Semiconductor Test Equipment Development Oral History Panel

Participants:
Phillip Burlison
Garry Gillette
Jim Healy
Dan Morrow
Harry Sello

Moderated by:
Paul Sakamoto

Recorded: August 14, 2009
Mountain View, California

CHM Reference number: X5501.2010

Paul Sakamoto: Hello, and welcome to our panel on the history of semiconductor test. My name is Paul Sakamoto, and I'll be moderating the session today.

By its very nature, semiconductor manufacturing is a process in which many chips or devices are made en masse on a single piece of silicon called a wafer,. Not all of these devices are good, and this is the way it's been since the beginning of the industry. The way that quality is guaranteed is by using testing to make sure that the devices perform as specified. The unsung heroes of the semiconductor evolution that has enabled the revolution in computing technology are the folks in the test industry. Without test, we would not be able to know if those devices actually worked, how well they worked, or how much they should be sold for. In fact, this is the way that we've actually been able to have any progress at all in the industry and have it as we know it today. The fact is that at the end of the process, we need to know if the devices good, bad, And how good are they? That's been determined by this industry that employs a few thousand people, is kind of an unsung hero of the whole process, and of which we are privileged to have these gentlemen here today representing some of the history of that 50 year old industry. So with that said, let's go ahead and capture some of the memories of those intervening decades and have a discussion with our panel today. We're going to go ahead and walk through some of their memories of the history of test. And remember, without test, there'd be no semiconductors.

To start off with, why don't we go ahead and each introduce ourselves and give a brief history of your academic and industrial background. We'll start over here on our left with Dr. Harry Sello.

Harry Sello: Hi. It's a great pleasure to talk about this, because it's been the largest portion of my life that I can remember. Academic, that's school, isn't it? I received a Ph.D. degree at the University of Missouri. It might come as a surprise to some of my colleagues here that my degree was in physical chemistry. Now, that's got absolutely nothing to do with testing integrated circuits. Little did I know that that it was a pretty good background to get started in. Somewhere along that background, while I was working in the chemical industry, I got a a mysterious phone call from a gentleman by the name of William Shockley. I was a little bit upset about the call, because he opened the conversation by saying, "Do you know who I am?" That’s not a usual start for a conversation, but that was William Shockley's start. He said, "I want you to consider coming to work for me." I said, "Well, I'm not in anything to do with your field, Dr. Shockley. You're a physicist, and I've heard that you won the Nobel Prize, congratulations." I tried to be sort of lucid about this, but it didn't go quite as easily as I'm saying now. At any rate, Dr. Shockley hired me. To this day, I don't know how he managed to find me. I've made many, many guesses; t was a lucky break I got. I was working in Berkeley, California at the time. I went down to Menlo Park California, Mountain View specifically, to go to work for William Shockley, the Nobel Prize winner, in the manufacture and the design and the testing of this new field of devices made of a material called silicon. Now, the only thing I knew about silicon was that it's a main constituent of sand that you find on a beach. From there, my electrical knowledge ended, because a physical chemist doesn't have much to do with these kind of guys that are around the table now who are all well acquainted with electrical and electronic testing.This was a very interesting experience, because I really got acquainted with two people that I remember very vividly. One was Dr. Gordon Moore, and another was Dr. Vic Greenwich, who also worked at Shockley with me. And I remember them particularly, because Gordon Moore was a physical chemist. So I said, "Gordon, if you can work here, then I can work here." He said, "Don't worry, if you don't know anything about this, just ask Vic, he knows." Vic Greenwich was a brilliant electrical engineer, a Ph.D. He introduced me to the subject of device testing. It turns out that what you do in the laboratory as a physical chemist to make silicon semiconductor devices,is that you know chemistry and physics, and maybe some metallurgy. The way you found out what you had made or whether it was good or useful, was that you had to have a guy like Vic Greenwich around, – an electrical engineer – who explained how to test these devices that we make in the laboratory. That was a tremendous experience because later Vic Greenwich and seven of his colleagues – who fondly got to be known as the Traitorous Eight – left Shockley Laboratories to form a new company called Fairchild Semiconductor. Shortly thereafter, they invited me to join them. I always felt very proud that I could join them, but I still didn't know much about electrical testing. What little I did know, I was taught by guys like Vic Greenwich and Gordon Moore. All we had to do at that time was to learn how to use a cathode ray oscilloscope made by Tektronix. You took two needles and you touched them down to the device. If the scope on the electronics machine – the tester – made certain patterns you knew you had a good device. If it didn’t make certain patterns, you knew you had a bad device. That was my introduction to the testing and manufacture of semiconductors, with which I've remained associated for the past 50 years.

Sakamoto: Thank you Harry. That's interesting that back at the beginning, the person or the engineer that was working on the testing was actually the controller or the computer for the test process. Dan Morrow, why don't you tell us a little bit about your background and where you come from.

Dan Morrow: Thanks Paul. My name's Daniel Morrow. I studied engineering. At the time, it was right at the front end of what's now known as computer engineering. My great passion at the time was signal processing; digital signal processing [DSP], as a matter of fact. I finished with a master's degree in engineering and took a job that was oriented towards understanding the information that was coming off of large focal-plane [radar] arrays. This was back in the Reagan era when “Star Wars” was a big thing, and we were analyzing the data coming off of those focal-plane arrays. I thus had an interesting mix of digital signal processing and device tests. I did that for a number of years and then moved from that organization to a company called Pacific Western Systems, where I was director of engineering. I was able to get involved in a long string of very interesting emerging technologies at the time.. Test gave me a chance to mix the analysis of signals and new devices. Over the years – I think I was there for 10–12 years – we covered a variety of different test applications. From there, I founded a company called OpTest that specializes in testing high-brightness, light-emitting diodes [HBLED] in the production environment. It’s another fascinating emerging market. In a nutshell, that's kind of who I am.

Sakamoto: Thank you Daniel. It's interesting to see that we've gone over those intervening decades from Dr. Sello testing individual diodes and transistors, to testing massively integrated devices and now back to testing individual diodes again. Phil Burlison, why don't you tell about your background and how you came to test. By the way, I was remiss in forgetting to say we should probably try to talk about the years involved in our stories.

Phillip Burlison: I started off my career without really having an idea what my career was. I had no motivation or intention to get into any of the high-tech industries. I was a kid out of Oklahoma who dropped out of high school to join the Navy, because that was my aspiration, my passion in life, to see the world in the Navy. It was my pleasant surprise that they [the Navy] trained you to do some practical things. They taught me how to take care of radar systems for missiles. I said "Okay, well, I've found my career. I'm a radar guy now, right?" Then I got out of the Navy in the mid-'60s, started looking for a job that had something to do with radar, and there were none. I remember that interview, my first interview, real well. It was in San Diego with a small semiconductor company I'd never heard of called Signetics. They were asking me – they were looking for electronic technicians –if I knew anything about miniature electronics. I said, "Do I ever." I mean, some of the vacuum tubes we used in the Navy were so small, you could hold several of them in your hand. Then he explained integrated circuits to me, which was my first revelation [introduction] into semiconductors. He said okay, well I can learn that. So Signetics, for some weird reason, hired me. Now I worked in the analog R and D department as a technician. About a year after that, the technology was so simple then, I actually was able to start designing some integrated circuits. So now I'm an analog circuit designer. That's my career. Going along with the building of these chips – they were simple back then – I figured out that you had to test them. So I started building testers specifically for the integrated circuit that I was designing. That was my first entry into test, which was basically to build a very specialized, simple, dedicated tester for whatever I was designing. And then the next IC I worked on, I ended up designing another tester for that. Through my short seven years' experience in the semiconductor industry designing ICs, my job gradually evolved to the point that actually no, I'm not a semiconductor designer, I'm really a test guy. I came to this realization in the early '70s when an ATE [Automatic Test Equipment] company, Macrodata, recruited and hired me.

Sakamoto: That's interesting. So we've gone from having, a person, the engineer, being the controller of the test process with an oscilloscope and a couple of probes to ATE, which is Automatic Test Equipment, now using a computer to control these very complex processes. In fact, we've seen the progress from non-specific instrumentation to purpose-built instruments designed to test a particular design and now to general-purpose electronics to test a variety of chips in automatic test equipment, or ATE. Garry Gillette, why don't you give us a little bit of your background and where you fit in this broad spectrum.

Garry Gillette: My name is Garry Gillette. I started out in the Sputnik year in college [1957]. I'll leave the number out, but everyone will remember that, I'm sure. I was at MIT at the time, and then I decided I would transfer to Stanford. After transferring to Stanford I graduated in 1961 with a bachelor's degree in EE. Then I went out in the world to design things. There weren't any test systems at that time, so I ended up working in a number of bench top instrument companies in San Diego. I designed a number of products there and then moved on to Orange County for a company called Dana Labs. While at Dana, – about a dozen years – I designed all forms of bench top instruments, DC amplifiers, counters, and signal generators; essentially, every kind of thing that competed with Hewlett-Packard in that era. After that, HP [Hewlett-Packard Corporation of Palo Alto, CA] taught us a lesson on how to get out of the business. So, in 1974, I moved on to a company called Teradyne. It was a little tiny company getting into the test business at that time. I liked the idea that they had somehow solved the problem of how to computer-control a test system. They had actually developed their own controller and were shipping computer controlled systems at that time. That, coming from the bench top instrument business, was a very big improvement in my interests. I stayed 18 years at Teradyne and I worked on 12 large computer-controlled test systems while I was there. I was responsible for the architecture and for the development process there. After that, I moved to the [San Francisco, CA] Bay Area and worked on architecting this kind of a test board <Garry holds up a circuit board with many devices on it. It is about 14 inches by 16 inches on a side> here, which is a whole tester on a single board. It's completely made up of very large-scale integration ICs [Integrated Circuits]. It has no relays, and it's self-contained so that you can increase the number of these board modules if you need more pins to test the device. The company I was with at that time was called Credence Systems. I was there about a dozen years. That kind of brings me to today.

Sakamoto: That's an interesting update that brings us to think about the continuous cycle of going from more complex devices to more complex test equipment which is used to test the next generation of chips to make the next generation of test equipment. Jim Healy, as our last person to talk about your background, why don't you give us an overview of that whole progression. I think you were around for a good part of it.

