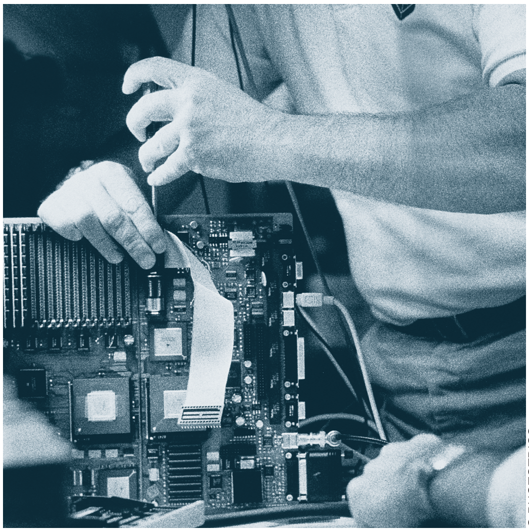
Guest Bytes

The Engineers That Time Forgot

■ **Jonathan Scott**



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You and I, dear reader of *IEEE Microwave Magazine*, are set to become more valuable day by day. Let me see if I can paint a picture of why.

I have always thought of microwave and RF as a graduate and professional specialization. The majority of electrical engineering (EE) students graduate their four-year EE degrees with very little exposure to the sort of stuff discussed in this column: Smith Charts, probing circuits of matched interconnections, why the peak-to-peak output voltage of a tuned amplifier approaches double the power supply voltage, what is a VNA and how to calibrate and drive one, what it is like to get an RF burn off a power amplifier (PA), etc. Oh, I know there are exceptions, such as EE graduates from my own university, all of whom are supposed to know how to use a Smith chart and many of whom can calibrate a VNA and measure the match on an antenna. Many years ago I saw a classroom at UCLA with six VNAs for class use, and students regularly fabricated a matched amplifier designed in Puff [1]. However, most undergraduate programs do not have room for students to receive any meaningful exposure to RF and microwave stuff.

The modern four-year EE program is full to bursting. There are places, such as the Melbourne School of Engineering, experimenting with what amounts to a five-year path to engineering. In the four years, students would typically program microcontrollers and field-programmable gate arrays (FPGAs), simulate coding schemes, study system design, learn about digital signal processing (DSP) and computer architectures, write programs, study biomedical technologies, and build electronic circuits, usually on breadboards, as well as studying an admirable amount of management and some financial subjects. These are all important things, but they are not RF things. The modern curriculum does not leave time to delve deeply into high-frequency studies. If you doubt me, ask a recent graduate to explain a directional coupler to you. (If you are reading this and you are a recent graduate who understands these RF matters, call me at once because I have a place for you in my graduate program.)

The message is that RF skills are *rare* to start with. I have to allow months for a new graduate student to pick up a proper, practical appreciation of matching, microstrip lines, and S-parameters, and this is a bright person who has already been attracted to this arcane world. Part of the reason RF skills are rare is that they are expensive to acquire. We have an expression about our labs that goes "if you are not blowing things up you are not learning fast enough." This is a consequence of pushing the envelope. This is a great phrase for reassuring students that it is OK to fry the occasional 10c BJT or US$1 MOSFET. In the case of power electronics, these destructive learning experiences tend

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Digital Object Identifier 10.1109/MMM.2009.935202

to be accompanied by flashes, noise, smoke, and a finite risk of bodily harm. In the RF world, they have a tendency to be expensive as well. Power sensors are fragile and not cheap. Sampling scopes are more fragile and less cheap. As a graduate student, I managed to apply power to a time domain reflectometer (TDR) in spite of knowing better. The microwave business is a rich man's game, as electronics education goes.

When I was an undergraduate, more than 30 years ago, it was an exciting time in nuts-and-bolts electronics, with transistors overtaking vacuum tubes, electronics magazines and electronics hobby shops booming, and ham radio people representing the domestic front of technology. If you asked the question "What got you into electronics?" you might hear answers like "I got a Philips/Norelco EE20 kit when I was a kid," "My Dad is a ham," "I pulled the tubes out of TV sets," or less specifically "It was a way towards space/satellites/science." People fooled with individual transistors. People also looked under the hood (that's the bonnet, English people) of their cars. They *tinkered*.

I wish more of my students could attend Tinkering School [2]. Pulling stuff apart is a great aid to understanding as well as being entertaining. Gever Tulley understands this, and he runs a summer school for small kids, but I increasingly feel I should send my graduate students there.

I wish more of my students could attend Tinkering School. Pulling stuff apart is a great aid to understanding as well as being entertaining.

