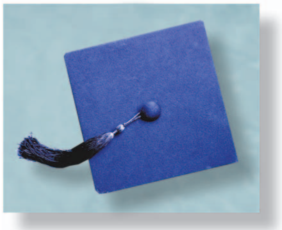

Educator's Corner

Curricular Implications of Trends in RF and Microwave Industry

■ Madhu S. Gupta

There is a parable, recounted in educational circles, about a remote, self-sufficient community somewhere in the arctic region that had a well-functioning educational system. The community entrusted their young ones with the educators and supported their school well, while the school prepared the new members of the community for the daily chores and hard reality of life in the cold climate. The young were taught how to fish on the frozen lakes, make igloos, and prepare polar bear skins to keep themselves warm. Over the years, the glaciers receded, the climate changed, and what was once tundra became a tropical forest, with trees, streams, and woods teeming with diverse species of birds and animals such as deer, monkeys, and lions. A delegation of community elders once visited the school for discussions and was given a tour by the principal. The delegation leader inquired if the school taught the children how to catch the deer and birds. "No," replied the principal, "there is so much knowledge to be imparted about the polar bears that we don't have time left for other things." [Origin unknown]

I am reminded of this story often when I read newly published textbooks, look at course offerings in universities around the world, and make my own course syllabus every semester. All

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Microwave educators have often desired a mechanism for sharing innovative ideas, pedagogical tips, and instructional materials with colleagues in their own discipline. Although a number of workshops and special sessions that are supposed to address these issues are organized in conjunction with various microwave conferences, their lack of continuity hinders their ability to advance microwave pedagogy by successive refinement, augmentation, and accumulation of ideas. *IEEE Transactions on Education*, which had earlier served a similar role, has recently changed its editorial policy and now requires submitted articles to be accompanied by assessment data on the curriculum content addressed. This new column is being established in the *Magazine* to promote and serve as a vehicle for communication among RF and microwave educators. The column welcomes contributions on topics of current interest to educators in the field of RF and microwave engineering, such as the following:

- alternative, novel, or pedagogically superior methods of presenting topics from RF and microwave engineering curricula
- expository material for learners that elucidates difficult concepts, makes recent developments accessible, or organizes disparate bits of information into a cohesive framework
- case studies or illustrative examples useful for instructional purposes
- clarifications of typical misunderstandings and errors in existing pedagogical materials
- reviews of educational materials available elsewhere in articles, books, software and Web sites
- discussions of curricular, instructional, philosophical, professional, organizational, and other issues pertinent to education.

— The Editor

microwave educators I know want to serve the students as well as the industry for which they prepare the students, and all agree that the curriculum should be modern and in step with the technology. However, since educators have different industries to serve in their neighborhood, different perspectives on significant technological trends in industry, and different views on what education is required to serve the needs of the industry, we end up with a variety of types of educational offerings around the globe in the same discipline of RF and microwave engineering. This engenders concerns about the adequacy of existing syllabi for serving the present and future needs of the industry that are further heightened by the rapid changes in technological knowledge base.

Should the educational program of an engineer be influenced by the industry's changing needs for engineering manpower with particular skills? Educators might differ in the degree of significance they will attach to such needs. Some might feel that the purpose of the university is to provide education, not vocational training; but such a philosophy can lead to a disconnection between students and industrial work and has the risk of making the education irrelevant—something that has already happened in other disciplines ranging from English literature to physics. In a professional field like engineering, it is clearly necessary to strike a balance between education and career preparation. Still, others might argue that the most important goal of the educational process is to prepare broadly educated engineers, well-grounded in the fundamentals, and capable of learning by themselves, who can advance their own education in a given specialty as and when the need arises. The ideal of a student prepared to undertake self-study in any area may be a good goal to strive for, but even for ideal students, a guided learning process may be more efficient in learner time than self-study. Moreover, this strategy might need to be supplemented by other approaches for all the nonideal students we seem to

Table 1. Trends in the civilian RF and microwave industry and their curricular implications.