James Healy: Well, I've been in the business a little less time than Dr. Sello. I got into it by happenstance too. I joined the Navy in 1958, and they sent me to a school. My first training was on solid-state devices, which was something new at the time. I learned there that holes <positive charge in a semiconductor> move. That was a concept that was pretty difficult for most of us to figure out – what these people were talking about. Of course then we worked on transmitters and receivers including a Collins radio with solid-state single side-bands. Some of these had these semiconductor devices in them. It was very intriguing. So when I left the Navy, I joined RCA working on the WS-133 Minuteman [One of a series of intercontinental ballistic missiles of the period] project. They put me in charge of the burn-in and test for transistors. That's when I realized that this looks like it's the thing that's going to happen because if they're putting them into missiles, they're going to put them in everything else. So I found it to be very intriguing, this whole area of tests, because it was very clear to me that to know if something worked, you had to be able to test it, and that the challenge was the testing of these transistors. Then one day, I was sitting in my office, and I got a flyer from Fairchild Test Systems that showed a machine called the model 500 transistor tester which was an automatic tester, and you could program it. This looked to me like heaven. I thought, "Wow." So I I worked my way out to the West Coast, and I finally finagled my way into Fairchild to join them. From there on, I spent about 15 years then at Fairchild working in the Fairchild factories here in the United States. They sent me to Japan for seven years, a year and a half in Hong Kong, and four years in Germany. All that time, I was in the testing business. That's where I first met Dr. Sello, where we spent a lot of time in the Eastern Bloc countries. They were called the Eastern Bloc at that time. One of the things that was interesting is that you learned very quickly that the devices you had to test were tested with older technology. So the challenge of test is to take old technology and use it to verify the integrity of new technology. This is an example of a transistor tester. <Jim holds up an item that includes vacuum tubes in it> You'll see these are vacuum tubes. And this vacuum tube-based tester, this is a component of it, was used to test the next generation, which were the transistors. Now here's part of a transistor-based tester <Jim holds up a circuit board with some transistor circuits on it> that tested transistors for another tester. These transistors were then used to test the next generation, which were integrated circuits. And now you have the integrated circuits on this particular thing <Jim holds up another circuit board>, which was used to test the LSI [Large Scale Integrated Circuits], and it goes on and on. So that is probably the most interesting and challenging part of the test is the ability to be able to test that next generation. Well, after I left Fairchild, I worked a little while at another company. We started a company called Trillium. Trillium came out with the very first tester, which was called a per-pin architecture. It was water cooled, and it did a lot of very unique things. But the thing it did more than anything else was that it put Intel on the map because it was used as a workhorse for the 386 processor and the 486, and from then on, it became history. After my stint at Trillium,we sold it to another company called LTX, I went to Credence, where I became the CEO. We took the company public, it was a very successful company, developing the very first zero-footprint tester. The objective here is to try to get testers smaller and smaller because of something called the laws of physics. If you're going to test the part, you have to get close to it. The further away you are from it, the more difficult it is or maybe impossible to test. So we're always trying to make things smaller. And that is one of the major challenges. Today I'm working for a company called Logic Vision, and we have the ultimate tester, it's on the chip itself. There is no tester. It's intellectual property. When you design the chip, you design the test capability into the chip itself. So in essence, the chip tests itself. So I've come from the very beginning to the very end.

Sakamoto: Thank you, Jim. I think it's interesting to note through the histories, how most of you have actually gone through a number of different companies, some more than others. So maybe the next thing to discuss might be what happened to cause each of you to move through your career? Was it the evolution of what was happening from a product cycle? Did you say, "Hey, let's go ahead and change companies to go to where the new products are?" Or, was it some other influence? You know there are internal and external factors. Maybe you can kind of relate that to the overall progress in the industry. And this time, I'm going to kind of randomize a little bit. Why don't we start with Daniel?

Morrow: In my story, I haven't jumped around quite a bit between companies. But I can say that I've also had the opportunity to work on emerging technologies, at least in the space that I occupy in the test and measurement world. I'm interested in the new things on the block. Jim had mentioned the first generation testing the second generation testing the third generation. At least in my career, most of what I have worked with has been first and second generation kind of equipment. In my years at Pacific Western Systems, we had the opportunity to work on a number of different technologies. I would have jumped pretty quick if that wasn't true. My interest is in the innovation and in the new applications. I did leave Pacific Western Systems and formed OpTest because of a new technology. When we saw the high-brightness LEDs, we saw that traditional semiconductor test and measurement was very comfortable with voltage and current. But we really didn't see too many test and measurement people that were taking on the world of color in highly automated processes. And it was new, it was interesting, and it was big enough that we decided to make the leap, and founded a company that specializes in those areas.

Sakamoto: That's interesting. So you kind of moved with a new challenge. Garry Gillette, maybe you can talk a little bit about whether you moved with the challenge or the challenge moved with you.

Gillette: Well, I can remember that reasonably well. I was at this company in Orange County called Dana Labs. As I'd mentioned before, we were getting taught a lesson about how to use deep pockets to basically obliterate competition in the bench top instrument business in the period of about 1970. My experience at that time with computer control of things was a DEC PDP-8 and an IEEE bus ([GPIB or IEEE-488] and a rack and stack kind of thing. And that's about all the bench top people really had on their agenda at that time. I looked out and there's this other industry that was successfully using software to program computers to run equipment or instrumentation that tests things. And so it became a very natural thing for me to move on. In this case, I moved to Teradyne, because they were local in the same Southern California area where I lived at the time. So yes, it was definitely a move to the higher technology, to the technology that used software on a regular basis to control the test, or in this case, the instrumentation.

Sakamoto: I think that so far we've got a couple of you who've said you kind of moved with the new technology and the new challenge. Jim, maybe you can give us a little bit of a perspective on how you made your changes.

Healy: Money. There's a lot of challenges out there, a lot of opportunities in the valley here to make money. And it became pretty clear to me that if you-- what I actually did is, after 15 years in the business, I more or less migrated into marketing and sales. In fact, I wrote a book, “Automatic Testing of Integrated Circuits,” back in 1981. This book is the result of the time I spent in Japan, where the Japanese do not speak a lot of English, but they read it and could write it. I would communicate by writing and reading the various aspects of the testers and how testing was done, which migrated to a book. Well, based on that book, I was told by somebody, we know you have these marketing skills. Why not look at how you can convert this industry from a very staid technical industry into something beyond? Where anybody could sell it. Where people would get the idea. So the challenge that I got was when there was a problem, what problem was it that needed to be solved? Like, when we started Trillium, we knew there was a problem.

The problem was that you couldn't get the device close enough – the electronics to measure the device itself close enough – because the heat would just melt things. So we developed a tester that was liquid cooled; the first in the industry. That allowed us to get very close to the device on our testers and be able to test these next generations. So in a way, it was the new technology that drove it. But really it was the problem the industry was facing; where they had a problem. And very often, a company you're working for is not interested in that problem. They say, "This is the way to go, we have this." Or to say it in another way, "We're making money on this, I don't want to go to that next level." So you almost have to start another company or go to another company where they're willing to make that investment. They're willing to have the vision to see that there is a problem out there that can be solved. Because look at the history of the ATE companies. You'll see that it's like a roller coaster. This company's up, then it's down.Then the next goes up and it's down. And that's one of the reasons for this. So it's really understanding what problem has to be solved, and then either solving it with the company you are working or then go somewhere else or start something where you can come up with that solution.

Sakamoto: Well thanks, Jim. I think that's also interesting to note that from an executive perspective, a lot of times the business models of the companies that we're participating in don't necessarily meet up with the demands of the industry or the customer in specific cases. Phil Burlison, why don't you tell us a little bit about how you made your career moves and how you hooked that to the industry.

Burlison: I think it was – money was always there – but I was really wanting the opportunity to do the things I wanted to do. I always thought this company was a better opportunity. As I mentioned, when I started off, I thought I was an integrated circuit designer for the first seven years. I found myself recognized probably as the company's test expert inside a semiconductor company. I said, “f I'm an expert in something that the company's not involved in, why don't I go to a company that would better appreciate my talents?” At the same time, I was intrigued by some of the newer testers that were being introduced. As I mentioned before, there was a company called Macrodata, which was really quite an innovative company for its time. This was back in the early '70s. I had evaluated one of their testers, and I thought it was fantastic. You know, I just fell in love with that architecture and approach. And so they recruited me. One of the problems was, I'm very attracted to the Northern California area – you know, family, various reasons – and Macrodata was a Southern California company. But I was able to work for a few years in that capacity being remotely located. And then the memory era started in the mid-'70s. And that was in 1K [1 kilobyte RAM]. We had the 1103, which I was actually part of the design team on at National [Semiconductor]. But the 4K [4 kilobyte RAM] was coming out and memory testers were now evolving. I remember we had this competition for the Intel 4K memory business. There was a small company called Xincom that had that locked up. Actually, I like to take a lot of responsibility for turning that around; for actually building a tester for Intel called the MD-104-M that actually won the Intel 4K business. Then, shortly after that, Fairchild bought Xincom. Fairchild approached me and recruited me. I was attracted for two reasons. First of all, Fairchild was a Northern California company. Second, Fairchild was a big company and it sounded like lots of more opportunities to do more things. So that's why I joined Fairchild and had a very great career working and developing some of the great memory testers of the day back in the '70s. Then two things happened. First of all, the memory tester business went away to Japan, following the memory [component] business. Fairchild, like all companies, was changing. It was purchased by Schlumberger and the opportunities changed. Basically, the arena changed. Oh, the other thing – location – I forgot to mention that. I joined Fairchild because it was a Northern California company, and two years after I joined it, they transferred me to Southern California. But it was my choice, because I got to work on a-- they gave me a fantastic opportunity, which maybe we'll come back to later, to work on something. But I wanted to get back to Northern California, and a company called Genrad came along. I joined Genrad. They were just starting their new semiconductor test systems business. I worked for them just a short period of time because it was the first exposure I had into being [exposed to] a little bit of the entrepreneur spirit. I was recruited by a startup, a company called Parallel Systems, to build a –very small company, there was like, four of us, I believe –, to build a very low-cost, nonvolatile memory tester. That company was acquired by another company called Megatest. I worked for Megatest until I went to Trillium, thanks to Jim here, a few years later. In '99, I figured out where the next great opportunity [lay], and I decided to start my own company. So in '99, myself and my co-founder founded a company called Inovys, which had a whole new angle on its way of testing, maybe it was a little bit before its time, of testing the chip. It helps testing the chip that could test itself through what's called DFT, design for test. I was with Inovys until it was purchased by Verigy at the end of 2007.

Sakamoto: Well, thank you Phil. And to just make clear something Phil said earlier when you talked about 4K memories, that means 4,096 bits, right?

Burlison: Yep.

Sakamoto: To put it in perspective, I think that's not even a millionth of the size of today's memory in 2009. But that was state of the art in 1974?

Burlison: '76.

Sakamoto: '76, okay. All right. Dr. Sello, you actually had made, I think we discussed earlier in the day, the fewest career moves. So maybe you can talk a little bit about why you stayed as long as you did at your companies.

Sello: I've been thinking about that question just before you asked it. I'm looking down the table, and if I count the number of companies that we've all been with, I'm down at the bottom of the totem pole. But there's a little bit of a lesson here. It depends on how you look at the problem. Now you can learn to go from one new step to the next one and to the next one after that. Each new step can be at a different company. It happens that way in the silicon business, in the semiconductor and in the integrated circuit business. There is another way. Another way is you can be a stick in the mud like Sello and you can stay at the same place and a strange thing will happen. The management will change. So I can count myself as being at four or five different companies without ever having to change my calling cards. It was the nature of the industry, but there's a little deeper thing in there. It's also the nature of the silicon semiconductor work. All of these wonderful devices that we are talking about are made from basically the material of silicon. The testers are made from basic silicon parts which go into function the tester. Now, it's an interesting note that while I was listening to these well-experienced guys, you can use a tester in two ways. You can use it to determine whether what you've made is good or bad. That's a hard job to do in itself, but you can do that. But there is another use you can put the tester to. You can use it to figure out the best kind of processing methods by which that integrated circuit should be made or that transistor should be made. In other words, the tester becomes a tool in the manufacturing line. Since I am more experienced in manufacturing line than these vastly experienced people at this table, that's where I was able to find a lot of satisfaction. The use of the tester in order to improve designs that are used to make the devices that go in to make the tester. So you learned to use the best tester you could get in order to see what you've done right or wrong on the production line for making those very same devices. It's a fantastic use and it's a very important one in our business.

Sakamoto: Thank you, Harry. If I might, why don't we shift gears just a little bit and talk a little bit about what influences the technology of tests. That is, in my own personal experience, the testers don't seem to be something that we come up with a new tester and then the rest of the industry follows with a bunch of new devices to get tested. It's usually the reverse. But perhaps each of you could give a little bit of a view on what are the inflection points over your career history that have changed tester technology, the fundamental driver of what that inflection point was, and maybe your part in it. So I'm going to go ahead and start with Jim this time.

