profile

THE FATHER OF THE SPICE PROGRAM AND DRIVING FORCE BEHIND THE DEVELOPMENT OF IC SIMULATION WILL RECEIVE THE 1998 IEEE MEDAL OF HONOR

Donald O. Pederson

AS A 10-YEAR-OLD, he scrounged around in junkyards, looking for materials he needed to build crystal radio sets. As a young professor at the University of California at Berkeley, he foraged for semiconductor processing equipment being discarded by industrial laboratories, and used it to build the first semiconductor fabrication facility at a university. And in the 1960s, he pulled together bits and pieces of computer code being used at various companies for circuit analysis and, adding his own research, turned it into Spice.

Spice has since become one of the microelectronics industry's standard programs for integrated circuit simulation, with over 100 000 copies in use. For this last achievement, Donald O. Pederson this month will receive the IEEE Medal of Honor.

Crystal radios and electric motors

While still in elementary school in Fergus Falls, Minn., Pederson built his first crystal radio, using parts given to him by an uncle and a cousin as well as his junkyard finds. Soon after, he got a paper route and saved his money to buy his first soldering iron and his first vacuum tube. His enthusiasm for electronics was apparent in his high school physics class, in Fargo, N.D., where his family had moved. From that class he was recruited for a weekend job repairing electric motors at the Fargo Electric Motor Co.

When Pederson graduated from high school at age 17 in 1943, in the thick of World War II, he had three months before the U.S. Army would pounce on him for service. Having spent his life so far in Minnesota and North Dakota, he decided to see the West Coast, and went to Seattle, Wash. His first stop was a shipyard, where he asked for a job working with electricity. He was sent to the union hall, and officials there offered him a post as an apprentice electrician.

"No," the teenager told the union representative. "I want to be a journeyman. I've been working for two years in electric motor repair, I must have learned something."

The union officials gave him an oral test. After he answered the last question, which he recalls had concerned safety precautions in working with hot electrical lines, a listening electrician laughed, muttering, "Well, the kid is wrong on that one." The shop steward corrected him. "No, the kid is right, you're wrong," he said, and

TEKLA S. PERRY, *Senior Editor*

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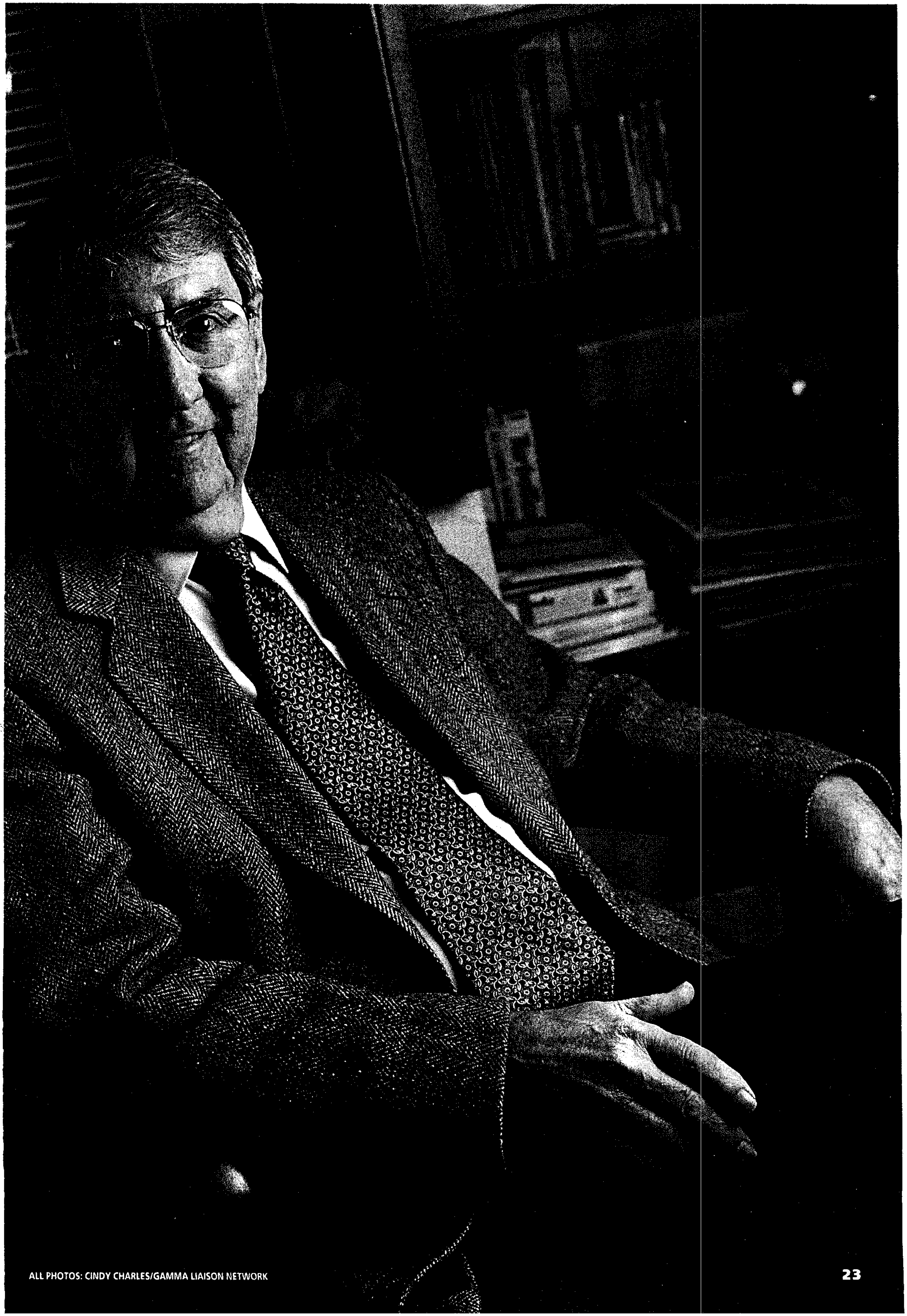