Market-driven product goals	Technological means for the accomplishment of those goals	Corresponding knowledge and skill set required by the technologists
Low-cost, high-volume producibility	–Monolithic realization with the highest possible level of integration –Use of low-cost technologies and components (e.g., Si as opposed to exotic semicondicutors) –Planar design and fabrication –Variability-tolerant design and layout to eliminate custom tuning or trimming and to accommodate manufacturing tolerances –High-yield manufacturing processes	–Mixed-signal design and design for large scale integration –Current status of available process technologies and components for lower cost substitutions –Planar manufacturing processes –Sensitivity analysis and robust design methods –Statistical process control and yield modeling
Short time to market	–Total reliance on CAD for control of design process –Accurate component characterization and models –Extensive simulation for one-pass design success (or minimal design iterations) –Use of components-off-the-shelf (COTS); minimal use of custom, or high-variability, parts or processes –Reuse of verified designs from library and existing intellectual property (IP)	–Proficiency in (or at least familiarity with) the use of CAD and CAE tools and methods –Modeling, characterization, and simulation of devices and parasitics –Modeling of interconnects and their effect on signal propagation –State-of-the-art in parts, processes, and designs
Compact, possibly portable, construction	–Lumped element realization of RF circuits –Active synthesis of passive components (hence, high transistor count per chip) –Efficient use of power supply –Integration of design with packaging –Moving towards system-on-chip (SOC) execution	–Analog circuit synthesis methods –Circuit design for single-supply, low-voltage, and low-power consumption –Capability and suitablility of alternative packaging technologies –Interfacing electronic design with physical design and simulation (mechanical, thermal, electromagnetic)
Multiple-feature, and customizable, system performance	–Higher speed/higher cutoff frequency active devices (e.g., shorter gate length FETs) for broadband operability –Compensation for component imperfection (nonlinearity, imbalance, noise, etc.) by DSP and digital components –Optimization at the system (as opposed to component) level, enabled by the high level of integration –Functionality enhancement through integration of RF, analog, digital, control, power, signal processing, and other elements –Programmability by incorporation of microprocessor, keyboard, and software control	–Knowledge of the capabilities and applicaations of newly developing RF microelectronic devices. –Knowledge of wireless communication and other RF applications –Knowledge of overall system operation and requirements –Optimization methods –Incorporation of digital circuits and digital signal processing algorithms in RF systems –Design of RF components with digital control.

have. For the remainder of this discussion, we assume that educators do need to respond to technological changes.

The process of identifying the emerging technological trends in the industry, and deducing from them some guidelines germane to curriculum design, is neither straightforward nor currently well established. One way to make progress towards developing such a process would be for educators to exchange with each other the results of their efforts in this direction. Accordingly, the sole purpose of this article is to present a first attempt at deducing curricular guidelines from industrial trends and to share the results with other educators so as to initiate a dialog among them on how such an undertaking might be carried out. The following summarizes the process followed by one educator, teaching one subject (RF and microwave electronics) in one geographical locale (dominated by wireless communication industry) to students with one career goal (terminal nonthesis Master's degree students aiming for industrial employment). These constraints influence the breadth of applicability of the conclusions reached.

The sector of microwave industry on which we focus here is the civilian RF wireless communications industry, partly because there is more information in the public domain about the goals and technologies of this industry and partly due to the growing importance of civilian work over defense-related work in recent years. This industry differs from others (such as the aerospace, defense, instrumentation, and industrial sectors of the microwave industry) in many respects, particularly its attention to product cost because it serves a cost-sensitive civilian market. The process of deducing the educational demands created by this industry is carried out in three steps as follows. First, we single out specific goals, such as high-volume production, that drive the industry. The goals, in turn, dictate the industry's choices from among the alternative technological paths, thus identifying technologies of interest to this industry. Therefore, we next ask how each of the market-driven goals can be reached through technological means, such as design approaches, design tools, components, and processes. The technological means employed by the industry to meet its goals define "technological trends" in the industry to which its suppliers, including the educators, can be expected to respond. Finally, we ask what demands those technological trends might place on the preparation of the RF and microwave engineering workforce, which might be relevant to curriculum design. The results from each of these three steps are summarized in Table 1 so as to put the logic of the entire process in perspective.

The first column of the table lists the possible ways in which the civilian sector of the RF and microwave industry can meet its commercial goals. The significant goals of this industry are clustered into four major themes:

1) the industry produces low-cost products for high-volume markets
2) the industry is very time-sensitive, and minimizes the time from the conception of a product to its delivery (so-called "time to market")
3) the products need to be very compact, and often portable, to receive customer acceptance
4) in order to achieve success in the market, the products must have a high functionality, defined in terms of the variety of functions performed by the product for a given cost or size of the product.