Healy: Well, if you go back through time, I think there were several challenges. One is called ITLOPS. ITLOPS stands for "it's the laws of physics, stupid." The basic fact of that is, in some tests, some devices are almost impossible to test because you come up against the laws of physics. For example, the distance from, as I mentioned earlier, the distance from the device to the electronics to make the measurement is too long and by the time you make the measurement, you can't make the measurement. So you have to find and design ways around that. One of the challenges is the laws of physics. How do I design a tester not to let you try to challenge the laws of physics but to work around the laws of physics? From more of a mundane point of view, it's generally been speed and pin count. The smaller and smaller devices get, when you follow Moore's law, the faster and faster they get. That means the testers have to continue to be faster. But since the tester is built with devices that are slower to start with, the unique thing is how do I take these slow devices and design it in such a way that I can make them run faster than the device I'm testing, which is a fast device? And the other part of that, which goes back to the laws of physics, is the actual pin count. In other words, as these become more and more complex devices, on the device you have more and more access points, input and output points, and these are coming up to the thousands. Today you can have 5,000 pins or more. Look at that probe card there [points to a wafer probe card on the table], that's an example of a 5,000-pin part that has to be tested at the wafer level. So that's part of the challenge as well. It's the laws of physics, the speed, and the pin count, I believe that drives testers today. Now as we move into this new era, today we're getting built-in self-tests. As I said, we design the tester on the chip itself, which is becoming – for the more complex systems on the chip – there's almost no other way to do it, okay? I mean, you have got to have some form of built-in self-test to do that. Now software starts to enter the picture; intellectual property. Today I think that most of the challenges and most of the advances in testing are more in the software arena and the IP arena as opposed to the pure hardware arena, which is what it was in the past.

Sakamoto: Okay. Well thanks, Jim. I think that's really kind of a great summary of the driving forces of what drives the architecture and the technology of test. Garry, maybe you could talk a little bit about relating that historically to where those inflection points, in your opinion, have caused testers to mutate.

Gillette: Okay Paul. Thank you. Thinking back and reflecting on this, there are two things that I think made a really significant difference in the architecture of test systems. One was the conversion from what I call analog timing. I'm using the word timing – I should probably explain it. It's basically a delay that's programmable in the program that tells you when an edge should occur at a certain point at the device that you're testing. It controls the whole timing of the test, the sequence of the edges that are presented to the device that's being tested. Well, to start with, that timing was basically done with analog, meaning voltage controlled kinds of circuitry. Somewhere along the way – and I think I had a lot to do with it actually – a computing technology developed in which you computed the time that you wanted, used a crystal oscillator to basically get you close, and then some verniers to get you to the last little fractional part of a cycle. This computing-controlling process was something that came out of the signal generator technology in the '60s. That was the first thing, the ability to get away from timing that's controlled by temperature or voltage or some other quantity that's not discrete. The second thing in my history was to realize that CMOS technology was the only technology to use for low cost and high performance in testers. Prior to CMOS being available in large density, all testers used what were called ECL, emitter coupled logic parts, to do the high frequency work. The work that determined the timing as well as the patterning that went to the device under test. These devices were actually very easy to use, but they were very, very power consuming. CMOS had the advantage of not requiring a lot of power to do that kind of work, and therefore it could be made in very dense circuits – VLSI circuits as they're called – that could basically compress all of the functions of a whole tester into one chip. The cost in doing that then would be minimized and the performance would be maximized. My answer is the movement to CMOS technology to do all the functions of a tester was a watershed point.

Sakamoto: Garry, maybe you can go back and just kind of put some timestamps at approximate years on when those inflections took place between analog timing, digital timing, and the ECL to CMOS conversion.

Gillette: Well, I believe the conversion to CMOS is probably about the vintage of this board here <holds up an ~ 12” x 18” circuit board>, which is somewhere in the time period of 1995 to the year 2000. It required use of VLSI circuits, because there's no point in using CMOS to do low-density applications. This particular board here is in that vintage, and it's made up of very high-density CMOS circuits for that time. Today it wouldn’t be regarded as very much at all because the increase in density over time is enormous with CMOS. So I would say the time period was 1995 to 2000 for the conversion from bipolar circuits or ECL [pronounced Eh-kell] circuits, as they were called, to CMOS technology. All of the companies did this, because it became very obvious to a lot of people at that time that this was the right way to build a test system to test the future of integrated circuits. So that's the timeframe. I don't know if I missed any other part of your question.

Sakamoto: I know, that's okay. We don't give away any points for winning the quiz on this particular game show. So I thank you Garry. Okay, I was trying to come up with my way that I was going to have Phil amplify this.

Burlison: Okay. And the question, we were talking about major transitional periods in testers.

Sakamoto: Right.

Burlison: I think there's very distinct, in my opinion, points in time where we saw major changes. And not so much in technology but in architectures and the approach of building products forward to solve the problem. I think that probably the first one was around the '70s. Before that, we saw all kinds of-- we didn't know they were analog testers, we didn't know they were digital testers, we'd just knew they were testers. There was no generic attribute to them. And then we started seeing distinctions in the '70s. First of all, I mentioned one: we had the memory revolution. So we started seeing for the first time dedicated high-performance memory testers that did one job, test memory chips. We also had logic chip testers. Fairchild, Teradyne, several companies, had testers that were good at creating the ones and zeroes for testing microprocessors, DSP [Digital Signal Processor] chips.[These are] basically digital content only – computing type of chips. Then we had the analog testers, which were actually earlier than these other two versions, which tested amplifiers, video, and audio types of analog circuits. These were not just separate testers. Within these ATE [Automatic Test Equipment] companies, tester companies, they were also individual business units that were sometimes competing against each other for resources, money, funding, and everything else. This lasted for a long period of time. That was the LSI generation. We saw that endure until the '90s. Until the '90s, and all this time, there were transitions with each of these ones. You know, as Jim had mentioned, we saw in the digital area we had pins being increased. We went from 256 pins up to 512. We went to 20 MHz, 50 MHz, 100 Mhz. Pattern memory, –how much pattern memory you could have. Those were the kinds of attributes that were driving the logic series. In the analog series, we were worried about dB [Decibels], noise, everything to do with testing analog chips. So they were pushing their performance their new generation smallness with those type of nomenclatures and abstract measurements of quality. Memory was how big a memory chip you could test. Starting in the late '70s, it was about how many chips could you test in parallel. Parallel test was first introduced in the late '70s as a way to lower the cost of test for memories. It was very predictable, because memories had very small pin counts and they all looked just exactly the same. However, the advent of the SOC, system on chip, in the mid-'90s started changing the way testers were built. We started seeing ICs that had very high-performance digital, very high-performance analog, and lots of embedded memory in them. There was no one tester to do all that. Then we started seeing the SOC tester, which basically combined all the attributes of all these other three models. This was not just a technology change, it was a change to the way the tester companies themselves were designed. These divisions were no longer individuals, they were basically put together as one business unit. Tester architectures were put together as one tester architecture that encompassed all of these architectures. We started seeing the advent of the SOC [systen on a chip] tester, Veriigy or Agilent, or Hewlett-Packard at that time was another one, the leader in this area. I think the next generation we saw was the one that really leveraged the chip to help test itself, designed for test. We saw testers that were basically optimized for relying on that nature of testability. I think that's really the role of the testers in the future, you're going to see more and more emphasis on less testing by the tester, more by the chip itself.

Sakamoto: Harry, you had a comment on this?

Sello: Yeah. I'm sort of odd man out here, since I'm not a test equipment person. But to answer your earlier question that I didn't answer and that is you can change to six different companies in your lifetime of work. You can also do it another way: stay put, and let your own company change by six different managements and you'll have the same address and the same location, but you'll have six different Vice Presidents and six different Presidents of companies. But that's not the answer I wanted to get at. We're missing a bet here and maybe because I'm on the side of technology rather than on testers. I hear this wonderful story of new testers being developed that are faster, you can get closer to the chip, you can test more of the chips at the same time, but at the same time, we in the manufacturing and the research industry of silicon devices are striving to make new and more complex chips and ever more functional chips. The fact that they come smaller is a benefit. Now we have learned by the simple brilliant observation of Gordon Moore that these things follow what has come to be known as Moore's Law, that there is a progression that is in certain years like every year and one-half or around two, technology will double the size of chips. Now look what's driving things? Not the tester. I mean you guys do brilliant work, but what's driving, what the tester has to do is the technology. Now when we poor, simple folk in the laboratory are sitting there trying to figure out how to use the a new type of technology like CMOS, or ECL, or PMOS or whatever is around. We are striving to make new technologies so that the chips can get ever more- ever smaller and more devices per chip. That follows the law that Gordon Moore observed, that these numbers of devices will about double every year per chip. And that has been going on for the length of the industry thus far. Now look what you tester guys are doing. You're chasing the chips that we are projecting to put into the- to put into the complexity.

Healy: I have a comment on that.

Sakamoto: Okay.

Healy: The problem-

Sello: So it's which end of the horse is leading the race?

Healy: Let me explain that. The problem is that the people who are making the design are foolish.

Sello: Are what? Sorry?

Healy: Are foolish.

Sello: Ah.

Healy: The thought process of the typical designer is that "my chip is perfect. I know how to design it". It will work but it never does. The tester should be forced to find ways to test it to prove that it works or see what's wrong with it so you can design it. The technology exists today when you do your design to design on chip the capability to test itself. And if you would use that capability a lot of these problems would be solved. The problem is the designer has to consider tests and consider manufacturing when they're doing the design, ot after the design is done. If they would consider that and design accordingly, a lot of the problems you're alluding to would go away.

Sakamoto: Well that actually is an interesting point. Having been more on the test side than anything I always felt like the problems rolled downhill into my lap, but Phil, you had a comment on this?

Burlison: To follow on the same comment, one of the things that we're seeing in today's technology is we pushed technology to its limits….that there's a nature in fabricating semiconductors called variability. Basically-

Sello: I'm sorry, I didn't-

Burlison: Variability in process.

Sakamoto: Variability.

Burlison: Variability. How well you control your process, and they're getting very bad at that but it seems like the designs are running faster than their ability to control the variability and parameters to make the design work. What happens is there's more unpredictability in how an integrated circuit is going to work as you get into these really small super high-performance dimensions. What we're seeing here is failures used to be very distinct. You know you had an open piece of metal [broken metal line on an IC]. You had a short. You had something that was bad. Now you're finding problems with the behavior of a very complex integrated circuit that is designed perfectly. There's nothing wrong with the design. There are actually no defects in it at all. But it doesn't work, and that's because it's- the variability's of the parameters and the process have been through a certain mix that it doesn't work together That's because these chips are too complex to understand how they work across an entire spectrum of variability. That's where we mentioned a point a rule of testing is changing quite a bit, is because how do you know what that is happening? And it used to be that the role of testers was really simple. The chip is good or it's bad. Nowadays you want to know why it's bad, what's bad? And is it really bad or is it just on. You know, marginal? With today's very complex designs you can't see that from the outside world. You have to look inside the chip itself.

Sakamoto: Garry?

Gillette: Well one comment and it's similar. If you look at the chips today, they're pin count limited, and there's this issue that you really cannot control everything inside with a limited number of pins without built-in self test. Likewise you can't observe it, you can't observe what's going on inside the chip without this additional help because the pins are so limited in terms of what they can show or tell. So what was done on, I'll speak specifically to the Kalos development was we simulated not just the chip with built-in self test on it, but we also simulated every other device that was on the board, and put them together as a complete unit to be simulated. We actually ran our software in a simulation mode through that simulated board and made sure that it in fact we got the behavior on the output pins that we thought we should have. We hadn't even built the thing and we knew within a very small degree of error that the design was already perfect. It didn't mean that we had perfection to start with. We had several hundred errors to start with. We had to get rid of each of those before we released the integrated circuits for layout design because once you send it to be fabricated, it's all over. You can't change it. The cost of fixing a bad chip once in this density is very expensive and very time-consuming. Not something you ever want to do.