The undergraduate of today has not tinkered. If his iPod breaks, he throws it away. If her car stalls, which they hardly ever do nowadays, she calls the AA[A]. (By the way, have you looked for the engine in your car recently, by the way? I do mean *looked for*, not *looked at*. Time was you could almost stand next to the block and follow the wires and pipes with your fingers. You could follow the path current took from battery to points to coil to distributor to spark plug. My last rental car, subjected to examination by a group of tinkerers, revealed no points, no distributor, and four spark plugs whose locations could only be implied from the sight of the rear ends of four ignition coils. No other evidence of cylinders or their number met the eye. Lately, it is tricky to recognize most of the gizmos in a car, let alone spot the engine concealed under the carpet of inscrutable boxes. But I digress.) This tinkerlessness is one of the problems, deftly stated by Yannis Tsividis in his marvellous articles

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on circuit education [3], [4], that make it hard to retain students in the field of electronics and circuits, let alone the high-frequency end of the business.

The waning need for every EE to be able to wire up a single transistor has given rise to a paradigm shift in the teaching of EE programs. More engineers need to understand complex modulation than need to understand the gain of a single stage circuit; much of the latter is taken care of inside an integrated circuit (IC) you buy in the faith that its designers have that detail under control for you. This leads to a second change in university electronics, not in the flavor of the intake but in the flavor of the teaching: University engineering is all too often shifting away from the lab into the lecture room. If I was to be cynical—and heaven forbid that in this column—I might comment that lectures and computers and books are cheaper than laboratories and components and equipment. In truth, this shift towards the theoretical from the practical is often a necessary response to the size of some first electronics classes. Mine is a small and elite university, and our first-year electronics class numbers about 140 and each and every student spends three hours each week in front of an oscilloscope, generator, power supply, meters, and so forth. However, a colleague in a more glorious university sees about 1,500 students in his version of the first-year electronics course and circuits in computer is what it is possible for them to see. At my university we count ourselves lucky if 15% of these students studying Electronics 101 carry on to obtain a degree in EE, the others go on to mechanical engineering, computer science, or things further removed. I find it disappointing to realize that, at many institutions, first-year electronics students may start off on a theoretical foot from which they never recover, but if the system works properly, the students who become EEs in that cadre will be the ones unharmed by the late entry to the lab.

I wonder how many readers caught a recent and significant event: The IEEE reported in early 2007 that a bunch of UC Berkeley students created a class, all by themselves, that allowed students to build their own electronic devices and see how exciting electrical engineering can be [5]. Let me repeat that for you—students added a hands-on laboratory program to accompany their theoretical course all by themselves and were roundly praised and rewarded for the effort. Of course, this requires that there be a course on electronics that does not have any practical lab associated with it in the first place. If you are thinking that this is negligence on the part of some academic, it is not. It is simply the way of things these days, where many people want to learn about electronics or are in degree programs whose conveners believe they should know something about electronics, but nobody feels motivated to pay what it costs to really get down and dirty with components. It is a huge effort for us to keep our course practical with around 100 students, I cannot imagine how difficult it would be with around 1,000 students.

The message here is that we, as practical types, have a skill that is getting thinner on the ground as the profession matures. More EEs graduate with less hands-on content, a trend that may be quite appropriate in a world where there is a growing need for logic circuits programmed into FPGAs and coding schemes implemented on distant hardware, but a trend that ill-equips people for the minutiae of analog and microwave.

Now let me introduce yet another observation. Figure 1 attempts to show the progress of electronics from its inception with the first diode up to recent times. The middle of the picture lists a smattering of the advances enabled by electronics throughout the 20th century against the approximate date. I want to stress that my figures here are purely indicative, as it is often difficult to say just when something happened exactly, so I don't want a lot of people e-mailing me to say that their great-great grandfather actually did such-and-such much earlier than I am claiming, OK?

By the way, we often forget what a vast social revolution occurred in the last century and how much it depended upon electronics. Without us, many modern anthropologists would not have much to talk about. If you think Moore's Law is indicative of faster revolution in the latter 20th century, consider that there was public radio broadcasting in place barely a dozen years after the invention of the first active amplifying device. No mean feat.

