What is Electrical Engineering Today and What is it Likely to Become?

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Abstract - This paper takes an introspective look at electrical engineering as it exists today and poses several questions about the future of EE. While traditional EE departments have been adding computer engineering and/or science degrees and expanding their titles to include the word computer, not all students want to do computing beyond what is essential to their specialty. So what is EE, as distinct from computer engineering, and what is its future? We address this question by examining it from the perspective of university EE programs and the needs of industry and society. As a result of our investigation, we also develop a definitional set of broad areas and specialties that define EE, both now and in the future. We conclude with a recommendation to give EE more curb appeal for prospective students. The perception of service to society is important in attracting students. EE has historically been critically important to society. If whatever form EE takes in the future continues to be of critical importance, we need to be able to convey this to prospective students and attract them to the field.

Index Terms – Electrical engineering, electrical engineering education, history.

INTRODUCTION

We stand at a point today where a fair question is, Just what is electrical engineering? Not electrical and computer engineering or other variants involving computing in the name, but just plain electrical engineering or EE. Some may say it is no longer a relevant question because EE has indeed morphed into electrical and computer engineering or the like. We think the evidence shows otherwise, that EE is a vibrant field, one that is essential to the future of the United States. Moreover, EE needs to be better sold to prospective undergraduate students if we are to do anything to meet the need for future US engineers and maintain US superiority in technology.

The name of a department does not necessarily reflect the actual degrees being offered; our own department offers three distinct undergraduate degrees in electrical engineering, computer engineering, and computer science. This paper is not about department names or curriculum construction. It is rather about what makes EE a field and how to better promote that field to prospective students.

We approach this problem from a number of points of view, starting with history. We then look at industry needs and what different universities are doing with defining EE and the various sub-disciplines.

HISTORY AND TRENDS

Electrical engineering has a long and distinguished history going back in actuality as far as one wants to go all the way to the ancients. Once the electrical industry started to develop, two separate disciplines, power engineering, which was called electrical engineering, and radio or electronics engineering grew rapidly [1]. One dealt with the generation and distribution of electric power and the other dealt with radio, radar, and television and all things built with electric circuits, tubes, transistors, and ultimately microcircuits and communicated via electromagnetic waves. In the United States, the creation of the IEEE as a merger of the American Institute of Electrical Engineers and the Institute of Radio Engineers in 1963 brought the overlapping fields together. Hence in the US, the term electrical engineering is often used to include both the traditional power field as well as the electronics engineering field. We will follow this terminology and refer to the field simply as electrical engineering. The advent of the computer has brought computer engineering and computer science into the fray, but again we are referring to electrical engineering as distinct from say computer engineering or electrical and computer engineering.

The history of the field presents a good starting point for defining EE today and into the future. For example, the whole field of power engineering including the use of alternative sources of energy remains a solid subfield of EE. Perhaps more than any other subfield, the attractiveness of the power field today and the opportunity to have a positive impact on society makes it something that we electrical engineers should be embracing and promoting. Society desperately needs innovative power engineers.

The other dominant historic subfield is electronics engineering and/or radio engineering. Even though we build radio circuits with digital signal processing components and software rather than discrete components and transistors for example, it is important that EE’s retain their dominant role in this area. Not only is microelectronics a key subfield of EE but so is signal processing or, if you like, signals engineering. However we do convolution and Fourier
Transforms in communications, it is still an EE domain. And at the heart of radio engineering is the whole field of electromagnetics, RF engineering, and optical engineering. So signals engineering, microelectronics, electronics in general, electromagnetics, optics, and telecommunications help define EE.

Out of World War II, the importance of radar, control systems, and instrumentaion all emerged. We often do not encounter a control system in the classical sense of, say, a manufacturing plant, but we nevertheless use control systems in, for example, phase locked loops in communications and the many applications of Kalman filtering, a concept straight from EE control theory. It perhaps might be better to broaden the term control systems to general systems theory, but it has historically been the electrical engineers that dominated the complex systems engineering field, and we need to retain this leadership.

Instrumentation today involves sensors and transducers, for example, and remains important. Again, electrical engineers have had the lead in instrumentation and should retain it.

And so what about computers? Electrical engineers, like all engineering disciplines, use computers to do their work. This is first and foremost the job of EE education, to ensure that students have all the right tools and know how to use them to solve EE problems. But there is one aspect of computers that is unique to the EE; we build much of the parts of a computer. Now the computer engineer is the one who builds the machine in collaboration with computer scientists and mechanical engineers, for example, but microelectronic engineers and others do build parts of the machine. But if you want to build computing systems, then we suggest you become a computer engineer and if you want to build computer software we suggest you become a computer scientist. And if controlling electricity, electronics, signals, and systems for the benefit of society fundamentally motivates you, then you should become an electrical engineer.

