Oral History of Wendell Sander

Interviewed by:
Dag Spicer

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Spicer: Hello and welcome. Today is May 30th, 2024, and we're here today with Dr. Wendell Sander. Wendell, welcome.

Sander: Thank you.

Spicer: We'd like to begin looking at your life, which has been full of amazing accomplishments, actually, especially in the electrical engineering field, with a look at your early life, your childhood, where you grew up, your parents, what did they do, that kind of thing. Can you tell us a bit about that?

Sander: Yeah. I grew up on a family farm in southeastern Iowa. It was a farm that had been in the family for multiple generations. My first year of school was in a one-room country school with no electricity and no running water. And I went from there to the town school, which had all 12 grades in one building. And we were two classes to a classroom at that point, so we got up to 10 kids in a class. And then in high school, there were about 100 students in the high school, so my class was about 24. It was in a rural area of extreme southeast Iowa, and interestingly, around us were three other small high schools of about the same size. One of them, about five miles away, there was a student, Jerry Junkins, who was a few years behind me in college. And he later became the chairman and CEO of Texas Instruments.

Spicer: Oh, my goodness.

Sander: And so that was kind of interesting. In another little town about 10 miles away, there was a preacher who had a son while he was there, and the son was Bob [Robert] Noyce. So, we grew up in a neighborhood where actually a surprising number of interesting people came from. So, this is a typical agriculture community, and I went on and I graduated from high school in 1952, and then I went to Iowa State University in Ames, Iowa, in electrical engineering and got my electrical engineering degree in 1956. From there, I went to work for a company, it was actually Gilfillan Brothers, which is a rather old-line company in California, because in the early days, it made lots of radios.

Before the World War II, it made radios and refrigerators and appliances and all kinds of things. I guess when World War II started, they came to Gilfillan and said, we need you to make ground-to-control approach radars. They said, well, we don't want to do that, we want to make radios. They said, well, you can either do it or we'll nationalize the company and then you'll do it. <Laughs> So, one way or another, they went into the military business.

In 1956, when I went there, they were doing ground-controlled approach radars and also they were doing a missile system, and I worked on the missile system there. And I left after a couple of years to a startup that was doing some contract work for the FAA. Then, in 1960, I went back to graduate school at Iowa State University and got my master's and doctorate there, graduating in 1963.

Spicer: Wonderful. Can I just interrupt for a second?

Sander: Sure.

Spicer: Yeah, because you've raised a lot of really interesting things. Iowa State, of course, is where John Vincent Atanasoff was based.

Sander: Yes, that's correct.

Spicer: And he was the winner of the famous legal case of Honeywell vs Sperry Rand as the inventor of the electronic computer. That's a very nice university there. Were people aware about Atanasoff's reputation when you went there?

Sander: No, they were not. He was fairly obscure there because, really, his work had not gotten much notice there. I guess he did some… my understanding is he did some projects for some of the physics department and things like that, but it was pretty unnoticed.

Spicer: Right. And now, Bob Noyce went to Grinnell, I think.

Sander: Yes, he did.

Spicer: Can you tell us a bit about that college?

Sander: Yes, Grinnell actually is a religious school. His father was a preacher, and he was a preacher in the town of Denmark, which is close to where I grew up, when he was born. It wasn't long after that they moved to Grinnell, and his father became part of the school since it was really a religious school of that religion. So that's really why I think why Bob Noyce ended up going to Grinnell for his first four years. That was his hometown at that point.

Spicer: Now, somehow Bob Noyce got hold of some very early transistors. I think they were point contact, but they might have been junction. I'm not 100% sure.

Sander: They probably were point contact, yeah.

Spicer: Yeah. And now, since you're getting your PhD just around the time when transistors are arriving on the scene, what did you make of transistors? What did you and others make of the transistor when it was first announced?

Sander: Well, it was pretty clear that this was a big breakthrough in electronics, from what we could see. And it was interesting because, of course, the classes and laboratories had not yet evolved to transistors. We did have a few transistors in laboratories. They were germanium transistors, probably junction transistors, but they were germanium, and they had things like thermal runaway. I mean, they could leak enough to <laughs> sort of bias themselves. But at the same time, in one of our laboratories, we built a vacuum tube radio receiver that we used as a project.

It was a classic old [design]. My lab partner happened to be a veteran, and he was working in town as a radio repairman. <Laughs> So we had an easy time with that. But I remember he put his little finger on ground and went around with a tap and says, oh, we've got voltage everywhere, <both laugh> because there was around 150 volts on those things.

Spicer: Oh, my gosh, yes.

Sander: But that was how he did it.

Spicer: Yeah, that was one of the nice features of vacuum tubes. We actually have the console from the UNIVAC-1, the maintenance console, and I think I counted 28 different voltages on it.

Sander: Yes, I believe at least that.

Spicer: So yeah, and that's a vacuum tube machine, of course.

Sander: We used to buy batteries for the battery-operated portables and vacuum tubes, and those would have multiple voltages, and they were quite challenging batteries.

Spicer: The A and the B batteries?

Sander: Yeah, A and B.

Spicer: Right. So tell us about your dissertation a bit. What was that about?

Sander: My dissertation was interesting because it was kind of far afield. What I had done when I was at the startup, I was doing a mixed analog-digital computer. They were trying to get flight path computations done. So I had worked with analog, I had built and designed an analog-to-digital converter and done a few things like that, and so I was interested in…for my dissertation, I was interested in coming up with a mathematical description of an A-to-D converter, because really there was no way to do that very well.

So — I had a major professor who was pretty laid back, but he was a very sharp guy. And so I saw him in the hall one day, and I mentioned, I think I'm going to do my dissertation on this topic. He said — we were there for maybe five minutes — he said, "Oh, that sounds pretty interesting." And so the next time he saw it was rough draft form. So this was really my own work, and what I did is I developed a theory of two-valued variables, so that you could describe things with orthogonal polynomials in two-valued variables. And by doing that, it allowed you to mathematically describe an A-to-D converter. But it also allowed you to describe Boolean results, so it was an alternative of Boolean algebra. And I had a few friends who took that up as their way to design logic after that. And so that was my theory, and it was interesting because for my PhD, they required two minors, and my minors were mathematics and statistics. Iowa State had a very strong statistics department primarily because they developed a lot of hybrid seed corn, hybridizing technologies, and that required a very sophisticated analysis of the sites to be able to get statistical results that were meaningful. When you're growing in fields, you don't have any control over much.

Spicer: That's fascinating.

Sander: So they had very strong statistics [department], and so I made the statistics professor on my thing very happy because I had inadvertently made a proof that there were certain conditions under which the orthogonal polynomials always converged, <laughs> and I thought that was pretty good. Anyway, so my dissertation was totally off in a different area than I ever worked in, before or after.

Spicer: Right. Now, although the fact you did it on A-to-Ds is—you did do some work with A to Ds later on, I think.

Sander: I did at times, yeah.

Spicer: And before as well.

Sander: Yes, I did before, and I did after, too.

Spicer: Can you tell us a bit— I'm just looking at the Tasker Industries stint that you had there. I'm curious, could you…

Sander: Yeah, that was the company. That was the startup that did contracts for the FAA. And the FAA was trying to get some equipment for their sites that were automated. And actually, I was doing a hybrid version of some of the computation, and there was another team, a company, actually, doing an all-digital approach, which eventually won out, which is pretty typical of how things were going in those days.

Spicer: Now, was this part of the ILS, the landing system?

Sander: No, well, yeah, we were trying to... It was the ground approach; it was the approach patterns we were trying to track. So we were doing flight paths, tracing flight paths, approaching flight paths, for time management of the landing. I don't know what it became really considered, but I was doing computations of flight path analysis and timing.

Spicer: Is this a radar-based technology?

Sander: Yes. Yeah, you were tracking, you had regular tracking with radar.

Spicer: And it was just one radar dish?

Sander: Yeah. There may have been more than one, but you were getting tracking information to try to control all this.

Spicer: I don't know if you know if...

Sander: This was in the 50s.

Spicer: Yeah, well, I was just, you know, it reminded me of the SAGE system. I don't know if you know that.

Sander: Yeah, it was probably contemporary. <Laughs>

Spicer: Yeah. Well, they had Height Finder radars and azimuth radars, and... well, that's very interesting. And so you were there for maybe a year or two, I think?

Sander: Just a couple of years. And then I went back to graduate school. Actually, I still worked for them during graduate school. I worked summers in there. I spent a summer in Atlantic City at NAFEC [National Aviation Facilities Experimental Center]. They had the test facility for the FAA was in Atlantic City. So I spent a summer back there on my summer vacations.

Spicer: Right.

Sander: And, you know, I did the usual things. I was a teacher, assistant teacher. One interesting student… I had a student who was legally blind. He was so blind, he had to use Braille. So I had a double E student who worked Braille. And so when he did tests, he would do them in Braille. And then afterward, I'd sit down with him, and he'd tell me what he did. But one of the most interesting things was, in order to get a degree in electrical engineering there, you had to pass a drafting course. And, of course, a conventional drafting course is just not going to work. So the drafting department actually formulated a special course just for him that he could show all the principles of drafting even though he was blind.

Spicer: Wow, that's nice.