For me today, the interesting parts of Figure 1 are at the top and the bottom. Across the top I have indicated the rise of the different active device technologies. Most people, and many EEs, think only of silicon when they think of electronics. We RF people know better. A significant amount of electronics still depends upon vacuum devices, especially where you want power and high-frequency operation together. The vacuum boys recently celebrated "100 years and still going strong" [6]. Late in vacuum's reign, transistors were fabricated in germanium. My Philips EE20 set came with AC126 PNP Germanium small-signal transistors. These powered the initial solid-state revolution, appearing in pocket-size portable radios and tape recorders that I bought as a ten-year-old kid. This was the solid-state age, and it was then the age of Germanium. Barely a decade later, Silicon was used to make transistors. These soon overtook Germanium in reliability and performance, and duly in price. Silicon went from strength to strength and from scale to scale, and it seems set to remain as the volume electronic workhorse for the foreseeable future. This was the dawn of the Silicon Age. You will notice that these ages pass with rather more alacrity than did the stone, bronze, and iron ages.

Silicon's magnificent achievements notwithstanding, limits in power-bandwidth and emitted photon wavelength stimulated interest in devices in the GaAs and then InP systems: compound semiconductors. This so-called III-V material system has about eight times the inherent carrier mobility (or some-such figure), and so transistors made out of it go faster for a given power density. The late 1980s and 1990s could be called the *age of III-V*.

Lately, wide-bandgap material systems, and especially gallium-nitride (GaN) have come into play. These pop into our story in one line, though they were in reality brewed up over many years of serious physics and alchemy. Papers on GaN MMICs proliferated about 2007; I think of this as the point when the wave broke. Silicon may be the volume technology but it is definitely not the highest-performing one. The noughties are surely the dawn of the *wide-bandgap age*.

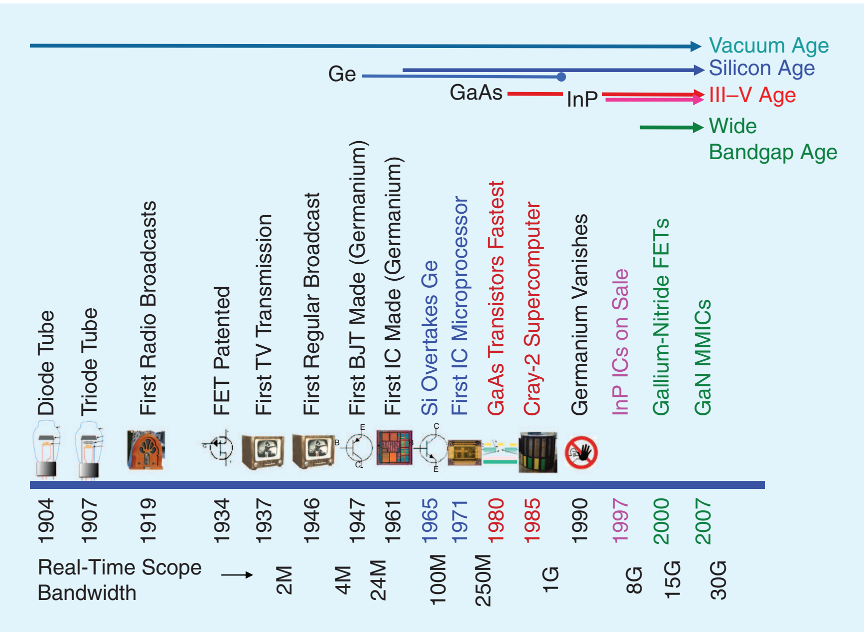

Figure 1. *A summary of electronic developments and the active device technologies that were used throughout the electronics era.*

Along the bottom of the Figure 1 have tried to indicate the frequencies of interest to electronics people by listing the bandwidth available to the purchasers of scopes. When I was starting out in this business, owning a Tektronix 465 with a bandwidth of 100 MHz indicated seriousness. As a grad student in 1980, 250 MHz was available with good sensitivity and 1 GHz if you could tolerate the brutal 4 V/division sensitivity to make up for the lack of electronics between you and the deflector plates. There was more bandwidth—18 GHz if I remember correctly—if you could use a sampling scope. Today, you can get tens of GHz in real-time and 100 GHz in equivalent-time. The phrase *signal integrity* sells a lot of fast scopes, and it entered the common lexicon as a consequence of mere digital engineers encountering the phenomena of dispersion and mismatch—things we RF people long since fully internalized.

This is all leading to the inescapable observation that digital engineers are increasingly going to need the skills of us RF engineers. Intel has, perhaps temporarily, come to a halt in front of the speed limits RF engineers have been confronting for years. Their attempts to take my money by selling me more cores without a faster front-side buss are falling flat. Everything, computers included, gets faster, faster than it is getting smaller, wavelengths become comparable to device dimensions, interconnects become antennas, and it's going to take us to sort out the problem. *Us* is high-frequency people, not EEs. That problem is called *signal integrity*, not so much to save saying dispersion, mismatch, and radiation but because the digital engineers (re) named it before they recognized it.

