AC 2010-237: ITS 2010 AND THE NEW ELECTRONICS TECHNOLOGY PARADIGM IS EMERGING

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Its 2010 and the new Electronics Technology Paradigm is Emerging

Abstract

Many faculty members at the two-year college level have struggled with outdated electronics technology curriculums over the past decade or more. Long gone are the days of repairing electronics systems to the parts level and the effectiveness of teaching the technology in a component centric manner. Moore's Law has accurately predicted the number of transistors on a chip for more than four decades now and gigascale integrated circuits that allow systems-on-a-chip technology are no longer a prophecy of the future. With the convergence of several electronics based enabling technologies there is starting to be an obvious shift in the electronics technology paradigm. That shift is towards what has been classified in varying disciplines as: intelligent infrastructure, enhanced systems, ambient intelligence, and the Internet of Things. The most important technologies in this convergence are sophisticated embedded microcontrollers, networking technologies (i.e. wireless), intelligent sensors and actuators, and reconfigurable hardware. The new electronics technology paradigm is one of complex networked systems that are a combination of hardware, software, and communications. Recently, through a growing concern about energy usage and the possible effects of climate change the United States government has, as part of the American Recovery and Reinvestment Act, put together an initiative to modernize the country's electrical grid. To, in effect, create a "smart grid." This extremely ambitious initiative is a coalescing point for the converging technologies cited previously but one would be hard pressed to find any two-year electronics technology programs that teach these technologies from a systems level perspective and that are ready to train the workforce that will be needed for this particular initiative or for others like it as we implement evermore enhanced networked systems in our buildings, vehicles, along our highways, and anywhere that they can improve efficiency, safety, and security.

Introduction

Five years ago, this author delivered a paper at the American Society of Engineering Educators (ASEE) 2005 annual conference[1]. The title of the paper was, *The 2010 Gigascale Imperative: Why the instruction of electronics technology must change!* The paper was submitted in an attempt to call attention to what the author felt was a growing and potentially critical problem that was slowly but surely affecting the education of students enrolled in associate degree programs in electronics engineering technology (EET) type programs, especially at two-year colleges, and, furthermore, bound to affect these students even more negatively as time went on. The problem (as it was perceived then) was that the typical curriculum of these legacy programs, with their emphasis on the electronic components of prior decades (that were used to construct the electronic systems of the day), was becoming woefully disconnected from the skill sets that these students would need in the future. The paper's contents addressed several crucial topics: it examined why the curriculum had come to be the way it was, the author's theory as to the root cause or driving force of the problem, and why the problem would be exacerbated as time when on. The paper also considered the oblique role of the faculty and the more than considerable influence of textbook publisher's to a widespread resistance to change. Finally, the paper made a case for the need to teach electronics technology from a system's viewpoint, but to this end, only offered general comments about how this was to be accomplished.

The author's use of the date of 2010 in the paper's title was symbolic in several ways. This date, five years in the future, was obviously the start of the next decade, a time when we humans tend to pause and reflect on the past decade and ponder the future events that the new decade will bring. Furthermore, the term "gigascale" (denoting a magnitude in the billions) actually referred to a prophecy by the International Technology Roadmap for Semiconductors (ITRS), based upon "Moore's Law", of the total number of transistors that the semiconductor industry believed that they would be able to integrate onto a single integrated circuit (IC) by the year 2010. This impending ability, to put such a vast number of active devices on an IC, would be the eventual catalyst for a paradigm shift in how technicians would deal with the electronic systems of the future. In terms of system maintenance, repair of electronic systems morphs into a type of "electronics forensics" similar in concept to the popular genre of television programs based on the original CSI (Crime Scene Investigation) series that takes place in Las Vegas, Nevada. The electronics technician evaluates system performance and deals with system problems by either replacing mal-functioning or defective sub-system components or up-dating or reprogramming system software to bring the system back on-line (see Figure 1below for the block diagram of a typical electronics system).

