Microwave Engineering Education

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Exploring some of the history, current trends, and what the classroom of the future may look like.

Abstract

According to recently released statistics by The Alliance for Science and Technology Research in America, slightly over 25 percent of high school students in the United States are interested in Science, Technology, Engineering, Mathematics and Statistics (STEM). According to the US Department of Education the percentage of bachelor's degrees conferred in STEM fields in the United States was lower in 2008-2009 (24.2 percent) than it was in 1998-1999 (25.6 percent). Engineering education and particularly majors in microwave electronics have gone through significant change in the past 60 years. Our *High Frequency Electronics* Editorial Calendar for April 2013 includes the topic of Engineering Education. Having an increasing interest in this general topic and having both taken and taught courses in microwaves, I decided to tackle this topic. This article explores some of the history, current trends, and what the classroom of the future may look like.

At the Campus Bookstore

The first textbooks available for the budding microwave technology field, which was often considered more of an art than a science in the middle of the 20th century, were 1) the incredibly comprehensive and still useful 28 volume *MIT Radiation Laboratory Series,* 2) a book titled *Waveguide Handbook* edited by Nathan Marcuvitz which famously became Volume 10 of the Rad Lab Series, and a few others such as 3) *Theory and Application of Microwaves* by Arthur Bronwell and Robert Beam, 1947. Interestingly, Dr. Marcuvitz died at age 96 in 2010, so he got to see and experience incredible advances. The addition of circuits with distributed constants in Fred Terman's *Radio Handbook* is certainly noteworthy. As time went by a number of contemporary textbooks became available such as *Foundations of Microwave Engineering* by Robert E. Collin, 1966; *Microwave Engineering Passive Circuits* by Peter A. Rizzi, 1988; and *Microwave Engineering* by David M. Pozar, 3rd Edition, 2004. The latter book, originally published in the 1990s, is widely used today. Numerous books devoted to specialized technology within our field have been published over the years. I would guess that active microwave amplifier and oscillator devices would top the list, including lots of material devoted to monolithic microwave integrated circuits (MMICs).

Prerequisites

The problem with many current EE curriculums is that only one Emag course is required. One reason that students hesitate to take other electives in this area is because they are intimidated by the mathematics. Defense-centric companies do little to promote their work and therefore students are generally unaware of the excitement and fulfillment derived from designing and building a radar system, satellite hardware, MMICs, antennas, etc. They generally pursue digital and computer courses, thinking perhaps if they go down another path they will miss out on the lucrative future opportunities. Now that A/D's are sampling at 5 GHz and higher, digital technology will play a large role, but there has to be an understanding that signals travelling on the digital signal lines are at GHz frequencies and hence a good knowledge of microwave transmission lines, radiation, noise, and signal isolation will be required. Most credible microwave courses require prerequisites, in addition lots of basic math and physics courses, such as Electro-Magnetic Fields and Solid State Device Physics. Because of heavy emphasis on materials technology and semiconductor foundry activity since the 1980s, there may be a necessity for materials science and chemistry courses, also. A downside is that a number of schools have dropped microwave engineering courses or relegated them to post-graduate status. The reasons are not clear, but likely the lack of interested students coupled with relatively high costs, particularly in maintaining laboratories, are factors.

There are approximately two dozen schools in the United States that offer microwave courses in the undergraduate curriculum. Examples are Ohio State University, University of Illinois at Urbana-Champaign, Penn State University, Georgia Tech, Arizona State, University of Colorado, University of Massachusetts, University of Mississippi, and the University of Michigan. There are very good schools worldwide with some emerging opportunities now in places like Brazil, India, and China. Schools offering both undergraduate and graduate level courses worldwide (not complete) can be found at:

