Use of Advanced Technologies in a RF and Microwave Engineering Course

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Abstract-- **In RF and Microwave Engineering course, usually students struggle to build connections between the theory they have learned and practical applications in the laboratory. The laboratory applications are usually very limited for hands on experience since the high cost and maintenance requirements of the equipment. Additionally, new engineers need to know how to use at least one engineering design tool in order to practice designing RF components, circuits, or antennas. In this study, a curriculum model including recent developments and technologies in the RF and Microwave Engineering field by addressing above problems of the course is proposed. This study covers the description of the content of theoretical and hands on applications, the integration model of the technological tools into the proposed curriculum, and the instructional approaches used in the new course design which covers the use of a remote laboratory environment, Concept Maps and an engineering design tool. The course is structured with a balance between theory and laboratory, including remote and in lab measurement experiments as well as modeling and designing microwave components by means of computer tools and design fabrication. The newly designed course is implemented at the Atilim University. The first semester implementation shows promising results.**

Index Terms*—*RF and Microwave engineering course, curriculum design, remote laboratory, simulation tools

I. INTRODUCTION

Advances in the telecommunications industry and the widespread deployment of wireless network services have affected the career programs related to high frequency technology. These developments have also forced practicing engineers, computer specialists, and managers to re-educate themselves in the area of telecom/radio-communications technology [1], [2]. Parallel to these developments, a report by an industry/education partnership (Global Wireless Education Consortium-GWEC) involving more than 30 universities and 9 large companies in the wireless sector in the USA has identified new requirements for such professionals as well as noted a lack of Radio Frequency (RF) specialists [3]. Accordingly, several related educational programs have begun offering courses covering electromagnetic, RF, antenna, and microwave concepts, which are important components of any Electrical and Electronics Engineering (EE) and computer-related educational curriculum [4] and technical colleges, which are usually supported by hands-on experimental environments. For example, a remote laboratory on frequency modulation experiment principles [5], a face-to-face laboratory implementation in the field of antennas [6] and RF-microwaves [7], an RF hardware design laboratory with project oriented approaches [8], and wireless information networks [9] have been integrated in the curriculum of these courses. As Cassara [9] summarizes, some of these implementations exist that generally focus on wireless networks, radio frequency-microwaves, antennas, radar or optical communications. These implementations and studies show the recognition of the importance of these topics in the educational arena.

Parallel to these developments simulation (and CAD) applications are also started to be used as a critical and efficient tool on these courses. Additionally, Web-based and Web-assisted education alternatives are a new paradigm that is started to play an increasingly significant role in the instructional design efforts in these fields [4]. Accordingly, in order to prepare engineers satisfying the requirements of the industry, new approaches need to be reflected and emphasized in the curriculum of these courses.

In this study, the current situation and problems of electromagnetic, RF, and microwave courses offered at Atilim University are discussed first. In order to address the identified problems, this study proposes a curriculum model that reflects recent developments and technologies such as remote laboratory environments, simulation tools, and mind map graphical representations. This study covers a description of the content of theoretical and hands-on applications, an integration model of the technological tools into the proposed curriculum, and the instructional approaches that are used in the new course design. The newly designed course has been applied during one semester in the EE education program at Atilim University. This study also describes how the newly designed course is offered, as well as the problems faced and gains achieved during this course.

II. COURSE DESCRIPTION

As juniors, students with an EE major at Atilim University take one semester-long required RF and Microwave Engineering course. The aim of the course is to prepare the students for their future professional careers in RF and Microwave Engineering and for the sequence of senior courses, such as Antennas and Propagation, RF Microelectronics and Optical Communication Systems and Design Projects. These courses are offered as technical elective courses in the curriculum of the EE program of the university. The course is structured with a balance between theory and laboratory, including remote and in lab measurement and evaluation, modeling and designing microwave components by means of computer–aided design (CAD), and fabricating.

A. Course Content

The course is designed as an introduction to RF and Microwave (MW) systems. The following concepts are covered in this course: analysis of transmission lines and waveguides, the Smith chart, scattering parameters and matching networks, LC networks, single and double stub tuning using the Smith chart, RF and microwave passive components and system parameters, high frequency configurations of filters and amplifiers, PCB realization of RF and Microwave circuits, microstrip lines, and RF, Microwave, and Antenna design tools and measurement techniques.

