AC 2009-1590: TEST ENGINEERING COURSE IN THE ELECTRICAL ENGINEERING DEPARTMENT AT SOUTHERN UNIVERSITY

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Test Engineering Course in the Electrical Engineering Department at Southern University

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Abstract

A test engineering course is being implemented at Southern University (SU). This course is an innovative design and testing course covering test engineering of analog and mixed signal circuits. This course will consist of a lecture (ELEN421) and lab (ELEN422). This course is fully supported by Texas Instruments (TI), and the course's content has been discussed and agreed upon by the engineers from TI and the faculty in the Electrical Engineering (EE) Department at Southern University. This design course is being taught in a way that will make the learning experience simulate a model of what happens in the real world. One of the great strengths of SU's EE curriculum is the emphasis on fundamentals that apply to real world problems. The ultimate goal of this design course is to bring together seniors in electrical engineering, and industrial design engineers with a focus on mixed signal testing of discrete components in the microelectronics area. The lecture will cover the following topics: modern analog and mixed signal technologies, an introduction to test electrical characteristics of integrated circuits (IC) and devices incorporating both digital and analog functions; the laboratory will give the students an opportunity to test a variety of circuits for AC and DC parameters. Mixed signal IC tests are very sensitive to structural details and hence to fabrication techniques. The course combines educational elements to produce a unique

class environment. These elements include the use of industrially sponsored design and build projects, a fabricated design approach and its modification, the integration of products and manufacturing process design, and emphasis on engineering and people skills. In this paper, the innovative design and testing parameters, the course teaching procedures, and some course materials will be discussed.

1. Introduction

Currently, mixed-signal IC test and measurement has grown into a highly specialized field of electrical engineering. However, test engineering is still a relatively unknown profession compared with IC design engineering. It has become harder to hire and train new engineers to become skilled mixed-signal test engineers. It may take one to two years for a mixed-signal test engineer to develop enough knowledge and experience to obtain adequate test solutions. The slow learning curve for mixed-signal test engineers is largely due to the shortage of university-level courses covering this subject [1-4].

What is test engineering? Test engineering is the discipline of verifying that a device performs within specified parameters. This involves three different tasks. The first is designing methods to accurately measure device performance so that automated test equipment (ATE) data correlates to lab data. The second is exhaustively characterizing the device performance over multiple worst case conditions (temperature, supply variations, etc.). And the third is troubleshooting specified mechanical requirements for the production environment.

As a test engineer, one can generate hardware and software that will be used by automated test equipment (ATE) to guarantee the performance of each device after it is fabricated. In most cases, a test engineer develops hardware and software that modifies the tests of the semiconductor die to normalize chip-to-chip variations or to compensate for manufacturing defects. Also, test engineers work closely with the designer to define the testability features and considerations that will reduce the test portion manufacturing cost. This process is calling Design for Testability (DFT).

The skills a test engineer should have include mastery of basic circuits including the ability to design and troubleshoot them using laboratory equipment as well as Automatic Test Equipment (ATE). The test engineer should also be able to program (C++, MATLAB, and LabVIEW) and to effectively communicate technical issues to both product marketers (possibly non-technical) as well as product designers (very technical).

The high demand of the electronics industry is the main reason for establishing new classes in universities. Practice based education is one of the many ways the "can do spirit" can be inspire in many students who want a hands on experience in addition to the usual theoretical information in coursework. This course concept was introduced by a group of TI (Texas Instruments) alumni who interacted with Southern University EE faculty after the last ABET accreditation. It was believed that combining a laboratory with a lecture course would provide a real world experience as long as it teaches electronics close to real life operation. The course is called Test Engineering of Analog and Mixed Signal Circuits. It introduces students to the existing test and process evaluation procedures and students are expected to use their knowledge of electrical and electronics circuits to understand, analyze, and evaluate given circuits. Adding the skills gained from this course to the experience obtained from an internship will help students understand the concepts at a faster pace. Also, this course will bridge the training period required for new TI employees. It would create research interests centering on RF/analog/mixed signal ICs, on- chip ESD protection for ICs, CAD and modeling of emerging semiconductor and nano-devices. Students would know the latest design procedures and evaluate and clone experiments that would achieve similar goals.

