AC 2011-55: DESIGN OF SIMULINK PROJECTS FOR AN UNDERGRADUATE COMMUNICATIONS COURSE

Chaitri Aroskar, Missouri University of Science and Technology

Chaitri Aroskar is currently pursuing her M.S. degree in Electrical Engineering at Missouri University of Science and Technology. She received her B.S. degree in Electronics Engineering from the University of Mumbai, India in 2009. Her major areas of interest are Wireless Communications and Signal Processing.

Yahong Rosa Zheng, Missouri University of Science and Technology

Yahong Rosa Zheng received the B.S. degree from the University of Electronic Science and Technology of China, Chengdu, China, in 1987, and the M.S. degree from Tsinghua University, Beijing, China, in 1989, both in electrical engineering. She received the Ph.D. degree from the Department of Systems and Computer Engineering, Carleton University, Ottawa, Canada, in 2002. She was an NSERC Postdoctoral Fellow from Jan. 2003 to April, 2005 at the University of Missouri-Columbia. Currently, she is an assistant professor with the Department of Electrical and Computer Engineering at the Missouri University of Science and Technology. Her research interests include array signal processing, wireless communications, and wireless sensor networks. She has served as a Technical Program Committee (TPC) member for many IEEE international conferences, including IEEE Vehicular Technology Conference Fall 2008, IEEE GlobeCom 2005-09, and IEEE ICC 2006-09, IEEE Wireless Communications and Networking Conference 2007-08, and IEEE International Sensors Conference 2004, etc. She served as an Associate Editor for IEEE Transactions on Wireless Communications for 2006-2008. She has been a senior member of the IEEE since 2007. She is the recipient of an NSF CAREER award in 2009.

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Abstract

This paper describes a set of six Simulink based laboratory projects designed for a junior level undergraduate communications course. The course is traditionally a lecture course with no laboratory component. The authors aim to add a laboratory component to the course to help students to better understand and analyze the theory taught in lectures. The laboratory component is structured by following effective teaching strategies which aids reinforcement and retention of information.

Background and Motivation

An introductory communications course is the essential foundation to learn advanced communications topics. At Missouri University of Science and Technology, the Electrical and Computer Engineering (ECE) department offers a junior level undergraduate course: Communication Systems I. The course is presently a three hour lecture course with no laboratory component. As a first course in the communication series, it covers a review of linear systems and introduces analog communication systems as well as digital baseband communication systems. The course, first reviews important concepts of Fourier series, Fourier transforms, power spectral density and linear systems which students have learnt in their preliminary courses. Next, the students are introduced to basic analog modulation techniques of Amplitude Modulation (AM), Frequency Modulation (FM) and Phase Modulation (PM) along with feedback demodulators. They are also taught pulse modulation, digital signaling and multiplexing. Then, they are introduced to digital baseband transmission which covers the topics of line codes, pulse shaping, Inter-Symbol Interference (ISI), Zero Forcing (ZF) Equalizer and synchronization. This course structure is meant to provide students with a solid foundation for advanced courses such as Communication Systems II, Communication Circuits, and Wireless Communications.

The lecture approach to teaching communication courses can be intimidating for many students because of the heavy theoretical and mathematical content, compounded by the lack of visual aids. The students find the aforementioned concepts difficult to grasp with block diagrams alone. The complexity increases as the course progresses and the authors wanted to help students cope with the complex theory without reducing the standard of the course content. Empirical studies advocate the need for innovative techniques to help students grasp the course material\textsuperscript{1,2,3}. A number of course developments implement MATLAB based projects to simulate theoretical concepts\textsuperscript{4,5,6,7}. Although the textbook\textsuperscript{8} provides MATLAB examples and exercises in the form of script files, previous offerings of the course have found that the lecture-only format does not lend itself to teaching simulation. Besides, more than 50\% of the students are not ready for the extensive MATLAB required by this approach.

The authors hence decided to supplement the traditional lectures with hands on simulation experience using a model based Simulink approach. Simulink is a graphical environment provided by MathWorks to enable model-based design and simulation. It provides an extensive
set of pre-defined blocks for modeling continuous-time or discrete-time systems or a hybrid of the two. It is an easy tool for beginners since, once the user has conceived a system, it can be built into a model by a simple drag, drop and connecting of blocks and wires. The models can be organized into modules in a hierarchical manner and display blocks can be used to visualize the results as the simulation runs. The model can be simulated for different parameters and users can learn from a ‘what if’ approach to such simulation. Simulink is integrated with the MATLAB environment and so the user may also utilize MATLAB features to define inputs, store results for analysis or post processing, or perform functions within a model. Overall, Simulink permits students to bring static representations of communication systems in textbooks to life. Thus, Simulink was chosen as a tool which could be used to make theory tangible.

