial passive devices. In comparing the performance of the system between commercial components and student-designed components the overall performance of the SAR system improved slightly since the power divider developed by a student team has less loss than the commercial components. The bandwidth of the system was slightly reduced, but this did not translate into a measurable degradation of SAR performance under the testing conditions that were available.

## Summary and Conclusions

A new course in high frequency design taught concepts of high frequency design by integrating a realistic system design project. The goal of the course was to introduce high frequency design ideas to students with some, but not significant, prior knowledge of electromagnetics. The structure of the course was to have material learned serve as a "technological enabler" to give students a working knowledge of RF system design. The course was organized in three parallel tracks: 1) students underwent training as a technician so they could independently perform and understand RF measurements, 2) in-class instruction provided a conceptual understanding of RF principles, and 3) fabrication of a microwave radar system allowed students to gain an understanding of RF system design principles.

Teams of two students each designed passive components for the SAR system in an iterative approach that included simulation, testing, and then final assembly of the system. Each team of students designed, numerically modeled, fabricated, and characterized a replacement component for a passive element of the microwave system. Student learning and progress was evaluated by qualitative evaluation of videos taken during measurement tasks, rubric based evaluation of student artifacts and design reviews, and a summative evaluation focused on conceptual understanding of microwave systems. While evaluation of course data is on-going, preliminary analysis shows that students were able to competently perform measurements using microwave instrumentation and design passive components. Some gaps in conceptual understanding were evident, and students had not developed the metacognition of experts in the overall design process. Further analysis will be presented at the conference and additional understanding on misconceptions will be clarified following development of the planned concept inventory instrument.

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**Appendix A Technician Certification Rubric**

| Rating | Score | Care and Diligence | Circuit Design |
|---|---|---|---|
| Professional | 100% | • Checked to see if connectors needed cleaning.<br>• Demonstrates how to properly screw on connectors.<br>• Puts everything back in its place once the lab is over.<br>• **Can perform basic measurements from the VNA/SA.**<br>• **Can present a plot of the data from MATLAB.** | • Circuit is built correctly according to the schematic<br>• Circuit is neat and clean, able to relate actual circuit with schematic drawing<br>• Minimum number of transmission line components are used, i.e. adapters, coax cable, attenuators, etc…<br>• There is minimum or no bending of the coax cable |
| Journeyman | 80% | • Completes 3 out of 5 tasks from above successfully.<br>• The bold tasks must be included in the completed tasks.<br>• Asks a few times for help from TA in completing the lab. | • Completes 3 out of 4 tasks from above successfully |
| Novice | 60% | • Completes 2 out of 5 tasks from above successfully.<br>• Only one of the bold tasks was completed.<br>• Asks TA for help continuously in completing the lab. | • Completes 2 out of 4 tasks from above successfully |
| Unacceptable | 0% | • Does not complete any of the tasks successfully.<br>• Student must demonstrate experiment at a different time. | • Circuit is built but does not meet any of the criteria for a Professional Rating<br>• Does not complete building of the |