Sakamoto: The role of software has really changed in both development and test. Daniel, you had a comment?

Morrow: I'd kind of like to broaden this out a little bit because my esteemed colleagues are, they're involved in a high pin count kind of applications. And certainly, if we go back far enough, there's a point in time where somebody builds something and a human has to say this is good or bad, right? A test is done at some point. In the early days transistor guys must have had some kind of means whether it was a volt meter or some current measurement. They bring in an automated test equipment guy and they say, "Okay, turn this into a process. "Turn it into something that a machine can design or a machine can run in an automated fashion so that we can do production on this." The people in charge of that process don't want to spend any more money. "Let's keep it cheap." They don't want to take any more space, they don't want to require any more labor. Everything that we're doing in the tester measurement environment is about this balance between providing a good answer, what's good and bad, and doing it as quickly and as cheaply as is humanly possible. Things get really complicated. The ECL circuits in the last memory [test] system that PWS, Pacific Western Systems, installed [ed. Colt series] was done in 1995. The power supply drawer for that old 4G memory tester system to drive the emitter coupled logic, ran about 15,000 watts of power. It was just this huge, giant, distributed. ECL based 50 megahertz CPU that required a space about like this <motions with hands> and jump jet fans [to cool it]. I mean this thing was the size of your bedroom closet. Since that period of time, the kinds of technologies that have fallen into the test and measurement person's hands include a phenomenal amount of CPU power. The amount of CPU power we have available to use today is unimaginable to what we would ever have dreamed possible. We can do things now in real time in software that would have required weeks with a Cray [Cray series supercomputer] in 1970. Unimaginable. We have miniaturization. I'm working on a project now that the analog section is all 16-bit analog electronics and it's all fitting in a little square about this big <makes hand gesture to show small square>. We add to that the issues of connectivity. The options that were available to the test and measurement people for just connecting [e.g. in the sense of data transfer or networking] the tester to anything else, we had floppy disk drives. You know; remember the ones that were this big <motions a roughly foot sized square>? We had GPIB [a.k.a. IEEE488 instrument bus], we had serial [e.g. RS232 or RS422]. These days the ability to move data you combine that with all of this miniaturization, both in terms of mechanical and electronic miniaturization, and you add that to the realm of connectivity. Then throw in the mix that semiconductor used to be about digital logic, about memory, about VLSI, things like that. Semiconductor now is a huge, huge market that touches all kinds of devices. High pin count devices. Low pin count devices. Things that emit light, get hot, and get cold. Mechanical assemblies that look at acceleration. Transmitters. The breadth of what we do in the test and measurement world is phenomenal. When I back up and I look at it, as an industry, this combination of these radical changes in the tools we have available, the breadth of things that need to be tested now, it's amazing.

Healy: Boggles the mind.

Morrow: Yeah, it's just boggles the mind.

Gillette: It always boggles.

Morrow: Yeah and-

Gillette: It's always boggled the mind.

Burlison: When was it ever simple?

Morrow: So Harry comes up with an idea for some great new widget. Harry wants to go into production and to get into production he's got to know if it's good or bad, and he's got to run his six sigma processes so that he knows he can build it cheaply. So he'll call up the test and measurement people. And yeah, I agree with your statement the front end, that what we do is we visualize what these static things that live in little plastic cases do. That's the heart of what we do is we provide visualization tools for the manufacturers for all the people that are trying to understand the problems and the good and bad.

Healy: One of the psychological, or perhaps, one of the cultural problems is that test is viewed as no value added. You can't pass the cost of test onto the customer. The customer is not going to pay extra because you did a good job with testing. That is anticipated as expected. So being a non-value-added function, even though there is value, don't misunderstand me, it is added; but from a point of view of the P&L <Profit and Loss center in a company> responsibility, the person bringing the device to market, the way they market it, they can't say "Oh by the way, we tested it really good so therefore we can charge you more." Now they used to do that many, many years ago before AMD <Advanced Micro Devices, Inc.>. When AMD came in they killed that, right? With no more quality [than Intel]. It was mil spec <military specifications or grade was a very high reliability and quality acceptance criteria for military applications> standard for them. So there's no [difference in quality due to test]. So test is viewed as non-valued-added. As a result of that you [test department] tend to be the stepchild. No one wants to do anything with it and you're always relegated to a position where you still have a challenge. It has to be done. Without it the device wouldn't exist, but in reality that's where we are, and always will be in my opinion.

Sakamoto: That's an interesting viewpoint that I also share which is that the best we can do is par – to be looked at as "not a value-subtractor." That does bring up another topic, which is quality, because I think that it's inextricable – tests and quality are linked. The way that we guarantee the value, the par value of any particular component, is through the test process. You know we kind of view it as a chain, right? The whole process is a chain. You don't get that value without all parts of the chain and in my time which spans from the mid-'70's, we went from two percent AOQ or Acceptable Outgoing Quality, that is two out of every 100 devices were expected to fail on exertion at the customer's application, to today I believe that par is about a hundred parts per million. If you're not able to do a hundred parts per million as a manufacturer, you're probably not shipping to very many people. So Harry, you had a comment on that process?

Sello: Yeah, I think you hit a very pregnant kind of a statement. You can't, you said and other's agreed, you can't test in quality. That's true. You can't. The tester can only find something that you can define as being not good quality or not a good result. Where do you build in the quality? The quality is built in at the manufacturer and the putting together be it small or large factory, in putting together the processes which make the devices function whether they're new or old or whatever. That's where quality begins. And until you find out which of the processing functions or which of these physical functions you've built in is failing, you won't know how good a job you've done. However, how do you find that out? You go back to your friend the tester. Now if you're building a new device the tester may not even know what to look for. So he has to go back and work intimately with the product and process engineer, in order to decide that, "Did you realize, Mr. Tester, that we cannot test- cannot give you anything where the runs <metal runs are conductor lines that "run" across the device> on the metal which connect the parts of the device can never be closer than 10 microns to the next run because physics will not permit it to happen. There will be failure. Now the test guy is going to scratch his head "Where did he come up with that one?" Well, if you give him an honest answer, you say "Well our tester showed that we were too close." But the point is they found out we in the laboratory and in the production, all of us participated in this found out that if you make runs of metal, it depends on the metal, and it's too close one to the other there is a natural failure that's going to occur, cause, called drift. It's just going to have electro-migration. It's just going to happen. Now no testing guy on earth is able to make that statement without finding out where that originates. He doesn't care if it's closer or far apart, to borrow the term, if these lines are closer or far apart. All he knows of is when he sees it he says "God, those things are close together. How can I measure the distance that he wants me to measure?" But he has to have had the information first. That's a bad sign.

Healy: Well that's where design for manufacturing comes in.

Sello: Yes.

Healy: In the last couple of years there's a lot of focus on design for manufacturing which says when you do these physical designs, understand the physical nature of the design itself so you don't violate certain capabilities within the fabrication itself or within, as I said earlier, the laws of physics. So, if you have two traces too close, and it's very high rates of speed, you're going to get crosstalk as an example.

Sello: Exactly.

Healy: Or, as you say, the metal line pitch <pitch is the density with which metal lines can be placed>, whatever it might be, so again it gets back to the design. Now I'm not talking about the designer who designs the functionality of the chip, but rather the designer who is actually laying it out; the EDA people that lay it out and physically position [features] on the chip itself. All this has to be considered. Because all tests can do is say, "this [device] failed. "

Sello: That's-

Healy: We can't even tell you if the lines are too close.

Sello: That's the problem right there. When are you tester guys going to be able to tell an engineer manufacturing a device-

Healy: Never.

Sello: That is metals are too close?

Healy: Never. Never. That's a whole new discipline. It's called design for manufacturing.

Gillette: Well you have to have design rules.

Healy: Design rules, yes.

Gillette: That's how you deal with this. You can't take each chip and isolate it and then say, "Well, let's analyze all the possible ways something can go wrong." You have to write rules that cover all the chips [for a given fab technology] so that if you behave with the rules, you're going to probably be okay.

Burlison: But I think we talked about this [issue], that they're pushing the technology so much. We had design rules and we had design for manufacturing rules which are actually much tighter than design rules, and still these designs, I mean we're into three-dimensional space now.

Sello: Yes.

Burlison: Right?

Sello: Yes.

Burlison: And we had so much that never processed- basically the number of things that can go wrong on a single spot of area is about a thousand times higher than it was a few years ago. And what that means is in terms of quality in tests, they call them escapes. And you measure test quality sometimes in Logic you say, "What's your fault coverage?" And you may hear, "My stuck-at fault coverage is 99.95 percent," which probably covers about half the problems that might go wrong on that chip. Because a lot of the problems those [tests cover] are what we call a stuck-at model. Like I said, the chip works fine except under this certain set of conditions. Some small things go wrong. It's not because of a defect. It's just because under those set of conditions we're trying to go too fast. We're trying to do something in the design that doesn't work under this particular environment process corner. And you can do all the modeling in the world. Those happen. And that's kind of a learning experience you have in design and that's where we see the expanding role of test is not to tell you that something's wrong. Where did it go wrong? Under what conditions did it go wrong? We want more information about a test failure now than just the fact that it happened.

Sello: But you said earlier too, you said earlier at the table that you don't want, Jim Healy said it, that you don't want to pay the cost of a tester to go in and find out what these problems are likely to be. So we're in a stalemate. We can't find out what they are because nobody wants to pay for it.

Sakamoto: Well I think that actually maybe-

Sello: And until we do-

Sakamoto: We alluded a little earlier to a trend that might kind of be along that line and I think it's been evolutionary. Daniel talked a little bit about data gathering at lunch. And there's been an evolution of data gathering going back from the early days when it was maybe a couple of lines written on a notepad, to something more. Perhaps you could talk about your view of the evolution of data and its importance in maybe fixing some of these problems.

Morrow: This has been kind of an interesting discussion for me to listen to. OpTest [Morrow's company] exists in a market space where we work with emerging technologies. One of the segments that we deal with are a set of customers that are building lasers in and on silicon in wafer form. Right? So it's not just an electrical device. It's an electro-optical device. And there are wave guides and there are reflection chambers and beam splitters and there's all kinds of weird-

Healy: On the chip itself?

Morrow: On the chip itself. Some of it is micro–machined. Some of it is bonded. And that kind of environment [recalls] Harry's point about when are you tester guys going to get your act together? And the answer is it is a partnership. It is a partnership between the test people and the designers. Part of the challenge Op Test has providing our test services to those companies is we are innovating methods to give them the volume of data that they need about these devices so that they can figure out whether it's a line separation problem, or it's a material problem, or a contamination problem. And our Op Test testers now, we often will have gigahertz CPUs, often will have customized pin electronics that sit right down on the device. We often have cameras that are running while it's testing. We often have spectrometers while it's running. Those kinds of tests will run 200 milliseconds, maybe a second and a half, but it's not hard for one of our testers to generate megabytes per minute of just raw data about the operation of the device. It doesn't cost us anything to do that, really. I mean we have gigahertz CPUs and we have gigahertz bandwidth going out to a server, so we dump that data out, and then it's up to the engineer. To sort through all that stuff and sort it out.

Sello: <inaudible>

Healy: Dr. Sello, I have one thing to say to you. Tear down that wall between design and test, tear it down.