http://www.microwaves101.com/encyclopedia/colleges.cfm

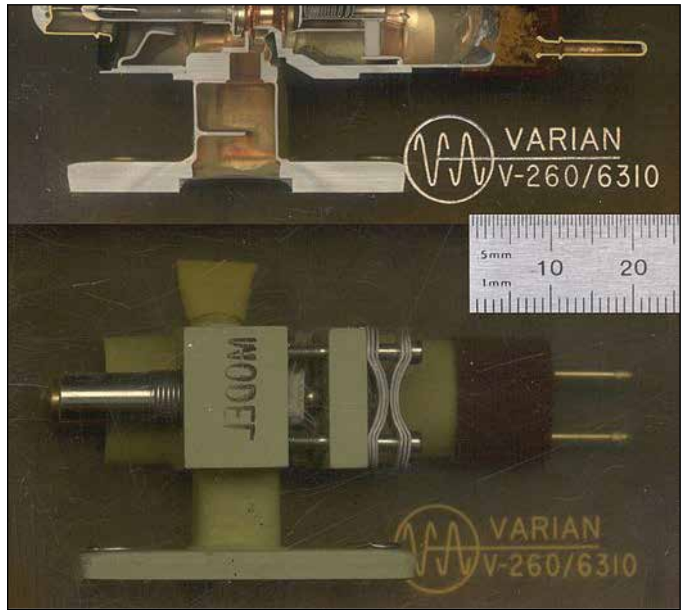

Figure 1 • Reflex klystron including cutaway view.

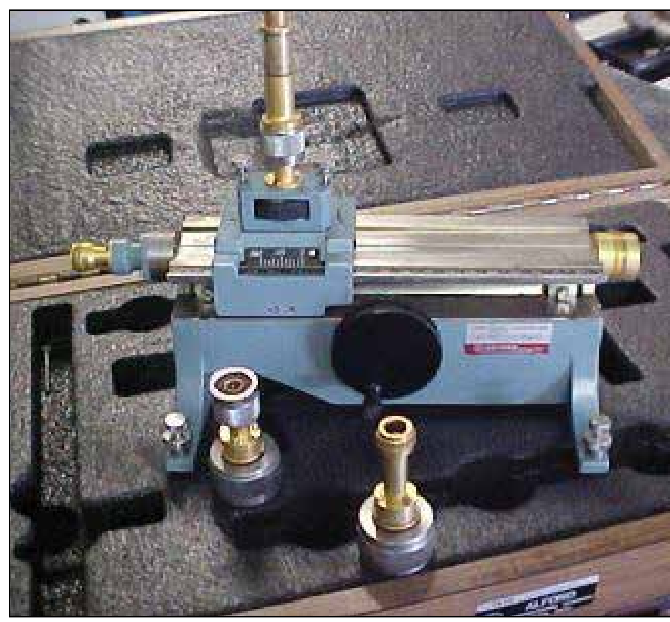

Figure 2 • Alford Model 3300 slotted line.

Example of a Comprehensive Study Program

The University of Michigan at Ann Arbor, has traditionally offered many in-depth courses in our field. The University of Michigan offers fundamental courses such as Microwave Circuits I focusing on CAD tools, passive and active circuits and use of modern laboratory equipment. CAD software providers often provide universities with free programs recognizing that the student user will grow into and request the products in the work environment later. The same goes for test equipment which is sometimes offered to institutions at a reduced rate or even donated.

Years ago this was often not the case. Labs were usually equipped with left-overs and discarded equipment even going back to WWII surplus gear. Not necessarily a bad thing—I once took advantage of the fact that I had worked with klystrons (Figure 1) in college. In the early 1970's, I was asked to make some time-consuming phase shifter measurements for a new project. All the then-modern microwave signal sources (like Alford sweepers) were in high demand. So I spotted a klystron with its somewhat draconian power supply on the shelf, hooked it up, and made my measurements. No one bothered my set-up for weeks, because most didn't know what it was—or maybe were afraid of high voltages. Speaking of old equipment, I have found that many recent graduates of microwave curriculums seem to have no idea of what Lecher wires or slotted line (Figure 2) is. This is a bit unfortunate because basic laboratory devices give one a "visual" feel for standing waves and related phenomenon. The Smith Chart may be going the same way.

