Interview

Interview With Vishwani Agrawal

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Nicola Nicolici: Good afternoon. Today, I want to welcome Prof. Vishwani Agrawal, who is currently professor emeritus at Auburn University, AL, USA, where, prior to retiring in September 2016, he was the James Danaher professor of electrical and computer engineering. He has over 40 years of industry and university experience working at Bell Labs, Rutgers University, Thompson, Ramo, and Wooldridge (TRW), Indian Institute of Technology in New Delhi, India (IIT Delhi), Edgerton, Germeshausen, and Grier (EG&G), and Automation Technology Incorporated (ATI). His areas of work include VLSI testing, low-power design, and microwave antennas. He received a Bachelor of Engineering degree from the University of Roorkee, India, in 1964, a Master of Engineering degree from the Indian Institute of Science, Bangalore, India, in 1966, and a PhD degree in electrical engineering from the University of Illinois Urbana–Champaign in 1971. He has published over 400 papers, has coauthored five books, and holds 13 U.S. patterns. His textbooks, essentials of electronic testing for digital, memory, and mixed-signal VLSI circuits, coauthored with Michael Bushnell, were published in 2000. He is the Founder and has been the Editor-in-Chief since 1990 of *Journal of Electronic Testing Theory and Applications*, the past Editor-in-Chief, from 1985 to 1987, of *IEEE Design&Test of Computers* magazine, and a past Editorial Member, from 2003 to 2008, of IEEE Transactions on Very Large Scale Integration (VLSI) Systems. He is the Founder and a Consulting Editor of the Frontiers in Electronic Testing Book Series of Springer. Welcome, Vishwani.

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Vishwani Agrawal: Thank you, Nicola.

Nicolici: Vishwani, you have received your engineering degree about six decades ago. The electrical engineering field must have been quite different in those days and has evolved quite a lot since then. So, what has motivated you to study this particular field?

Agrawal: The reason why I am an electrical engineer—when I was in college, I was fascinated by physics, and in physics, the portion that was electricity. And, so I decided that I would study electrical engineering. I studied electrical engineering and have ever since stayed in that profession.

Nicolici: You started your career, if I understand correctly, in antennas, so many, many decades ago. And then at one point, you have switched to electronic testing. Were there any particular reasons that caused this change in direction?

Agrawal: At the time when I started as an engineer, the computer science was not as developed. In my college days, I did not study computer science. So, there was really no question of doing computer science at that time. When I was doing my master's degree, I got introduced to antennas and electromagnetics, and I got interested in that. So, I continued in that area when I got to PhD And after PhD, I went to industry to work on antennas. But getting into the computers was an accident.

When I was graduating with my PhD degree, the job situation in the United States was pretty bad, and I could not locate a job. So, I started working near the campus in a startup company. University of Illinois at that time, where I was a graduate student, was building a multicomputer known as Iliac 4. And for building the circuits of Iliac 4, they used a consulting company, which was run by some of the former staff of the university. They were recruiting students from

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the university for building those circuits or helping with the circuit design, verification, and test. At that time, my wife, who was also a graduate student in the university, had an assistantship funded by that company. She introduced me to her boss who immediately gave me a job. But it had nothing to do with the antenna work I was doing in the lab at the university for my degree. The job that he gave me was to write a program to implement the D-algorithm so that they can generate tests for the circuit boards that they were designing for the Iliac 4 computer. The computer programming and testing were completely new for me. And that was the year 1969–1970 Roth's paper on the D-algorithm [1] had just appeared and my new boss gave me that paper. He said that here is an algorithm that you can go ahead and program. So, I had to learn the algorithm from the beginning. I read through the paper over and over, to learn the algorithm, and then programed it. And that was actually used for generating test vectors. Until that time, I don't remember how the tests were generated. They were written by looking at the circuit diagrams by the designers. There was also random testing using the stuck-at fault model and a fault simulator. So, once I wrote the program, we could generate the algorithmic tests. That means given a stuck-at fault, we can get a test, rather than hitting the circuit with random vectors. However, we found that the random vectors were much faster to generate. So, we continued with the random vectors. But when we found that the fault coverage was not increasing by random vectors, at that time, we would switch to the D-algorithm. And so, the program that came out of that effort was a combination of the random vector generation and the D algorithm vectors and the fault simulator. And that was my first paper published in the area of digital computing in IEEE Transactions on Computers [2].

Nicolici: It's very interesting. That particular project was probably one of the first few implementations of the D algorithm to be used in practice?

Agrawal: Yeah. Well, Roth may have implemented it in IBM. But yes, it was one of the first. At that time, there were no CAD programs. There were no commercial programs available.

Nicolici: Yes.

Agrawal: Let me add one footnote. I took it as a computer programming job and it did not impress me to that extent that I would change my field at that time. So I still continued to look for a job in the antennas, and I did find one.

Nicolici: And when exactly did you switch to electronic testing then?

Agrawal: So that's another incident that made me switch. I continued in antennas. I worked on radars and antennas, designing those and publishing papers. I was working in California where my wife was attending University of Southern California working for the PhD. This is several years later. I was working at TRW systems, designing spacecraft antennas. Everything was going fine until she graduated and started interviewing with companies. And she got an offer from Bell Labs in New Jersey. So the interviewer asked her, "What about your husband?" And he gave an application form for me that I should fill out because he knew that she's not going to accept a job in New Jersey if I were to continue in California. I filled out the application and I took an interview in Bell Labs. They had me interview in different departments, which included, generally speaking, the electromagnetics and antenna type of work, except for one department that was in the area of computers. And that is because we had published papers on the work I had done on digital test generation. I got an offer. The system that they had in the labs was that if you interview with several departments, then the candidate actually has to rank order those departments in order of preference. And they will ask the first one, from your preference, whether they want to make an offer to the candidate. It's only when that department declines that they will ask the second one. So when I was filling out that ordering of the departments, I put the testing department first. And that is because it was in Murray Hill. The Murray Hill was the most famous lab. So because the testing job was in Murray Hill, I chose that as my first choice. The second choice was an antenna group that was in Holmdel in New Jersey. The first one accepted me, so I ended up in Murray Hill, which was my choice of the place, but it was the work on computer testing. So that's how I got involved in that. And that was the beginning of my real career in electrical testing.