Sakamoto: There have been a bunch of walls that have come down during the time that we've all been working in it. I think one of the walls was between the East and the West. All of us have careers that easily span [a couple generations.] Garry Gillette had alluded earlier to Sputnik and the space race. At least several of you were part of the military and have that background of, you know, at all times we had people perched on the "destroy the world" button. But during that time I think there were some interesting side stories from a historical perspective of how technology was trying to make its way not only from company to company, but also from West to East. That is, there was a lot of issue of exporting technologies to restricted countries. I think the acronym for the particular state department group was called COCOM, C-O-C-O-M, was in charge of regulating that export and I think that touched all of our lives so kind of just switching gears here a little bit and going back to sort of what I'll call war stories. Certainly some of you must have some interesting stories about folks trying to purchase your good testers for no good reasons. Anyone want to offer? Harry jumped up there, okay.

Sello: Yeah, I only jumped in because I made part of my living in a later portion of Fairchild trying to find out what COCOM was doing. I wasn't very successful but it was an interesting search. Even today if you look at regulations for testers, you find that a tester which is testing at a ten megahertz test rate, ten megahertz test rate, is forbidden for sale to any of these unknown, not wanted countries. Now you can't hand-- in a tester's business you might as well go out of business. That is not a way it can be done. And still do business. Jim Healy-

Healy: We were both on the COCOM committee if you recall.

Sello: That's right. That's right.

Healy: We both worked on it, and a lot of the rules made absolutely no sense – as one probably can expect from the government. I don't know.

Sello: Right.

Healy: And it was-- we had situations where I was able to sell testers into Beijing in 1987 since they would be used for developing televisions. Now we were selling to the Chinese Air Force. We figured it out –because the address we shipped to was the [Chinese] Air Force. It was okay because [they said] they were using it and they were going to use it for making televisions. So and that's just one small example, right? Or we would sell a tester to Zaire. Zaire didn't have any semiconductors It would end up in Czechoslovakia somewhere, and I never could figure out whether people just turned a blind eye to it because some of it was so obvious that this was not being used for what you thought it was being used for and it was like people turned a blind eye.

Sello: You got to let me add one little flip to that because Jim stimulated me. There was a time at Fairchild when in the systems technology division which still exists, not at Fairchild, at Schlumberger <Schlumberger spun this group out as a separate company – NPTest. This company was later purchased by Credence Systems which was in turn purchased by LTX Corporation, where the assets currently reside as of December 2009> there was a time when Fairchild Systems Technology had the capability to sell any tester anywhere except for where the competition was better and you could get there first. Well, I came up with a brilliant idea. I said "Well," COCOM, and this is now ten years ago, nine years ago. "If the limit is ten megahertz test rate on the tester, on a bench top," I said "These guys haven't got much money to pay for all of this stuff. Why don't we manufacture a line of testers," I asked our systems technology division, "that has a test rate, a crystal test rate of ten megahertz? You can sell them like it's-like popcorn. It's going to fit in all the COCOM regulations." Well it was one of these logical technical questions that didn't fit into the marketing pattern of Fairchild's Systems Technology, bless their heart, and they canceled the project even before they built the tester. It was called a qualifier, remember that one?

Healy: That was about 20 or 25- <Healy attempts to inject that this occurred 20-25 years ago which is what I would have guessed –ed.>

Sello: It was a desktop. It would have sold like the proverbial hotcakes. And all you had to do was tell the government that these are perfectly good. They could be using them to make parts of atom bombs but it's a ten megahertz tester. This is how stupid those regulations can come.

Sakamoto: Garry?

Gillette: There's a broader subject here. If you go back into the '60s it was very visible. At that time you couldn't buy a component in the '60s without government permission. Everything was basically on a priority system, and if you didn't have a priority customer, you know, someone in the missiles and space game who was out there testing in this case hardware for space programs, if you didn't have a customer out there, you couldn't stay in business because you couldn't buy any components. I'm talking about chip caps, transistors, all kinds of general stuff. It was all on a thing referred to as a DX-A2 priority. If you didn't have that stamp on your req. <purchase requisition> when you sent that out, you weren't qualified to get the part. So everything was government-controlled at that time. Later on in the early '70s and moving on to the late '70s you still had the precedent that the government should control everything. That we were still dealing with people who were hostile and we are not in a competitive world and therefore we can afford to tell people what to do. And what we all learned from that is very obvious; If we didn't sell it someone else would.

Sello: And did.

Gillette: And did. And so later on I had an interesting revelation when the company Credence Systems that I was with hired a number of engineers from Yerevan, which is in Armenia. Well, that was the former testing capital for the Soviet Empire. These people were using all the familiar testers we knew to test integrated circuits in Armenia. We learned about this later on and it wasn't surprising. It just points to the fact that government is not big enough to control things on a technology like this. It just isn't and it can't. It would just lead to ridiculousness. Even countries now. like [the People's Republic of] China are trying to control digital technology and digital media – DVDs, whatever – and it has become obvious that it's not going to be practical. And they don't learn very quickly in totalitarian countries, but even they are realizing that you can't rule out the Internet. So I think this is just an example of governments trying to control things and realizing it's not going to happen.

Healy: Like I used to say you could sell the five-function calculator but not the computer. The five-function calculator was, you know, plus, add, subtract, multiply, divide, trajectory to Washington.

Sakamoto: Yeah, I think a personal story for me is later when the COCOM limit for China had been raised to 40 megahertz and I was at Credence Systems and we had a system that ran 50 megahertz and we had to go through similar kind of evolution to what Harry was talking about, changing it to a 40 megahertz tester to be shipped. And in fact I think I was working for Jim at the time, but the point of the story being the next year my wife and I had taken a vacation trip to China and right there in the middle of one of the cities, Shanghai when we were on our tour, was an Intel sign for buying 110 megahertz Pentium chips. Apparently Intel was able to export 110 megahertz Pentium chips to China. Just to get an idea like the craziness of government regulations, we should have let them go ahead and try to make their own 110 megahertz Pentium. You know it would have really slowed them down a lot, but instead they just shipped them the chips and I think they made up a lot of ground because of it.

Let's try to reach back a lot at this time and talk about how intellectual property, that is the patents or the trade secret knowledge, to do things like test non-volatile memories, micro-processors, DRAMs, and other parts, how that kind of knowledge made its way from company to company. Maybe you have some anecdotes or stories from your own experience where interesting migrations occurred. I mean one of the big ones in semiconductors was when the original "treacherous eight" moved to form Fairchild is and example. I think in our industry that there were probably a lot of little movements that kind of made big differences later. Anyone want to start on that? Maybe Phil?

Burlison: I have a few things. There were two things. Patents were so easy to come by. You could patent anything, right? Patent the obvious, and the biggest one of these was MCT <Micro Component Technologies of Minneapolis, MN> who patented the "tester in a single box." You know, testers used to be two boxes, right? Well of course everybody started building a “tester in a test head” as it was actually referred to, and it became the norm, right? And there were a few, actually there were some suits filed by MCT for that. But most of these IP [intellectual property holdings] were never prosecuted in the midst of enormous copying of really great ideas. Like I said, these are not great ideas as much as obvious and somebody figures out they’re obvious before another person does. Like I said, the majority of patents out there in the ATE <Automatic Test Equipment> industry I’m sure have been violated by another ATE company and have completely gone without any action on them. And just because the technology changes so fast by the time you win or lose a patent argument, the value is long gone.

Healy: To be able to fight the patents means you have to have deep pockets. Take FormFactor <Form Factor Inc. of Livermore, CA – a manufacturer of advanced probe cards and contact technology> where I worked. They’ve been suing everybody for violating their patents because we would patent anything that would move. Thousands, I’m dead serious, thousands. We would spends thousands and hundreds of thousands of dollars on patenting everything. And then they would go out and fight that in many places and have not been very successful. On the other hand, Rambus <Intellectual property company specializing in DRAM I/O circuits and standards> has been very successful through their patent process. So if you’re going to enforce your patent or if you’re going to use it as a strategy, you’d better have deep pockets. It’s going to cost a lot of money. You need cash flow.

Burlison: And time.

Healy: Cash flow and time. You can see that Rambus has been pretty successful at it. FormFactor has not been as successful. I don’t know if MJC <A Japanese probe card company> in Japan is they’re violating their patents or not, but they’re certainly challenging them in terms of market share with a very similar technology.

Sakamoto: Can any of you think of any IP wars that happened between tester companies? Phil said there were a very few. Garry?

Gillette: I think I was probably involved in the most costly destructive case that ever came up. Yes, I had patented the obvious to some people, I suppose, but a particular pattern generator architecture when I was at Teradyne <Teradyne, Inc. of Boston, MA> and they discovered that Megatest <Megatest Corp. of San Jose, CA – since purchased by Teradyne> in fact appeared to be infringing. So here it’s once again the issue of deep pockets. I can tell you from my observation of what went on that there’s no merit in this. This is strictly who’s got the deepest pockets and who’s going to be able to be the last man out in the court case because it involved a Full Employment Act for offices full of lawyers in Boston and in Palo Alto. They went after each other with millions [of dollars] in [legal] bills, and finally Megatest lost because they didn’t have as deep of pockets. An agreement was made for a few million dollars and a certain amount of percentage of shipments. And then of course later on Teradyne acquired Megatest and nullified whatever the penalty cost except for the legal bills. But it’s true, I’ve had things that I’ve patented that were patented by bigger companies later on. One of those I’ll give you an example of was something called “fractional-n synthesis”. It’s a technique used to generate signals of arbitrary frequency and it lends itself today to integrated circuits very well. So it’s in every cell phone. It’s in virtually every PDA, everything in the world that has a variable frequency in it has this synthesis technique in it. And it was basically ignored by the world. It was patented, but Dana Labs, the company I was with at the time didn’t survive the onslaught with HP. So it really didn't matter but it was actually re-patented by HP ten years later. This whole patent process I think is faulty at its very essence. It doesn't protect the inventor.

Gillette: I was just going to make one last comment and that is that TI in the early '90's had all of its income from patent royalties. That is, if you looked at its [product] income for the year and the income from the patent royalties [it] was the same. Now, you could say there were other contributors for that but nevertheless one way of saying how significant it was is that TI was the largest company in the semi-conductor business selling licenses by far.

Sello: There's one favorable aspect to patenting that should not be thrown aside, but it has to do with the point that Phil raised: exhausting your money. A number of very aggressive lawyers working for Fairchild at the time, Roger Borovoy and Allan McPherson, learned quickly that instead of fighting patents, if you have a patent portfolio, just make a deal with TI who had more patents than anybody did – that was quite correct – and cross-license them.

Burlison: Yeah.

Sello: So don't fight them. Just say, "well, we want the rights to use your patents. We don't know if we're going to use them, and you have the rights to use our patents, we don't know if you're going to use them." So the patent attorney's only have to fight a battle of how many patents [each company has] on each ladder, but they didn't have to sue each other. They didn't have to use lawyers' money for that purpose. They'd find lawyers to do something else. But you cross-licensed large libraries of patents for devices and for gadgets that you would never use. But only for the possibility that they wouldn't bother you and you wouldn't bother them. IBM Was great at this because they marketed very little in the technology field and device field, but they had libraries of patents.

Sakamoto: I guess the test guys never got to that level of sophistication. We just went to war. So Daniel, we haven't really been in your area so much but maybe as a person who was Vice President of Engineering for a robotics firm like, Pacific Western, you could talk a little bit about the history of the evolution of handling the components. The rest of the panel dealt with the electronics, the actual test boxes and the test processes. You are the person who might be able to give us some insight as to the evolution of the handling aspect. How did we actually evolve from people actually hand-testing devices one by one? I think Dr. Sello was talking about someone actually sitting there with a couple of probes and a device and a microscope. Then the industry went to automated equipment. Can give us a little bit of background about how you think that evolved.