Thanks to its attractive features, Simulink has been identified as an ideal tool for laboratory projects and has hence been adopted for teaching a variety of courses by many instructors. For example, in digital communication theory is taught by using Simulink exercises. However, none have attempted to introduce Simulink for teaching analog communication theory in core level communication courses, where students do not necessarily have a strong programming capability. The benefits of such a laboratory course are twofold. Firstly, students learn simulation, which is widely used by engineers in the industry to verify and validate system designs. Secondly, these laboratory projects have been designed following the Gagne’s nine events of instruction which leads to an enhanced learning environment. Also, when compared to hardware based labs, such as with EMONA TIMS, Mobile Studio and Ettus USRP, Simulink has the advantage of lower cost and ease of maintenance.

Simulink Laboratory Projects for Communication Systems Course

Six Simulink laboratory projects are constructed to teach Simulink skills in parallel with the theory. Table 1 enumerates topics covered in the six labs and the Simulink skills gained therein. The first two projects relate to the review of frequency domain analysis and linear system concepts to reinforce previously learnt basics. At this stage, students are introduced to the primary skill of building a model and creating subsystems and masks. The next two projects deal with analog communication systems. Here we introduce students to design techniques such as creating libraries and using model referencing. The last two projects are on digital baseband communication systems. The fifth lab also introduces the Stateflow tool of Simulink to implement complex control logic in Simulink and the sixth lab introduces integration of models with MATLAB scripts as a formative step towards more advanced implementations in Simulink. The projects have been designed with a gradually increasing complexity to provide the necessary confidence boost to students for subsequent projects.

<table>
<thead>
<tr>
<th>Lab</th>
<th>Topics covered</th>
<th>Simulink skill</th>
</tr>
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<tbody>
<tr>
<td>I</td>
<td>Frequency Domain Analysis</td>
<td>Building a Model</td>
</tr>
<tr>
<td>II</td>
<td>Linear Systems</td>
<td>Subsystems &amp; Masks</td>
</tr>
<tr>
<td>III</td>
<td>Amplitude Modulation</td>
<td>Library Building</td>
</tr>
<tr>
<td>IV</td>
<td>Frequency &amp; Phase Modulation</td>
<td>Model Referencing</td>
</tr>
<tr>
<td>V</td>
<td>Pulse Code Modulation &amp; Line Codes</td>
<td>Using Stateflow</td>
</tr>
<tr>
<td>VI</td>
<td>Zero Forcing Equalizer</td>
<td>Interacting with MATLAB</td>
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</tbody>
</table>

Table 1. Simulink Laboratory Projects
In this paper we discuss two of the laboratory projects. Firstly, we discuss Lab III (AM lab) and how it implements the features of Simulink outlined earlier. This lab is split into two parts, one to implement the modulation techniques and one to implement the demodulation techniques. Typically, the equation for an AM signal is given by,

\[ x_c(t) = A_c \left[ A + a m(t) \right] \cos(2 \pi f_c t) \] (1)

where, \( A_c \) is the amplitude of the unmodulated carrier wave \( A_c \cos(2 \pi f_c t) \), \( m(t) \) is the message signal, \( a \) is the modulation index and \( A \) is the DC bias. The inclusion of a DC bias results in the carrier component to be included in the AM signal. Further, the Double Sideband (DSB) modulation and Single Sideband (SSB) modulation are variations of AM itself. DSB can be achieved by simply multiplying the carrier with the message signal.

\[ x_c(t) = A_c m(t) \cos(2 \pi f_c t) \] (2)

The SSB signal can be generated from the DSB output by the method of sideband filtering. The illustration in Fig.1 shows a complete model of the modulation half of the lab. It includes a scope for visual comparison of the modulation techniques. As can be seen from the figure the model is a direct translation of the equations into an intuitive assembly of blocks. All the blocks have been taken from the variety of block libraries available in Simulink.

