UC Boulder Students Make MMIC Design Routine

by Barry Manz, Contributing Editor

or graduate engineering students focusing on RF and microwave technology, designing microwave circuits is one of the prerequisites to obtaining an MSEE degree. However, in almost every case, they are not MMICs, and any MMIC experience ends with a design created in a high-frequency simulation tool, since without a foundry there is no way to fabricate the device or test its performance. That’s what makes Dr. Zoya Popovic’s computer-aided, active microwave circuit design course so special.

Popovic, who is the Hudson Moore Jr. chaired professor in the Department of Electrical, Computer and Energy Engineering at the University of Colorado at Boulder, has teamed with AWR Corp. and TriQuint Semiconductor to provide the final links to a complete “MMIC design experience”. Together they have made it possible for Dr. Popovic’s students to design MMICs, transfer their layouts to a foundry, obtain working devices, and evaluate their actual performance against simulated results. AWR provides its Microwave Office high-frequency design software to the university and TriQuint provides one quarter of a GaAs wafer multiple times per year -- more than enough room to accommodate many student designs.

Although this type of partnership might seem logical and even essential for students intending to pursue a career in microwave engineering, it is highly unusual and available only at a handful of universities throughout the U.S. The reason is simple: processing a wafer through a foundry is expensive and there are only a few foundries available with capabilities like those of TriQuint. In addition, success requires a three-way relationship between the university, a company that offers a complete family of high-frequency design tools, and the foundry. That’s a tall order. As a result, most students are typically only able to develop hybrid circuits or perhaps microwave integrated circuits (MICs), which can be fabricated and tested at the university. While MICs are still ubiquitous throughout microwave subsystems for both commercial and defense systems, wafer-scale microwave technology such as RFICs and MMICs will be an essential ingredient in the small, light, power-frugal, cost-effective, systems that will drive future commercial and defense systems.

A Formidable Presence

After speaking with Dr. Popovic, it’s not difficult to see why she might be one of the first people to make such a program succeed. After receiving her MSEE and Ph.D degrees in electrical engineering from Caltech, (her doctoral thesis was on large-scale quasi-optical microwave power combining), she joined the faculty of the University of Colorado in Boulder and soon became a full professor. She has developed five undergraduate and graduate electromagnetic and microwave laboratory courses and co-authored (with her father Branko, an electromagnetics pioneer), the texts “Introductory Electromagnetics,” and “Introductory Electromagnetics and Practice Problems and Labs” for use as a junior-level core course for electrical and computer engineering students.

She has twice received the Microwave Prize journal paper award from the IEEE MTT Society, became an IEEE Fellow in 2002, and has received a string of other awards from the German Alexander von Humboldt Foundation, University of Colorado (female role model), Eta Kappa Nu (professor of the year by student vote) URSI Issac Koga Gold Medal, and White House NSF Presidential Faculty Fellow Award.

However, she is most proud of her graduate students, and has to date graduated 32 PhDs who are now contributors in government labs, academia, and industry. Her current 15 doctoral students are solicited for employment by government and major corporations. “They’re what this is all about,” says Popovic, “and I can’t tell you the satisfaction I get when I find these students have taken on important roles in the government, commercial, or defense companies, and to see them lead happy and fulfilled lives.”

The Program Concept

The partnership, which took shape in 2007, was implemented in the spring 2008 computer-aided, active microwave circuit design course, with seven students participating. Popovic and each student together chose a circuit for design as a MMIC that supported their respective thesis research projects. These projects are funded by an impressive list of spon-
sors, ranging from government agencies such as the National Science Foundation (NSF), National Institute of Standards and Technology (NIST), Defense Advanced Research Projects Agency (DARPA), Sandia Laboratories, and Office of Naval Research (ONR), to corporations including such as Nuvotronics, BAE Systems, National Semiconductor, and the Coleman Institute.