Morrow: I'll do my best. I'll say up front that I'm kind of a little bit of an odd duck for this particular topic. If we back up to the '60s things started off with silicon ingots that ran what an inch and one-half or perhaps and Inch and one-quarter? So we get through the '70s and we're talking maybe two, three inches. We get into the '80s. We start talking six, eight inches. And somewhere along the line when we got to about four inch diameter wafers the world kind of split in two, and a lot of the high-volume products like memories and VLSI <Very Large Scale Integrated Circuits>, these large geometry chips, the wafer sizes just kept getting larger and larger and larger. Now we're running 300 millimeter and I don't know what the roadmap says. Is there such a thing? There's a 400…..

Burlison: Three fifty.

Morrow: Somewhere along that trajectory of wafer sizes getting larger and larger and larger, the problem of particulants become more and more profound. Geometry the lines are getting smaller. Clean rooms become a huge issue. There was a point in time where we could do our test stuff and you could walk into a room and many of the pictures you'll see there are guys sitting in their clothing, their regular street clothing, and they're testing things. Somewhere around four inches all of that went away and we start going to mini-clean room environments, and then hyper-clean room environments. And from the test and measurement perspective the speeds increased, the parallel tests increased, the environmental factors [and] whatnot all become more and more of an issue. From the robotics standpoint the handlers move from being fairly simple, with their wafer stage travel on the order of maybe two inches for a wafer handler <wafer prober> that would move around these things [wafers] might cost ten thousand bucks. Many of them had little hand controls that you could turn knobs and dial around. Today, some of the newest systems that are handling these 300 millimeter wafers, they tie into complete factory automation systems where pods of wafers were landed into these machines and they're pulled out by robots. The stages when they move the wafer, the stages have anti-vibration systems that anticipate the mechanical motion [of the probe system] and counteract it so that when the wafer comes up into the tips there's no shaking or vibrations. Maybe somebody down on the table that could talk about how much force did it take. How many pins did we say were on this?

Healy: Mine has four by sixty-four, I don't know. Close to a thousand.

Morrow: About a thousand and a couple ounces per pin?

Healy: I think it's a half I think.

Morrow: Half an ounce so we can do the math and-

Healy: One and one-half ounce, I think.

Morrow: One and one-half ounces, couple thousand, you can imagine the amount of force that's required to make contact with the wafer. We compare that to the old cards. I brought in one of the old cards. This is one of the early probe cards with the little hand soldered probe tips and you can't see it from that distance <DM surmises the camera can't show the detail and points to the card>, but there are actually little teeny screws in there so if you want to planarize <the act of adjusting the probe tips to all be in the same geometric plane for even contact with the IC> the probe tips you get in your microscope and you turn the little screw and the probe tips go up and down. You know, this happened in a period of what, 15 years?

Healy: Less, more or less, yeah.

Morrow: And the great irony and why I say I'm a little bit of an odd duck out, I brought in one of these. This is what they make a lot of the LEDs on. That's a two-inch wafer believe it or not. This week I got a call from a customer asking me for a two-inch wafer prober.

Sello: Going backwards.

Morrow: I think if we went downstairs in the museum here we could find some stuff on the wall that was done back in the early '70s that would work quite nicely for this application. It's one of the things I love about test and measurement is, you know, just about the time when classic semiconductor is hitting full maturity, devices like this comes along and we get to start all over on something completely new. So yeah, we are going full cycle. The changes we had talked a little bit about – the computing power and the microelectronics and all those kinds of things. The handlers now are so fast. So amazing. The work that they do with control systems, positional accuracy and the masters it's amazing I think. You guys can probably speak better to some of these technologies than I but to think that you can put a sub-micron probe-tip down on a pad with micron accuracy dozens of times an hour.

Healy: Thousands of times an hour.

Morrow: Thousands of times an hour.

Healy: Millions of touchdowns.

Morrow: Millions of touchdowns. Going and going and going.

Healy: Fifty thousand devices, Fifty thousand points at one time per wafer, for full parallel [test] memory, flash memory in particular.

Morrow: It's incredible.

Burlison: But the irony of that is this sounds impressive but the cost of those probes of touching chip is surpassing the cost of the tester.

Gillette: Just a throw away business.

Healy: I remember when I first started with FormFactor and people would have probe cards that'd look something like this. They cost three thousand dollars. So FormFactor got their first probe card for memories, and it cost thirty thousand dollars. Now they're three hundred thousand. Then it was thirty thousand dollars. You can imagine now you think about the guy who buys these or the woman who buys these in a company. They're usually a rather low-level person. Works there for three thousand bucks that can sign off to five thousand. You want to say "I got a new probe card for you. It only costs thirty thousand dollars" which is five, ten times what their signature authority is. So you got to go up above. Well the guy above has no idea what probing is.

Sakamoto: Yeah.

Healy: So now how do you convince this person to spend when the person who has the budget to do it says, "I can't. My boss would kill me if I came in and told him I had to spend that much money." So to sell those probe cards we had to go to senior management; to CEOs of companies and say with this kind of probe card you could improve your yield by one percent. Then when a DRAM one percent yield is millions of dollars. Which is lost on the people down below doing the actual work in manufacturing, and through that management we were able to convince them and eventually get FormFactor to where we now all know how successful they have been. That's because we were able to increase DRAM yield one percent. Now that example for an LSI device wouldn't apply because the volumes are too low. So there's always a trade off between the technology and the return on investment. The return on investment is what is critical even though I said test is not value-added. There's an example where maybe the pure test isn't value-added but certainly the design of that probe card which allows you a higher yield is tremendous value.

Burlison: I have a question. Used to be where testers were all capital equipment right? And probe cards were consumables.

Healy: That's the most expensive consumable.

Burlison: Are probe cards …?

Healy: Three hundred thousand dollar consumable because as soon as the memory is in production, what do they do? They shrink it. Soon as they shrink it you need a new probe card. Another three hundred thousand dollars.

Sakamoto: As a largely an equipment seller over my lifetime I always thought it was great that all they had to do was just change one pin in the DRAM design and you guys got to sell another card. I thought, you know, it almost pays you to pay buy a nice lunch for that DRAM designer. Just kind of moving on to some other topics here I kind of wanted to get a personal flavor of some of the characters in the industry. Each one of you probably has a favorite war story about the wild person that used to work for you? Maybe it was you. You know that road trip from hell, the big deal that you got, the key discovery that was actually – if everyone really understood at the time the process that was used to come up with the key discovery – that they'd be really shocked. So if you can sort of just come up with that. Yeah, Jim, why don't you give that a stab.

Healy: When I was living in Japan for those seven years, you'd come back to the United States, and it took a long time since you had to go through Hawaii or somewhere like it, to get back to the [mainland] United States. You wouldn't get back very often, and all the communication was done by teletype. So there was an issue with communications. And I'm over there as a technician doing what typically is done by an engineer, a EE, and I was not an EE at the time, so I had to build relationships. There's a guy who's very famous in the industry, he died recently, Robert Huston and he was a genius. He could sit in front of the tester and play it like a piano and magical things would happen. I learned that he smoked Lucky Strikes and he drank Southern Comfort. So every time I came to the United States, I'd bring him a carton of Lucky Strikes and a bottle of Southern Comfort and go to see him and he'd work around the clock. We'd work two or three days without any sleep and I'd learn everything I needed to know. Exhausted then, I'd go back to Japan and he would go on his way. Well, to make a long story short, he didn't die because of that because he actually became a Mormon and stopped drinking and stopped smoking and that's what killed him <laughter>.

Sello: He died because of that.

Burlison: We'll strike that one out.

Healy: Although that's a very true story, the point is, though, when you're external to the world, when you were in a place like Japan at those times, you had to find ways and characters in the United States you could communicate with and work with. You had to be very creative about that and Bob was a genius, there was no question about it.

Sakamoto: That's an interesting note because at that time phone communication was probably back in the dollar a minute days, right, so it was just tremendous.

Healy: If you could keep the line on.

Sakamoto: Yeah, good point, good point. I have to ask, Jim, did those planes have propellers on them, is that...

Healy: <Laughter> I still belong to the Clipper Club of Pan Am. I still got the ticket.

Sakamoto: Wow, yeah, that would have been the time. Certainly, some of the rest of you must have some war stories that you could share.

Sello: Yes, I'd like to add a war story because-- at least one, one good one, one bad one. As impressed as I was many, many years ago, with Nobel Prize winner William Shockley, which resulted in-- his greatness resulted in my staying in the company a bit longer than I should have. I was impressed and depressed by the fact of how little he cared to know about the people who worked for him. It wasn't his interest. But he was the man who ran this Shockley Semiconductor Laboratory, and his opinion was what counted. And it drove the so-called "Traitorous Eight" to go ahead and leave and found Fairchild. But what impressed me and the sadness of the story is that he was the "Moses of Silicon Valley" as he has been termed by other writers. He could have owned the world. Almost every semiconductor company that started later could have traced its benefits back to William Shockley. But he was not the kind of a man that knew how to lead people or knew how to inspire them. So a whole industry was born as a consequence of the activities of one man. On the contrast, just to make my story short and what makes it so poignant was when Gordon Moore and Bob Noyce, two of the major founders of Fairchild, left to form Intel, I was crushed because I had so much respect for those two guys and what they knew and how they worked with people, how they would talk to you and make you want to do what you were doing faster and even slipped in a little money extra, by way of bonuses, even that which is done very little these days, unfortunately. But I didn't go with them, big mistake! At least I thought about it at the first. But the point in the story I want to make poignant is that along comes C. Lester Hogan, who in his own technical right-- in his own technical rights and lights that he was good in was a brilliant man. And I said, "Well, I'm not going to hang around here. Who is this C. Lester Hogan and these gangsters he's bringing with him from Motorola? I'm leaving here because I have a place I can go. I mean, my friends are starting up another company." And he came around and he said, "I don't want you to leave." No reason I that I could think of why he should say that. He said, "I don't want you to leave," that very statement, without any money attached, without anything else attached. I said, "Well, I have no reason to stay. The things that I was working on are over." He said, "No, they're not." And I gave him a bunch of little negatives about this and he finally asked, and I'll always remember this statement, "Tell me what you want to do and you have that job." And it worked, I stayed. My wife will kick me all over the place for staying, like I did, because I spent the next 10 years of doing the work that I wanted to do. But the point I want to make is there is an essence of management that resides in very few people and what I would like to tell somebody to take away with him is find a person like that and just follow him, just follow him. If he does something you like, do it. Go where he goes, without reason. Don't try to be too-- a Ph.D. analyst about it. And I remember those personal stories very well. Les Hogan didn't hang around very long, he died early and all this sort of stuff, but he-- I wrote the job spec and I got the job.

Burlison: Talking about interesting characters. One of the most interesting person I remember very well, was William Mow or Bill Mow. He was the founder and owned the company Macrodata, was my first ATE company, and I really liked him. He was probably an early version of Larry Ellison. Basically free-spirited, did what he wanted and he sold Macrodata to Cherry, which eventually became Eaton, very early on. I ran into him a few years later and wondered what new high-tech venture he'd gotten into and was there any opportunity there for me at the time? I asked him and said, "What are you doing now?" He said, "No, I'm out of this [high-tech] – I'm importing shirts from Taiwan." You know, I was just– I was crushed.

Healy: He created Bugle Boy.