B. Course Objectives

In this course, students should acquire the following skills and be able to:

- state the applications of electromagnetic spectrum above 300MHz frequency band;
- identify wave propagation on transmission lines and expand it to include microstrip structures;
- identify the fundamentals of transmission line systems, radio frequency (RF) and microwave components, sub-systems, and technology;
- operate tools and equipment used in the design and analysis of RF and Microwave components and sub-systems,
- design microwave components such as a microstrip line, microwave filters and single-stage microwave transistor amplifiers.

C. Laboratory Activities

Laboratory experience is an important part of an electrical engineering (EE) education. As shown in recent Internet-based remote and virtual laboratory studies, effective learning in EE education can only be achieved by approaches that combine theoretical courses with laboratory work where the learner can practice as necessary [1]. Laboratory experiments are usually performed as demonstrations on the following subjects: scattering parameters measurement, VSWR measurements and transmission line impedance, power measurements, and antennas measurement.

D. Problems with the Course

The course instructors face with several problems in this course. We can group these problems under three main headings: Laboratory hands-on experience problems, implementation of new technological tools in these courses and implementation of new instructional approaches used in these courses.

Problem 1: Since the only chance to provide the laboratory experiments by means of demonstrations in the laboratory, it is usually not clear for the students that what they have learned and how to relate it with the theory that they learn during the classroom instructions.

Problem 2: The instructor usually group students into 8-10 for each demonstration section. However this number is also still high for the demonstration sections and it is usually not possible to organize smaller student groups because of the high number of students enrolling this course.

Problem 3: The instructors also face with some maintenance problems in the laboratory since students accidentally broke some parts of the equipment. For example, once a student has broken while connecting 2.4mm to SMA adaptor of the Vector Network Analyzer (VNA). The instructor had to order this part from the company and it took three months to fix the problem. Accordingly, the instructor could not be able to use this port of the VNA in that year and only be able to show measuring S11 parameter.

Problem 4: There is a need for implementation of new technological tools in these courses. It is very important for the industrial organizations that the new engineers should know how to use at least one engineering design tool in order to practice on designing RF components, circuits or antennas. For example, our graduates are usually getting a job offer easily and becoming more competitive if they have experience on the design tools for RF, microwave or antenna. Additionally, the simulation tools such as CAD, help them to better figure out and experience the real-world industrial applications based on the theories that they have learned in the classroom. Introducing a simulation tool in such introduction courses also help students to better prepared for the advanced level courses such as RF and microwave circuit or antenna design and design project courses. In these courses they have a quick start without loosing time on learning and practicing on the simulation tools.

Problem 5: There is a need for implementation of new instructional approaches used in these courses. The instructors of these courses should provide some instructional approaches for building relationships between the theory and practical content of the course. Otherwise, students are having problems to build this relationship by themselves and they think that some of the theoretical content is not applied in theory. As a result, students usually forget the theoretical information because of the loss of connection with the theory and practice components of the course. During the laboratory hours, students always complain about finding related theory on a specific experiment that they are working on and performing and usually their intension is on thinking that the lecture instruction (theory of the course) is not related with the experiments that they are performing. On the other hand, students' learning expectation differ each other. Some students prefer to reach directly to the content that they are searching for, while others prefer to study the content from the beginning and then continue the experiments. Some of them prefer the graphical representations while the other prefer to read the text [10]. Accordingly, the instructors may have problems offering lectures that meet the needs and expectations of the students.

III. Background of the Study

In order to solve the above problems, we have researched the literature to investigate appropriate solutions. Some studies that address the problems faced in this course are summarized in this section. In traditional ways, the laboratory applications of these courses are offered by means of face-to-face training in particular laboratories. Usually, even for ideal cases, face-to-face laboratory applications in these courses have some limitations for both the instructor and the learner [11]. For example, offering such courses requires a large number of educators and supporting personnel as well as high setup and maintenance costs for some EE laboratories (such as those covering radio frequency and microwave techniques) [5]. If an open laboratory environment is not provided, students are restricted to a specific schedule and location for a particular course and are not be able to repeat the experiments as often as they wish or possibly need. Students also tend to have very limited opportunities to analyze the experimental data mathematically: usually the measurement device itself is unable to handle a large amount of data. In the absence of time constraints, students have the opportunity to process experimental data by using powerful software analysis tools, thus obtaining a clearer notion of the functionality of a certain device or setup.