Sander: Isn't that something?

Spicer: Yeah, that's really nice. They accommodated him.

Sander: Yeah, they accommodated him.

Spicer: You know, there's another famous programmer. I don't remember their name. I think they were on JOHNNIAC, but they also had severe vision problems and just extremely bright but limited by their vision. So you've got your PhD now. What's next?

Sander: Well, I went back to the same company for about nine months.

Spicer: Sorry, this is Tasker?

Sander: Tasker, yeah. And then I got recruited. At school, one of the other students was Bill Smith, and he had gone to work for Rex Rice at Fairchild R&D Labs. Rex had this digital systems research department at the laboratory. And his background, I don't know if you're familiar with Rex Rice, but his background, he had been at IBM. He had actually started his life as a mechanical engineer, doing stress analysis and got involved in one of the really early BINAC doing stress analysis on computers and developed that[1]. And he went to work at IBM and worked there for a number of years and was a recruiter for them. One of the places he recruited was at Iowa State for PhD candidates. When he went there [Fairchild], he was recruiting at Iowa State. So he took a couple of the graduate students I'd gone to school with to Fairchild. And so they got a hold of me and recruited me up to Fairchild [as well]. And that's when I went to Fairchild R&D Labs, which was quite an experience.

Spicer: That's wonderful. A couple of quick questions. Does the name Cuthbert Hurd mean anything to you?

Sander: I know the name, but it doesn't... Yeah, I don't place it.

Spicer: He was IBM's Director of Applied Science, and he and Jim Birkenstock went out and got orders for the 701, IBM's first large-scale…

Sander: Those names I know.

Spicer: …computer, yeah. And then…. Rex Rice was also in charge of the Symbol project, right?

Sander: Yes. That was the project they did there, and that's what I was recruited to work on.

Spicer: Okay. I want to– oh, this is really interesting. You know why? We have the Symbol machine.

Sander: Yes, I know you do.

Spicer: Here in the collection.

Sander: Yes.

Spicer: So why don't you tell us– well, let's go in order. And so tell us when you started there.

Sander: Well, I started there, and I worked… I was in the Symbol group, but I didn't stay there long. But I was in the Symbol group, but I was there long enough because Rex was also one of the inventors of the dual in-line package [or "DIP"]. And so they had dual in-line packages, and I did some of the very first thermal analysis of the ceramic DIP package for thermal characterization. <Laughs>

Spicer: Oh, wonderful.

Sander: So I got to work on it real early. But, yeah, I didn't work there long, so I didn't do much on the Symbol myself, but I knew the team well. And I actually went back to the team later to do the ILLIAC-IV stuff.

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[1] [Interviewee's note] Rex Rice worked at Northrup where the BINAC was developed.

Spicer: Now was the dual in-line package developed for Symbol?

Sander: No. It was really developed for Burroughs — well, for both. I mean he made the comment when he got there, basically what they showed him was a little flat pack with a bunch of flimsy leads on it. He said that was pretty impractical on the state-of-the-art printed circuit boards, that it was a nightmare. <Laughs>

So he wanted to do something different, and he worked with Burroughs. They were interested in coming up with a practical package that they could use automatic insertion on. So he worked with them, and actually, because he was a mechanical engineer, it helped because he was able to determine how you shape them and the fact that… I mean, the leads had a spring to them, and they were designed so that you could grab them and put them in these plots and everything all worked. It was a fairly significant amount of mechanical design [that] went into the dual in-line package so that they could do automated assembly. And so that was kind of his contribution to it.

Spicer: Can you divide the– between Burroughs and Rex Rice, or...?

Sander: Well, between those two, I was mostly… Rex is the one who came up with the package. But Burroughs, he just worked with Burroughs, and they were a counterpoise. The patent, I think, went t… I think the patent actually was Rex and somebody else there. There was another engineer or there were a couple other people at Fairchild that really did the… they did the package. But they aimed it at the problem Burroughs presented them for the parts they wanted to buy.

And it was really first used on an IC logic technology that never really had too wide a usage. It was used on some of the early Burroughs machines and used on Symbol. They called it CTL, complementary transistor logic. So they developed it for that, and then, of course, it just took off once they got it. The package showed up. Everybody wanted their parts in that package. And so it exploded then.

Spicer: Yes. Well, that's wonderful. Can you comment on the Symbol machine? What were the goals of the project?

Sander: Well, the goals of it… Rex had the concept that software, there's just too much software definition. You need to have more… that things would operate more efficiently if you put it in hardware. It would operate more rapidly. You could accomplish these objectives more efficiently and rapidly in hardware than you could in software. So I mean, in other words, a special purpose machine was going to run faster than a general-purpose machine for the same thing. So they aimed it at doing this. They developed their own high-level programming language, and they implemented the language in hardware. The other thing was databases, because he felt that all computers ought to be variable field length. You shouldn't have to talk about how long things were. You should be able to handle an unlimited word length if you wanted to, bit length, you know. The numbers should be variable, and it shouldn't be confined to these 'chops.' And so everything was done in a streamed fashion so that all the arithmetic was effectively independent of the size of the variables.

And his search, he was always interested in all kinds of search algorithms for searching information. Of course, at that time, most of the information was fairly short information. It wasn't like the web…. you know, it wasn't like searching on the web where you're looking for massive– it wasn't massive data analysis. It was more confined. But he was very interested in all those aspects. So the Symbol machine was an attempt to build a machine had the variable field length. All of the variables were variable field length. And so it was just a different way to do things.

Spicer: And can you describe how you implemented the instructions, the software?

Sander: I'm not even that familiar with it.

Spicer: How would they have done that? They didn't have ROMs. Maybe a diode ROM?

Sander: Well, it wasn't coded. You understand? It was logic. It was done in logic, not in code.

Spicer: I see.

Sander: That was the whole point. You do everything in logic and it goes faster.

Spicer: So it's just regular combinatorial…

Sander: It was just combinatorial logic. So you had a massive amount of logic.

Spicer: Okay.

Sander: And that's how it was done. Yeah, you didn't think in terms of any programming.

Spicer: Did Symbol have any positive outcomes?

Sander: Well, there were a number of articles written about it. And so it made some in the literature. That was really all it did that was positive. Certainly things like… well, you can say the dual in-line package was partially an outcome of the research and stuff like that. So there were a few outcomes. The packaging technology of the Symbol was done in a fashion that was very similar to the process element memories (PEMs). It was the same physical structure was used for Symbol and the PEMs that you have for the ILLIAC.

Spicer: Can you describe what you mean by that?

Sander: Well, the connectors were cam connectors. So they dropped in and you turned cams to force the pins against [their mating surface]. And that was done to guarantee you had reliability because you were able to get enough pressure and wipe when you clamped those things that you guaranteed a result.

Spicer: Yeah.

Sander: And that, again, was Rex's mechanical engineering background. He knew what you had to do to make a very reliable contact. And he knew he was putting in these rows, which he had, I think, 400 contacts, a board or something like that, and about 20 or 30 boards. He had thousands.

Spicer: Oh, my gosh.

Sander: Huge numbers of contacts. They had to all work. And they did.

Spicer: Wow.

Sander: He knew how to do that.

Spicer: That's incredible. And is it time to talk about the ILLIAC IV?

Sander: Well, yeah, we can talk about that.

Spicer: Do you have something in between?

Sander: Well, it's a longer process. Because what happened was I was off doing some work on large-scale integration, and so I did some of the earliest gate arrays. I had a group doing the earliest gate array work there at Fairchild. So, actually, even the first ones that came out, I forget, the 3100 or whatever it was, that was really developed in a group I had. So we were looking at all kinds of ways to do large-scale integration, because that was what you do after the small parts, you do big parts. Gate arrays were one structure we looked at.

Spicer: Are you still using manual layout tools?

Sander: Well, at first we were. Actually, we built some where we actually used conventional PC board taping to create masks. <Laughs>

Spicer: Okay. Right.

Sander: But, yeah, we didn't have really much in the way of computers yet. And so when the computers came in, of course, all that started changing a lot. So I did that group, and then it went off, and I was just doing some research, and I started working on memory chips. And so I looked, and I came up with a way to make a 256-bit chip in the R&D labs. And so I built a 256-bit memory chip, the working memory chip, in the lab that was… the way it was structured, it was very fast. It was sort of based on the CTL process, which had used AND gates for logic and stuff like that. But I was able to make a very small memory cell, because I used the EPI (epitaxial) space as resistors for the loads for the chip. And so you could just float them in space, and you could just drop in… you could make a very, very tiny bipolar cell that way.

And H.T. Chua, I showed H.T. Chua, and he saw that, and he did it a little different. But he took that, and that's what made the 4100 [aka 93400]. So he took my design for the 4100. [The Fairchild 4100 was introduced in 1970 – Ed.] As a matter of fact, I had also built a tester, because the first time they tested it, when I had built the first ones, the tester basically wrote all 1s and then all 0s and then read all 1s and read all 0s. Well, a flip-flop passes that test. <Laughs> And so they made a few chips that were basically a flip-flop. All you were reading was one bit. But anyway...

Spicer: And this is a 256-by-one-bit part, right?