## Appendix B Design Review Scoring Rubric

| | 0% | 60% | 80% | 100% |
|---|---|---|---|---|
| **Understanding** | • Lack of understanding. Ignorance risks team's project | • Does not fully understand how their design works. Significant gaps of knowledge. | • Understands their design enough to complete but not improve work. | • Thorough understanding of the design and shows insight from research and simulation. |
| **Simulation Results** | • No successful simulation results<br>• No specifications | • Data presented but no connection to desired operational specifications | • Data presented and connected to desired specifications | • Data presented and connected to desired specifications |
| **Simulation Prototype/ Fabrication plan** | • Simulation Prototype not built (in ADS) or not functional. **OR**<br>• Lack of strategy to solve technical issues. | • Simulation Prototype fully built (in ADS) but with limited functionality. **AND**<br>• Clear strategy to solve remaining issues. | • Simulation Prototype fully built (in ADS) and mostly functional. **AND**<br>• Clear strategy to solve remaining issues. | • Prototype fully functional (in ADS). |
| **Valid Design** | • Used an Invalid technical approach | • Used questionable or unnecessarily complicated technical approach | • Used a valid technical approach | • Used an optimal technical approach |
| **Block diagram / System Integration** | • Block diagram not a valid or complete representation of system<br>• No understanding of impact of component on system performance | • System complete, but poor understanding of function of modules.<br>• No understanding of impact of component on system performance<br>• Unable to make suggestions to improve designed component | • System complete, good understanding of function of modules.<br>• Reasonable understanding of impact of component on system performance<br>• Able to make suggestions to designed component | • System complete, good understanding of function of modules.<br>• Good understanding of impact of component on system performance<br>• Able to make suggestions to improve other components |
| **Presentation: Organization** | • Audience cannot understand presentation because there is no sequence of information. | • Audience has difficulty following presentation because presentation jumps around. | • Information is presented in logical sequence which audience can follow. | • Information is presented in a logical, interesting sequence which audience can follow |
| **Presentation: Delivery** | • Speaker mumbles, incorrectly pronounces terms, and speaks too quietly for students to hear. | • Speaker incorrectly pronounces terms. Audience members have difficulty hearing presentation. | • Speaker's voice is clear and pronounces most words correctly. | • Speaker uses a clear voice and correct, precise pronunciation of terms. |

Zhi (2009) used the stochastic frontier method to analyse the technological innovation performance of Chinaâ€™s electronic information industry. Han (2010) also applied the stochastic frontier method to conduct an empirical analysis of the innovation efficiency of Chinaâ€™s high-tech industry.Â  The chapter is organised as follows: the first section is the introduction; the second section briefly analyses the characteristics of Chinaâ€™s high-tech industries during the transition period; the third section introduces the model and accounts for the variable selection; the fourth section details the empirical analysis; and the final section contains the conclusions and policy recommendations. In RF design, we are able to separate signals with different frequencies, and hence we can assign different frequencies to different applications so they will not interfere with each other. This is seen much easier in the second domainâ€”the frequency domain. 1.3 Power. 3. (a).Â  Generally, lower frequencies will travel much greater distances, but they are also more susceptible to physical obstacles, such as a wall. Also, lower frequen-cies will propagate with a much wider footprint than will higher frequencies; in other words, higher frequencies have more propagation loss than lower frequencies. Higher frequencies are much more directional (hence the use of microwave signals for line-of-sight point-to-point transmission systems). Thus, the use of technology and teaching students have to use it has become a high priority in the public schools. Today, there is a common focus on raising student achievement while integrating technology as a tool. Policymakers and educators are renewing their commitment to programs and instructional practices that to enhance maximum effects on instruction and student outcomes.Â  Many studies have shown the advantages of using technology in classroom instruction. Technology can be used as a tool for establishing meaningful projects to engage students in critical thinking and problem solving. Technology can be used to restructure and redesign the classroom to produce an environment that promotes the development of higher-order thinking skills (Kurt, 2010). The last years increasingly raised the issue of using modern technologies in the educational process. It is not only new technical means, but also a new forms and methods of teaching, new approach to learning. The main goal that we set for ourselves, using modern technologies in learning a foreign language it â€˜s to show how technology can be effectively used to improve the quality of teaching foreign language students, the formation and development of their communicative culture, learning the practical mastery of a foreign language. This paper aims to highlight the role of using modern technol... In general, high implementation costs and unclear benefits of this technology are considered as barriers to its widespread adoption. Therefore, the primary aim of this paper is to develop an assessment framework for evaluating costs and benefits of information systems (IS) investments based on an AR-based application scenario in the construction domain.Â  As a result, the current design storm event [Show full abstract] overtops the existing earthen embankment. WinDAM B software predicts the resulting erosion from an overtopping event.Â  Multi-frequency eddy current test (MFECT) is an important NDT technology, and it can be applied to realize multi-parameter detection and interference elimination effectively.