Recent developments in Internet-based services also encourage training and educational organizations to attempt e-learning models. Nowadays, educational and training organizations, particularly universities, are frequently using Internet technologies to enhance and supplement traditional face-to-face education. For example remote laboratory platforms enable learners to access physical instruments at a distant location and perform experiments remotely on the Internet [12]–[15]. Hence, a remote laboratory application in the RF domain seems to be a very critical tool in order to improve and support current educational environments.

Additionally, computer simulations have been used in the curriculum of some EE courses such as electromagnetics, RF, microwave, and millimeter-wave areas [16], [17]. As Gupta et al. state, these simulators encourage building realistic design examples, verification of these designs, evaluation of the effects of real-life parameters on circuit characteristics before investing in the actual fabrication of the circuits, and building case studies that bridge the gap between classroom instruction of microwaves and the practice of microwaves in industry [4]. According to Gupta et al., for the first time in the history of microwave education, the aim of providing classroom instruction that is 100% relevant to the practice in industry is becoming possible [4].

On the other hand, concept maps are the tools used to build relationships among concepts. These tools have been used in educational environments to better connect the relationships among theory and practice as well as among other concepts covered in a course. These tools also help the learners build relationships between previous knowledge and newly introduced concepts, encouraging meaningful learning rather than rote learning (memorizing concepts, no relationship to previous learning) [18].

IV. Newly Designed Course

To improve the course, new approaches have been proposed for the laboratory and theoretical parts. This section summarizes the proposed curriculum for this course.

A. Laboratory

In new course design, laboratory session is supported by Remote RF laboratory [12]. In this environment for teaching how to use VNA, an electronic performance support system (EPSS) tool is used [19], [20]. Remote experiments provide fundamental knowledge in electromagnetic wave propagation, knowledge about the analytical and graphical methods used in deduction of formulas used in microwaves, the ability to make correlations between the physical phenomena (what is happening and which are the causes) and the ability to handle high complexity measurement devices (e.g. VNA). European Remote Radio Laboratory (ERRL) provides RF and microwave remote experiments (http://errlmoodle.atilim.edu.tr/).

Implementation of Computer Aided Design Program (CAD)- Additionally, the new course curriculum is enriched with the applications on Computer Aided Design Program (CAD) and The AWR® Design Environment (donated by AWR Corporation) experiments. Laboratory hours include design tools to be used in the design, fabrication and analysis of RF and Microwave components. The students, after learning how to use Microwave CAD program step by step asked to design RF microwave filter for a substrate and design requirements given by the course instructor. Selected filters whose have best properties (not all of them) are fabricated in our laboratory by using PCB prototyping system, LPKF Promat C100/HF. Fabricated RF filters are measured by using VNA and analyzed.

Laboratory Applications Design Of the New Course

First week, laboratory equipment' are introduced to the students in the Remote Lab environment. For this purpose, an electronic performance system (EPSS) tool is used which provides just in time training for the users by providing the instruction according to the user needs and expectations [19], [20].

Second week, the students learn how to use RF Remote Lab website in laboratory hours. Now, the students are ready to use laboratory at anytime and anywhere without guidance .

Students freely perform the following remote lab experiments any time and any where according to their preferences:

Remote Experiment 1: Measurement of Scattering Parameters of Open, Short and Match load. This experiment is developed in order to familiarize users with control panel of VNA, fundamental principles of VNA. Furthermore, they can do basic measurements with VNA and calibrate of VNA, and observe SWR and impedance measurements with VNA. Figure 1 shows the actual physical laboratory setup for the experiment.

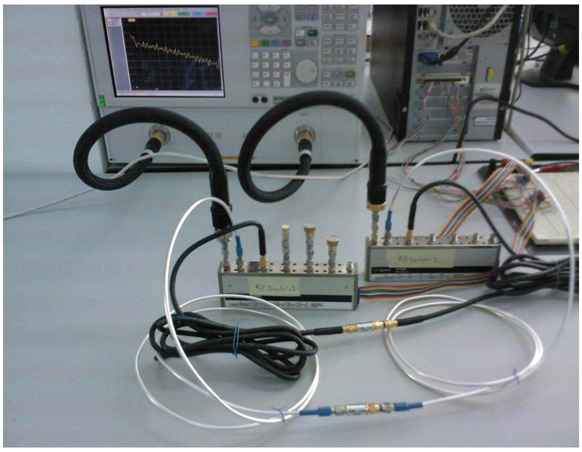

Figure 1. Setup for Measurement of scattering parameters of open, short and match load experiment

In this experiment, fundamental functions and controls of AGILENT's 8363B VNA is examined. Open load, short load and 50 ohm load are used as DUT (Device Under Test). Calibration procedures are defined, as well. VNA are used by the users to validate concepts like VSWR, reflection, and impedance matching by means of Smith Chart. Users can observe differences between theory and experiments since a remote laboratory works with real physical effects.