ALL PHOTOS: CINDY CHARLES/GAMMA LIAISON NETWORK gave Pederson his journeyman assignment. He was put in charge of providing temporary electric power, when needed, for lights and tools on a destroyer that was being built.

But his knowledge of electrical safety was to be tested further. Often he had to work with live wires, so as not to cast workers in various sections of the destroyer into the dark. "I would get a couple of very dry pieces of wood," he said, "put them on the metal deck, make the break, hold the two ends, then remake the connection. But the guys from a welding crew would sneak up on me and, just when I had broken the line, pour salt water on my feet. The shock would knock me down, and they'd laugh."

Pederson said he retaliated by cutting off power to the co-workers when they were in the farthest reaches of the ship, and eventually a truce was called.

Interrupted education

Just before turning 18, Pederson joined an army training program in engineering. He completed one term at Iowa State University, in Ames, but then the program was terminated and the would-be engineers ended up in the infantry. After combat in Germany, France, and Austria, Pederson was sent to the Philippines. The war ended shortly after he arrived, but he remained there for about a year, taking charge of the regimental power station.

"I had two primary missions," he remembered. "The colonel had to have power for his shaver and the troops had to have power for the movie at night."

Pederson returned to the United States and to college in 1946, when he enrolled at North Dakota State University, in Fargo. After a day of aptitude tests, a counselor told him that if he wanted to make money, he should forget about college and go to work for a local electric shop, buy into the business, and have a nice life as an electrician. But Pederson hung on to his childhood ambition to be a radio engineer.

After half a semester of college, though, the freshman found himself a C student. That, he concluded, was not going to get him anywhere; clearly he couldn't have fun and be an engineering student at the same time. So he found a study partner, set up a pattern of working day and night for six days each week, and took an overload of courses to speed through college ahead of other returning veterans. He finished his bachelor's degree in two years and one term, and, at the urging of a professor, applied to several graduate schools, eventually choosing Stanford University in California.

The late 1940s were an exciting time at Stanford. William Hewlett of soon-to-be Hewlett-Packard fame had just discovered the distributed amplifier, a broadband amplifier used in fast circuits. An analysis and redesign of that device was to become Pederson's thesis project. But before tackling it, he left California for a summer job at the Los Alamos National Laboratory in New Mexico.

His tasks there included building a special-purpose oscilloscope, which he considered an interesting instrumentation problem, even though, because of the laboratory's tight security, he was not told exactly what the oscilloscope was to be used for. Two years later, he figured it out. Paging through *Life* magazine, he came across a photograph of the H-Bomb team—the group of people he had worked with that summer.