Now back to the University of Michigan example. They have a Radiation Laboratory (RAD). Quoting from the University's webpage:

"Areas of focus include antennas, from HF to terahertz frequencies; computational electromagnetics and modeling techniques; electromagnetic wave interactions with the environment; microwave and millimeter remote sensing; plasma electrodynamics and space electric propulsion; polarimetric radars and radiometric imaging; radar scattering computations and measurements; radio wave propagation predictions for mobile communications; RF and microwave front-end design for wireless applications; RF integrated circuit design; and RF/ microwave and millimeterwave micromachined active and passive components and subsystems; Terahertz electronics and applications; optically-assisted millimeter-wave integrated circuits; low-temperature plasmas; laser physics and spectroscopy; plasma chemistry; plasma and photochemical materials processing; amorphous thin films; pulse power plasmas; environmental applications of plasmas; fundamental electromagnetic theory; engineered electromagnetic structures (metamaterials, frequency selective surfaces, electromagnetic bandgap structures); antennas; plasmonics and near field optics and imaging."

Obviously the cost for all this is significant and may explain why some schools have dropped actual hands-on laboratory activity completely from their curriculum.

Coming of Computers

Starting over four decades ago, computers have had an impact on how and what is taught in engineering programs at the college and university level. No longer does a student have to walk to some remote campus computer building with no windows – yes, pun intended - to submit punch cards for processing in an IBM 1620 or similar system. Now we have portable devices that can be taken virtually anywhere that have far more calculating power than imagined back then. We can access just about any information instantly, greatly eliminating the need for a conventional book library. While technology has made incredible advancements that impact most people's lives, the use of this technology in engineering education offers a great challenge. Students can perform significantly complicated calculations accurately in a very short time with fantastically high fidelity visual data results. RF and microwave courses compete for funding and students with more popular computer courses and other technologies such as medical electronics, nanotechnology, robotics, etc.

Analytical tools have improved significantly over the past ten years. Finite Element analysis, which was mechanical engineering's foremost analysis tool, made its way into the microwave/EM arena. This has made possible the design and then simulation of devices. The advanced adaptive meshers and matrix solvers in combination with the large computer memories have driven the development of tools such as ANSYS HFSS, FEKO, Microwave Office™, Sonnet, CST and COMSOL, to name a few, for microwave EM analysis. Without these tools, the development cycle of new circuits and devices would be much slower and therefore more expensive.

Modern Classroom Amenities

Classrooms of old were typically equipped with black or green chalkboards, chalk, and erasers. Now they are equipped with white boards, computer projection systems, internet connections, and Wi-Fi services. Even more recent are electronic white boards with lecture capture cameras. According to Dr. Robert Henry of the University of New Hampshire, these amenities introduce higher costs, including 3 to 4 year replacement cycles for hardware, cost for new software, more square footage per student, more initial course development time, training faculty in use of the equipment and software, and additional IT support personnel. Students often bring devices such as iPods, laptop computer, and smart phones into the modern classroom. Resources now available include electronic textbooks, Wikipedia, YouTube, search engines, Skype, and free content lectures on radar, electronic warfare, LTE, etc.

Instructional Delivery

Prior to the advent of electronic media, it was generally accepted that face-to-face delivery was the best method. Increasingly, we now have on-line delivery augmented by incredibly well orchestrated graphics and possibilities for demonstration of wave motion, electron flow and other realism. Blended means for instruction are now a strong possiblility. The actual classroom experience and opportunity for questions is still hard to beat. We will likely see a progression from less use of the white board to more use of PowerPoint slides and animated videos. Use of programs like Blackboard (ironic name) can provide the student with posted class notes, assignments, solutions, electronic submission of homework, listing of links/web sites, chat sessions and blogs. Teachers can e-mail comments on homework or lab reports back to the student rapidly. Also, material can easily be archived. The availability of all these tools should not be an excuse to sleep, miss class or surf the web when one should be paying attention to the instructor. Unfortunately, this can be a downside of these technology advancements.