We are seeing in many cases computing courses crowding out the more traditional EE courses. There is a need for example for RF engineers, but many universities have moved away from this area and substituted “more fashionable” courses in computing [2]. This is a disturbing trend that needs addressing. Again, we believe that a part of dealing with this issue is to recognize that EE is a viable field that uses computers as other engineering disciplines do and builds components for them but doesn’t engineer computers or software themselves.

There is an urgent need to increase the number of engineering students in the United States if we are to retain a leadership role in technology [3]. While governments need to address this issue through scholarship funds, etc., we engineering faculty need to do our part as well. Engineering needs to be better promoted to prospective students. Societal impact is important. But in particular, we need to address electrical engineering as a field and point out the benefits to society that can come from being a EE. When women students shy away from electrical and computer engineering because “computers are ‘just so geeky,’” [4] we should be pointing out that electrical engineers just use computers like other engineering disciplines (most other professions for that matter) rather than letting EE be associated with any negative side of the image of computing.

**INDUSTRY AND SOCIETAL NEEDS**

The US Department of Labor documents trends in employment in many fields. Their most recent table is notable in several ways [5]. First of all, electrical and electronic engineering is listed as a separate field, distinct from computer hardware engineering or any of the computing disciplines. It shows that EE is projected to grow by over 5% by 2016, a modest growth but certainly not a field that is going away. Among the projected growth areas, both percentage-wise and numerically, in EE are:

- Wireless telecommunications (36%)
- Waste management and environmental remediation (28%)
- Professional, scientific, and technical services (27%)
- Wholesale trade (electrical and electronic devices) (15%)
- Management (15%)

Areas that are projected to decline are:

- Wired telecommunications (-15%)
- Manufacturing (-10%)
- Federal government (-5%)

The manufacturing decline includes a projected 13% decline in semiconductor manufacturing. This is in contrast to the picture painted by leaders of the industry who project a continued need for good microelectronic engineers [6]. There is also an argument that the federal government maybe unable to fill its need for engineers over the next 10 years because of a large number of pending retirements [7]. This is not necessarily in disagreement with the USDoL projected decline in federal jobs for electrical engineers. The *Prism* article also points out that the biggest need in the federal government will be electrical engineers in the Department of Defense.

Some interesting and significant information appeared in a 2004 Money magazine/CNN survey [8]. The survey showed that among all college degrees, EE ranked fourth among bachelor’s degrees, second among masters degrees, and first among doctoral degrees. Computer science and computer engineering were also among the top degrees on the three lists with computer science ranking third on the bachelors degree list. This particular survey is another demonstration that EE as a freestanding field remains in strong demand.

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THE SITUATION AT OTHER UNIVERSITIES

Electrical engineering core requirements for 15 of the top 20 schools – as assessed by U.S. News and World Reports – were examined [9]. Although there was quite a bit of diversity in the core requirements, there was some notable common ground. For example, all schools had core requirements that included the following subjects (parentheses indicate the number of schools, out of the 15 examined, that stated the requirement):

- Electromagnetics (14)
- Circuits (12)
- Electronic or Semiconductor Devices and Lab (13)
- Signals and Systems (15)

To a lesser degree, the following subjects were required:

- Probability (6)
- Computing and Programming (8)
- Design or Capstone Project (9)
- Digital Electronics (10)

Two other traditional electrical engineering subjects – controls and materials – were essentially absent from the list of core courses. In most cases, the requirement for material science is satisfied by a required physics course, and control engineering is available as an elective. On the other hand, some schools chose to insert into their core courses that are generally considered as electives by most schools. Most notably, telecommunications and microcontrollers were included.

A DEFINITION OF ELECTRICAL ENGINEERING

There are certain broad areas that are important to EE across the board. In addition, there are prominent specialties that many may consider a subset of one or more of the broad areas, but they are notable in that they are distinctively EE. We propose the four following broad areas that are fundamental to EE (in no particular order):

- **Electromagnetics and Optics:** The entire field of controlling electromagnetic phenomena, electromagnetic waves of all frequencies, including optical, are clearly the domain of the electrical engineer.
- **Signals Engineering:** The processing of signals that historically have been generated by electrical or electronic devices and electromagnetics remains a critical domain of the electrical engineer. Where once the signals were processed by analog devices and continuous time mathematics, today digital signal processing dominates. Many signals today are important in bioengineering.
- **Systems Engineering:** By this we mean solving complex problems that can be modeled by, in general, complex calculus based matrix mathematics.