Into industry

AFTER TWO YEARS as a postdoctoral researcher at Stanford, designing high-performance electronic amplifiers, Pederson was recruited by Bell Laboratories, in Murray Hill, N.J. "Bell Labs had a superb recruiting effort," he recalled. "They would spot the young students who were coming along, then nurture that relationship. It seemed that every time I turned around, there was somebody from Bell Labs in the hallway, so when it was time for me to leave Stanford, it was natural that I would consider Bell."

At Bell, he continued working on electronic circuits, switching from tubes to transistors. He doubts he made any major technical breakthroughs during this period, but achieved solid day-to-day development. "I earned my keep," he said.

Soon after he started at Bell Labs, he received a phone call from a former North Dakota State professor, Harry Dixon, who was then head of the electrical engineering department at the Newark College of Engineering (now the New Jersey Institute of Technology). Dixon asked Pederson to teach a course on electrical network theory, saying he had committed the school to offering this course in the fall and did not have the knowledge to teach it himself.

Despite having decided years earlier that he would never pursue an academic career, and despite the objections of his supervisors at Bell Labs, Pederson agreed. His former mentor was asking for help, and he felt that he owed him.

Preparing for the course and teaching it filled up most of Pederson's nights and weekends, but when the year was over, he concluded that he had enjoyed teaching better even than his work at Bell Laboratories. He taught another class the next fall, and the following year, 1955, contacted acquaintances back in California and obtained a position as assistant professorship at the University of California at Berkeley.

This was the turning point in Pederson's career, and, out of all his accomplishments, he is most proud of his efforts working, he says, with so many "bright, eager students."

"He certainly didn't do it for money," commented John Whinnery, one of those who helped to recruit Pederson and now a Berkeley emeritus professor. "He took a big [salary] cut to come to the university. The idea of teaching was what motivated him."

"He could always excite students," recalled Ernie Kuh, a Berkeley professor emeritus, who followed Pederson from Bell Labs to California.

Bruce Wooley, one of Pederson's students and today a professor of electrical engineering and director of the IC laboratory at Stanford University, also recalls Pederson's enthusiasm for teaching. "He made the field sound exciting and new," Wooley said. "I hadn't given any thought to graduate school, but once I started working with Don, I ended up staying through my Ph.D."

To many of his students, Wooley said, the man was a second father. "He was a role model. He would push you to think on your own, but he was always accessible. He was demanding, and expected you to go off and do great work, but he was always there when you needed him."

IC influence

In 1959 the integrated circuit was developed, and the world of electronics changed. According to Pederson, some engineers thought the IC was merely another way to make amplifiers and switching circuits, but others, including himself, realized that ICs opened up a new world, one in which people would be able to do the till-then undo-able.

It quickly became obvious to Pederson that to undertake research in ICs and to teach students to develop them, the university needed its own semiconductor fabrication facility. When he voiced this idea, he met a host of objections—building a fab was too complicated; Pederson's group was made up of engineers, not chemists; the university had no money for expensive fabrication equipment; and the project simply couldn't be done.

Ignoring the objections, Pederson, with a few sympathetic professors and a group of graduate students, started designing the facility.

"Never wait for approval, don't tell anyone you are doing something, just do it," Pederson told *IEEE Spectrum*. "That's my motto."

It was back to scrounging. Industry was willing to turn over used processing equipment as the technology sped ahead to a new IC generation. A sympathetic department chairman reassigned offices to free up space. A few university grants to young faculty and graduate students, along with some money from the Army Research

Vital statistics

Name: Donald O. Pederson

Date of birth: 30 September 1925

Birthplace: Hallock, Minn.

Height: 1.8 meters (5'11")

Weight: 84 kg (185 lb)

Family: wife, Karen; four children, two stepsons

Education: BSEE, North Dakota State University, 1948; MSEE and Ph.D., Stanford University, 1949 and 1951

Patents: none (staunch advocate of public domain)

Most recent book read: *Inside Intel*

Favorite periodicals: publications of the IEEE, National Academy of Engineering, National Academy of Science, and American Academy of Arts and Sciences; *Newsweek*

Computer: Hewlett-Packard Pentium PC

Car: Honda Accord

Favorite restaurant: Prima, Walnut Creek, Calif.