A collaboration between Southern University and several members of the technical staff of TI, has lead to the development of a test engineering course at Southern University (SU). This course was taught for the first time during the Fall 2008 semester. This course covers the area or topic of testing analog and mixed signal circuitry. This course consists of both a lecture (ELEN421) and a lab (ELEN422). The contents covered in the lecture and lab have been discussed and agreed upon by the engineers at TI and the faculty in the Electrical Engineering (EE) Department at Southern University. It was important to the technical staff at TI that this course be taught in a manner that will make the training period more effective when students enter the workforce. Another goal of this course is to bring together senior electrical engineering students and industrial design engineers so that student will be aware of this emerging field that focuses on testing microelectronic circuits that process mixed signals. In a snapshot the lecture focuses on modern analog and mixed signal technologies, an introduction to test electrical characteristics of integrated circuits (IC) and devices incorporating both digital and analog functions. This unique elective course in the electrical engineering curriculum concentrates on how circuits are tested and on what future changes are likely. The laboratory portion of the course will provide the student the chance to get a better understanding of these topics by measuring various parameters from circuits that were designed by test engineers at TI. The course combines educational elements to produce a unique class environment. This course utilizes the expertise of faculty in teaching students complex information through lectures and laboratory assignments with the expertise of engineers in private industry to give students skills and knowledge that will make them effective when they enter this field of engineering.

In this paper, the innovative design and testing parameters, the course teaching procedures, and some lab materials will be discussed. This paper is organized as follows: it first gives the course overview and materials, followed by several lab examples, and then some concluding remarks.

2. Course Overview and Materials

In setting the course's goal and materials, some ABET standards are used, and details are given in below.

In the catalog, Test Engineering of Analog and Mixed Signal Circuits (ELEN421) is described as follows: *it's a 3 credit hours course, with 3 hours lecture. It will map Modern Analog and Mixed Signal technologies, an introduction to test electrical characteristics of integrated circuits and devices incorporating both digital and analog functions. Mixed signal IC tests are very sensitive to structural details and hence to fabrication techniques. This course concentrates on how circuits are tested and on what* *future changes are likely. Pre-requisite: Linear System (ELEN 390) and Logic Design (ELEN303).*

The course objectives are as follows: (1) to give a review and working knowledge of Analog, Digital or Mixed-Signal Technology, (2) to introduce the students to CMOS fabrication processes, (3) to develop an understanding of basic semiconductor fabrication, real world circuits and testing, (4) to introduce the students to characterization versus production testing, (5) to introduce common devices such as data converters, amplifiers, filters comparators, regulators and mixers etc., (6) to develop basic knowledge of DC and parametric measurements, (7) to introduce the students to digital dc tests, (8) to develop sampling theory, and (9) to introduce DSP- based testing, signal analysis and analog channel testing.

The course also has two educational strategies. These strategies are to allow students ample opportunity to develop and demonstrate their comprehension of course materials and related ideas through guided class discussions, homework assignments and tests as well as to use related software packages to supplement the textbook.

The following course contents are covered: Fundamentals of MATLAB, Introduction to Test Engineering, DC and Parametric Measurements, Sampling Theory, DSP-Based Testing, and Signal Analysis and Analog Channel Testing.