Each of these four industry goals drives decision making, manifesting itself in the technologies pursued by the industry. Thus, the goal of low cost may be achieved through reduction in product size and, hence, the bill of materials; high level of integration, so as to reduce parts count and assembly work; planar construction of all parts for lower fabrication costs; and the variability-tolerant designs and robust processes to improve the product yields. Similarly, each of the other three goals also influences the technological choices, and these are listed in the second column of the table.

Finally, technological choices require engineering personnel who are knowledgeable and proficient in the technologies involved. Thus, we can identify some of the skills and background required by the engineers, as listed in the third column of the table. The set of skills so identified is not exhaustive, and many other (such as interpersonal skills, teamwork, and ethics) are also needed in industry, but are not discussed here further. Clearly, not every engineer in the product team need be familiar with each listed area of knowledge and skill. Neither does every skill have to be included in university curricula: the professional preparation of the engineers includes not only university-based education but also short courses, on-the-job training, and work experience. University-based education is more cost effective than on-the-job-training only when it is carried out for large numbers of students in common; therefore, in a fast-moving field, university curricula will invariably lag the state-of-the-art in engineering practice. The list of required skill sets is nevertheless useful as a source of guidance in selecting broadly applicable principles to be taught and as a source of examples and case studies to illustrate those principles.

Clustering the wide range of topics and skills included in the last column of the table along the lines of classical academic subjects shows that the industrial needs draw upon a variety of academic disciplines, including mathematics (optimization methods, statistics), basic engineering sciences (heat transfer, structural mechanics), materials engineering, wireless communication systems, digital circuit design, digital signal processing, active devices and passive components, electronic circuit design, microwave circuits and transmission lines. It is safe to conclude that the evolving needs of the RF and microwave electronics industry cannot be met by suitable design of just the course(s) in RF and microwave electronics but, instead, require the confluence of many parts of the academic curriculum. This conclusion has a broad generalizability, and is a consequence of the problem-oriented thinking in industrial fields, as contrasted with the discipline-oriented organization of academic fields.

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Designing a curriculum that follows industrial trends can be rife with difficulties and potential risks. The time constants of curricula are much longer than those of technologies; consequently, the university-based curricula need not respond to every fad and short-term need, which are better handled by short-courses and extension programs. There is only a limited amount of time available in the educational setting, and it is not possible to accommodate all the desired subjects in every student’s program. Educational programs must not sacrifice a thorough grounding in the fundamentals so as to remain relevant to a variety of learners and industries, and prevent the risk of early obsolescence (the so-called “cut-flower syndrome”) due to the limited shelf-life of applied technological knowledge. Clearly, there is a need to strike a balance between the fundamentals and current state-of-the-art; take advantage of local strengths and available facilities; and allow a diversity of paths to accommodate a variety of types of industry, and learners with different career goals and preparations.

All indications are that, in the future, the industry will need microwave engineers who are broadly trained not only in RF engineering, but also in analog, electromagnetic, digital signal processing, and wireless communication technologies. This conclusion stems from a number of observations. First, we have already arrived at a stage where designers carrying out mixed-signal designs routinely cross any vestiges of boundaries between the RF and analog domains. Second, the efficiency of modern design tools has greatly decreased the need for large design teams, where narrow backgrounds for individual team members might have been acceptable. Third, the imperfections (of linearity, delays, matching, synchronization, crosstalk, etc.) in the designed circuits are increasingly compensated for by digital signal processing and digital control devices, rather than by microwave techniques that suffer from higher complexity, cost, and tolerance sensitivity. Finally, in highly integrated systems, the importance of the layout of the circuit has been greatly enhanced because it governs a variety of performance measures (such as frequency response, interference susceptibility, yield, and degree of matching among sub-circuits). As a result, the knowledge of electrical design must be supplemented by skill in physical design.

Future educational programs will face multiple challenges in their mission. Microwave educators might find it increasingly difficult to maintain a distinct identity and justify a distinct training path for designers in the future. This has implications for the design of microwave curricula and syllabi; the content of textbooks; required mathematical background (e.g., in optimization methods); and the advising of students regarding the breadth of preparation required for a successful career in the field.