Additional Advantages of Electronic Media

Mostly obvious other advantages are help available to all students, ease of making announcements such as special events or guest speakers, student-to-student interaction via various media, growing access to industry events, remote access from anywhere and secure access to grades. Finally, we will likely see increased *Asynchronous Learning.* According to Wikipedia, this is a student-centered teaching method that uses online learning resources to facilitate information-sharing outside the constraints of time and place among a network of people.

A Different Approach

In researching this topic a bit, I stumbled upon a paper written by Maryland-based educators describing an innovative microwave engineering course with a concurrent laboratory. The paper states: “This course is offered in the context of a collaborative electrical engineering program among Salisbury University (SU), University of Maryland Eastern Shore (UMES), and University of Maryland at College Park (UMCP). In contrast to the traditional lineup of topics, we develop the course using circuit theory all the way through ABCD and Scattering matrices, transmission lines and impedance matching. Only then, about mid-semester, do we make our first reference to Maxwell’s Equations and develop the theory of waveguides. In order to address the pedagogical concern expressed in the literature, we have retained the almost moribund slotted lines while concomitantly introducing the snazzy network analyzers in the laboratory experience. The need for designing such a course was motivated by the inexplicable - but welcome - presence of over half a dozen microwave companies concentrated in a narrow rural corridor on the lower eastern shore of Maryland coupled with a severe shortage of qualified engineers desperately sought by these companies.”

There is indeed a unique concentration of competitive microwave companies, mostly who design and produce filters in this area. These companies must compete for talent with areas such as greater Atlanta, Boston, Silicon Valley, Long Island, etc., having multiple schools geared for microwave training.

Student Group Projects, Student Papers and Hardware Competitions

Worth mention is the emergence of on-campus sponsored hands-on projects, student paper and hardware competitions. In recent years a feature of the IEEE Microwave Theory and Techniques Symposium has been dedicated contests in papers, poster sessions and competitions between school campus teams. The hardware competitions might include building amplifiers with lowest noise figure or highest efficiency, filters with highest Q, just to name a couple. This encourages activity beyond the classroom only experience that ruled the past. Obviously a lot of team spirit, much like a sports event, goes with this. Hurray for the nerds!

Universities have become smarter by requiring capstone projects for seniors. These often get industrial sponsorship. The sponsor company often participates in on-campus evaluation of the projects. This provides the opportunity for companies to get to know students and possibly invite them for interviews.

Beyond the College Classroom

Certainly worth mention are focused microwave courses taught with the purpose of providing updated or new knowledge to the engineering or industry-related professional beyond the formal college education. These courses are often company-sponsored (perhaps to a lesser extent than in the past due to financial constraints) or taught by outside entities such as Besser Associates. This approach serves to fill a partial void and can be adapted to the audience background, level of expertise and depth of need for understanding. I have personally taught many microwave courses to engineers who weren't sure whether they wanted to pursue microwave engineering, support personnel such as mechanical engineers who wanted to better understand the technology, and sales people who often are intimidated by technical details because no one ever explained even basic terminology. Of course the depth of the material has to be tailored for the particular class audience. This activity can be very rewarding for both student and instructor.

Conclusion

The instruction in high frequency electronics, like many other disciplines, is undergoing a paradigm shift mostly influenced by the explosion of electronic media, computer-aided design and sophisticated test equipment. One question is whether schools are preparing students adequately for the confluence of high frequency analog and digital technology. The basic one semester EM course is insufficient background for the next generation of EE students. Because the push is for ultra-wide bandwidth, driven by the internet and smart phone services, etc., many students must deal with frequencies above 1 GHz. A basic inductor, capacitor, resistor (lumped devices) electronics background is not sufficient to solve high frequency problems. There should be a push to include at least two EM requirements in the undergraduate curriculum: basic EM and microwave techniques. It's interesting to contemplate that many of the microwave technology advancements of the last two decades have enabled changes in the way courses are taught, e.g., wireless internet access, thus being self benefiting for our high frequency trade.

About the Author:

Tom Perkins is the Senior Technical Editor for *High Frequency Electronics*. He wishes to thank *HFE* Editorial Advisors Dr. A. Abedi and Dr. R. Gilbert for review and advice.