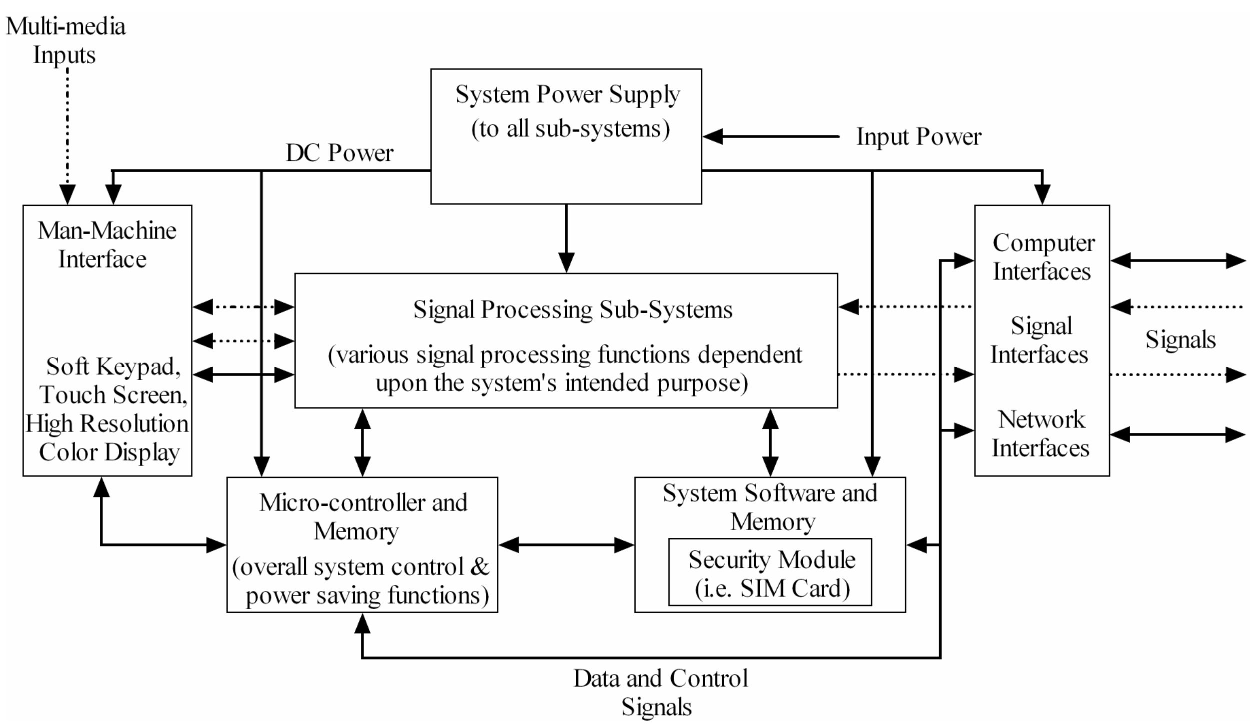
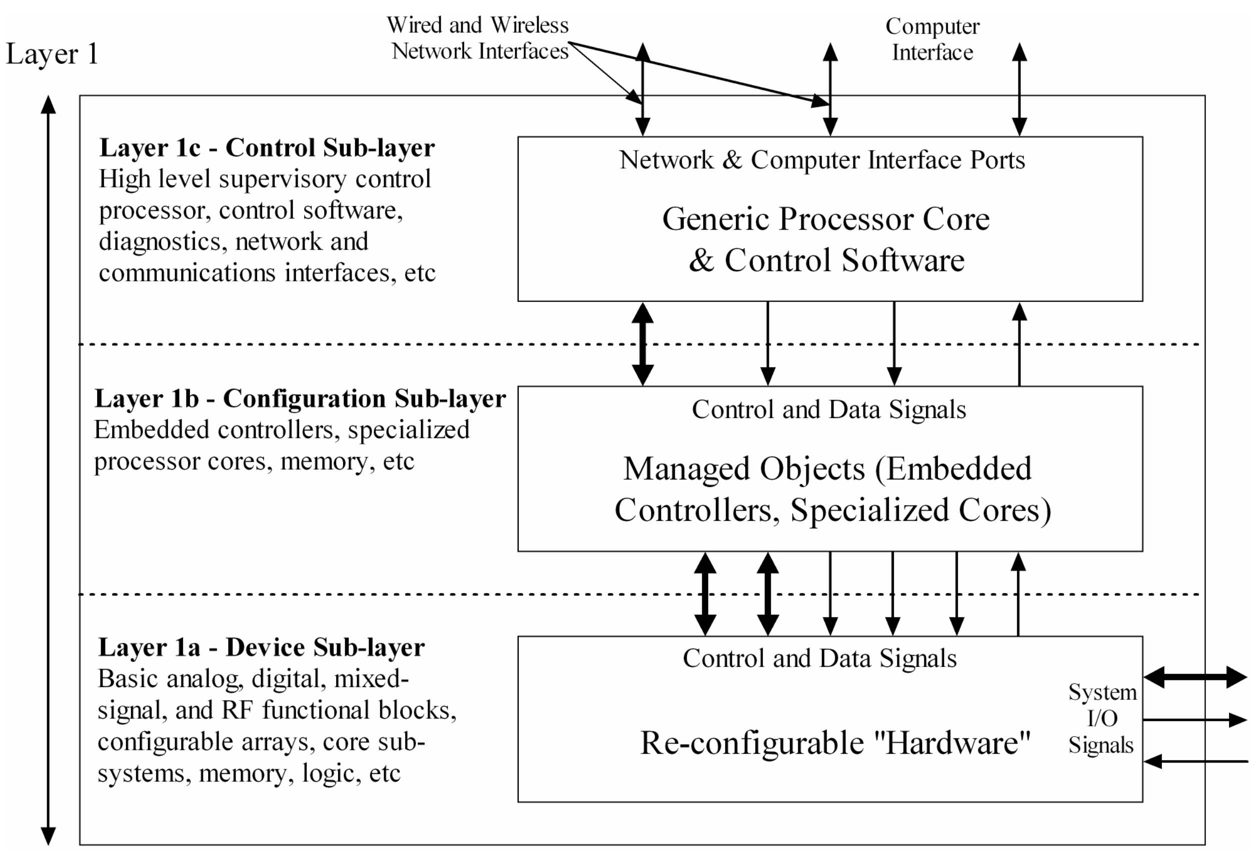