Sander: Yeah, 256-by-one-bit. Had this peculiar encoding on it, because the encoder, when you had to do inversions, took longer time. And I was trying to make a really fast RAM [Random Access Memory]. And so we used this combinatorial coding to do that. Anyway, so you could get away without inversion on the chip. And Chua followed that, too, because the 4100 had that kind of addressing on it. But anyway, so I built this tester, hardwired a tester to go through and do a few other patterns, like checkerboards <laughs> and diagonals, and things like that. And they used that tester in production for I don't know how many years. <Laughs> Then I'd put it on this board and I'd put my name on it. So it was the Wendell Sander Tester.

Spicer: Oh, nice.

Sander: And they called it that, and everybody in production called it that.

Spicer: Oh, that's nice. So the 4100, did that become a big seller?

Sander: Well, it was pretty big. It really was the beginning of their static RAM business they did, which were the bipolar... It used the oxide-isolated process stuff.

Spicer: Did you have any competitors at the time? Was anyone else making it?

Sander: Right, at that time, no. For at least a number of years, we were the only ones making a 256-by-1.

Spicer: Wow.

Sander: We had a couple of years there, at least, and so we built the process element memories (PEMs) for Burroughs. And we actually also built a couple of replacement megabyte RAM units for IBM machines. There were boxes that you'd take to put them in and replace the boxes.

Spicer: Now, I read in one of your interviews, is this the one that drew 12 kilowatts?

Sander: Oh, yeah. Oh, man, it had…

Spicer: Five volts at 600 amps or something?

Sander: Something like that, yeah. Oh, yeah. It was a tremendous amount of current. We had these huge copper bars, <laughs> because those chips drew a lot of power. They got hot.

Spicer: It reminds me of the Cray-1 downstairs we have. That was an ECL machine, so the minus five volts supply is 1,200 amps.

Sander: Yes. These bars were close enough together that you took off all jewelry when you worked around that thing. <Laughs>

Spicer: Yeah. Very dangerous.

Sander: That was a welder ready to go. <Both laugh>

Spicer: That's right. Yeah. I'm very curious about the ILLIAC IV memory, because we have one, a PEM, which I thought stood for processor element memory, but it's process element memory. Is that right?

Sander: I don't remember. But yeah, it is process element, that's what we called it.

Spicer: I'm sure you're correct. And tell us why that was so unique and how you got the contract for that.

Sander: Well, the problem was they [Burroughs] needed a pretty fast memory, and magnetic systems weren't there yet, really. The only thing that came close was magnetic film memories. I can't remember the gentleman's name, but there was one guy who was their memory expert at Burroughs, and he came and saw what we were doing in the bipolars and those things, and he was very interested in seeing it. So he was a big backer of it at Burroughs.

But basically they were struggling to do the film memories with that performance or reliability they needed, to be very honest. It was a tough one to do, and they were concerned, but they needed it. I mean, these things, they needed, I think it was, 100 nanosecond access time, which at that time was screaming fast. So we could meet his speed requirements with these 4100s, and we showed it a few times, and that was enough.

They ended up saying, okay, if you make them, they wrote the contract, and that was very significant, because nobody had built a real seriously big computer with semiconductor memory, and there was a certain amount of question as to whether semiconductors were really reliable enough. I mean, cores had the reputation of this really good reliability, although they still did have error rates. But it turned out that these semiconductor memories, that one was particularly hardy, because it was a bipolar technology, which at the time, versus the MOS [Metal Oxide Semiconductor] of the day, was certainly a more rugged technology at that era.

Spicer: Was it faster as well?

Sander: Well, it was faster. It was a lot faster, but it also, you got away from all... People were still fighting the little ghosts of the floating ions and all that stuff in MOS. It wasn't completely gone, even in that era. So it was really solid, and then it went in this case that Rex Rice had designed with all these super connectors <laughs> that were guaranteed to make connections, and the result was that the unit just never failed. Burroughs told us later that they were really reliable.

Spicer: Oh, that's excellent.

Sander: They were very happy with the results.

Spicer: So the unit we have, which is on casters, by the way, which is great.

Sander: That's a whole processor…. That's a whole unit, though.

Spicer: That's a 256K by... is it? Do you remember?

Sander: I can't remember. Actually, I don't remember. I think it's 64, but I'm not sure.

Spicer: Right. And that must have been just an enormous contract for Fairchild.

Sander: Well, it was. We just did the memories.

Spicer: The chips.

Sander: The chips and memories. It was pretty good, but it wasn't a big home run thing. But it did put us into the position, well, okay, now we'll go try making these big memories for the IBM world and see if we can make those. We did a couple of those. There was more struggle to that, though, because we were putting these on these IBMs, big IBM System/360s. They were dual processors. I forget the number, but they were the big ones. And they had so many cables. I mean, they had four of these massive buses. And I seem to remember there was, you know, like a couple of hundred... coaxes were in the hundreds you're talking about <laughs>, that were coax connected. The backplane of these, because you had two peripheral buses and two processor buses you were dealing with, and all of them were, you know, 64-wide everything. I mean, it was just huge.

Spicer: Wow. Now, ILLIAC IV had a lot of problems, of course.

Sander: Yeah.

Spicer: Not related to memory, I don't think.

Sander: No, no.

Spicer: I mean over budget and late. But did that help you get sales from other customers, being able to point to ILLIAC and say…?

Sander: Well, what it did, from the viewpoint of the semiconductors, yes, because the semiconductor memory now was suddenly okay. So now the bipolar memory group did their thing, and they had a pretty good business in bipolar SRAMs [Static Random-Access Memories].

Spicer: By the way, I have a quick question. Is there a difference between Fairchild Semiconductor and Fairchild R&D?

Sander: Well, yes. But R&D was really the R&D laboratory for Fairchild Semiconductor.

Spicer: That's what I thought.

Sander: Yeah, is what it was. So generally you didn't produce things in R&D.

Spicer: I see.

Sander: It was not common. There were a few exceptions. There were a few exotic semiconductors they made. They made some early light-emitting diode arrays for the military that they used for… they did massive arrays of light-emitting diodes that they put on stamped film for keeping track of the film, I guess, is what they did. I don't know.

Spicer: Interesting.

Sander: But anyway, at that time it was because they were lead-bonded, and every diode needed a lead bond on it, you know. <Laughs> They had one lady who could do it, that had the skill set, like one person with the skill set to make these things.

Spicer: It's amazing how fragile things were in the early days, and even today.

Sander: Yeah.

Spicer: Still doesn't take much to disturb the system. Well, tell us a bit more about Fairchild. Let's close out that chapter, if you like. Tell us what you did.

Sander: Okay, then. Well, it’s kind of is a segue to the next world. Because we had done these big systems, and I was getting ready to leave because I was getting kind of burnt out and some stuff, and Jim Early was the head of the laboratory at this point. And Jim Early said, “oh, no, you can't. We want you to be head of the department for another project we have here,” which was that they had set up a memory research department to do a bipolar dynamic RAM [DRAM], a dynamic RAM done with bipolar technology.

Because a couple of us had come up with some ideas for ways to try to do that, and there had been some proposals made by one of the guys at Bell Labs of possibly there was a way to do that. So they built a project to do that. So I was made director, head of the department, which was kind of interesting because I was reporting directly to Jim Early, who was head of the laboratory. And they gave me a process line, process engineers, design engineers, and all that. And so I designed this circuit, this bipolar DRAM circuit, and we built a 4K bipolar DRAM.

Spicer: Wow. Now, what year is this?

Sander: This was, it would have been starting in about 1974. It was actually… we started our project, I believe, before Mostek announced the first one. Because what was interesting was we had already designed it with address multiplexing when they announced the address multiplexed RAM. Okay? So the result was that actually our two chips were remarkably similar in terms of their design. They were a 4K x 1-bit, and they had address multiplexed inputs that just looked almost the same.

Spicer: Were these 16-pin DIPs?

Sander: Yes, 16-pin DIPs. Yeah, the objective was to get it in 16 pins, which is the same thing that Mostek did. And so I was working on this, and we got it done, and we had chips… we had some working chips. And so one of the things I wanted to do was I wanted to put my chips in a real computer and see that they worked properly in a computing environment, and make sure [there was] no more funny business in them, and so that was the beginning of the hobby computers in the mid- ‘70s. So I went out, and I saw an Apple I, and an Apple I used Mostek DRAMs. That was their RAMs, and I knew that I could easily map mine into the same operating system they did. So I could replace those with my bipolar DRAMS. Well, I bought one.

Spicer: Sorry. Did you have a type number for this bipolar DRAM?

Sander: It was a 93481, I believe is the number.

Spicer: Oh, that’s a long one. Okay.

Sander: I have a rather poor copy of the datasheet. It was on datasheet form. I mean, it was brought to the point before they gave up on it… that they were about to...

Spicer: Oh, I see. Okay.

Sander: What happened is they actually found a fatal… a problem with making it in the process. There was a problem they'd missed, and they didn't have an easy solution for it, and so they just dropped the project rather than try to fight it more because the MOS parts were just getting too hard to compete with. So but they had taken it to where they were starting to get ready to roll it into production.

Spicer: Now the MOS, as you mentioned, you know, can’t compete on speed. So I guess it competes on power.