One more observation arising from Figure 1: The device technologies identified by the lines across the top do not simply increase. Germanium vanished, except as a compound ingredient, and the Germanium age ended. As this column is not afraid of controversy, I will venture to make a prediction: GaAs will go the same way. Vacuum has yet to be assailed for ultimate power-bandwidth, silicon seems assured of a long reign because of its huge performance per unit currency, but wide-bandgap technologies look set to beat GaAs in every respect. Nobody designed in Germanium after about 1965, but the last supplier of Germanium devices that I could find expired in the 1980s, so it is safe to assume GaAs will be with us for some time, but if I was a betting man I would not be betting on it for new designs much further into the future. This is a prediction, dear reader, not a deduction, but you heard it from me first [7].

So, in summary, we have a narrow and arcane field, falling intake, and increasing need: ingredients of a seller's market, you might think. Could the first sign of the coming sea change be the proliferation of papers at our conferences that feature CMOS VLSI circuits? One might speculate that this is the start of a flood, it is certainly the trend I have most noticed on the conference circuit of late. It remains to be seen if we original RF people are treated as gurus or washed aside by a flood of people reinventing and repackaging the wheels of RF and microwave engineering, but I am extremely optimistic. I've got a feeling that the years of tinkering have built up a skill that will not easily be encapsulated into something fast and mass-producable, the way the years of experience building computers has been packed into Pentiums and is stamped out en masse in FPGAs. If that was about to happen, I doubt that the term *signal integrity* would have caused such consternation. It's time to open the Veuve and party, not sink into our deck chairs for a last Sapphire and tonic.

References

[1] S. Wedge, R. Compton, and D. Rutledge. (2009, June). PUFF: Computer aided design for microwave integrated circuits. [Online]. Available: http://www.its.caltech.edu/~mmic/puff.html

[2] Gever Tulley's School. Available: http://www.tinkeringschool.com/, is best seen in action at TED: http://www.ted.com/talks/gever_tulley_s_tinkering_school_in_action.html or http://www.ted.com/talks/gever_tulley_on_5_dangerous_things_for_kids.html

[3] Y. Tsividis, "Teaching Circuits and Electronics to First-Year Students," in *Proc. 1998 IEEE ISCAS*, vol. 1, pp. 424–427.

[4] Y. Tsividis, "Turning students on to circuits," *IEEE Circuits Syst. Mag.*, vol. 9, no. 1, pp. 58–63, 2009.

[5] A. Bogdanowicz. (2007 Jan.). *Students create hands-on electrical engineering course* [Online]. Available: http://www.theinstitute.ieee.org/portal/site/tionline/menuitem.130a3558587d56e8fb2275875bac26c8/index.jsp?&pName=institute_level1_article&TheCat=2201&article=tionline/legacy/inst2007/jan07/featurestudents.xml&

[6] V. Granatstein, R. K. Parker, and C. M. Armstrong, "Vacuum electronics at the dawn of the twenty-first century," *Proc. IEEE*, vol. 87, no. 5, pp. 702–716, May 1999.

[7] J. B. Scott and A. E. Parker, "Performance and applications of gallium-nitride monolithic microwave integrated circuits (GaN MMICs)," in *Proc. SPIE*, Australian National Univ., Canberra, Australia, Dec. 4–7, 2007.

IMS2010 Student Contest Announcement: ASH Receiver

MTT-16 and MTT-2 are pleased to announce the first Student ASH Receiver Design Competition, which will take place at IMS2010 in Anaheim, CA. This Competition is open to all students and graduate students registered at an educational establishment. The competitors are required to design, construct, and measure an Amplifier-Sequenced Hybrid Receiver (ASH receiver) at a frequency of 433.92 MHz. The winner will be judged on the design which demonstrates the lowest power consumption while providing the highest sensitivity. The ASH receivers must be brought to IMS2010 where they will be tested to verify their performance. A representative of the design group must be present at the testing to assist with the evaluation. The winner will receive a prize of US$1,000 and will be invited to submit a paper describing the design and the experience for *IEEE Microwave Magazine*. Contestants must notify the MTT-16 committee by emailing to Mr. Stefan Zorn at zorn@lfte.de or to Mr. Benjamin Laemmle at laemmle@lfte.de of their intention to compete in the contest before 15 April 2010. This notification should include information on the university or educational affiliation of the entry, the faculty advisor and a short abstract about the intended design.