High Speed Systems Engineering: A New Trent in Electrical and Computer Engineering

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This paper introduces the main ideas and program objectives for High Speed Systems Engineering (HSSE). HSSE (funded by NSF CISE-EAI)[1] has been proposed by our team as a new and viable platform for integrating engineering education, research and development. This approach identifies and integrates the common aspects, methodologies, and knowledge bases in Networking, Communication, RF, Microwave, VLSI, Electromagnetic, Optics, and Optical Communication/Networking into a series of classes to be added to a regular/traditional EE program. We will introduce our plans and current implementations of HSSE at the department of electrical and computer engineering at Iowa state University. Our recent work is presented that shows very promising trends in utilizing High Speed Systems Engineering as integrating pedagogical and research platforms to train modern engineers and future researchers. The newly developed classes and changes in the curriculum will be introduced and discussed. We will show how the new HSSE laboratory (with an electronically controlled optical backbone and high speed measurement capabilities) is enhancing interaction between faculty, graduate and undergraduate students. Finally the paper will examine how HSSE has been successful in encouraging students from all undergraduate levels (freshman to senior) to participate in learning and experimenting in the State-of-the-art laboratory and are encouraged to be involved in research and graduate studies.

The motivation

Current fiber-optic technology will soon be augmented to allow transmission of data at 40 Gb/s over a single communication link. 40Gb/s is soon the state-of-the-art of the electronic systems[2,3]. Comparing this to several decades ago when a single link, early versions of a twisted copper pair, would transmit data in the rate of 100 kb/s, we see that these new communication links will transmit in the range of a half-million times the data of those very early systems in a unit of time. The whole area of electronics', optical networking and communication, system design, and even device related electronics and optoelectronics are being affected due to the needs for higher speed and data transmission rates. At high speed engineering will be dealing not only with traditional electronics and optoelectronics challenges but also with many new challenges that are characteristics of high speed systems. The area of high speed system engineering and consideration is going to be inseparable to any of the future developments in VLSI, Electronics, Optical systems, networking, communication, and devices developments. However, most of the engineering school still has traditional tracks for each major specialization. Consequently, in many cases the students will have very limited exposure to high speed system considerations.

The concepts of HSSE

High Speed Systems Engineering (HSSE) encapsulates the concepts, ideas, and system level thinking that are needed to work in a group of interrelated, but traditionally separated areas in Electrical and Computer Engineering that are developing faster processors, systems, channels, signals, and detectors and are ever going to be even more extensive in the future[2-4].

In order to provide a better understanding of the importance of the cross disciplinary nature of HSSE one needs to identify the important concepts and subject matters for the future engineering needs. We identify the important emphasis in the future of electronics, networking, and communication technology.

- Networking and dependable systems:
  Networks methods, protocol, fault tolerance, dependable design
- Optics and optical measurement:
  Understanding of what needs to be done and how is it done in the field at the physical layer between electronics and photonics.
- High-speed electronics methods:
  Getting signals, circuits and controllers to react correctly in a sub-nanosecond time periods (signals approaching 100's of GHz)
- Network devices:
  Understanding the issues of interfacing devices and network interconnections in optical/electronic/ and wireless environments.
- Signal processing and transmission (high-speed signal processing):
  Filtering, and reshaping in limited embedded system environment as well as advance routing at speed compatible with the future optical time division and wavelength division multiplexing (OTDM/WDM) systems
- Electromagnetic compatibility:
  Wireless, propagation, compatibility, immunity, wave guiding and other issues that are limiting bottleneck of many hi-speed optical/electronic/wireless links
- Network security:
  Understanding the interactions between network protocol and management of the physical layer.
- Advance coding and information theory:
  Modern communication, multi-platform communication
- VLSI and RF engineering:
  Developing systems, subsystem including high speed clocks, high speed data transfer (wired, wireless, optical, optoelectronics), high speed receivers and controls

All of the students in undergraduate programs are traditionally specializing in certain fields such as communications, networking, VLSI, semiconductor devices and fabrication, optoelectronics, or EM and microwave systems. While each of the traditional area have their great strength they will train the over all engineers that are needed for the future high speed needs. This program is to design a set of classes that will integrate the above emphasis and add the multidisciplinary issues of high-speed systems. Areas such as challenges with optical networking, and optical communication systems of tomorrow capable of Tera bits of information, or electronics for the

high data rate communication systems are among many areas that will need the above listed knowledge base. Consequently, Figure 1 depicts how HSSE and the concepts relate the many different traditional disciplines together.