The above model can be better organized by making subsystems for the individual modulation techniques and then combining them to form an AM techniques subsystem. This is an example of a two level hierarchy being designed in a bottom-up manner. Similarly, a top-down design is possible by making empty subsystems and entering constituent blocks into them individually. Fig.2 shows the final hierarchical model. The amplitude modulator can now be stored in a library to be used for other model designs, for example in the other half of this lab, AM demodulation
techniques. In Fig. 3 we see the compact design of the AM demodulation techniques is made possible by the hierarchical design feature of Simulink.

Fig. 2 Hierarchical design of amplitude modulation lab

Lab 3 Part A
Comparison of Amplitude Modulation Techniques

Fig. 3 Modularized AM demodulation lab

Lab 3 Part B
Amplitude Demodulation Techniques

By playing around with different parameters and settings, the students can satiate their curiosity about what happens when a certain parameter in an equation is changed or a block from a block diagram is omitted. Such an interactive interface allows the students to learn from a 'what if' approach. One of the post-lab questions asks students to vary the modulation index in order to observe over-modulation and check if correct demodulation is possible.

The second lab discussed in this paper is the final lab project on ZF equalizer. The objective of this project is to let students implement a multi-tap ZF equalizer and to learn to incorporate
MATLAB scripts into Simulink to make the models more attractive. The MATLAB required here is not as extensive as required for building the complete models using MATLAB programming.

An N-tap ZF equalizer is a filter designed to accept a channel output response affected by ISI and produce an output pulse of value one with \( \frac{(N-1)}{2} \) zero values samples on either side. Let the channel coefficients constitute the matrix \( P_c \) and the desired equalizer output constitute the matrix \( P_{eq} \). The equalizer coefficient matrix \( C \) can be found as:

\[
C = [P_c]^{-1} [P_{eq}]
\]

As a pre-lab task students are asked to find the equalizer weights when given the channel coefficients as \([-0.05 \ 0.2 \ 1 \ 0.3 \ -0.07] \) and \([-0.05 \ 0.2 \ -0.1 \ 0.3 \ -0.07] \).

An eye diagram is a good visual representation of the system performance. It is constructed by plotting segments of a digitally modulated baseband signal, typically two symbol periods in length, so that the segments overlap. The optimal sampling time for a receiver is when the eye is most open. A ZF equalizer’s performance can be gauged using an eye diagram since an eye will be more closed due to presence of ISI and the ZF equalizer’s job is to minimize ISI and maximize the eye opening. Thus, this lab uses eye diagrams to view results.

In the specimen solution discussed here, we modulate a string of binary data using Binary Phase Shift Keying (BPSK) modulation and then pass it through the specified channel and Additive White Gaussian Noise (AWGN). The received signal is equalized by finding the equalizer weights for a three-tap ZF equalizer and implementing them. The result of equalization is observed using an eye diagram. By implementing this lab students are able to verify their answers obtained in the pre-lab task. The complete Simulink model for this lab is given in Fig.4.

In this model, the binary stream and the BPSK modulator and demodulator blocks are taken from Simulink’s Communications blockset library. The channel and ZF equalizer are user defined subsystems. The channel is constructed using a filter with the given channel coefficients.
followed by an AWGN block while the ZF equalizer is constructed using a MATLAB function block followed by the equalizing filter. The computation of the equalizer coefficients is done using a MATLAB function block and then the result is passed to the equalizing filter. The implementation of both the subsystems is seen in Fig.5.

Fig. 5 Channel and ZF equalizer subsystems

Fig. 6 depicts eye diagrams for the distorted signal before and after the equalization stage. The AWGN distortion effect has been kept to a minimal value. As can be seen from the eye diagrams, for the first set of channel coefficients, a three tap equalizer can improve the performance against ISI whereas for the other set of channel coefficients, the degradation caused by ISI is so severe that the eye closes and the equalizer fails to rectify it. By increasing the number of taps, students can see that a better performance can be achieved even for the second set of channel coefficients. An extension of this lab involves studying the effect of using pulse shaping filters along with ZF equalizer to combat ISI.

Fig. 6 Eye diagrams for two sets of channel coefficients

The scope buttons at the bottom are designed to open or close the scopes during simulation. They all are masked subsystems, which is a Simulink skill introduced in the second lab. The button functionality is implemented by using a MATLAB script. As can be seen this skill is essential for introducing additional functionalities to the model.
Pedagogical Consideration

Effective teaching and learning models demand an organized approach to the classroom teaching. In 1977, Gagne provided an instructional model with focused learning outcomes. The Gagne’s nine levels of instruction are enumerated in Table 2 along with their corresponding learning outcomes. The six Simulink projects are created and will be implemented in the classroom following Gagne’s model. Overall, conforming to this model of instruction facilitates a pedagogically rich learning environment.