Historically, this included such things as state space equations, convolution, mathematical transforms, minimization/maximization problems, etc. whether analog or digital. In particular linear system theory has been a cornerstone of advanced electrical engineering work, and we should retain the ownership of it. The interdisciplinary nature of the world today makes systems engineering indispensable.

- **Electronics, Microelectronics, and Circuits:** This all-encompassing field has long been the domain of the electrical engineer. The understanding of this area remains important, and competent electrical engineers, even if they are not designing circuits, still need to know how circuits work. The semiconductor area still needs competent electrical engineers, and there are predictions of a bright future for engineers in this area [6]. Power electronics is important to the electric power industry. Photonics is here to stay. There is demand for consumer electronics, avionics, navigation, vehicular electronic systems, and computer components.

The four specialties we propose are listed below. Again, some may contend that they are subsets of the above broad areas, but that is fine. These specialties in particular help characterize EE.

- **Telecommunications and Radar:** This is the specialty that has evolved from traditional radio engineering, and includes wireless communications, radar, remote sensing, networks, wired communications, information theory, error correction coding, detection and estimation theory, etc. Today, telecommunications is playing a larger and larger role in medicine and radar is helping us understand climate change. Where once all radio devices were constructed with analog electronic components, today much of the signal processing is done with software. However, it doesn’t matter how the systems are constructed; it is still telecommunications and radar and the domain of EE.
- **Electric Power Systems:** The generation and transmission of electric energy including alternative sources of energy and the impact on society and the planet is an important part of EE. Although not many EE programs offer power emphases anymore, we propose that at a minimum a set of power electives should be available. This is clearly an area where future EE’s can help make a difference in the world, and it is also an area where an interdisciplinary approach is crucial, e.g. economics, network theory, political science, law, etc.
- **Instrumentation and Control:** Both instrumentation and control systems are classic domains of EE. Much of classic control theory is an integral part of what we have labeled systems engineering, so the heavy mathematics may more appropriately belong there. With instrumentation, we deal with transducers. The signals today may be represented digitally, but we feel that...
transducers, the building of these devices, and the processing of the signals remain the domain of EE. This specialty also includes robotics. And one notable EE contribution, among a number, to the biological revolution is in the area of medical instrumentation.

- **RF Engineering:** This again is a classic specialty of EE, and good RF engineers are in demand. The specialty includes antennas, receivers, transmission, and the RF portion of telecommunications and radar.

**PROMOTING ELECTRICAL ENGINEERING**

As we have said, it is vital that the US attract more engineering students including electrical engineers. The way those of us who went into EE in the 1960’s and 1970’s by being attracted to the fun of electronics and tinkering with electricity won’t necessarily work today. Waving a cell phone and saying, “You can build these things,” is not necessarily a way to attract today’s student. We need to get away from talking about the devices and move to how EE can change the world. A good example of how not to promote electrical engineering can be found in the recent otherwise excellent ASEE Engineering, Go for It publication intended to promote engineering to students. The description of EE is frankly unexciting [10].

A particularly good example of a positive way to promote EE can be found at the Georgia Institute of Technology [11]. Instead of playing the “gizmo card,” Georgia Tech promotes their program with words that talk about the “so what?” For example, among the things that they tell prospective students that they might be doing after graduation is, “producing imaging techniques that diagnose diseases like cancer.” Another bullet says, “providing solar energy systems to communities that exist without electricity.” We need to inspire prospective students with the feeling that they can truly make a difference to society, and then educate them so that they can.

**CONCLUSIONS**

The conclusions reached by the committee that wrote the report Rising Above the Gathering Storm [3] are frankly scary. In the midst of this, besides the recommendations of the committee, we find ourselves at a point where electrical engineering, one of the key lynchpins in the technological success of the United States during and since World War II, is no longer the favored subject of most of today’s bright student. This is not to say that EE students are not bright students…they most assuredly are…but too many additional bright students are choosing other fields, not just other engineering disciplines, but areas outside of engineering and the physical sciences such as law and finance. We think it high time to reassert EE as a dominant engineering field and to promote EE to prospective students as a way to make a difference in the world.

**REFERENCES**


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