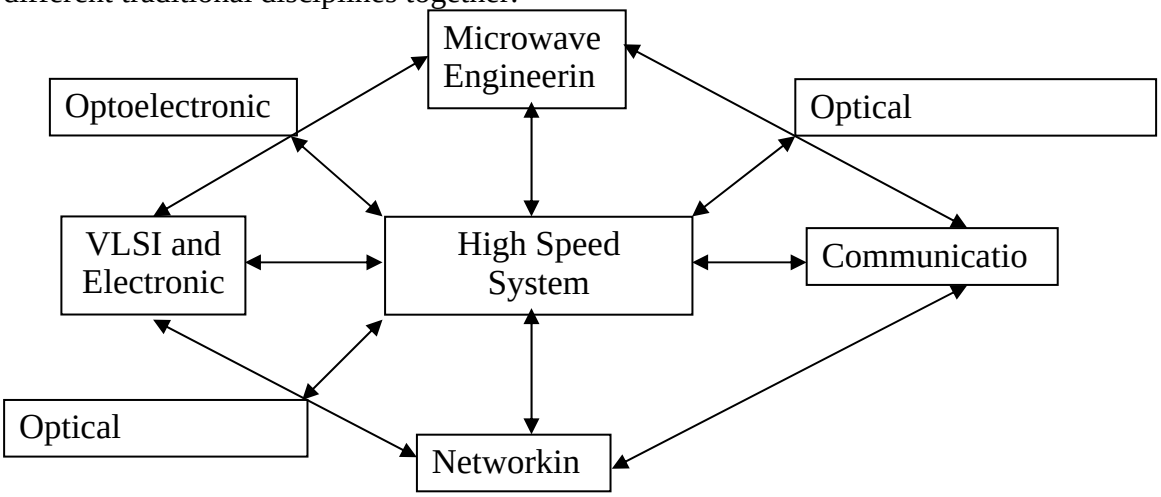

Figure 1 HSSE and traditional disciplines

The implementation of HSSE at Iowa State University

We believe this will help students learn more about their fields as well as encourage them to pursue more advance degrees in the related fields and/or participate in the current fast pace industries. The students are taking many classes as a part of their required curricula. Since there is a huge over load in most of the curricula and we do not want to make intangible and impossible changes in the program, we propose minimal new classes/labs and some augmentations in the current classes.

As a part of this program we will train the students based on our new research findings the basis of optical time division multiplexing/wavelength division multiplexing (OTDM/WDM), which is the emerging dominant networking technology as well as the basic physical layer consideration for Electromagnetic (EM), wireless, fiber optics, and other requirements. A new laboratory to train the student with the state-of-the-art measurement capabilities and concepts associated with high-speed measurement is established. It is important for the new breed of students to have a fundamental understanding of EM, microwave measurements methodologies, and optical measurements and communications concepts and methodologies. We consider the following items to be important for all of the students and practitioners of HSSE.

High Speed Electronics Methods	Signals, circuits, and controllers for > 40 GHz
Electromagnetic, microwave, and optical measurement	What can be measured and how and how and have hands on experience
Networking and dependable systems	Methods, protocols, fault tolerance and dependable designs
Networking devices	What is available and what are the

	principals and limitations
High speed signal processing and transmission	Issues of high speed signal creation, processing and treatment
Electromagnetic Compatibility and immunity	EM issues for high speed design for propagation, packaging, VLSI
System security	Data security, secure communication and robust systems design
Information theory and coding	Information theory in communication and advance coding schemes used with emphasis of the limitation of high speed systems

To help the students with the fundamental advance understanding, they will be taking four classes:

1. Measurements and Testing for High Speed Systems Engineering: Electronics, digital, RF, microwave, and optical measurement and instrumentation laboratory, contains the basic ideas and fundamentals of measurements, and trains the students with the type of instruments, the quantities that are measurable and the instrumentation. This class will cover the basics from measurement, the known measurement methodologies, digital and analog systems, and will go into the detail of what it means to methods of measuring from microwave, to optical domain. In this class has a laboratory component to allow students start utilizing the requested equipment. The purpose is to teach students the type of equipment that is available and even look at the compare and contrast of some electronics vs. photonics measurements. A strong component of this class is education students with time based and frequency analysis of signals, systems and the related issues with measurement.

2. High speed system characterization: In this class we cover the ideas that are used in high speed system integration, and measurement. It is known that the design and characterization criteria for high speed systems are different than those of DC and low frequencies. The goal of this class is to get the students familiar with the high speed issues. Including in this class w will talk about how the circuit components for high speed systems are characterized. The equipment that is requested in this proposal will be utilized in this class. In class the student will be familiar with the type of possible measurements for component and system level characterization. The students will learn how to set up for right measurements and how to work with electronics and photonics systems.

3. High speed hybrid systems (Optical/electronics hybrid interconnect systems) Will cover the issues and compatibility problems with the optical and electronic bases systems. The issues of EM compatibility and immunity will also be considered. This is the final class that will utilize the current available systems in different laboratories in the department and try to teach integrations of the ideas for hybrid systems. The focus on the available tools for system integration and the limitation of each and the strength of them. Most of the systems at this level can be computer controlled and computer based instrumentation that are available through the industry.

4. Advance Robust networking will train students with the right knowledge base for the new scheme and future systems in networking. The terra Hetz systems and beyond. The class will cover the current ad future system consideration, and will make the student familiar with the ideas of robust, fault tolerance and secure systems. The class will also cover security issues of the computer networks and communication systems as well as way to create robust systems both from the security and dependable performance.