The course uses three different software programs: MATLAB, LabVIEW and PSpice. Although students have some familiarity with MATLAB from other courses, a review of this software is necessary at the beginning of the course. Introduction to Test Engineering covers the basic concepts of the field of test engineering such as when and how to test for open circuits and short circuits. For the topic of DC and Parametric Measurements, lectures focus on the emphasis and the purpose of each test and what the measured results will reveal about the device under test. The concepts covered in lecture for the aforementioned topic are: continuity, leakage, offset, gain, DC power rejection ratio, and many other types of fundamental DC measurements. During the Sampling Theory lectures, Shannon's Theorem is presented, harmonic distortion, and quantization theory are covered. For the DSP-Based Testing, sampling theory concepts and DSP-based testing methodologies, which are at the core of many mixed-signal test and measurement techniques, are further developed. FFT fundamentals, frequency domain filtering, and other DSP-based fundamentals are presented. Finally, for the Signal Analysis and Analog Channel Testing, the concept of how basic AC channel tests can be performed economically using DSP-based testing is covered. Only non-sampled channels, consisting of combinations of op-amps, analog filter, PGAs and other continuous-time circuits are presented.

The most appropriate text for the lecture course is "Introduction to Mixed-Signal Test and Measurement" by Burns and Roberts [1]. This textbook was written for students who are studying mixed signals and test engineering. The book was written in collaboration with an engineer working in the test engineering field at Texas Instruments.

In order to let students to master the materials, labs related to lecture topics are set for the courses, and the details are given in the next section. Again, the faculty at Southern worked with the test engineers at Texas Instruments to ensure that the lecture materials and the lab materials were appropriate and to also ensure that the lab assignments were suitable to re-inforce the theoretical concepts covered in the lecture.

3. Laboratory Experiments Related to the Course

Many students are never exposed to job areas beyond design work. Test engineering is an area that SU students could immediately make a contribution at TI (and industry at large) after earning a BSEE. The information in the test engineering course is cumulative, requiring students to merge knowledge from multiple courses. A targeted course such as this would give students a competitive advantage when searching for jobs. Texas Instruments has donated several pieces of laboratory equipment to the Electrical Engineering Department at Southern University (e.g., Keithley meters, Agilent oscilloscope, data acquisition boards, etc.). A piece of equipment that test engineers would be trained on when working at TI is called Teradyne Catalyst ATE is shown in Figure 1.

Figure 1: Teradyne Catalyst ATE

The students go through several laboratory assignments as given in the lab manual during a semester of study [5]. The titles of these 9 labs are as follows: Using MATLAB, Introduction to LabVIEW, Learning how to Use the Equipment, DC Parametric Measurements-Part 1, DC Parametric Measurements-Part 2, Sampling Theory, DSP-Based Testing, AC Parametric Signal Analysis, and Testing the TPA2012D2 Audio Power Amplifier. The first two labs assignments (i.e., Using MATLAB, and Introduction to LabVIEW) are incorporated into the lab portion of the course in order to get the student familiar with these tools before they collect data from circuits. The remaining lab assignments are the core of the course in which the students use predesigned circuit boards to make measurements and since some of these labs utilize MATLAB and/or LabVIEW, the students need to be familiar with their operation. Each of the labs typically includes a pre-lab assignment and a post-lab assignment (in addition to the data collecting required for each lab). Brief details about each of these labs are provided below.

For the MATLAB lab, students are given several problems with lab type data and they are required to use MATLAB to manipulate matrix data, perform necessary calculations, and graph data. The LabVIEW assignment involves creating a virtual waveform generator as well as a virtual oscilloscope to record the signal from the generator. The Learning to Use the Equipment lab involves understanding several features of the lab equipment (e.g., saving signals captured with the oscilloscope, creating a user defined signal with the Agilent signal generator, etc.). The next two experiments, DC Parametric Measurements-Part 1 and DC Parametric Measurements-Part 2, involve checking the continuity of pre-wired circuits (to determine open and short circuits) and determining the input resistance & leakage current levels, respectively. The Sampling Theory lab introduces the student to the Nyquist theory and Shannon's theorem. The DSP lab allows the student to use FFTs to process a waveform and understand the frequency parameters of the signal. In the AC Parametric Signal Analysis experiment, students explore signal to noise ratio as well as total harmonic distortion. Finally, in the Audio Power Amplifier laboratory, students measure the transfer function of an amplifier circuit and analyze the non-linear characteristic of the circuit.