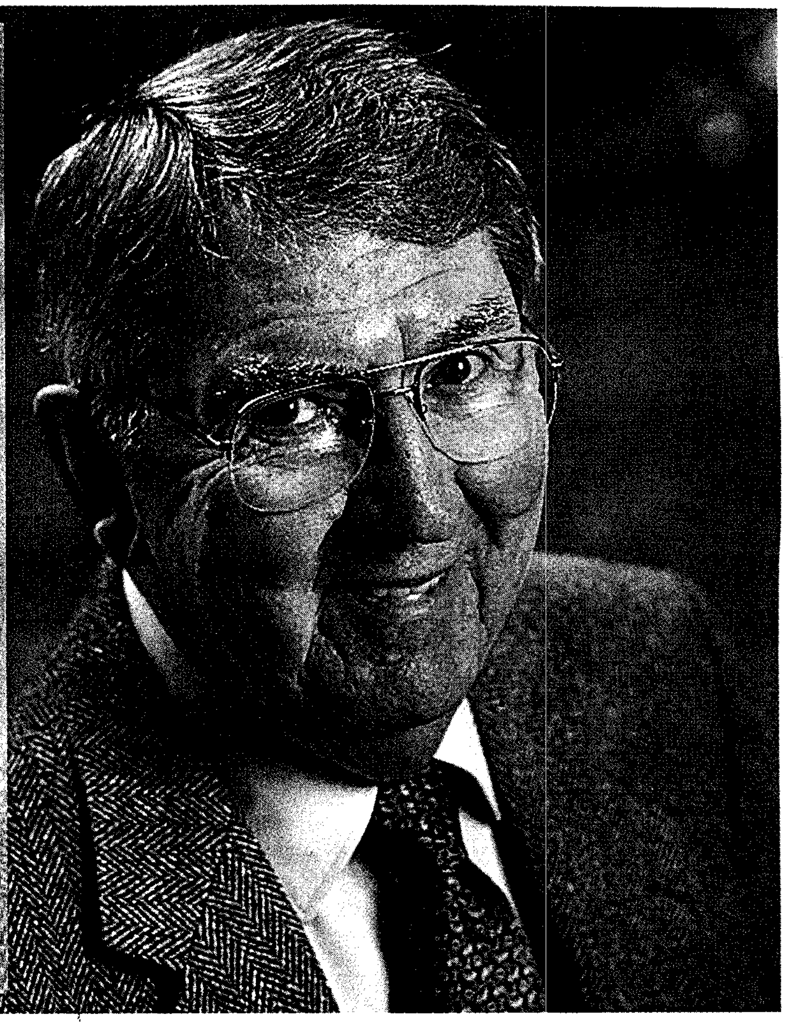
Favorite movie: *Patton*

Motto: "You don't get any credit for doing 95 percent of the job."

Management creed: "Figure out the job and do it."

Organizational memberships: IEEE, NAE, NAS, American Academy of Arts and Sciences, American Association for the Advancement of Science

Awards: 1998 IEEE Medal of Honor "for pioneering contributions to the computer-aided design of integrated circuits;" 1969 IEEE Education Medal; 1996 Computer and Communication Promotion Prize; numerous others



Office and the U.S. Air Force, provided needed funds. And in 1962 Pederson announced at a conference of the Institute of Radio Engineers (IRE), the predecessor of the IEEE, that his group had produced its first working circuit. "We stole [the fab] fair and square," he said.

Before the university could consider whether or not to give the project formal approval, notable engineers from industry were visiting and praising the facility, the first IC fab at a university.

"His vision, which gave Berkeley an IC fab way ahead of any other universities, proved to be a key move for the university, for we trained a large number of outstanding students," Berkeley's Kuh said.

"Other universities were arguing at the time that a university can't possibly keep up in the microfabrication field, because you can't afford the most modern facilities," Whinnery, the Berkeley professor who helped to recruit Pederson, told *Spectrum*.

"This is true, but Don saw that if you didn't have reasonable facilities, you wouldn't be able to contribute to the field at all. That was one of the farsighted things he did that really paid off. Students that came out of that program became leaders in the semiconductor industry."

Birth of Spice

Having a fab gave the Berkeley IC design effort a substantial boost. But by the mid-1960s, Pederson ran into two seemingly insoluble problems.

At an IRE meeting in Philadelphia in 1966, he struck up a conversation with a former student, George Haines, then working for Sprague Electric Co. (since dismantled). Haines told Pederson he had used his best knowledge from his studies to design a certain amplifier, but, once built, the device turned out to be an oscillator. The engineer then concluded that some second-order effects, not considered in the design, were moving into the forefront and causing the problem. Therefore, simply teaching students first-order effects was not adequate.