Once the circuits were selected, the students designed them using Microwave Office software, and their manufacturability was verified using ICED, a no-cost plug-in feature in Microwave Office 2008. The students then used AWR’s process design kit (PDK) for TriQuint’s TQPED 0.5-µm E/D pseudomorphic high electron mobility transistor (pHEMT) process, which allowed them to easily transfer their designs to fabrication. The devices were fabricated and returned to the university in about a month. The students then characterized their fabricated devices using a probe station, and in some cases packaged them for full testing.

The circuits ultimately chosen included:
- Distributed amplifier for a Josephson junction voltage standard
- Nonlinear transmission line for pulse compression in ultrawideband (UWB) radar
- Power amplifier impedance tuner
- Class E power amplifier with different lumped-element harmonic terminations
- Low-noise amplifier and multilayer test structures
- Broadband lumped-element power amplifier
- Current-mode, Class D power amplifier for a digitally-fed sigma delta transmitter array
- TRL standards and lumped-element Wilkinson power divider

Lots of Work...Not So Much Time
One of the program’s more obvious challenges was attempting to shoehorn the design, layout, verification, fabrication, and measurement of the MMICs within the confines of a single university semester. Getting the devices to the foundry was accomplishment enough, but once the parts were returned the students were anxious to learn how closely their performance agreed with their simulations.

Prof. Popovic’s research lab is well-equipped for microwave measurements, and is available for class measurements depending on the research schedule. Since the MMICs take several months to get fabricated at the TriQuint foundry, the students obtain one extra credit for measuring their circuits in the following semester.

Another challenge was that in addition to the design work, most of the students were not familiar for the Microwave Office software. To the delight of Dr. Popovic (and AWR) the learning curve was quite painless. “Frankly, I found the ease with which the students learned the software rather remarkable,” said Dr. Popovic. “They attended a single AWR training class and got great help from an AWR applications engineer along the way, but otherwise they were on their own. And they did it.”

Complementary Agendas
Each partner had specific interests in the program as it progressed, the circuits themselves, and the overall results. For Dr. Popovic, in addition to the obvious benefits the students would receive in such a comprehensive course, success could lead to others in which the three partners could collaborate. For AWR, it was a test of one of the company’s core missions. That is, since its inception AWR has strived to create a complete suite of high-frequency software tools that were not only accurate and comprehensive in scope but also easy to use. For TriQuint, the university-foundry collaboration offered the possibility of bringing some rather unusual circuits into the foundry that could push the limits of its pHEMT process.

As it turned out, all were rewarded. The course proceeded from inception to completion without major obstacles, and the students made it from start to finish, which was in most cases a paper describing their results. Those results were not always what the creators of the circuits had hoped for, but in such cases ways to improve the results were clearly evident. Lessons were learned and imaginations were stimulated. AWR verified that with modest training, totally “green” students could learn the basics of a professional high-frequency design suite, use it to create circuits, learn how to transfer the circuit layouts to a foundry, and in some cases measure the results and compare them with the simulation -- all within a university semester. Engineers at TriQuint were impressed with the complexity of the devices.

So Was It Worth It?
A course as comprehensive as Dr. Popovic’s obviously requires more effort on the part of both instructor and
student than most engineering courses. Nevertheless, Popovic feels the result was worth the extra work. “I’m very proud of the work they’ve done,” she says. “The ability to actually fabricate and test the MMIC devices they create is incredibly helpful to my students. Some of these circuits are truly unusual and to get results that agree so well with the simulation is both a credit to the students, AWR’s Microwave Office software, and the quality of TriQuint’s pHEMT process.”

Having successfully passed the first test, Dr. Popovic looks to the next course, and a new crop of graduate students. This time it is a new semester, and a new group of 23 engineering students - more than three times as many as before. This month, 16 of them completed their MMIC designs that passed all the DRC tests and are ready to be sent for tape-out. “We’re definitely going to continue this course,” she says. “If there ever was a ‘win-win’ situation, this is it.”