Our Experience show that the new classes to be designed together with modifications of the currently available classes in EM, Antenna, networking, VLSI, control etc to make sure that concepts of physical layers (wired, wireless, optical optoelectronics), compatibility and immunity for instrumentation, and basic optics are covered and treated to an acceptable level. In order to provide a good background and foundation for the student it is recommended to have overlaps between the classes. The material and concepts overlaps would be beneficial if each class covers them from slightly different perspective and approach. A good example to illustrate these concepts is the idea of spectrum analysis. This concepts can be covered in a series of classes including electronics, VLSI, EM, signals and systems, networking, control, and communication and each will (and hopefully should have) slightly different approach. If the overlaps are designed well in the curriculum and followed well by the instructors the whole process will enrich the students' general engineering concepts as well as electrical and computer background benefits of which will last them a lifetime.

Research/education opportunities for graduate and undergraduate

As we have demonstrated by nature HSSE will require an environment that few areas to collaborate together. The students of different areas would be working together in their classes in multidisciplinary projects. In addition since the laboratories and the projects are on going, the HSSE laboratory becomes a natural environment for graduate research programs and students to also collaborate and develop new ideas and systems. Currently, in the HSSE laboratory we have three main projects that have developed by the PIs and the PI collaborations with other faculty in the department of Electrical and Computer Engineering. Figure 2 shows the optical test best with the optical and electronic instrumentation that was assembled as a part of the HSSE program and in also being used for advanced research in the areas of optical and electro optical networking, devices development, control and characterization[4]. The current system is used for research and training of over 30 undergraduate and 10 graduate students per class. In the area f research there are 2 PhD and 2 MS students working directly on system and few other students working on related projects. In addition the HSSE laboratory hosts other research projects for both graduate and undergraduate students in the areas of embedded systems, security and physical layer investigations.

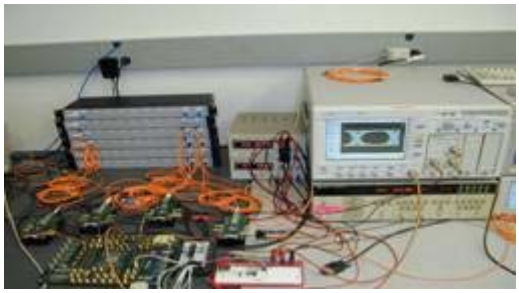

Figure 2 Light Trail Test Bed

The current stage of the program

We are in the 2nd year of development of HSSE program at Iowa State University. We have tried the first versions of the first three classes and have educated and trained the first 2 groups of students. As expected the students come from a wide range of background and interests and find the subject very attractive. Table 1 shows the students' interest area in the Fall 2003 HSSE class. At the same time all of the students find the class very challenging and informative. Our assessment shows that the experience of taking the class in HSSE and participating in the laboratory and test design experiments and projects have improved their understanding of HSSE and the concepts and issues.

Table 1: HSSE Class Fall 2003

INTEREST AREAS	RESPONSE
Microwave Design	6/7 = 85.7%
VLSI Design	4/7 = 57.1%
Computer Network Design	2/7 = 28.6%
General EM	4/7 = 57.1%
General Computer	3/7 = 42.9%

Table 2: Concepts Learning Fall 2003

	Before HSSE Class	**After HSSE Class**	**Difference**
High speed system Engineering	2.00	3.00	+1.00
High speed Networking	2.00	2.57	+0.57
High speed optical systems	1.71	2.71	+1.00
Methods for high speed systems	1.71	2.57	+0.86
Importance of high speed systems	2.29	3.00	+0.71
Kinds of High speed systems	2.14	3.00	+0.86
Measurement and test methods	1.86	2.86	+1.00
High speed methods	1.71	2.71	+1.00
How high speed is related to other fields	2.14	3.00	+0.86

Table 3; Key used for the concepts measurements in table 2

Number	**Definition**	**Description**
1	Unfamiliar	Unfamiliar with concept or technique
2	Basic Understanding	Understand basic concepts or techniques
3	Understand and Experiment	Understand basic concepts and techniques and feel comfortable experimenting with their application
4	Apply Concepts	Feel quite comfortable applying the concepts and techniques

Conclusions and future work

The development of HSSE from the conceptual state to the development, course design, course implementation, all the way to enrichment and active participations of the PI and other faculty in research and new areas of education has been a truly enriching experience. There are 2 of the classes that are designed and tested and show successful results. The challenges have been augmented and the experience is showing greater promise during the 2nd year implementation of the classes which includes a strong laboratory and measurement components. Students find the challenges worthy of their group efforts and have been constantly helping the PIs to develop better classes and laboratory experiments. Due to the graduate students involvements the depth of the HSSE efforts has been increasing and the laboratory is enriched with a combination of undergraduates (freshman to seniors) as well as graduate students, and faculty from 4 to 5 different areas. We believe this has been a great effort and look forward to the new areas and completion of research in the collaborated areas. We believe with this new HSSE program we will not only enrich the students' learning, integration of their knowledge based and provide them a state-of-the-art conceptual, theoretical, and hands on, but also will enrich the graduate program by providing the laboratory experience and interesting multidisciplinary projects. We look forward to evaluation and measurements of the success of the 2nd year implementation of the HSSE program.

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