Figure 1 – Block Diagram of a typical modern electronic system (showing typical system sub-systems and the interconnections between them)

Surface mount technology (SMT), multilayer printed circuit boards (PCBs), and the on-going transition from board-level system technology to system-on-a-chip (SoC) technology have continued to make PCB repair to a part-level increasingly rare and eventually will render it obsolete in the vast majority of cases. In its summary, the paper pointed out a growing concern, on a nationwide basis, among many faculty, teaching at the two-year college level, that the traditional role of the electronics technician was in transition at best and becoming superfluous at worst. In a somewhat related fashion, at the four-year college level, concerns have arisen about the future of engineering education (albeit in a different context) and these concerns have resulted in the well publicized National Academy of Engineering's (NEA) report, *The Engineer of 2020*[2]. Unfortunately, at the associate degree level there has not been a similar meaningful summit of industry and education stakeholders to examine the state of the education of electronics technicians in today's rapidly changing technological environment.

Over the next few years, this same author delivered several other "position type" papers[3,4,5,6] that reported on a number of other observation about the electronics technology field and possible changes that might need to occur in the training of technicians due to the continued adoption of electronics systems by non-electronics based technology fields, the continued march towards the system-on-a-chip (SoC) paradigm, and the emerging trend of networking electronic systems. A common thread embodied in these papers is the notion of a multi-layer or stratified model of the physical layer[7] (shown as Figure 2 below) that this author contends is (or should be) a primary driver of future curriculum changes in the EET education area when considering the needed skill set of an electrical/electronics two-year college graduate.



The "new" Physical Layer - Re-Configurable Electronics Systems on a Chip (SoC)

Figure 2 – Mullett's model of the new Physical Layer (From: *The New Electronics Technology – Circa 2015*, Proceedings of the 2009 ASEE Annual Conference and Exposition)

This emerging hardware architecture has the ability to be reconfigured and communicated with (typically, through some type of network connection). This evolving ability of the physical layer of an electronics system to be reorganized to provide a different system functionality gives rise to cross-disciplinary skills needed by the EET student when dealing with these types of systems that involve networking and embedded control. It is now 2010, five years have past, and it might be an appropriate time to reflect upon what has actually occurred in the field of electronics technology and its potential impact on the education of future EET technicians.