Sander: Well, it couldn't compete. Well, it couldn't compete with these on speed. These bipolars were definitely faster.

Spicer: Right. Yes, with yours, yeah, but it does compete on power, I suppose.

Sander: Oh, it's cost. Well, on power, actually, they were about the same power. There wasn't really a power advantage. They were very similar. They were just really fast compared to the existing ones. When they were at 400 nanosecond access times, these things were 100 to 150. They were like three or four times faster. So there could have been a specialty market for it. We did talk to Cray about it because they obviously would fit that category.

Spicer: Was that a capacitance issue in the...

Sander: No. It turned out there was a sneak path in there that it literally was determined with a 'surround-disturb' test. I don't know if you know what a surround disturb is.

Spicer: No.

Sander: Well, in core memories, that was a common test, a surround-disturb, because one of the things that would happen with cores is if you did a whole bunch of reads, and you had a row, and you had a whole bunch of reads close to a bit, because there was common current flow, you could disturb the bit and cause it to flip if you didn't hit it once in a while...

Spicer: I see. Right.

Sander: ...and this was enough that we could overcome the refresh. The refresh wouldn't catch it yet, quite.

Spicer: And what do you call that again one more time?

Sander: Surround-disturb.

Spicer: Surround hyphen disturb.

Sander: Surround-disturb testing.

Spicer: Testing.

Sander: Yes...

Spicer: Excellent.

Spicer: ...and then that is an old core memory test...

Spicer: Wow. That's interesting.

Sander: ...and so that was how it was found.

Spicer: Yeah, and so this semiconductor....

Sander: But actually, my Apple I worked fine.

Spicer: Oh, yeah. Sorry. Let's get back to that. So you put your own DRAMs in.

Sander: In the Apple I.

Spicer: Did you replace the existing?

Sander: Yeah, I replaced the existing ones. So they were gone, and I had my own in there, but also, it had twice the memory in it because I used more chips. So I just....

Spicer: Did you just piggyback chips and move the...chip select?

Sander: No, I had to make up a little kludgy floating board to fit down on the board pins, and I made it work, and it was pretty reliable, and so but at the time, I had just gotten re-married, and between us we had four teenage boys.

Spicer: Oh, wow.

Sander: So I started writing games for it, you know, porting games through it, obviously.

Spicer: That’s great.

Sander: So I wrote a Star Trek game, and of course, I’d bought an Apple I.

Spicer: Where did you learn programing, by the way?

Sander: Well, I just...

Spicer: Just picked it up.

Sander: ...picked it up. Yeah. No formal training, but when you bought an Apple I, it was at that era you had the two Steves and this other guy who drew the schematics, and so I had written this. So I had gotten to know Steve [Jobs] because I'd call him up, and because when I first got it, the BASIC in the Apple I was still being written. I mean, one of the first versions of BASIC I got didn't yet have an input statement, for example.

Spicer: Wow.

Sander: Yeah, it was just… and every time you wanted an update, you called Steve to see if you could get an updated version of BASIC, and so that's it.

Spicer:. You mentioned you knew Steve. So tell us a bit about that. How did that happen?

Sander: Well, that happens because I needed an upgrade to the BASIC. I knew I did because I knew the BASIC was old. So I called the phone number on the thing...

Spicer: So you were getting to that.

Sander: ...and that got you Steve Jobs. If you called that phone number, that's who answered.

Spicer: Really? Wow. I guess so.

Sander: Yes. Well, there was nobody else. It was just the two boys. That's all there was, and so he answered the phone, and he'd say, yeah, we got another one, and I'd say, okay, and I'd go down to over to the house over there and pick it up. Right?

Spicer: This is the one on Crist Drive, right? [2066 Crist Drive, Los Altos, CA 94024 – Ed.]

Sander: Crist Drive, yeah. So anyway, I got to know him, and I mentioned to him once that I had written this Star Trek program for the Apple I, and he said he'd like to see it. So my son Brian and I went over and took it over there and showed it to him, and he thought it was pretty neat because it was running on a little bigger machine. I had more memory space. I could do it a little fancier than, you know, and then a little while later, he asked me if I could port it to the Apple II. They were doing the Apple II, and he wanted to port it.

So in the early months of 1977, which is when the corporation of Apple started, in January of ‘77, but by February or March, I was over there sitting at a prototype Apple II porting my program to it. So I got to know Mike Markkula and the Steves, and I thought this is pretty interesting. So I decided to make the switch and move over to Apple, and that was how I got into Apple.

Spicer: Wonderful. Now, from a technical point of view, were there things about the Apple I that you found clever, or was it just...?

Sander: Oh, yeah, actually, Woz is just very clever. First of all, that Apple I was basically a TV typewriter with a processor on it. So conceptually it's a very simple structure, and I always say it's the last computer you could fully understand -- understand all of the software and everything. You could understand the whole world of Apple I, but it was because what had happened is Woz had been asked to design a TV typewriter for one of the local timesharing services that were selling timesharing service to people… hobbyists who were all over the place, and so they want something...

Spicer: Oh, okay, maybe Tymeshare?

Sander: It wasn’t Tymeshare. It was a different company in Mountain View. I can't remember the name of it right now, and I'd used them too. I knew them. I knew who they were. But anyway so he had designed this TV typewriter. Actually, he says he designed it before he saw Lancaster's version of it, but he had used basically the same chipset that Signetics had made...

Spicer: I see.

Sander: ...and he built this TV typewriter, and a TV typewriter was a thing with a… you’d get a keyboard hooked to it, and then you'd have your TV set, and this thing would hook to a modem over here, and then your keystrokes would send a serial stream to the computer over a modem, and then you'd get back a serial stream which came up on your screen, and so what he did, he just took his TV typewriter and real quickly puts a 6502 in place of the modem and everything else, and just ran it, and you just run a serial stream in and get a serial stream out, and that's all it is. So it's really simple. So that's its beauty is its simplicity. Now apparently, even before they started shipping the Apple I, he was already designing the Apple II, and the Apple II, quite honestly, is a marvel of efficient design. He is brilliant at certain things.

Spicer: Well, this is where I'd love to pick your brain a bit about this. Are there any specific things that you found? You can get technical if you need to.

Sander: Well, yeah, the one that's very clear on that was his method of using the color channels on a TV set and being able to manage the color graphics because he had a couple of techniques he used that took advantage of the characteristics of the set that…obscure in some cases, not obvious characteristics, to get the color to work, and his designs tended to be very efficient. He worked very hard to do things that were at… there's one example that he did that I thought was pretty remarkable, for example, when he tried to do a printer peripheral to run a printer, he had a code to run it, and what he did, you’d get a handshake back.

After the printer was ready for another character, it’d send a handshake back. So you’d get this handshake signal back. Well, most people would run that back and go into the computer and stuff like that. What he did, he took a handshake back, and he went and put it into an address line of the code. So what would happen is you'd be running code, and you'd get to a spot where it would just branch to itself, and then when the handshake would come back, it would change the address, and now it would have a different whole set of code that he'd go to. So it would now follow the new code and drop through and loop. That was the handshake. If you think about it, to me, that one struck me as being one of the more clever. That's an example of the kind of stuff he did.

Spicer: You know, he's also good at software and hardware things, right?

Sander: Yes, he was good at software too.

Spicer: That’s pretty unusual.

Sander: Well, yeah, and the way he did software was a different world too because you got to understand, he never used an assembler. I don't know if he ever used an assembler, and two things about it. He basically did the assembly manually, everything, and he could do hex in his head like nothing. I mean, he did hex like everybody else does decimal arithmetic. He did hex. So he dealt with the branches without problems, and so he could just practically directly write linear code once he knew what he wanted to do.

Then the other thing was that in the early days of the Apple I, in particular, he didn't have any memory system, any hard memory. So if you turned off the power, everything's gone. That means every time you want to start up again and turn the power on, you got to load everything by hand, in hex. So he could type hex faster than most people can type, period. So I saw him type hex, and he was blazing fast. So he had this property that he was completely comfortable typing, you know, several thousand bytes of hex because at the Homebrew Computer Club, he would sit down and type BASIC in. Turn on the power, type his BASIC program in, and then be able to demonstrate his computer. So he'd type two or three kilobytes of words while they were getting started with the program.

Spicer: Yeah. Now one of the technologies that I want to talk about because you had a big role in it is the disk controller, and the IWM, which is the Integrated Wendell Machine.

Sander: No. The Integrated Woz Machine.

Spicer: Or Integrated Woz Machine. Take your pick. Tell us about that.

Sander: Okay. Well first of all, the encoding he used, you got to understand that he didn't have any background whatsoever in disk encoding. I don't even know if he knew how they did it. It didn't matter because he just looked at what was coming out of the disk drive. He took a mechanical disk drive, understood what was coming out of it and what he put into it to do things, and he figured out his own encoding scheme.