As an example of what the students have to do, consider DC Parametric Measurements-Part 1 lab experiment. In these lab assignments, the students are given background information about what they need to consider when interpreting a measurement. In addition to the text, figures are often given to clarify the information. Figure 2 shows how pin measurements should be interpreted when looking for short circuits and open circuits.

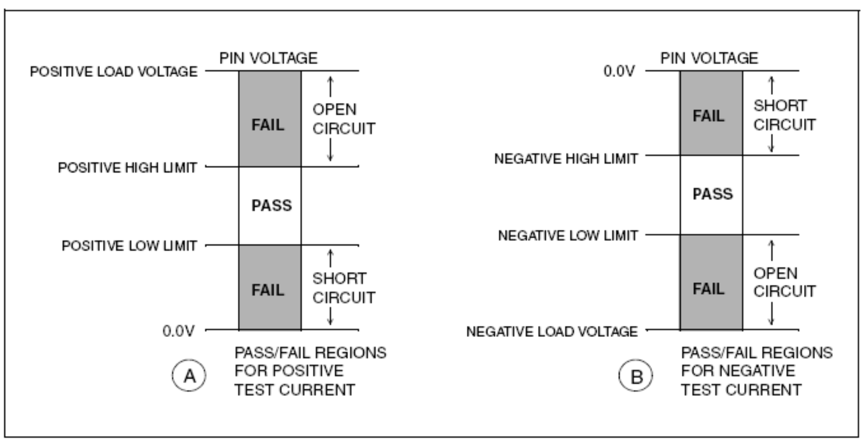

Figure 2: Voltage value limits to determine open and short circuits.

Students are then given a list of equipment that they will need to use during this experiment. They are then given a procedure that they must follow. For this experiment, the procedure is given below:

1. Connect the input of the Keithley 2400 Source Meter to the first combination under test, the negative continuity case. Here we will use the continuity board to determine
   - How to measure positive and negative continuity using source meter

- ➢ Observe the identity of an Open
- ➢ Observe the identity of a Short
- ➢ Observe the presence of the ESD Diode

2. Connect Source Meter per diagram below then source 1ma and record the results follow by sinking -1ma and record the results.
3. Put data into tabular form per **Table 2A-1**.
4. Repeat Step 2 and 3 for the all remaining position on the continuity board.
5. Set AVDD1, AVDD2, DVDD1, and DVDD2 to 0.00v and connect the input of the Keithley 2400 Source Meter to the first pin under test per Table 2A-2 for the TLV320AIC10. Here we will use the TLV320AIC10 board to check continuity on all signal pins.
6. Use Source meter to force 100ua on each pin then record voltage.
7. Repeat step 6 using -100ua.
8. Log the results of each measurement into **Table 2A-2**.