Burlison: Yeah. And I said, "What's the name of your company?" and it was Bugle Boy.

Healy: They had a private jet.

Burlison: Yeah. Well, he was the only person I've seen really that had a Jensen. Do you know what a Jensen is?

Healy: No idea.

Burlison: It was a very up-scale British sports car back in the early '70s.

Sakamoto: Interesting. Garry?

Gillette: It's an anecdotal story, but what I'd like to communicate is an understanding of the culture that existed in the Valley in the early '60s. I worked half time at HP at that time, while I was a student at Stanford. And so I got to walk around [H-P] when the whole company was in two buildings. But with the culture there, you knew that if you worked there, you were a privileged individual, that you were important, I mean, they had doughnuts twice a day, for heaven's sake, at the coffee breaks. They had progressive policies that companies would only emulate decades later. It was an exciting place, by all measures. The employees were very supportive of all the measures in the company and, if you stuck around after a coffee break and didn't get back to work, somebody would remind you to get moving. It was very, very, if you want, dissimilar to what you'd see today out in the Valley. Well, I was working in the semiconductor lab designing some equipment there and I walked in one afternoon and everyone was in an uproar. It was just catastrophic panic. What had happened is that someone had apparently stolen a microscope. There was a microscope there, and it was no longer there. It was unthinkable, in the culture of the company at that time, that anyone would steal from the company. I mean you just wouldn't even dream of it. So everyone was running around, this was just a terrible situation. Well, finally it was determined what happened. Bill Hewlett had a bull on which he wanted to monitor sperm count, had borrowed the microscope, and forgot to bring it back over the weekend.

Sello: They only had one microscope in the company?

Gillette: Oh, well, this was in the semiconductor lab. I mean…

Sello: I see.

Gillette: …they were very expensive and, you know, these were not the kind of things that most ordinary humans would want to deal with.

Sakamoto: In either respect, yes.

Gillette: Anyway, that's my story.

Sakamoto: That's hilarious.

Morrow: I think I mentioned I came into semiconductors a little bit further down the road than many of you. I think I probably missed the great, grand days. My first SEMICON, I do remember was down in Santa Clara <probably San Mateo, CA? Ed.> in the big tent and it was quite a show. I was working for Pacific Western Systems. Their corporate culture, I can tell you that I was the first executive that was brought in that was not military. So I worked in a community of Navy and Marines and their leadership structure, their way of doing-- the corporate culture all was very, very colored by that. Early on, I was down in the office and I saw Tom Mann up in the front office working on an expense check. He was buying 24 cases of something and, apparently, he had given a gift to a purchasing agent that had gone sideways and the way to fix that then is he had to deliver, I believe it was gin, to the purchasing agent's boss to balance out the accounts and get everything worked out, just kind of how it was in those days. Pacific Western Systems was on, I think it was, 10 acres, 8 acres of land down there, most of which was a vineyard. And once a year we would go down and the company would close down, we'd go in the back, we'd pick grapes, they'd stomp it, they'd stick it in bottles and it would be distributed. I won't say we always drank it because if you're around when you see the people stomp it, it really flattens the whole adventure. But I can tell you that a lot of fond memories from what I consider the wild days and they were wild. They were wild.

Sakamoto: You know, I think, even though I'm off camera I'll inject one of my own. You know, one of the more interesting career moves I made was to leave Intel in 1983, after having been there for six years. To put it in context, the company wasn't actually doing that well then-- and I was going to move over to the “higher margin, more successful” realm of semiconductor equipment, thinking that somehow that was a good move. The company that I picked was this company called Megatest, which was at the time, a vendor to Intel. And I have to say, you know – hopefully my kids aren't going to ever watch this video – but I didn't really make that decision based on the most profound business reasons or anything else. I was still in my twenties and I thought that they had a little more exciting lifestyle than say the folks at Intel did, including, you know, lots of eligible gals and things like that. So at any rate, I went to Megatest and this is actually with foreknowledge of some of the events, which I thought were kind of counter-intuitive. You know, when I was at Intel, this is the vendor that was actually famous for one event in particular where they ran an evaluation on our tester floor. They had-- a bunch of their Megatest testers were testing the 8086. They were in competition with the much larger and more well-heeled Fairchild Company and they were actually doing pretty well, right up to the point where there was a snap inspection on the Intel floor of the Megatest equipment cabinet and one of the Megatest apps engineers had been storing a fifth of scotch in the Megatest equipment cabinet on the Intel test floor. And this <Intel> is a company that at the time, had very, very strict rules about any substance on campus and actually said, "You know, it's time for a snap inspection of your equipment cabinet." And the general manager of that particular group opened the cabinet and the first thing he saw was a fifth of Southern Comfort. That was it for the Megatest evaluation, they were done. Fairchild won the evaluation and the history of that company was markedly changed.

Healy: Boy, I'll tell you, I was at Fairchild at that time and I don't believe that story. We beat you on technical merit.

Sakamoto: Hey, you know, I was with the customer. I said, "You know, that sounds like fun, though, you know, it sounds like a fun company if not necessarily the most successful." So, I think we're coming down to about the last half of our tape here?

Sakamoto: Why don't we, along that same vein, talk about what do you think was the biggest advance that you personally participated in, in the ATE industry? What particular change or method of doing business? It could be a particular test technology, it could be anything like that, ; something that you think was particularly pivotal that you either created or participated in. Anyone want to lead off? Phil?

Burlison: It was not maybe the most influential or the biggest impact, but by far the most interesting experience I had was back in the late '70s. I was working for Fairchild Test Systems and somebody approached me about developing a new tester for something called magnetic bubble memories. And I was asked if I wanted to head up that venture to figure out what it was and how to build one. So magnetic bubble memories, I would characterize more as a science experiment in the industry than a business venture. It was basically run by scientists who had no experience in semiconductors, manufacturing of anything, but it was very intriguing. I remember the first conversation I had, I visited this semiconductor company and asked what does-- I was ready to go in there and explain to them what our existing tester did and how well it would fit and figured out real quickly there was nothing that correlated between testing a semiconductor chip and testing magnetic bubble memory. So they were explaining, all right requirement is we build these magnetic bubble memories and they put them on a wafer much like you do silicon, but they're not silicon, you know, exactly the same thing, and we need to create a rotating magnetic field around the wafer, it's got to be accurate to plus or minus a half an oersted right there on strip of the die. And of course, being part engineer and part marketing I said, you know, first it was, "No problem." Second question is, "What's an oersted?" And so we went off and developed a magnetic bubble memory tester and, as did Megatest and a company called Watkins-Johnson and there was four semiconductor companies, AT&T, Rockwell, Intel and National Semiconductors was actually doing this. What was so interesting about that was just the novel new things to be done. It was still test, but no correlation. We were, you know, "How do you create magnetic fields, how do you create pulses in magnetic fields?" Magnetic bubble memories were the first to announce this fault-tolerance concept, so we learned a lot which would later be applied to regular memories, how do you build that? So I designed this tester and I designed something back then, a tester, and it was called the magnetic bubble memory computer or something like B-- a pattern generator, right. it was ridiculously complex, it never worked, and I got two merits out of that. First of all, at one of the tradeshows, I was the laughing stock of the tradeshow for designing this. You know, they were showing pictures of this. And also that year I won the Fairchild award for the most innovative development, all in the same year. Again, it was a short-lived venture.

Burlison: The whole industry shut down after a couple of years of that, but it was by far the most interesting little niche market, in my career, in the area of technology.

Healy: I can give you one. At Fairchild we developed the Sentry Tester and, if you recall, back in the '70s, testers were the ugliest things on earth. I mean, Teradyne's were all green and they had knobs and switches and dials and they looked like heck. They had wires hanging out of them. So we got together at Fairchild – Jim Bolin <ed: Bolin was general manager of the division> was there at the time – and we said, "We're going to merchandise this product." We developed the Fairchild tester, which looked like a piece of furniture. We had multiple colors and it's amazing the impact that has. I'll never forget – I was living in Europe at the time when we did this – I was trying to sell testers to ICL, which was a big computer company at the time. We were up against Megatest and Megatest had knobs and dials and switches and cables and everything on it. We came in with this. This is a million-dollar deal, so we had to go present to the board. So, how do you present a tester to the Board of Directors? I came in with my flip <ed: overhead transparency> that says, "It comes in five colors," and it actually did. We spent an hour at the Board of Directors of ICL discussing the tester, how it fits, and deciding "what color it should be?" They picked blue, because it matched their computers, which are blue, and that's how we sold a million-dollar tester. And we started merchandising this. The other thing we said is that because it's computer controlled there aren't any switches and dials. Now, you would think that's great, right. Well, there was a company in Norway, Kongsberg, and we thought we had that business for sure. I'm at a show one time in Munich talking about the sale and that we were expecting an order from Kongsberg any moment, and I find out that our competitor, Megatest got the order and the reason they're going to get the order is they have switches. I couldn't believe it. So I left the show, flew up to Norway, brought my guy in from there, and we found out that people who were making the tester decision were afraid of it; they weren't computer literate. They liked their knobs and dials and switches; this thing scared them. So now what do you do? Well, we found out that the CEO of Kongsberg had hired a guy from IBM to modernize the company. And he had nothing to do with tests or manufacturing. We got a meeting with him and explained the situation and he saw this as an opportunity for him to make a point in the company, and he got the CEO to overrule the engineers and buy this tester which was computer controlled as opposed to all the knobs and dials and switches. So there are many things that influence the sale of a tester that have nothing to do with the ability to test the part. This was innovative.

Sello: That's going to start a new field, color coded testers.

Healy: It did for a while.

Sakamoto: Steve Jobs must have picked up on that. Garry, you were going to say something?

Gillette: Well, I mentioned one thing, which was the co-development process on a system like this. <holds up a Kalos memory tester circuit board to the camera>. That was a revolutionary endeavor because that meant we could verify a design before we'd really built it. With the cost of the high levels of integration in the design, that saved us a lot of time and basically allowed this product to survive. However, I can remember another situation when I was at Teradyne. We were in the memory test business, and had announced a new test system called the J389. And the salespeople had been out there getting orders. It had a lot of great specs and promised future options. The only detail was it didn't work. We had sold a dozen of those [testers] to key customers that we had in the memory test business. The one thing you know in the memory test or any other tester business is you really can't be killing your customers very often because, if a customer buys a very expensive system and it doesn't work, then he doesn't usually survive. He's usually not going to make it. And, of course, the company that sold him the testers is going to be even worse off because they'll be banned forever. So we had a dozen systems out there. I was given the job of figuring out what to do in this situation and the solution was pull them all back and, in six months replace them with a system that worked. This meant we had to bring all these systems back and completely redesign the system. Every person in the department was pulled off of what they were working on and put on getting the new tester working. It was then re-introduced and hopefully would save face before we all got killed. The new memory tester product was called the J937. It eventually sold very, very, well, even through a downturn in which the only memory customers in the world were in Japan. There was only one customer in Japan at that time that didn't have its own ATE company. It was Mitsubishi. So the good news was that Mitsubishi did buy a ton of these and basically paid the division overhead until the market turned around.

Burlison: That was something back in the '70s and '80s was kind of unique, you don't see nowadays. Companies would buy testers based on paper and promises and, unfortunately, there was no FDA-type of approach to testers back then, right. So testers were sold with capabilities that didn't exist. And most testers-- you know, a large number of the “Virtual” testers never stayed there. They were being replaced and actually sometimes, replaced a few times with ones that worked. I remember a lot of my career was based on going in there and saying to the customers, "Right, well, we've already received your order, but it won't do this, okay, but it'll do this…" So, you explain your way out of that. And then next month you're doing the same thing again. That just seemed to be nature of doing business back then because back then, in testers, you were pushing hard on the whole concept of speed, pin count, and things like this. You were making promises when you were taking orders, it seems to me, and there was a whole lot of effort, as he [Garry Gillette] said, recovering from that. And it was very expensive for the ATE industry to make good on some of their promises. Like I said, replacing testers is a very expensive venture.