Following three weeks (3-5th weeks), the students learn how to use CAD program and to design simple microwave components :

AWR Experiment 1: Design a Simple RC Filter to be familiar AWR environment and to understand how to simulate, create graphs and analyze a circuit in AWR.

AWR Experiment 2: Transmission Line and Microstrip Line Analysis to study the behavior of an ideal transmission line (TL) at various lengths , to calculate width and length of microstrip line by using AWR and to gain an ability to use some AWR tools , to store the information of the substrate material used in the microstrip line, to solidify students understanding of transmission line theory and be able to design a microstrip line.

AWR Experiment 3: Design a 10-dB T-Attenuator by Using Lumped Elements in order to strengthen to simulate, create graphs and analyze a circuit in AWR, to design a passive RF component, to analyze the network behavior of multiport microwave systems.

AWR Experiment 4: Smith Chart and LC Matching Network to get familiar with the Smith Chart by plotting different impedance values and design a LC matching network, to use Smith Chart when solving transmission line problems, to analyze generator and load mismatched transmission line.

AWR Experiment 5: Single Stub Tuning to gain an ability to use some AWR tools, to improve the ability of simulate, create graphs and analyze a circuit in AWR to design a microstrip line, to use Smith Chart when solving transmission line problems, to analyze generator and load mismatched transmission line, to design single stub tuning networks in the design of microwave components and circuits

Remote Experiment 2: Measurement of Scattering Parameters of RF Filters. In this experiment, users are familiarized with the basic microwave passive elements and measurement techniques. The objective of the experiment is to observe the concepts of reflection and transmission (return loss, standing wave ratio, reflection coefficient), to measure the frequency responses and the behavior considering the direct and reflected wave of a microwave filter and insertion loss, bandwidth and out-of-band-rejection. For the experiment on measurement of scattering parameters the user must set VNA parameters such as the frequency range and number of points. One of the scattering parameters must be chosen. In this experiment, a user can view transmission characteristics of the filter and find the type of the filter (band pass, low-pass, high-pass, or not-sure), the frequency at which the minimum attenuation for the filter occurs, minimum loss and the 3dB cut-off frequency for the filter, defined as that frequency where the transmission coefficient is reduced by 3dB from the minimum attenuation.

Remote Experiment 3: Extraction of Physical Parameters of a Coaxial Medium with Vector Network Measurement is performed. When a typical calibration is processed, the measurement reference plane is moved to the very ends of the test cables. But what would happen if we had a transition (such as connector, cable, adaptor…) between the DUT and reference plane. In this experiment we perform two measurements, with transition and without transition (Fig. 2). After the measurements we decide the effect of transitions. The effect of a transition on phase and reflection coefficient (S11) is examined and phase constant (β) and relative permittivity (ε_r) are calculated by means of these measurements.

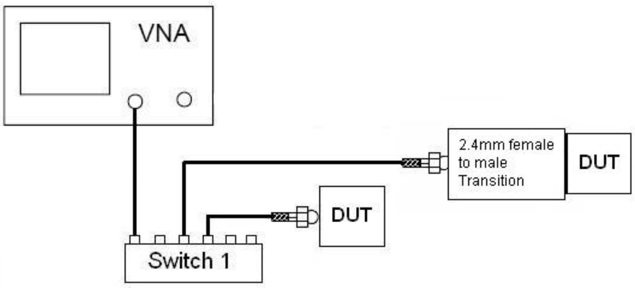

Figure 2. Remote experimental setup for extraction of physical parameters of a coaxial medium with vector network measurement experiment.

At certain frequency, phase constant (β) and relative permittivity (εr) are calculated by using the measurement results and $\lambda = \frac{2\pi}{\beta}$ $\varepsilon_r = \sqrt{\frac{\lambda_0}{\lambda}}$

During following two weeks (weeks 6 & 7), students perform the following experiments freely by using the distance laboratory environment [ERRL referans]. During this period, students are also free to use the physical laboratory environment to design any RF component.