For the past decade, researchers in many diverse fields have been exploring the possibilities of the use of sensor networks to perform a host of various tasks that in most cases are used to enhance the operation of systems. This emerging technology paradigm essentially consists of the deployment of complex sensors and advanced actuators coupled with embedded (ambient) intelligence. Combining this distributed ambient intelligence with modern data-transport and networking technologies and application-enabling software gives rise to new and potentially quality-of-life changing applications and in many already existing situations, the ability to increase system efficiency. Unfortunately, the high cost of deployment of such smart systems, especially if they are geographically dispersed, and the lack of appropriate standards involving various aspects of these systems has, to this time, prevented the widespread deployment and adoption of such systems. A notable exception to the implementation of this promising technology is the automotive industry and its extensive use of sensor networks within vehicles. However, in the automotive industries' case, the economic barrier of geographically large networks does not come into play and, to a great extent, emissions and fuel efficiency regulations have been the driving force behind the adoption of this technology. In the near future, further fuel efficiency and emissions regulations combined with safety initiatives will most likely extend the reach of vehicle networks beyond the vehicles themselves.

As the 2010 decade commences, several factors have combined to give applications of sensor network technology a boost. Advances in wireless networking technologies and the continued deployment of fixed and wireless broadband network systems by major telecommunications service providers, has put society another step closer to ubiquitous high-speed Internet access. Recently, with a new administration in place, initiatives in clean and renewable energy and efforts to improve the efficiency of our aging infrastructure have rapidly gained traction on both a federal and state level. Under the 2009 American Recovery and Reinvestment Act (ARRA), funding through the Department of Energy (DOE) for $36.7 billion dollars has been allocated to various energy related initiatives. The Office of Electricity Delivery & Energy Reliability (OE) has $4.5 billion dollars for Smart Grid and efficient energy transmission projects. Sensor network technology is the primary enabling technology for the Smart Grid and applications that it will enable.

However, if one examines the current curricula of most EET programs, they are predominately component centric in their approach to the teaching of this technology[8]. This gives rise to the question, where will the workforces for the Smart Grid or other network enabled complex electronic systems come from? As stated earlier, the Smart Grid is a complex system based on sensor network technology that will utilize state-of-the-art networking technology and electronics sub-systems that typically are impossible to repair to the part level. The skill sets needed by the technician dealing with the Smart Grid are not those being taught in a component centric curriculum. The previously mentioned DOE "jump start" of the construction of the Smart Grid just might be the push needed to transform EET education at the two-year college level.

A Sensor Network System Example – The Smart Grid

Just what is the Smart Grid? There are many levels of deployment to the Smart Grid and at this time no single definitive architecture. In theory, a Smart Grid is really a service platform that will help to reduce energy consumption and greenhouse gas emissions. This service platform will drive optimization, improve utilization and efficiencies, and enhance the reliability of the nation's transmission and distribution infrastructure. Furthermore, it will allow the interfacing of green, cleantech sources (i.e. alternative energy) and energy storage systems to the grid. At the simplest level, on the consumer side (known as customer facing functions), a Smart electric meter (e-meter) can be installed that allows for the simple disconnection of service at the meter, controlled by a signal from the distribution system or power supplier. At a much higher level, a Smart meter with communications links to the customer and various energy consuming devices in the residence in conjunction with energy management software tools can allow the consumer to control their energy usage and costs. In between, or in conjunction with the last case, is the scenario where the electric power supplier remotely controls thermostats and other energy consuming devices in the residence. Other Smart Grid functions that deal with the distribution system and alternative energy sources are termed "distribution grid-facing functions" by the power industry. Included in this class of functions is the remote monitoring and control of the distribution grid and anything connected or interfaced to it. Most of the technology required to build the Smart Grid already exists. A typical Smart Grid architecture with all its envisioned parts is shown here as Figure 3.