So he virtually totally invented the scheme. Now it was a scheme. It was a group coding they called it, which IBM had… they just sat around and dreamed up things like that and patented them. So they really had patents in a sense on a lot of that kind of stuff, but he just came up with this group code scheme, and it's just astonishing. He and Rod Holt, who was the analog guy, and he was really adept at analog design. So the two of them were a deadly pair on this because Rod came up with this to simplify the work, and Woz tried to compensate to minimize how much stuff he needed from the drive, so he could keep that simpler, and but his encoding was this group code, and he was able to do it in the state machine, and do all this, and do all the things he had to do to get the thing to cal [calibrate] and took other shortcuts, and it was just a marvel of design. It was really an exceptional, and you end up-- we showed it at the computer fair the year later, and of course, they bought these bare drives from Shugart, and Shugart themselves said later they'd just send us the stuff that didn't work very good, so yeah.

Spicer: Huh-oh, and yet it still worked because of Woz's controller, is that right?

Sander: It still worked. He worked around it. It probably helped him design a more rugged design.

Spicer: You know, one of Seymour Cray's first machines he built using surplus transistors, and he put enough margin in there that they ran just fine, and so that's really interesting. Wow.

Sander: So they had these things that ran, but he was able to figure out the way, and the state machine was really nifty, and I actually went through and analyzed it totally because I was trying to figure out a way to test these things. How do you test a disk drive now, and I went through, and I learned to understand the complete pattern of the state machine, which had to take different branches here and there, and it was just nothing but a 256 byte ROM, and a register, and that was it, and but when I went through it, I went through, and I realized that there was one path where he was off by one bit in the timing. It was one count off on the timing, and so what was interesting was, when they were starting production, they were concerned because they weren't getting a good enough error rate. They had to have a 1 in 10 to the 9th error rate. Well, let me back up. It was never known how good this thing was when it started. So the fact that it even could do 1 in 10 to the 9th was not obvious. I mean, you didn't find out until you started running these test programs. So I look back, and I think, man, he really nailed it to be able to one. Well, but he didn't. The ones they were testing were not passing, and I had this ROM where I'd corrected this one bit like this. I say, "Here, try this," and so they stuck that in, and it passed. So all of a sudden it worked, and they ended up giving me disk drive serial number two.

Spicer: Oh, nice.

Sander: Which I later sold for a lot of money.

Spicer: Oh, yeah, and so one of the steps involved taking-- was it 30 chips or so?

Sander: Yeah, well that was the thing when you...

Spicer: Then getting it down.

Sander: That was the thing. You got it down to this board. The control board was like seven or eight chips, and they weren't that expensive.

Spicer: Well, one of them was a PAL, was it?

Sander: No, there was no PALs. It was all ROMs.

Spicer: Oh, okay.

Sander: The state machine was a ROM, a 256 by 1 ROM or 256 by 8 ROM, and they had a 256 by 8 ROM for the code too, and that and a couple of registers were all that was on there, and Rod had taken the analog board and cut it by more than half. He was down to like one third the number of chips, and so when we showed that at this computer show after we had it done, and they were demonstrating doing loads and everything on it, and it was really a shock. I think it was really a shock to Shugart.

Spicer: I can still hear those drives in my sleep, the unique start up sound. It's just classic. So I'm just curious. That must have been a big money maker for Apple because they sold those for $495.00.

Sander: Look, there were a lot of things [that were] big moneymakers for Apple. They were very profitable. Yeah, they were, and more importantly, the fact that they had a drive that was practical. Even at $495, that was still a bargain because if you tried to buy the Shugart equivalent for your personal computer...... If you tried to buy… the card was like $300, and the drive was another $400 or $500. So these were bargains, and they were tiny.

Spicer: That's right, and, you know, the typical configuration was to have two of them. So there's $900. Well, almost a thousand dollars in drives right there.

Sander: And you got to realize the other big hit was when the first spreadsheet was put on the Apple, and the reason it was put on the Apple was because they had a floppy drive.

Spicer: Oh, is that right?

Sander: If you think about it...

Spicer: VisiCalc.

Sander: ...basically, it wasn't feasible to do VisiCalc really without some kind of drive or...

Spicer: A storage system.

Sander: ...storage system that worked, and this was the only one that was really very practical for most people.

Spicer: By the way, since we mentioned storage system, the Apple I did have a cassette storage, I think.

Sander: Yeah. Well, okay, and even that was done… even that was a very clever design because basically, yeah, and that was another example of Woz's clever design stuff because what he did is you had one cycle of one kilohertz for a one, and one cycle of two kilohertz for a zero. So the result was that--I mean, so the length of the record was dependent on what the data contained was.

Spicer: Is that a form of FSK, that encoding?

Sander: I don't know what you'd call it because it is kind of, but it's the only format I've really ever seen that if you record 4K bytes of it, the record length could be variable by two to one, up to two to one, and I don't know of any other storage coding system that does that. I'll be very honest.

Spicer: Yeah. You know, I know our IBM 1401 has a variable field length, the one that-- we have one running, by the way.

Sander: It does. Oh, it does. It has variable field length.\?

Spicer: Yeah. Downstairs. We have two actually. They're both running.

Sander: Oh, maybe they do. Maybe they were common. I don't know, but this one...

Spicer: Well, they had a lot of core memory, and you could, I think, run out of memory, obviously, theoretically.

Sander: But anyway, yeah, this wasn't variable content. This was the variable length of time to store a fixed amount of data.

Spicer: Right. I see what you're saying. Yeah, and I always found-- you know, I used cassette storage maybe two or three times. I found it very unreliable.

Sander: Oh, well, this was hard to use.

Spicer: It almost never worked.

Sander: Yeah, it was hard to use, but what was interesting with the variable field length was it… I only really did it in recent years, but I realized that the way to check if you got a good load or not was to check the last two bytes because, since if you ever got a bit error, if you ever read a bit wrong, then the length of the record was wrong because the ones were shorter. One was half the length of time of a zero. Okay. So by the time you read the length of time of the tape, if you dropped a bit, then that meant that the length of the record had to be wrong. So you had to have compensating errors in order for it to come out right.

Spicer: Wow, yeah.

Sander: So you could always look at the last bytes and see if they came out right, and if they didn't, then it wasn't a good load.

Spicer: Now, was that the Kansas City Standard that it used, or did that come later?

Sander: No. That was strictly Woz's.

Spicer: His own thing.

Sander: That's unique. It was used in the Apple II as well.

Spicer: Okay. Yeah. Is there anything else you want to say about the Apple I or Apple II? We didn't talk much about the II. How did you...?

Sander: Okay. Well, I did a lot of the peripheral boards on the II.

Spicer: Yeah, let's talk about that.

Sander: Yeah. Woz had done a prototype printer card, and I kind of cleaned it up for production and did that, went through the firmware, and made sure it was consistent with what we were doing, and there was a serial card that was just a super… it was just purely a serial in, serial out data thing, but then I did a comm [communications] card.

The interesting ones I did… well, I did the RAM card actually, but that was kind of an interesting story because Bill Atkinson was doing… he was doing this other program, a language program. He was trying to put a new language on, and I actually had done the ROM card too. You know, when they add Applesoft BASIC, they needed the ROM card to be able to switch between. That's the first solution they had was they sold it as a ROM card, and so I designed that, and so what Bill was doing while he's developing this program on the Apple II was he was using EPROMs and putting them into a ROM card, so that he could… you know, when he was developing the program, but he was just continually burning ROMs to do that. That's a terrible way to do programs at all.

Spicer: It's a very slow process.

Sander: It sure is, and so that's what he was doing, and I was looking at it, and it was Pascal is what he was putting on, and so I was thinking, well, I'd like to play with Pascal, so I ought to… but I didn't want to buy all those ROMs. They were darned expensive, so I wasn't

Spicer: Pascal came on ROM?

Sander: Yeah, Pascal came on ROM initially. That's what he was developing it on.

Spicer: Oh, okay, I see, for development, yes.

Sander: Because that's what he was trying to do. So I said, well, gee, I can make a card that has just a DRAM, and plug it in the card, and pick up the… you know, how you put the little dongle over to plug it in onto the main board, and I can do that, and I can get that running. So I wire wrapped me up a card like that. So I could just load Pascal by moving it up onto my RAM card. So I took it in, and I showed it to Bill, and I described what it was. He says, "Oh, I need that." He took the card, and I never saw it again. So that was the prototype RAM card.

Spicer: Neat. Was that similar to the Z-80 SoftCard that Microsoft was doing?

Sander: Well, it wasn't, but what it was is the RAM that replaced the onboard ROMs. So what it ultimately was...

Spicer: Oh, for development.

Sander: ...you could put now a whole different program up in the RAM card.

Spicer: I see. Right.

Sander: Right. So the ROM card did the same thing. It replaced the onboard ROMs.

Spicer: Got it.

Sander: But this was a RAM to replace the onboard ROMs.

Spicer: So that device was more of a development tool then, is that right?

Sander: Yeah. What? No, everybody got one eventually.

Spicer: Oh, really? Oh, wow.

Sander: Yeah, everybody bought those.

Spicer: Nice.

Sander: There were tons of them. That was a huge one. So I did the RAM card

Spicer: What was the most popular, the bestselling option card?

Sander: Probably the RAM card, without a doubt because you had to really have it because that way you had both Integer BASIC and Applesoft BASIC on your Apple II.

Spicer: Did it interact with CP/M at all in needing that extra...?

Sander: Not really. CPM needed the Z80, and so that was why you had the Z80 cards.