<table>
<thead>
<tr>
<th>Event</th>
<th>Instructional event</th>
<th>Learning outcome</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Gaining Attention</td>
<td>Reception</td>
</tr>
<tr>
<td>2</td>
<td>Informing Learners of the Objective</td>
<td>Expectancy</td>
</tr>
<tr>
<td>3</td>
<td>Stimulating Recall of Prior Knowledge</td>
<td>Retrieval to Working Memory</td>
</tr>
<tr>
<td>4</td>
<td>Presenting a Stimulus</td>
<td>Clear Perception</td>
</tr>
<tr>
<td>5</td>
<td>Providing Learning Guidance</td>
<td>Semantic Encoding</td>
</tr>
<tr>
<td>6</td>
<td>Eliciting Performance</td>
<td>Responding</td>
</tr>
<tr>
<td>7</td>
<td>Providing Feedback</td>
<td>Reinforcement</td>
</tr>
<tr>
<td>8</td>
<td>Assessing Performance</td>
<td>Reinforcement</td>
</tr>
<tr>
<td>9</td>
<td>Enhancing Retention</td>
<td>Cueing Retrieval</td>
</tr>
</tbody>
</table>

Table 2. Gagne’s nine events of instruction

Gaining attention: A brief introduction to Simulink and its benefits along with attractive demos capture the attention of the students. A demo exhibits the potential of the new technique and hence makes the students want to focus and concentrate on the matter that is to follow.

Informing learners of the objectives: Learning objectives are clearly specified at the beginning of each project instruction. For example, the AM lab outlines learning objectives as simulating amplitude modulation techniques and learning to build libraries in Simulink.

Stimulating recall of prior knowledge: Lectures on theoretical concepts are given prior to each project. Pre-lab reading and questions are also assigned and they are required to be submitted at the beginning of each project. Also, each lab includes practice of Simulink skills learnt in previous lab projects.

Presenting a stimulus: The objectives outlined in every project instruction, coupled with clear step by step procedures provide students with a direction and the necessary stimulus to perform the task.

Providing learning guidance: Every project instruction begins with an example of the Simulink skill to be learnt. Sample outputs and theoretical results are provided to students for comparison with the Simulink generated results. The use of a Teaching Assistant (TA) to assist in lab sessions and outside the classroom Learning Enhancement Across Disciplines (LEAD) program reduces student to instructor ratio and improves student-teacher interaction.
Eliciting performance: Desired performance is elicited by designing a grading policy which requires projects to be performed in teams of two where individual members have different roles. Peer rating is used to assign individual grades. Bonus points are awarded for outstanding performance.

Providing feedback and Assessing Performance: In each lab session, students can try varying block parameters and simulate the system to get an immediate feedback on their understanding of the concept. Moreover mistakes made in a simulation will give instantaneous feedback. The post-lab questions after each session provide a feedback on their progress towards the learning objectives of the course. The lab reports are promptly graded and returned to the students along with lab-critiques which address various factors associated with understanding the material. Thus, the students receive an elaborate and informative feedback on their performance.

Enhancing retention: Each project utilizes some basic concept learnt in an earlier project or lecture. For example, the ZF equalizer lab uses the subsystem and masking skill learnt in the AM lab. This repeated use of prior knowledge to build projects helps students retain information.

Evaluation

These laboratory projects are ready to be tested and will be implemented in class during Spring 2011. Planned assessment tools are entry, mid-term and exit surveys, to understand how the students are coping with the introduction of a lab component. Also, students are asked to list the difficulties faced by them during the projects, in their lab reports, thus providing regular feedback on individual projects. Data will be collected and analyzed to ascertain the effectiveness of this approach. It will be compared to the data from previous lecture only offerings of the course. The projects will be further refined over upcoming semesters by incorporating feedback obtained from the students. We anticipate these Simulink projects to transform the dry theory into vivid illustrations and thus increase retention and stimulate students’ interest.

Summary

In summary, this paper introduces the benefits of Simulink to teaching a communications course. Six Simulink laboratory projects are discussed in brief. Also, the implementation of effective teaching methods with this laboratory course is explained. Therefore, a twofold benefit of ingrained fundamentals and an enhanced simulation skill set is achieved with the proposed course.

Acknowledgements

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References