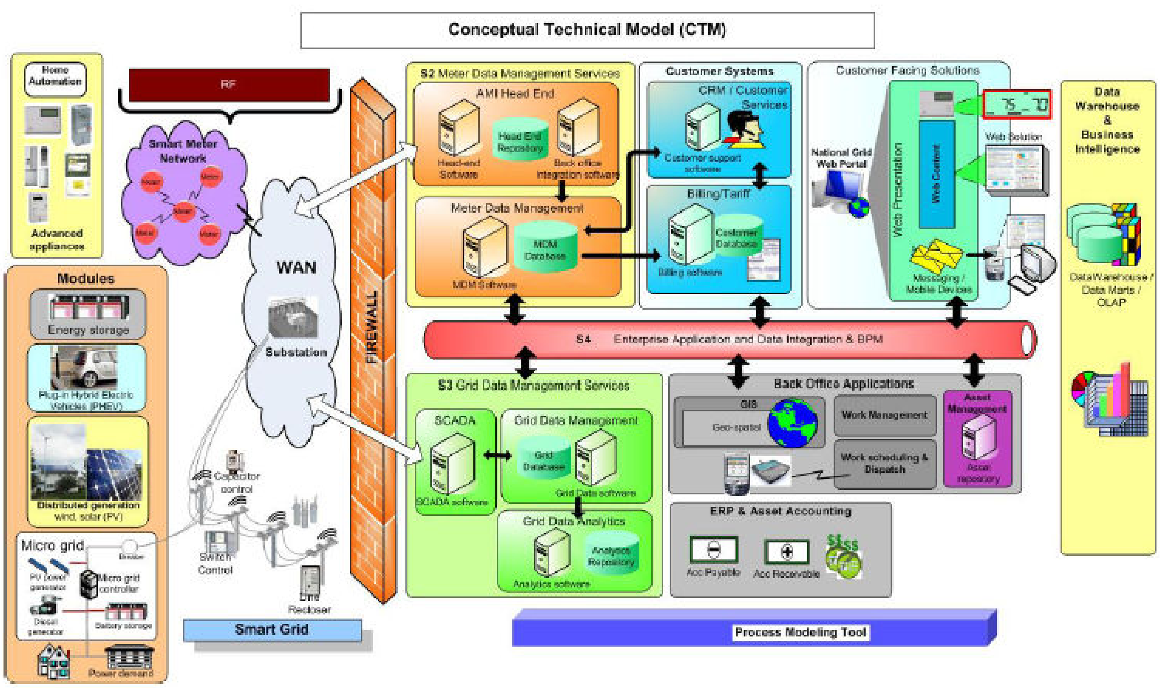


Figure 3 – Conceptual technical model of the Smart Grid (Source National Grid - Proposal submitted to Rhode Island Public Utilities Commission – Smart Grid Pilot Program[9])

At the present time, we are only at the infancy of the Smart Grid and it will take some time (years) before experience with the system will be translated into turn-key applications. However, the potential to provide energy savings is real and significant. Some have predicted that once installed, this technology could save 10-15% of the energy presently being used in this country.

How is the Smart Grid implemented? To implement the Smart Grid requires that a two-way communications system is overlaid on the electric grid. This network must have both the speed and capacity to enable advanced metering, home energy automation and management, distribution automation and management, and the interfacing of distributed generation and energy storage. Furthermore, home area networking (HAN) technology, another emerging area, is needed to enable the consumer facing applications and SCADA (supervisory control and data acquisition) is typically needed for distribution grid-facing applications such as the integration of alternative energy sources onto the grid[10].

Required Skill Sets

So, just what are the skill sets needed by the electronics technician to deal with this developing type of technology? The EET that graduates in this decade will most likely still need to have a knowledge of basic fundamental DC and AC concepts, be aware of signal characteristics, and have the ability to use instrumentation and make measurements. Additionally, they will need to be knowledgeable about: embedded controllers and have the ability to interface signals to these devices (i.e. a familiarity with sensors, actuators, A-to-D and D-to-A converters, amplifiers, filters, etc), basic networking systems, wireless technologies, system structure and operation (i.e. programming, operating systems, electronic system building blocks), and the ability to perform software diagnostics/downloads coupled with electromechanical skills and dexterity with small hand tools. Like today, in the future, system failures will still occur due to interconnection problems and power supply failures (refer back to Figure 1) and the technician will still need to be able to deal with these issues.

Towards the end of this decade, one might want to drop the term “electronics” in EET and replace it with systems or at least add the term systems to the title (i.e. ESET). A systems engineering technology (SET) degree might more accurately reflect the skill sets needed by the person that deals with the electronics based systems of the future. Furthermore, this technician of the future will most likely be equipped with a handheld, web connected, multi-purpose “electronic measurement /diagnostic toolkit” as opposed to small hand tools! The need for a soldering iron with today’s and tomorrow’s reliance on surface-mount technology, multilayer printed circuit boards, and system-on-a-chip technology will be extremely rare! Not to be overlooked, hand-in-hand with the evolution in technology is the need for the technician of the future to have the soft skills necessary to deal effectively with the end users of technology and/or the team that makes up the group with overall responsibility for the design, manufacturing, sales, and updating/maintenance of sophisticated electric/electronics based systems.