Sakamoto: Harry?

Sello: I have a question that I'd like to direct to my tester colleagues and comments from a more process oriented device character. Moore's law says a device's complexity is going to grow at a doubling rate every couple of years, every year and a half, couple of years, and has been doing this now ever since 1985 [ed: 1965?]. My question is, we're up to something between five and ten billion transistors per chip, having started out at a level of five way back and the curve is still linear. Does this mean, in any way, that it marks the coming end of the tester business, the tester industry, when it gets beyond this number or to this number? I wonder what the limitations are relative to testing? Other guesses have been made relative to processing.

Burlison: I'd like to answer that. Yes, it does mean the end of testing as the way it was done and this happened in this mid '90s. Back in the mid '90s we used to talk about this linear curve and the pitch line was, "When will we get to the $20 million tester?" You know, that was a topic of conferences, papers, everything else, but basically using a straight line, they said, "We're going to be at $20 million by the end of this decade for a single piece of test equipment." Obviously, that didn't happen. And that was one of the revolutions was in the late '90s was that semiconductor companies finally figured this out and started actually changing. They didn't slow down the complexity of these ICs, but they started relying less-- they started being more intelligent, as Jim kept reminding, about designing their devices, so it wouldn't have to be tested on a $20 million tester. It could be designed-- tested on much simpler testers. And that's where design for test started infiltrating, and really replacing this burden of the straight line curve challenge to the ATE industry. So, yeah, that happened in the mid '90s.

Sello: So it's already happened.

Burlison: It's already happened.

Sello: And they've climbed that curve already.

Burlison: —Let's just elaborate on one point a second. The most ridiculous things you're talking about. Looking at [the size of] testers and you'd made a mention about this, somebody made a mention there's a tester that's as big as a closet. There was a product that LTX built called the Delta 100, which never made it to market. It was not as big as a closet, it had a closet! It was actually big enough – I remember when we designed it, you remember this well, Jim – it was two rails of electronics and you had racks and you had to service both sides. So what we did is it had a walkway down the middle of the tester that people went into. They opened the door and walked down to service the inside of the tester or you could service it from the outside.

Sello: Holy mackerel!

Burlison: It was an enormous ECL <Emitter Couple Logic – a high-performance/high-power bipolar circuit technology of the period generally used in fast mainframe computers>. I think 33,000 watts was the power consumption of this one. There was another one <large, high-power tester> that actually made it to market – the Teradyne Tiger. <ed: The Megatest Polaris, MegaOne, and Teradyne j953 were also of this power consumption class of power consumption, as was the Schlumberger S9000 series>

Healy: Well, I caught D'Arbeloff <Alex DArbeloff was the CEO of Teradyne, a competitor to LTX> in the tester at SEMICON after hours. He was just looking at it.

Sello: He was in the tester?

Healy: Yeah, he had got in the door. I said, "What are you doing, Alex?"

Burlison: But that was-- I'd say that was the end of an era, those two testers.

Healy: Yeah, that's true.

Sello: So new ways of testing.

Sakamoto: I'm curious, Jim, about getting Alex out of the closet.

Healy: <laughs>

Morrow: Yes. So, if I understand this right, what the tester people are going to say is that Moore's law works to our advantage because, as the device densities get greater, the cost of putting the tester in with the device is much lower.

Burlison: Right, that's correct.

Morrow: Right?

Burlison: It's necessity. There's no alternative than making the chips smarter about testing themselves.

Morrow: It becomes [a moderate] cost instead of $20 million-- and the tester architectures don't have to be all that complicated.

Gillette: Right.

Sakamoto: As we wind down towards the conclusion of our discussions today, I'd like you all to think back through your time in the industry and come up with a statement about what you would give as advice to anyone who wants to come into the field now, if you even think that's a good idea or not. Also just where you think things have a tendency to want to point their way towards in the future. I'd like to wind down with that, as the end of our talk today. Anyone would like to kick off?

Healy: Well, I think, if you're going to get into the field today and you want to have an exciting time like we had, get into the linear area, the analog area, because there are so many testing problems in analog. More and more analog is going on these digital chips and these problems have not been solved. And many of the parametric type testing problems have not been solved either. And when I say solved, I mean in terms of having economically viable tests. You can take these very complex memories, you can take the complex logic, and you can build in built-in self-tests and the chip tests itself and do the things we talked about, which makes a much simpler tester in that area. But on the analog that's not the case. I know we've tried at LogicVision – developing built-in self-tests for analog. It has not been easy and we've found that we have to use digital techniques to do it. We've made some strides in there, but I think there's a lot to be done in that area. So if I was getting into anything to do with tests, I would focus on that area because I think that area can grow. That's where people make money, and they can certainly self-actualize, in the sense of coming up with very unique designs that would make them happy.

Burlison: I think I would have to agree with Jim. I would add the one caveat. Well, not a caveat it's just an extension of that. Back in the old days, good old' days as they're saying, you know, the passion, the innovation was all homed in around tester hardware. Building something with more pins, faster, cheaper, whatever, but it was all hardware intensive and to solve the big challenge of tests. The test challenges today are bigger, they're moving faster and are much more complicated than they were back then. But they're not being solved with tester hardware any more. I think the opportunities for test is going to continue to grow and they're going to be in the area of having the chip be able to test itself. So you're almost being a silicon designer. I say designer, but you are a test engineer at the heart of it. You're just working in a different environment. The other area is software; enormous opportunity and need in the industry for software to handle the information and to make sense of what's going on during a testing process and this is involving a testing that's able to deliver more and more information about what it's finding inside an integrated circuit.

Sakamoto: Okay. Thanks. Garry?

Gillette: I think we ought to think about the fact that it wasn't too long ago that there was more silicon in renewable energy then there is in ICs. If you want an adolescent market, it's photovoltaic panels, it's a whole lot of things. And that business is in an adolescent phase. It's growing incredibly fast and there aren't a whole lot of, if you want, agreed upon solutions on how you test for the reliability of the products in the field. Dan has got a really good, I think, niche, I think, where he is. In addition there's a lot more of those out there for people that want to get involved, not just as a test engineer, but also get involved in something that's going to be significant for the long-term benefit of the country. So I've looked at this and if you want to go build huge amounts, let's say $500 million worth of panels, you have a problem today in figuring out how you're going to test those and how you're going to guarantee that they are, in fact, going to last 25 years, which is the standard that's written into most contracts when they're purchased. There isn't a whole lot of reliability data on that kind of material for that long, with all the materials that hold it in place. So I would tell someone, go take a look at that and see if they can't get involved in what is an incredibly exciting business right now. It feels like IC tests did 20, 30 years ago.

Sakamoto: That's great. I think that is a clear winner. Daniel?

Morrow: I would say if you love problem solving, if you love science, then there is no richer environment for innovation. There's no richer environment where you get to build things for all kinds of crazy situations than test and measurement. I admit I am a technologist at heart. I love solving problems. In my short career, I have tested everything from tomatoes to fishing poles, asphalt facilities, just because it sounded kind of interesting.

Sello: Don't forget probers.

Morrow: And probers. We've tested a lot of different semiconductor devices. It's one of the few engineering disciplines where mechanical meets software, meets robotics, meets electronics, meets optical, meets analog, meets digital. I can't think of any engineering discipline that is isolated from the set of problems that we deal with in the test and measurement community. Am I about right on that?

Gillette: The exception might be high-power microwave.

Morrow: Microwaves.

Gillette: High-power microwaves.

Morrow: I've done a little microwave, too.

Gillette: That's why I said high-power because it excludes IC's.

Morrow: High power I don't do.

Gillette: You know, big coated waves guides and things like klystrons (big vacuum tubes).

Morrow: I would say if you're a problem solver and you love science, this is a great industry to get involved in.

Sakamoto: All right. Thanks. And, Harry, maybe you can close us out.

Sello: Well, I'm not a very good closer, but I'll end. Test equipment and my experience with testers and test equipment came from the side of processing, how to make devices. And then later, how do you find out whether they're good or bad, that's the test industry. Wrong way around. I suffered from the fact that I didn't understand and didn't seek to understand anything about the devices that I was involved in designing and making. And I didn't understand or look for; how am I going to measure or how am I going to tell that I've accomplished what I want to accomplish on that device? For example, the basic law of drift in metallic conductors, drift in aluminum conductors, which was a finding that came out of nothing to do with silicon devices themselves, but there was nothing that I was-- that I learned anywhere or was exposed to that caused me to think about some of the physical phenomena that take place, when you want to measure a device and when you want to make observations. And there were no test equipment people to go to, to do this. So I would opt for new people, new entrants to get in to try to get the measurement and the testing field closer to the processing field and ride in with it. So that a guy graduating all the way from a B.S. to the Ph.D. level can always be told there's a job where you're going to be measuring something and you're going have to explain how you can do it better and what it told you, right from the beginning in school just like we teach solid state science today for semiconductors. We have excluded the whole field of test and measurement mostly because it started out as mechanical problems. You didn't-- you thought in terms of well, I want to do something, then I'm going to have to find a machine that can tell me what I do. No, that's not the right way. Do the design and do the building of the new device, maybe it's an optical device, maybe it's a protean conductor of P-N [ph?] junctions, but put the guy who is interested in making measurement right in with courses in that kind of device work. We don't do that. We wait for the person to go out in the field and find a job, like we've heard here, brilliantly done by guys design me something that I can do. You should work in with the learning of it, right in the-- become part of the actual manufacture and the use of that device.

Sakamoto: Okay, thanks. Well, thanks for sharing just a few of your many memories with us today. I think it's been...

Sello: What would you-- I'd ask you, Paul, that same question. What would you advise a new entrant in the fields today?

Sakamoto: What would I advise a new entrant? You know, part of my whole view of this is, I've seen it go from just before my time, when maybe people were manually testing devices and you'd have someone in the lab individually looking at individual devices with lab instruments, to where I picked up. We already had automatic test equipment and the test engineer or product engineer had to understand everything about the device, its application, and its actual end use, wherever that was. Perhaps it was something that's going into a military product or maybe even some kind of consumer application. The test engineer was always tasked with understanding that entire scope of operation of the device. Today, I would say that everyone in the test operation is a specialist. The whole task has been divided up a lot and that most of the people coming in today and that are going to prosper in the business today are more managers of data than they are folks who can design circuits or use a soldering iron or any of those others things that herald from, say 20, 30 years ago. You know, today's successful test engineer has to be able to understand device design, device simulation and the built-in self-test technology, automatic test pattern, or ATPG generation. They have to be able to understand a lot of system, computer system jockeying, in order to get all those resources put together. And so to a certain extent, I'd say that today's and tomorrow's test professional is and will be an EDA [Electronic Design Automation – the software tools used to design semiconductor devices] and data manipulator person and not so much a man or woman of iron and wire, as maybe we grew up with. So with that, let's say we've seen ourselves go through that whole process, from a transistor to billions of transistors to in come cases back, Daniel, to individual diodes; and wafers that went from two inches to some day 450 millimeters and back to two inches again. It's interesting how the circle continues to go. I wouldn't even bet that probably some of the substrate material has gone from germanium to silicon to back to germanium again.

Sello: Oh, God forbid.

Sakamoto: So with that, I thank you all very much for sharing your memories with us today.

END OF INTERVIEW