Nicolici: Very interesting trajectory. Thank you for providing this historical perspective. Now, throughout your career, you have spent time in both industrial research labs and academia. So how would you compare the two experiences?

Agrawal: All my work has been on-the-job learning or on-the-job training because none of these things that I do were actually taught in college. The only things that I learned in college, probably I can

say, are the fundamentals, the mathematics, and the fundamentals that allowed me to pick up other things. I think that's the way it is generally because when you work in a field for 30, 40 years, things change. And what you learned in college becomes sort of obsolete. So that's the way it is.

Nicolici: Over the years, you were instrumental in organizing the research community. You have co-founded both symposia and conferences, as well as magazines and journals. Can you elaborate on some of these important endeavors?

Agrawal: I think those things happen automatically. In general, when you work in a field for a long time, the people start looking toward you to do something of that kind. For example, in case of the journal, it was a publisher who approached me and said that this is about the time that we have a journal in testing, and would you like to do it? So that's how I got involved in that. I think most of the conferences also start that way. You are approached by some people or a group of people who want to have something like that, and they want you to help them. And that's how we get in.

Nicolici: You were also the Editor-in-Chief of *IEEE Design&Test* magazine. So that was, if I'm correct, about four decades ago.

Agrawal: That was my first involvement with publishing. I joined the editorial group of this *Design&Test Magazine*. It was actually started by a fellow named Roy Russo. The magazine had just started, and he recruited me as an Editor. He was the Editor-in-Chief. Soon after that, I think it may have been a year or so down the line, and he became the president of the IEEE Computer Society. So his responsibility required him to quit the editorial work. I agreed to his proposal and he appointed me as the Editor-in-Chief.

Nicolici: Thank you. As everyone who has studied or worked on electronic testing is already aware, you co-wrote one of the most widely used textbooks on the topic that has educated many generations of professionals. How would you estimate the impact of this textbook?

Agrawal: I think that the textbook had tremendous impact. I meet people all over the world, and they mention that. Many people got started in this area of testing through the textbook. That is very satisfying. But when the textbook was written, there were a couple of other textbooks in the market. We looked at the needs of the field and found that there was no textbook at that time that actually covered the digital and analog testing together. So we decided that we are going to write a book which will be in some ways complete. And we included three items, digital testing, analog testing, and the third one is memory testing. That was published in the year 2000 [3]. And we found out soon after, that RF circuits became popular, and RF testing is missing now in that. There are a few other things too that are missing. So the book really needs some kind of a revision to include those. Because the course that I used to teach at Auburn University on testing, I included RF testing but it's not there in the book.

Nicolici: You have also received many awards and recognitions over the years, and your contributions have been quite diverse as discussed above. Are there any particular activities that stand out, in your opinion, in particular if the broader long-term effects are yet to be seen?

Agrawal: I cannot put my finger on any one of those. I think that I always keep thinking that probably the best part of my work may be yet to come. So I must keep going.

Nicolici: Thank you. Considering your long and distinguishing career, are there any particular thoughts that you would like to share with the future generations of scholars and practitioners?

Agrawal: I think the most satisfying part of my career has been actually teaching. When I worked in Bell Laboratories in New Jersey, they were fairly relaxed about the type of things that people did there. And I used to spend one day in a week at the Rutgers University, which was locally situated. That's when I met Mike Bushnell, who is the coauthor of my book. We developed a course on testing. We also directed some PhD candidates at the university. We started teaching that course, which actually gave rise to the book. I found the process of teaching to be extremely interesting. I often think that if I have to start my career from the beginning, I will probably start with teaching. However, working in the industry provided some sort of on-the-job training, which was very useful, especially for this new area that I had never studied in college. I started learning new things as they came about. I think that some combination of industry and academia is probably ideal. To everybody who works in the university, I would suggest that they should spend some time in the industry because that allows them to gain from the practical environment.

Nicolici: Thank you very much, Vishwani, for this interview.

Agrawal: I want to say one more thing, Nicola. That is, the broadening or diversification of your field. Just like from antennas, I moved into digital testing or teaching business. I had read your book on low power that you published [4]. I think that's part of your PhD dissertation. I was working on a particular problem of testing. At that time, delay testing was becoming popular in the industry. I found that in applying the delay test, there was a problem that needed to be solved. That was to deal with the glitches in the logic signals. The delay tests had to avoid the glitches and things like that. I realized that for CMOS circuits, actually, it is the transitions that consume power. The glitches actually cause a large number of transitions in combinational circuits, and they all consume power. So that is how I got into the low-power design. That means designing the circuits that will not have the glitches or getting rid of the glitches for low-power design. Thus, low-power design was actually something that I learned from the area of testing. What I want to say is that in going ahead, you build upon your existing knowledge from your area of work, but equally important is the knowledge from other areas. Combination of ideas from diverse areas can lead to something new. And that's exciting.

Nicolici: Thanks again. Thank you very much, Vishwani, and let me wish you all the best for your current and ongoing endeavors.

Agrawal: Thank you, Nicola. I appreciate the incentive you have taken in inviting me to this interview and then carrying through a thought-provoking conversation.

Nicolici: Thank you. ■

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