While soft skills have been a buzz word in the United States for some time (since the late 1990s), the European Union has more recently undertaken a program of change (*Education and Training - 2010*) to incorporate more of these soft skills into their post-secondary technician education system and to move towards a student centered approach to teaching[11] that focuses more on outcomes and competencies and promotes a culture of life-long learning for all citizens. Smart Grid technology is a world-wide initiative and intelligent infrastructure enabled by sensor networks is not limited to projects in the United States. It is unclear in this author's research whether or not a systems approach has been at the center of any discussions associated with the European Union initiative. Recently, there seems to be more international conferences on engineering and technology education. This is a good development, but international collaborations of faculty are much more typically found at the four-year level than at the associate's degree level. International collaborations at the two-year college level that could foster curriculum innovations are certainly lacking at the present time and unless there are more government sponsored initiatives to promote this type of faculty activity this will probably remain the case for some time.

How can we prepare for and implement change?

A recent survey of over sixty ABET accredited electrical and electronics associate degree programs reveals that the vast majority (over 94%) of these programs still teach the classical component oriented fundamentals courses (i.e. two circuit theory courses (DC and AC), two analog electronic devices courses [sometimes three], and a digital devices course). What has changed somewhat in the programs is the earlier introduction of a digital logic course in the sequence of courses, but what has not changed is the emphasis on components as the focal point of the courses. As components are reduced in importance, due to evolving technology, these legacy style courses lose their relevance to the real world that will greet graduates of these programs if they indeed join the workforce upon graduation. How do we get from where the typical electronics technology programs are today to where we must go if we are to maintain relevance to the workplace? The answer is fairly simple, by morphing our EET programs from a component based focus to a system oriented emphasis, however that is easier said than done!

Of course, we can not totally disavow the existence of electronic parts and components but we just don't have the luxury of spending a great deal of time on individual components unless it is in a laboratory or project based setting. The bulk of circuit design should be left to the electronics system designers not technicians. If EET programs continue to place theoretical focus on the components, one loses the big picture of the systems that they are part of. Today, electronic components are arranged into basic building blocks and connected together to create more complex systems that eventually are marketed as products. These electronics systems are eventually headed towards architectures of digital cores and/or processing centers surrounded by interface circuitry (i.e. ADC and DAC, voltage and power level converters and drivers, etc). This being the case, the product's system functionality is what needs to be emphasized. A basic active device, the transistor, if properly configured through biasing, can be made to amplify or switch signals among other things. But, in today's era of disposable electronics, what is more important for the EET student to learn, the correct way to bias a particular device (component level operation) or the concepts of frequency response and/or the gain of the resulting amplifier sub-system (system level concepts)? Another case in point is digital logic. Today, the technology of field programmable logic arrays (FPLAs) is mature and these digital cores have basically made 7400 series logic obsolete (that is, unless one looks at a typical textbook about this topic). As previously pointed out, the question of component level versus system level becomes even more pertinent in light of the technician's increasingly difficult task of physically accessing a transistor or a particular component or sub-system integrated within a system.

More of the EET curriculum should be focused on activities and projects that involve practical systems. Starting with structured activities/projects and simple systems to more open-ended projects and more complex systems, the future EET curriculum should prepare the program's graduates to deal with typical electronic systems. Furthermore, the program focus should be on giving the students experience with the evaluation of system performance and hands-on activities that allow the student to deal with the system through software and network interfaces (e.g. embedded controllers and FPLAs, etc). At Springfield Technical Community College (STCC), we have recently moved our Electronics Systems Engineering Technology (ESET) program in this direction by adding courses in embedded control, networking, and sensor systems. Our newly modified ESET curriculum (with course descriptions) is detailed on the college's web site[12]. Due to the recent implementation of these curriculum changes, no data to support or refute the effectiveness of this approach is available yet except for encouraging anecdotal accounts from recent graduates concerning their workplace activities.