Spicer: That’s true. Right.

Sander: No, as external cards go, Z80s were pretty popular, but although even externally, Microsoft made RAM cards, and everybody. A lot of people made these RAM cards.

Spicer: Yeah. Quadram, that’s another one.

Sander: But all of them, interestingly, in order to pick up the address, multiply addressing, you always unplugged a real RAM chip and plugged this board into it to pick up the RAM addresses, and years later… well, yeah, I'll jump forward a few years. After Apple, we did a contract company, a company doing contracting. We were contracted by Apple to develop a RAM card with SRAMs instead, and that didn't need the dongle thing, and the reason they asked us to do that is because they had gone to the Apple IIEs, and for the schools, they made a deal where you could do trade ins of their old ones, and so they ended up with all these old Apple IIs that were not IIEs.

So they wanted to do something with those, and so they wanted to sell them, ship them to third-world countries, okay, and so but they needed RAM cards in them to be able to do all the programs. So they had us design a whole new generation of RAM cards because the old RAM cards were too expensive to build because the DRAMs were hard to buy now. They had gotten hard. They had gotten scarce and were really expensive. So we did another RAM card.

Anyway, the other peripheral cards that I worked on was the comm card. I ended up trying to design it in a way that it interacted directly with BASIC, so you didn't have to write any code to use the comm card, and it basically talked to a modem, which talked to the phone line. That was the purpose of a comm card, and so I developed one that was easy to interact, but to do it, it only had 256 bytes of ROM to write a code in. That code was incredibly tight, and it was so tight that, Andy Hertzfeld looked at it and That was the tightest code he'd ever seen, and he said, “One of the reasons I wanted to come to Apple, I wanted to come to someplace where they write code like that.”

Spicer: Wow. That’s pretty nice.

Sander: I thought that was a pretty nice compliment, but anyhow I wrote a couple of programs. I wrote one really interesting program for using that card because you could make the computer a remote computer. You could make the Apple II a remote computer. You could set it up for dialing. So you could set up your Apple II, and have it on your modem, and dial into the modem with a terminal, and talk to your computer. Or you could have an Apple II at home and talk to your computer at work that way. So you could make two Apple IIs talk to each other with each running their own.

I also wrote a program I called Tele-Pong, and it was a Pong program that each person at the end of a phone line would load Tele-Pong and then you could launch it so that it would start, and both programs would operate simultaneously, and you can now play Pong between the two because the only thing it had to send over the phone lines was the paddle position when it got to the wall. So there was almost no transmission needed, and the two computers actually operated independently on the two computers while they were playing the game. So it was a true interactive computing situation, and later on, it was actually used at least in one legal case as an early example of interactive computing because it was a true interactive computer over a phone line.

Spicer: That's amazing.

Sander: Isn’t that something?

Spicer: Yeah, and did Apple ever make its own modem cards?

Sander: Modems? No.

Spicer: Don't think so.

Sander: No.

Spicer: That was Hayes and all those other guys.

Sander: Yeah. That one of the guys, Marty Spergel, he actually had a Pennywhistle modem that he sold. It was a kit, and he did.

Spicer: Now was that a Lee Felsenstein design, the Pennywhistle?

Sander: Probably, very likely. They were good friends. But anyway, no, and I guess the last one that I designed in peripheral cards, I designed the graphics tablet, which was the one where you could draw on the tablet, and so I did that. That was all done in the ‘78, ‘79 timeframe.

Spicer: Did you work with Rod Holt on that?

Sander: Yes. He helped me on drivers for that.

Spicer: Yeah. Because I interviewed him, and he was actually kind of annoyed that Apple didn't market it properly, and they kind of just let it, you know. They didn't think the market was big enough, so they didn't bother really, but anyway, that's the way it goes.

Sander: Did you? You interviewed Rod.

Spicer: I did, yes.

Sander: Oh, man. He is an interesting guy.

Spicer: Oh, yeah, lovely man.

Sander: I really liked working with him.

Spicer: Yeah. Oh yeah. Yeah. Because both of you are just so accomplished and so smart. Well, Apple now, is it time to talk about the Apple III?

Sander: Yeah. Okay. Basically, the motivation for the Apple III is really interesting because the problem they had was they were making the Apple II and the FCC had in the games world… the home games…

they had developed a standard-… [for radio frequency interference from digital devices – Ed.] What do they call it? I forget now, the title.

Spicer: Part 15.

Sander: Part 15. They developed Part 15 for games, and the standard they wrote, it was very tight, very difficult, and Rod, in particular, was concerned that it was going to be very difficult to meet that with a personal computer. So the aim of the Apple III was to develop a computer that could meet the gaming Part 15. That was one of its primary objectives. It was to, you know, be an upgrade too, but really, that was one of the big motivations of it.

So that's why it ended up in these cast iron things with all these screws in it. You know, it was something else mechanically. It weighed a ton, and that was largely the result of a combination of the industrial design and things. I mean, at that point, Jobs was involved in calling out the industrial design, but at that point, his heart was with the Lisa stuff, and, you know….

So anyway, we ended up with this box that was a confined box to stick our electronics in. So we built it up, and then I put probably too many bells and whistles in it, and it got too many parts, and it was tough to lay out and everything. So it was a difficult board, but one of the biggest problems it had, you know, was the intermittent failures. We traced them because we had, you know, 50 of these things sitting in a room burning-in, and we'd have random failures, and what we traced it to was… because it was a confined space, we'd stack boards. We had a board, and we had a board stack, and the connectors to the board stack were some Molex connectors that were unreliable. Good old Rex Rice should have been there. We needed him. They just didn't have enough wipe and pressure to meet the specifications, to work.

Spicer: Are these the kind of like DIP headers or SIP headers?

Sander: Well, they're like with the pins. Yeah.

Spicer: They're like pins that stick up.

Sander: Yeah, they're quarter square pins, and the connector slips on. The connector was a Molex connector that it was a single pin, single wipe, and not enough pressure.

Spicer: I used to make those when I worked in the summer as a high school student. One summer I made hundreds of those. Anyway, yeah, those Molex connectors are familiar!

Sander: Yeah. Those things didn't have enough reliability for what we were doing, and fortunately, this one guy found a connector that had been developed for the appliance industry that was an exact replacement fit that had a really strong double wipe. They were a fork-type thing, a metal fork that just slipped over. We replaced them, and the problems went away. I mean, that just fixed it, and nobody-- you know, it was too late because by then, people had a reputation, but Apple went ahead, you know, and a year after they shipped the first Apple IIIs, they replaced every Apple III. Every board was replaced. In fact, I, one time, had one of the old boards, but I don't. At this point, I have no idea who has in existence an original Apple III board. I don't know of any.

Spicer:. Because they were taken out of circulation.

Sander: Those were taken out of service and replaced. I mean, Apple used Apple IIIs for many years. Everybody in the company used Apple IIIs, and for years and nobody ever complained about reliability problems.

Spicer: Yeah, and, you know, one thing that I heard, and it's probably an urban legend, is that if it started working weirdly on you, you would pick it up six inches and drop it, is that true?

Sander: Oh, absolutely. You'd pick it up about an inch and drop it, absolutely because it was a connector problem. All you had to do is just jar the connectors, and you were going to fix it.

Spicer: So that's totally true.

Sander: Totally true.

Spicer: Wow. Okay.

Sander: It absolutely worked.

Spicer: And Apple actually issued a service-- you're not sure.

Sander: I don't know if they did. That I don't know, but I know that it worked.

Spicer: But word got around. Yeah. Wow. Okay.

Sander: And that was because it had those connectors, and obviously, that's exactly how you fix a connector problem. You jar it, and it's gone.

Spicer: That makes sense.

Sander: Yeah. It worked.

Spicer: Right. How long a product life did the Apple III have? Do you remember?

Sander: I guess close to 10 years, I think.

Spicer: Wow. Because the Apple II was 17, I think I read…

Sander: Yeah. Well, no, the Apple III may have been just seven or eight. Let's see. They were about six or seven.

Spicer: With its variants, the IIe, II+, IIc, II2ci, IIcx, all of those.

Sander: Yeah, the Apple IIs were very...

Spicer: Yeah. Some of those are Macs. So I just threw that in there by accident.

Sander: Yeah. There was a Mac board for running the Apple IIGS, I think. I think there was. Yeah.

Spicer: Oh, neat. Now, was the Apple III software compatible with Apple II?

Sander: Well, it wasn't really and that was a problem too. There was… basically, —marketing… let's face it, this was the beginning of the marketing of PCs, and they didn't really understand their marketplace very well yet. So, there was sort of an assumption that well, if you don't obsolete the old software, then nobody's going to use the new software, and that was a total mistake. Everybody's going to use all their old software. So, the Apple II emulation mode was not supported properly and there were some poor decisions made there. That didn't help.

Spicer: How about on the peripheral front? Were there...

Sander: There were never a lot of peripherals made for them.

Spicer: But it used standard...

Sander: It could use the standard ones.

Spicer: Parallel and serial?

Sander: Yeah, it could. Yeah.

Spicer: By the way, I'm always curious about AppleTalk. Do you know the history of that or how that came about?

Sander: Well, not entirely. I know Rod worked on it and there was a...