Pederson assured him he was wrong, that Berkeley's teachings were perfectly adequate, and that Haines simply was not designing the circuit correctly. The two made a $5 bet, and Pederson took the design and went back to Berkeley to prove himself right.

There he gave the problem to a graduate student to analyze, assigning him use of a Control Data Corp. computer and two existing design analysis programs, Calahan from the University of Illinois and Pottle from Cornell University. Both programs were limited to looking at the frequency response of linear circuits.

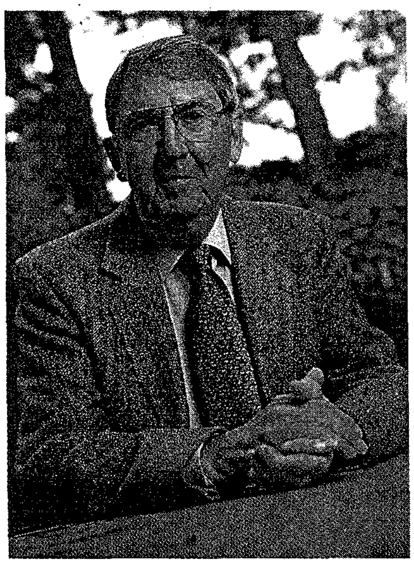
For three months, professor and student went back and forth over the results, often finding errors in the computer analysis. Finally, the student produced an error-free analysis that proved the second-order effects were coming into play, and Pederson put a $5 bill in the mail.

Around the same time, another former student of his, Bill Howard, an assistant professor at Berkeley, asked for help with a problem he had encountered during a visit to an Army research laboratory. A researcher at the lab had posed a problem involving the performance of an amplifier under varying temperatures. Using back-of-the-envelope calculations, Pederson took three approaches to solving the problem—and came up with as many different answers.

The difficulty in solving these two problems got Pederson thinking. "Here," he said, "we had used our best design technology, but it wasn't adequate, because it didn't predict that interactions [among components on the IC] would affect the outcome."

Working with another graduate student, Pederson then used available computer-aided analysis tools to review previous IC designs. According to these analyses, it appeared that perhaps half the designs analyzed were in error because of unexpected interactions. But the programs simply were not good enough to do an analysis of the current generation of ICs, which typically packed 10 to 20 components on a chip less than 2.5 mm on a side.

Finally, Pederson concluded that, although he and his graduate students were not computer programmers, they would have to write their own programs to simulate the behavior of a complex IC.



A slew of programs

One of the first to create a program was Berkeley's Howard. He worked day and night one weekend, using an IBM 1130, writing bits and pieces of code that could solve his variable temperature problem and could be applied to other nonlinear phenomena. Howard called the program Bias. Pederson then suggested that a graduate student use that code as the basis for his master's thesis, turning it into a unified program for nonlinear static circuit analysis. That became Bias 2.

Over the next three to four years, the programs evolved. A different student looked at the problems that had stumped the Calahan and Pottle software, and with Pederson's help, wrote a linear analysis program, dubbed Sprague. An undergraduate student wrote another version of a linear analysis program, using more stable algorithms, and dubbed it Frank. Then one of Pederson's Ph.D. students, at his urging, rewrote Bias 2 into a more sophisticated piece of software, Bias 3.

Around the same time, Ronald Rohrer, also an engineering professor at Berkeley, took a group of a dozen students and developed another IC analysis program, Cancer. This independent effort produced circuit analysis software similar to what Pederson's group was writing.

While these circuit simulation programs evolved, Pederson kept groups of students focused on the problem. "Many of us worked on some aspects of it," former student Wooley recalled, "though it seemed to many like an insoluble problem. The key that emerged was just to keep working the problem, not to think about getting to a finished product and stopping." The difficulty was the growing complexity of the circuits, and the lack of proof that a set of simultaneously solved algorithms would converge on a correct solution.

By the spring of 1970, Pederson said, Bias 3, Frank, and Cancer were real circuit simulators. They could handle both linear problems, producing frequency response data, and static nonlinear problems, giving the dc state of the circuit. What they lacked was the ability to handle dynamic nonlinear problems, in which the behavior of the circuit changes over time.

Scrounging again, Pederson discovered that engineers at Rockwell International Corp. (today headquartered in Costa Mesa, Calif.) had developed a dynamic nonlinear analysis program, called Trac, which they were using to analyze specialized military circuitry and whose code they were willing to share. Trac used simple mathematical routines to set up the circuit data and included several assembly language programs.