Remote Experiment 4: RF Amplifier Measurements experiment. In this experiment basic measurement of power amplifier (Fig. 3) with VNA is performed for constant input power. Frequency characteristics are measured for different frequency values. This experiment allows the user to become familiar with the power amplifiers and their frequency band measurement with VNA. When completed, the user has an idea about characteristic such as gain, flatness, impedance, return loss etc . Vector network analyzer measurement capabilities are also improved.

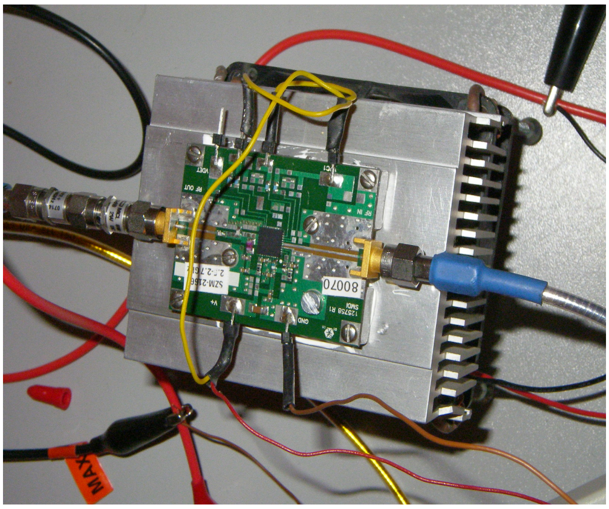

Figure 3. RF power amplifier.

Remote Experiment 5: Antenna Analysis. This experiment is focused on the measurement, of reflected-transmitted power, of input impedance vs. frequency and SWR of several antennas (Fig. 4). With this experiment various measurements on wire, horn and patch antennas are performed with the Vector network analyzer. Aims of the experiment are measurement of loss power, reflected power and transmitted power of the antennas and the SWR and the input impedance of the antenna at the certain frequency range.

Last three weeks (8-10th weeks) are reserved to the students for designing, implementation and measuring their own RF microwave filters. Students work in a team to design a filter with specifications that is provided.

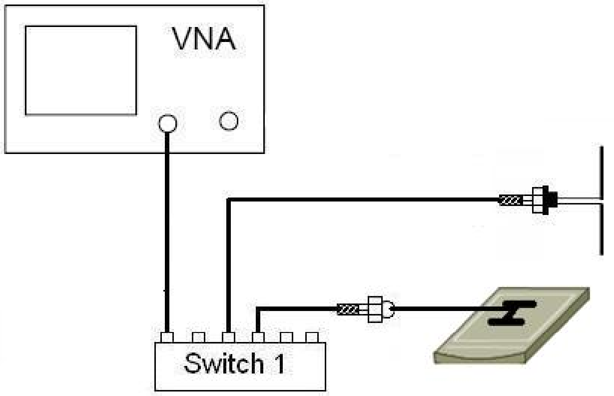

Figure 4. Remote experimental setup for antenna analysis experiment.

B. Theoretical Instruction

One of the problems of this course was building relationships between course content and laboratory applications. Accordingly, as shown in Figure 5, we have developed a concept map in order to help students develop these relationships. The map in Figure 5 shows how the relationships between the course content and laboratory experiments can be formed. The graphical represantation also helps to better visualize the possible relationships.

In this concept map experiments are connected by lines to the course content by using keywords. In this way it is expected that students will be able to build relationships between the experiments and theoretical content and analyze the experiment results accordingly. They are also able to find the theoretical details by using the search functionality of the remote laboratory environment[1].

We have applied this newly designed course for one semester at Atilim University. Students' feedback and course instructor's opinions were very positive after the implementation of the new course. They all declared that the problems that they had faced in previous years were all addressed with the new course design.