Spicer: I wonder if the Apple III would have had AppleTalk on it?

Sander: It didn't have it built-in, native.

Spicer: No, no networking?

Sander: Yeah. It didn't really have that.

Spicer: Still too early?

Sander: Yeah.

Spicer: What year is that, '80, 1980? [The Apple III was announced May 19, 1980. – Ed.]

Sander: Yeah. I think it was in the 80s. That was the other thing-- the Apple III went from concept to production in about 18 months.

Spicer: That's amazing.

Sander: It was really fast.

Spicer: That's really amazing. Yeah.

Sander: Actually, the software for it was written really fast. That team did a very good job in terms of keeping a schedule. Software teams are notorious for not keeping schedules. They did a remarkable job of keeping a schedule on that.

Spicer: I've heard from many interviews I've done that the longest lead time thing is actually the injection molds.

Sander: Oh, yes.

Spicer: Those things have like a six-month lead time and so everything else has to wait for that.

Sander: That was one of the early problems with the Apple II. When I first got there, they were just going over from doing this early short-term tooling, which was very crude to trying to get it clean. They finally decided to pay the price of getting the proper molds formed so they could start running that stuff. It's getting the molds, moving the machine to molds is...

Spicer: Another thing Rod told me was the early Apples really weren't very compliant with Part 15.

Sander: Well, no, they weren't. Well, see, Part 15 didn't quite really apply...

Spicer: It didn't exist yet, I don't think. Yeah.

Sander: It didn't quite exist for computers and so, yeah, they were-- oh, they were terrible. The Apple I was absolutely atrocious because I remember running my Apple I and being able to see it on my TV set, see the picture, the screen on my TV set.

Spicer: That's incredible.

Sander: Didn't need a cable.

Spicer: That's amazing. So, on the Apple III, what is your fondest memory of that project?

Sander: Well, I think just getting it out and getting it going. Of course, it was a bit frustrating with all the reliability issues, but in the long run, the other thing was seeing it be totally adopted at Apple for a number of years. Three to five years, Apple IIs were gone. No Macs were there yet. It was just Apple III days.

Spicer: Neat. So, the company at least probably bought several thousand machines.

Sander: Oh, they bought a lot.

Spicer: Yeah. That's great.

Sander: Let's see. That pretty much is really the Apple days.

Spicer: Okay.

Sander: I was there for about five years at that time, so, in the early 80s, '82, '83. I was part-time there for a while and then the Huston brothers and Bob Lashley and I formed a company called The Engineering Department and we did a lot of contract work for Apple.

Spicer: Now, what kind of things did you build for them?

Sander: Well, this strange language card. We also did a contract for a card that ran the PC software in an Apple II and so, we did the IC that could read the MFM protocol of a standard IBM disk drive. So, we did that, and we worked with Apple to do what's called the SWIM Chip, which was a Super Wozniak Integrated Machine or sometimes… it was really commonly called the Sander-Wozniak Integrated...

Spicer: Nice.

Sander: Because my son, Brian [Sander], was the one who did the implementation of it because he had graduated from college and so, he came to work for us there and he and I worked together for many years, virtually all his career.

Spicer: That's a really lovely part of this story that I want to capture. Didn't you show me a picture? I saw a picture of Brian when —he was just a little kid and you were...

Sander: Yeah. There are pictures around, I think.

Spicer: Yeah. Well, let's talk about that because he’s graduated and just joined you. this is the perfect time to bring him up.? I think you were mentioning hanging out with the two Steves with Brian?

Sander: Brian went with me when we took the demo over there. He was in high school.

Spicer: Okay. To think of him as a vice president later is really cool.

Sander: Well, he was a manager… a director there. Basically, well, I keep saying it's just like the old family farm analogy. In the family farm, the way it worked was you brought the kids into the farm, and they farmed, and they worked for you for years, and then when the farmer got older, he retired and then he went to work for the son, who now had the farm. Right? So, we did the same thing. Anyway, he worked for me there. So, he and I then worked as a team a lot and generally, I tended to come up with these crazy ideas and he was a really skilled IC implementer and so, he could make it work. So, we did a lot of projects where I'd work on architecting something, and he would do the silicon implementation. We did that at a number of startups in the days when you could do that.

Spicer: So, he learned VLSI design at college and stuff?

Sander: Oh, yeah. Well, he didn't learn it in college. Basically, we really learned it on this first chip we did because he started doing this chip, where we did an MFM encoded disk controller, and then Apple decided they wanted to integrate that in with the IWM and have both types of formats they could run on the same disk controller chip. So, Bob Bailey worked with Brian and really, Bob Bailey helped train him how to do that. Bob Bailey was the one who did the original IWM for the Apple II and went on and the two of them did the SWIM chip and that's why it was called the Sander-Wozniak...

Spicer: Wow. Yes.

Sander: But yeah, that was-- so, those were the-- that was the SWIM chip.

Spicer: Okay.

Sander: That ended up going in the Mac and everything. SWIM was the one that went everywhere.

Spicer: Oh, wow. Yeah. What was the processor in the Apple III, by the way?

Sander: It was the 6502.

Spicer: Same. Yeah.

Sander: But I extended the addressing by trapping out on some of the codes and doing some extended addressing. So, you actually could do 24-bit addressing if you wanted to.

Spicer: Oh, wow. That's a big address base.

Sander: Yeah. That was not for execution, but that was only for data. It was kind of a tricked-out strategy.

Spicer: Yeah. Any other cool products that you worked on there?

Sander: Then later, Brian and I did this controller… with Wolfgang Dirks. Interestingly, his father was Gerhard Dirks, who you may have run across before.

Spicer: No.

Sander: Gerhard Dirks was an IBM fellow who really enabled disk drive technology. What had happened is he was in Germany, and he had developed a disk drive technology there, a recorded disk drive technology, and IBM had done the same and they were beginning to compete in their patent world and so, IBM just bought him out and he moved over to the United States and worked here in San Jose. He was in the San Jose facility as their IBM Fellow, and he was sort of.. the father of disk drive technology.

Spicer: Wow. Did you know some IBM engineers?

Sander: No, I didn't, really. Well, I did meet Gerhard.

Spicer: Oh, yeah?

Sander: But Wolfgang was his son, and Wolfgang was the disk drive guy at Apple.

Spicer: Wow.

Sander: So, anyway, Wolfgang was working there and he wanted to get a hard drive that he interfaced directly to the [Motorola] 68000 they were using. He wanted one to put on the processor bus for the internal drive instead of having it through any of the scheme. He wanted it right on the bus and so, he came to us, and we developed a controller for him. So, we worked on doing that and then Brian went to work for him eventually, and worked at Apple on disk drive controllers.

So, that was another step and let's see, other things… the disposition of The Engineering Department was kind of interesting because one of the projects they picked up on the way was this obscure one, where there were some guys in Gilroy who were interested in the shipping containers that ship produce from all over the world. And one of the problems with produce is it takes time to ship it, and it spoils before it gets there. So, they were looking at ways to extend the shipping life of produce. So, they had come up with some environments that would extend the life by maintaining the atmosphere in the shipping containers. At certain levels, you could extend the life of the produce. So, what they needed was a controller to control that and we ended up developing a controller for the shipping containers to extend the life. So, ultimately, The Engineering Department was sold to them.

Spicer: Oh, interesting.

Sander: How's that for an exit?

Spicer: That's interesting. Yeah. It kind of reminds me of bananas. We get them in New York where's. there's a huge central market for bananas. They come from South America and so on and they're mostly green and they pipe in ethylene gas to ripen them.

Sander: To ripen them, yeah.

Spicer: Anyway, so, we're still at… it's got a really interesting name, now, The Engineering Department.

Sander: Yeah.

Spicer: How did you come up with that name?

Sander: Well, we wanted to do contract engineering. So, we just said "Well, we'll be The Engineering Department if you want one."

Spicer: That's good. Okay. How about one more Engineering Department product that you worked on, if you can think of one?

Sander: Oh, that really is about...

Spicer: Too much? Okay.

Sander: That's about it for that.

Spicer: We can move on. Yeah.

Sander: Then, The Engineering Department had been sold and I was visiting my wife's family in Texas I got this call from Andy Hertzfeld who said, "We've got a new company startup situation, and we need a hardware group." So, I said "Well, Brian and I are available." So, that was General Magic.

Spicer: Nice, both of you got to go there. That's nice.

Sander: Yeah. So, we both went and also, the guy who did the Apple IIE, Walt Broedner, also went with us. So, the three of us went to General Magic to do their hardware because they have all these software ideas, but they had to put it on a platform.

Spicer: Right. So, tell us about that because it was a very compact system, right?

Sander: Pretty compact for its...

Spicer: For its time.

Sander: It involved designing a couple of chips, including a system-on-chip-type thing.

Spicer: Oh, wow. That's pretty early for that.

Sander: Yeah. This was relatively early in the system-on-chip days. It used one of the contract chip designs you can buy.

Spicer: For people watching or reading this interview, General Magic, just tell us what they made.

Sander: Okay. General Magic, there's actually a documentary of General Magic that exists, and the idea was they were going to come up with a way to have instant communications on a platform and it would be the kind of thing you'd order your groceries…you'd order things for them and you'd have instant communications to people…you could write notes and things and they were doing the whole ball of wax. They were going to do the hardware, the software, and even the communication interface structure to do it.