Unlike programs being developed by other industrial laboratories, which used higher-level mathematics, Trac's correctness could not be proven because of the problem of converging simultaneous equations. But, Pederson said, it worked reliably, unlike higher-level software, and was easier to deal with and broader in its application. And it was consistent with the techniques used in Frank and Bias. So he adopted the Trac algorithms. One student rewrote the assembly language instructions into Fortran; two others worked on revising the algorithms. The complete rewrite was named Sinc.

In 1971 Pederson's group was using two analysis programs, Sinc and Slic. The latter was developed by merging Frank and Bias. Rohrer's group had gone on developing Cancer.

Staying in the public domain

There was one big difference between the two professors. Rohrer had insisted that his work be kept proprietary, reasoning that companies would spend money to support it. Pederson, who by choice has garnered no patents throughout his career, is a vocal advocate of putting research in the public domain, arguing that open sharing with fellow academics and industrial researchers has been key to all developments in microelectronics.

This philosophy, Berkeley professo emeritus Kuh said, was important t Pederson's success as a standards-sette "Some people had the idea that you coul make money off these programs," Ku told *Spectrum*. "That never entered hi mind. Instead, he wanted to make an impact. More important than money wa getting the thing out."

So when Rohrer announced that h was leaving Berkeley and aske Pederson to take over the supervision o graduate student Larry Nagel, who wa then spearheading the Cancer work Pederson agreed on one condition—tha the program be rewritten so as to be different enough from the then-current proprietary, Cancer to be put in th public domain. Rohrer agreed, and i May 1972 the private Cancer becam the public Spice.

At that point Pederson was faced wit a decision. While Spice, Sinc, and Sli were all active research programs, he fel he had to choose one for use by student designing ICs in their coursework. H picked Spice, he told *Spectrum*, because h did not want to favor his own student over the graduate student he had recentl "adopted." The other two programs faded although a version of Sinc was used for a time at Motorola, and Slic was used a Signetics and Philips.

During the early 1970s, Berkeley graduated over a hundred students a year wh were accustomed to using Spice. The started jobs in industry, and loaded Spic on whatever computers they had available. (By that time, Spice had been adapted to six of the most popular compute systems, including the CDC 6400, IBM 360/370, and DEC VAX 11/780.) Spic quickly caught on among their co-workers, and by 1975 it was in widespread use.

The technology made another leap i popularity in 1984 when MicroSim, Corp., Irvine, Calif., came out with P-Spice, a version of Spice for personal computers. (Businesses were authorized to base products on the free Spice code, but could charge customers for the user interface and technical support.) Other commercial versions were also developed. Today's Spice can simulate circuits containing active components, such as bipolar transistors, field-effect transistors, and diodes, along with resistors, capacitors, and inductors.

Meanwhile, Pederson turned his attention to speeding up Spice, and spent some 10 years, on and off, at that effort. (A simulation of a circuit with under 200 critical components took a few minutes on the VAX 11/780, 10 times that on the PC XT.)

"We tried a steady stream of things," he told *Spectrum*. But the results were distinctly disappointing. "Every time we thought of a new technique, we hoped for a factor of 100 to 1 [in] speed improvement. We would accept 10 to 1.

The Spice of engineers' lives

DAN HARRIS

Designed in the early 1970s at the University of California at Berkeley, Spice is a general-purpose electronic circuit simulation program. It has become the industry standard for analog simulation, thanks in part to the free distribution of the original text-based program by the university.

As its name implies, the Simulation Program with Integrated Circuit Emphasis started out as a tool for analyzing the internal structure of ICs. But because its architecture describes circuits in a general way as a network of constituent elements (resistors, capacitors, sources, and so on), it is equally well suited to board-level analysis. In fact, simulation of board-level circuits is the most common use of Spice today.

To describe the circuit topology, a netlist file is input to the Spice simulator. Line statements identify circuit elements, their electrical characteristics, and their nodal connections. For instance, the line "R12 1 4 100-kOhm" defines a 100-kΩ resistor that is connected between nodes 1 and 4 in the circuit. The first letter of the reference name (R12) identifies the element type as a resistor.