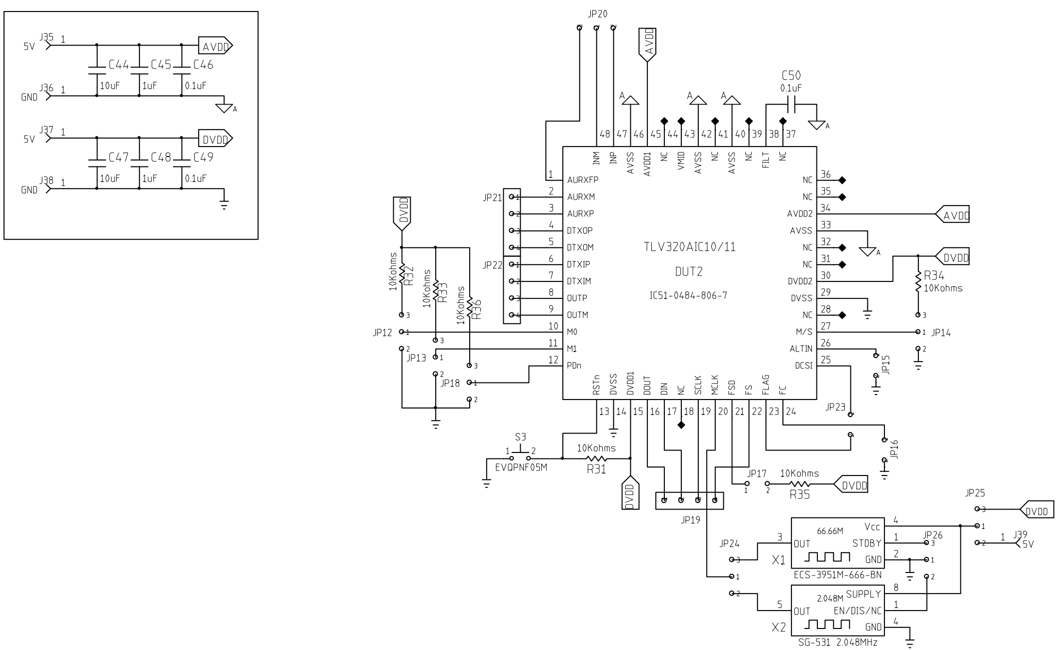

Figure 3: Pin configuration for the continuity board

The continuity board is provided for the students to test and a circuit diagram is also given with the pin configuration (see Figure 3). Tables are also given with the pin names listed in which the students fill in their data (see Table 1a); typical results recorded by a student during this lab are provided (see Table 1b). Post lab questions are required for this lab and they are as follows: (1) Compare measurement to the expected values in the data sheet, (2) Explain any errors in measurements, (3) Based on your analysis of the data, would you ship this device to your customer? (4) Explain why or why not ship the device to the customer.

Table 1: (a) Table to record measured values, (b) Results from a student enrolled in the course

(a)

TLV320AIC10 Break-Out		
Connection	**V(+100μA)**	**V(-100μA)**
AURXM		
AURXP		
INP		
INM		
DOUT		
DIN		
M0		
M1		
RESET		
PWRDWNZ		
FC		
MCLK		
SCLK		
FS		
FSD		
M/S		
OUTP		
OUTM		

(b)

TLV320AIC10 Break-Out		
Connection	**V(+100μA)**	**V(-100μA)**
AURXM	0.671V	-0.456V
AURXP	21.00V	-21.00V
INP	0.668V	-0.456V
INM	0.668V	-0.456V
DOUT	0.491V	-0.448V
DIN	0.625V	-0.455V
M0	0.624V	-0.455V
M1	0.625V	-0.456V
RESET	not measurable	not measurable
PWRDWNZ	0.623V	-0.456V
FC	not measurable	not measurable
MCLK	0.623V	-0.455V
SCLK	0.489V	-0.447V
FS	0.513V	-0.447V
FSD	not measurable	not measurable
M/S	not measurable	not measurable
OUTP	0.489V	-0.454V
OUTM	0.449V	-0.454V

4. Conclusions

A series of materials used to teach Test Engineering of Analog and Mixed Signal Circuits (ELEN421) and (ELEN422) have been presented. The course accomplishes its objectives of providing students with an overview of analog, digital and mixed-signal technology, an introduction to CMOS fabrication processes, an understanding of basic semiconductor fabrication, a knowledge of real world circuits and how to test these circuits, an understanding of the difference between characterization and production testing, and an introduction to common mixed signal circuit components such as data converters, amplifiers, filters, comparators, regulators and mixers. This course provides novel information to help students learn basic knowledge of DC and parametric measurements, it introduces students to digital DC testing, it helps students develop an understanding of sampling theory, and it introduces students to DSP- based testing, signal analysis and analog channel testing. After students take this course, they will be much better prepared to immediately make a contribution for their employer by reducing the time required for adequate training.

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