[1] http://errlmoodle.atilim.edu.tr/

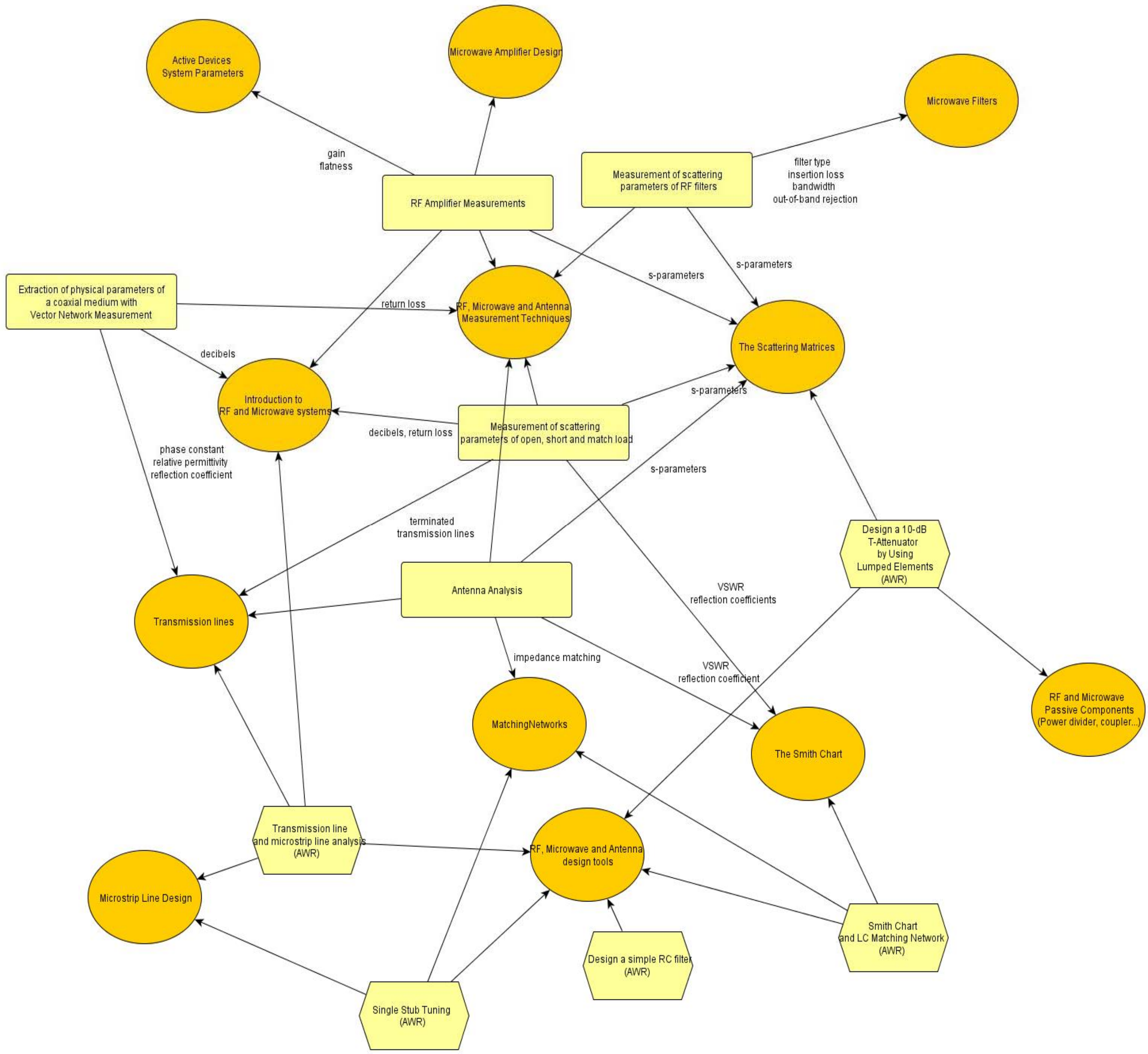

Figure 5. A Concept Map of Course Theory and Hands-on Application Activities

V. DISCUSSIONS AND CONCLUSIONS

In this study, we first listed the main problems of the introduction to RF and Microwave (MW) systems course. Then, in order to address these problems, we proposed a new curriculum model for both the laboratory and theoretical parts of the course. Finally, we applied the new curriculum of the laboratory activities for the course over one semester.

The course instructor believes that, because of the new approaches used in this course, instructors will have more time to extend course content and provide more experiments for the students. For example, in this semester the course instructor had time to demonstrate seven experiments that had not been studied in previous years.

The course instructor also reported that the remote laboratory environment significantly improved students' understanding of the experimental studies when compared to previous years. Additionally, since the students were better prepared to understand the background of the RF/Microwave components design, they were able to fabricate and measure the RF/Microwave component.

After taking the newly designed course, the students will not need to learn how to use the design and measurement tools featured in elective courses and design projects that follow in the sequence of the EE program at this University. These skills are expected to eliminate the need to provide repeated instructions on the usage of these tools throughout the curriculum, which allows for additional time for the instructors to perform other activities.

We believe that, in the long term, the students will receive greater numbers of job offers and their job performance will improve because they will be better prepared for industrial environments due to their exposure to the new technologies and more practical hands-on, trial-and-error type experiences.

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