Recently (January, 2010), the EET faculty curriculum group associated with the collaborative Verizon NextStep Program[13,14] took a large step in this direction when they essentially revamped a typical analog devices electronics course that formally had a heavy emphasis on Op-Amps as the basic active device building block component. In an effort to provide the Verizon employees enrolled in this associate degree telecommunications program with a course that would be more reflective of their world-of-work and at the same time provide them with a useful course on maintaining and troubleshooting electronic systems used in the telecommunications industry, a course titled "Electronic Systems" was conceived by the group and is in the process of being developed for implementation in the Fall of 2010. Furthermore, at the same curriculum meeting, the telecommunications faculty group approved a new course in "Home Automation and Networking" in an effort to address the perceived applications of the future to be enabled by high-speed broadband Internet access (provided by Verizon or others). The electronics systems course, as it is organized, is systems centric (the course outline is available at www.nspinfo.com) and addresses the sub-systems of modern electronics systems as depicted earlier in Figure 1. This diagram indicates that the typical electronics based system consist of basic sub-systems like the power supply, sub-system control, the man-machine interface, signal processing sub-systems, memory and processing cores, I/O interfacing, network interfaces, etc. These are the topics that the course will be built around with individual components viewed as the core building blocks of these sub-systems (i.e. amplifiers, filters, logic sub-systems, etc).

Presently, there is no known textbook that has been published that would be appropriate for this course and therefore support and text materials will need to be created (a systems-centric text is in process by this author). It should be noted here that the available texts, typically used to teach legacy electronics technology, will need to be revamped fairly significantly if this transition to a systems approach is to happen. However, one might note that the most popular circuit theory, analog electronics, and digital logic texts are all component oriented and all seem to be in their 8^{th} through 10^{th} (and beyond!) editions. These texts have become very high margin, profit centers for the textbook publishers and they will not fade away willingly! Hopefully, in this age of electronic publishing some ambitious souls will lead the way with textbooks about these same core topics that will be written from a systems oriented perspective.

Conclusions

In conclusion, electronics technology has always been one of the fastest changing technologies and today continues to morph and evolve in some ways that are easy to predict and in other ways that are not so easy. For many years, these changes, driven by the evolution of semiconductor manufacturing, have provided a steadying influence on the field because it was easy to predict how technology would improve in the next several years in a particular sub-discipline of the field. The industry was driven by a predictable increased capacity and speed in a component oriented technology and the educational programs appropriately reflected this fact. During the last century, the invention of new devices was the driving force of technical change in the electronics industry. During the early years of this century, the implementation of complex systems combined with the communications capabilities afforded by the Internet and mobility enabled through wireless technologies will be the primary drivers of technical change and this should be reflected in our technology curriculums.

Today the electronics industry is again on the threshold of another paradigm shift with the current and future levels of semiconductor, MEMS, photonic, and nanoscale device integration that are becoming possible and the convergence of these system-on-a-chip technologies with data communications facilitated by the Internet. The Smart Grid is but one, better known, example of an emerging application of this converged technology. Recently, during a keynote address at the IEEE 2010 Consumer Communications and Networking Conference (CCNC), Dr. I. P. Park, Vice-President and Director of Computer Sciences Laboratory, Samsung Advanced Institute of Technology, Samsung Electronics outlined what he believes the path will be to eventually bring us to what he has coined as the "life web"[15] as applications of the Internet continue to evolve and as a consequence involve closer interactions between it and mankind. This term refers to the day when all consumer electronics devices are connected to the Internet and data from various sensor networks is routinely mined and available for the creation of new information and applications that will be accessible to humans through various unobtrusive, immersive interfaces.

As surely as this evolution of the web will affect how society works, plays, educates, and cares for its elderly, it will also have an ever increasing effect on EET education. The electronics technician of this decade will not need to be an expert in the building or repairing of circuits but will instead need to be able to evaluate system operation and performance through their knowledge of the system's intended function and a further knowledge of its acceptable parameters of operation. This system evaluation might take place *in situ* but, more often than not, could be accomplished through a network connection from anywhere in the world at anytime and facilitated through diagnostic software and sophisticated built-in-self-test (BIST) at both the sub-system and system level. EET programs with curricula that does not respond to this changing environment and become systems oriented with an emphasis on system interfacing and networking communications are doing their students a disservice. On the other hand, forward-looking EET programs that embrace the teaching of electronics from a systems approach, craft their curricula carefully to be systems centric and hands-on, and embrace new teaching techniques that give their students the skills to become life-long learners will be preparing their students for the technology of the future. That technology will be here sooner than we think.

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