The circuit response is determined by solving Kirchoff's Laws for the nodes in the circuit. The simulator puts these equations into a large matrix and, for each time point, solves them using iterative integration techniques. Basically, Spice does three analyses: nonlinear dc (determining the circuits' dc operating point with inductors shorted and capacitors opened), nonlinear transient (calculating the output variable as a function of time), and linear ac (computing the output variable as a function of frequency).

By making use of the brute-force capabilities of computer-based computation, these three analyses form the foundation for a larger set of powerful analyses. An example is the Monte Carlo analysis, which performs a series of dc, transient, or ac analyses, each time randomly varying circuit component values within their specified tolerances. This program can simulate building and testing a large batch of boards, each of which has slightly different characteristics because of the finite tolerances of the parts used.

While the core Spice engine has changed rather little since its creation in the early '70s, electronic design automation vendors have wrapped user friendly interfaces around the engine to make the program a more practical tool. Designers of early Spice simulators had to write complex netlists and spend considerable time debugging the netlist files until they were syntactically correct. In today's commercial Spice simulators, graphical front-ends for easy schematic entry are frequently included. The software tools then automatically generate Spice netlists from schematics, freeing users to focus on design issues rather than the intricacies of the Spice language.

The benefits of using today's advanced, yet easy-to-use, Spice simulators abound. They include:

- Cost savings. Simulating a circuit with Spice is much cheaper than analyzing the same circuit in a real laboratory because it can replace expensive measurement and analysis equipment. What's more, because simulation components are free and plentiful, designers save money by not having to purchase as many real parts.
- Faster prototyping. Prototyping is an essential part of any design because it often uncovers surprising results that were not anticipated by hand calculations. Spice is a valuable tool for verifying circuit behavior. To start with, simulating with Spice is much faster and easier than breadboarding. Then, too, for troubleshooting or exploring design alternatives, Spice lets users make circuit changes without having to plod through lengthy hand calculations.
- More advanced analysis. While Spice can perform all the analyses traditionally performed in the lab, it can also do what's impossible in the real world. Its simulators can probe areas of a circuit physically inaccessible on a real board and even let users investigate electrical signals within components. While designers in the real world can make only assumptions about the internal behavior of components, with Spice they can look inside a part.

Despite all the power and flexibility of Spice simulation, the program does have limitations. For one, it can be slow on circuits that have disparate frequencies because its time-step–controlled simulation algorithm selects time-steps based on the highest-frequency source in the circuit. Consider, for instance, a circuit with a 1-kHz source and a 1-MHz source. If the program chooses to evaluate 100 points per cycle for the higher-frequency signal, it will evaluate an overwhelming 100 000 time-steps for each cycle of the lower-frequency signal.

Another drawback is that a Spice simulation is only as accurate as the precision of the models used. And modeling Spice components uses different properties from those found in data books, requiring the user to go through an extraction process to translate data book values into Spice values. Therefore, users should always try to obtain Spice models from the most reliable sources.

Dan Harris is the marketing manager of Interactive Image Technologies Ltd., Toronto, makers of the Electronics Workbench circuit simulation program. Harris holds a B.A.Sc. in electrical engineering from the University of Toronto. He can be reached at dharris@interactiv.com.

but we would only get 3 to 1, which wasn't enough to beat the improved speed of the new hardware coming out of Intel. So the computer makers always beat us in speed improvements."

Pederson retired in 1991, when over 100 000 copies of Spice were in active use at universities and in industry. In fact, there are currently about 20 companies providing Spice products commercially, including Deutsch Research, Interactive Image Technologies, Intusoft, and Micro-Code Engineering. The public domain version is obtainable from Berkeley.

According to Donald G. Fink and Donald Christiansen's *Electronics Engineers' Handbook* (3rd edition, McGraw-Hill, New York, 1989), many circuit-simulation programs have been written during the past 20 years, but "the most widely used is Spice." Spice was used to simulate critical analog circuits in virtually every IC designed in the United States in recent years, Pederson said.

Although today arthritis and Parkinson's disease keep Pederson from visiting the university often, he logs onto Berkeley's computer every day, and reads some 10 to 20 technical journals monthly.

Former students continue to seek him out for advice. "More than anyone else, Don is who we will turn to, because he will always give us a straight opinion, and never has his own agenda," Wooley told *Spectrum*.

"For a lot of us in the IC community," Wooley said, "he is the godfather, in the best sense of the word." ◆

For a look at the 1998 IEEE Medalists, see pp. 62–67. —Ed.