So, it was actually launched by Apple. It was a spin out of Apple. Marc Porat and Andy Hertzfeld and Bill Atkinson were starting this at Apple and Sculley decided to spin it out and so, that was the spin out and they added… Sony became a part of it, Motorola and AT&T… all of them were part of this venture. So, that was… I mean, their board included the president of Apple, the president or vice president of every one of those corporations.

Spicer: Wow.

Sander: I felt they had to have an antitrust attorney at every meeting.

Spicer: If I recall, each one of those companies contributed a specific thing. Like, AT&T did a cellular modem, I think, right?

Sander: They were providing the infrastructure. I mean, remember, the internet didn't exist. So, it was like building the internet.

Spicer: Okay. So, it was a radio modem kind of thing?

Sander: Yeah. That was the idea. It was going to use cellular...

Spicer: Cellular.

Sander: Yeah.

Spicer: And then what were the other ones you mentioned?

Sander: Well, Motorola, they were just hardware. They were just going to produce the hardware, and they did. They built hardware and sold it.

Spicer: And it's like a tablet-like device, right?

Sander: It was like a pretty good-sized tablet with the stylus and all...

Spicer: It's got little wings, little speakers on the...

Sander: I don't remember. I actually had one. Anyway, so, this was the subject. So, they had three different, really, staffing things. There was the hardware staff, because we actually built the prototypes for Sony and Motorola to build their products. Both of them actually manufactured and sold products.

Spicer: Wow.

Sander: This went all the way.

Spicer: So, Sony was Asia and Motorola was North America or whatever?

Sander: Well, they competed. They were really competition.

Spicer: Oh, they both competed in...

Sander: They could compete. They were both sold in the US. So, it was really quite a project. It was very high profile and because of all those sources, they were able to draw from all these places. So, they got some very skilled people, obviously, out of this.

Spicer: Do you remember what you and Brian worked on? Was it these chips that were...

Sander: Yeah. We worked on the prototype hardware. I mean, we actually had to design the entire product itself because we provided the working schematics for how this thing was built and any special chips that were needed were provided. All this design work was provided by us. Now, we didn't actually sell them the chips or anything. We just provided them the design.

Spicer: Who did the mechanical design?

Sander: They did. They did the mechanicals.

Spicer: Sony and...

Sander: Sony and Motorola did the… they had their own teams working on them. So, we were just providing the electronics.

Spicer: The reference design.

Sander: Reference design. We did a reference design. That's basically what we did and they both built product for...

Spicer: I didn't know that. That's really interesting.

Sander: Brian was the manager of the product team.

Spicer: Oh, wow.

Sander: So, he was the one who did that and he had hired this new engineer, Tony Fadell.

Spicer: Oh, yes.

Sander: So, Tony came to work for him. He was a dynamic individual, leave it at that, and Megan Smith was another one, one of his hires. She worked for him.

Spicer: Wow.

Sander: So, that was… and then I worked for him too there, basically.

Spicer: Did Apple profit in any way from… or benefit in any way from the technology, maybe, or...

Sander: Not really. I don't think any of that technology really sunk in anywhere, to be very honest. It was a working experience. So, everybody got experience in that world, but that was about it.

Spicer: Were you there during the Newton years at all?

Sander: Well, yeah. Well, Newton… I wasn't at Apple, but well, Newton is kind of weird because Apple had spun out this thing [General Magic] to get it going, then they went and started their own project to compete with it. So, I never quite understood.

Spicer: It's had a long life. It sort of started and stopped a few times, I think. Anyway, okay...

Sander: So, that was General Magic.

Spicer: Yeah, General Magic.

Sander: So, tons of stories about it.

Spicer: How long were you-- well, maybe tell us one or two.

Sander: Well, like eBay started there. Omidyar worked there as a programmer and he had a working [web]site under his desk and his wife wanted to sell some stuff. So, he formed up eBay and just started running it, because this is a little side effort to make things happen and it ended up growing into eBay.

Spicer: Oh, my gosh. That's fascinating. I remember reading the first thing he sold was a broken laser pointer, which is very eBay.

Sander: Yes.

Spicer: It's like "It might be broken. You never know." Anyway, anything else you want to say about General Magic, what the environment was like?

Sander: Well, it was a very...

Spicer: High-stress or mellow or...

Sander: Well, it got pretty stressful as things didn't pan out. They should have just jumped on the internet and drove it. As Brian pointed out a lot of times, it was one of those situations that was… it was an idea, but the technology wasn't ready for it.

Spicer: Just a bit too early, yeah.

Sander: It was too early. That was one of the advantages of Jobs was he was really good at getting the right thing at the right time. That was really important.

Spicer: Yeah.

Sander: So, that was...

Spicer: Neat.

Sander: That was really kind of General Magic.

Spicer: What year did you leave General Magic?

Sander: Probably about '96, something like that. When I went-- about the time I went to...

Spicer: November ’97, actually [referring to notes].

Sander: Brian was there quite late. For some reason, they hung on to the hardware side of it longer for… I don't exactly what the deal was, but they kept looking to be able to sell some of the system-on- chip stuff they did.

Spicer: Did they ever do a rev two [second version] of the system?

Sander: No, they didn't, but I think he was working on what they were going to do. He was a very skilled designer because he'd done so much. So, they did one chip after things [went south] and he was the only chip designer left at the company and so, he was alone. So, he did a full rev of the chip and released it, built it and everything else solo and almost nobody does that because he was the only… he was about the only person I ever worked with who could check his own work, because invariably in semiconductor, you have to have somebody [else] checking.

Spicer: Absolutely.

Sander: Absolutely. He was able to do solo designs.

Spicer: Wow.

Sander: I don't know how he did that.

Spicer: Very carefully.

Sander: I couldn't do that, for sure.

Spicer: Probably got some of your genetic influence there.

Sander: That trait was not one of mine.

Spicer: Okay. So, ChipScale, that's your next venture.

Sander: Oh, well, that...

Spicer: Do you want to tell us about that?

Sander: That really was really a whole new area. ChipScale started because early on, I invested in this company doing microwave diodes. That is a very niche market. Anyway, long story short, along the way, they developed this technique for packaging semiconductors, where what they did is they would make wafers and then he would etch grooves in them from the back, and then he would put plastic on them. He'd spin the epoxy on it, cure the epoxy, and then he could just carve out finished chips.

Spicer: Oh, wow.

Sander: It was all packaged. He was doing batch packaging.

Spicer: That's interesting.

Sander: So, it was interesting. So, a few of us got fascinated by that and so, we ended up trying to do a company and make something out of it and we really couldn't get anywhere. It didn't really go anywhere, but we did get a whole series of patents in ChipScale technology, which was then sold to a guy who was trying to collect patents and make money collecting patents.

Spicer: This is really interesting because several people, companies, as you know, have tried wafer-scale integration. Gene Amdahl is probably the most famous one with Trilogy Systems. I'm not sure if you're aware, but they've come up with a company called Cerebras now...

Sander: Yes. They're somewhere-- begin making it go.

Spicer: It's real now, wafer-scale integration. It was a long time coming and Cerebras told me they spent one year on one specific thermal management problem that was a showstopper because they had four different materials to deal with and they were all expanding at different rates. As they did so, they would disconnect..2.6 trillion transistors on that single wafer.

Sander: Yeah.

Spicer: Hard to wrap your mind around that. But anyway, so, that's good. You sold the company and got some patents out of it.

Sander: Yeah. We actually got some patent income. That was the only time we ever got any.

Spicer: By the way, speaking of patents, I noticed you have 115 patents.

Sander: Yes.

Spicer: That's remarkable.

Sander: Yeah. What's interesting, if you look through them, you'll discover there are a lot of different topics.

Spicer: I did.

Sander: A lot of different subjects.

Spicer: Very diverse. Yeah. You've done a lot of really interesting things.

Sander: Yeah, because my next one was another interesting one.

Spicer: Okay. Tell us about that. Tropian, is it?

Sander: Tropian, yes. I ran across this guy who was trying to do digital RF stuff and so I connected with him and this work I'd done on the disk controller was a digital solution to a disk controller, which is unusual. It is little phase-locked loops and things like that, which not a lot of people had done a lot on and so, I was working on those, and we had talked about things and he decided to start a company. So, he started this company, and he was going to do a… it was one of the standards for cell phones that he was looking at doing a… what do they call it? A version of a modulator, which separated the AM and the phase modulation. So, you did a phase modulator and then you did an amplitude modulator and that that created the signal. He needed a phase modulator, and I had ideas for doing a digital phase modulator for RF in the range of 1 to 2 gigahertz.

Spicer: Interesting.

Sander: So, that's what we worked on. Brian and I went there, and we started working on this phase modulator idea and we-…a third guy… I can't think of his name-..came with us, who was a PhD in communication theory. He had taught at the University of Pennsylvania. So, the three of us got it working and so, we built it. It never really went anywhere. At one point, we got a new president who decided he wanted to do cell phone design because we were kind of making them for cell phones.

So, we actually got some kits and made some… did design a couple of cell phones there too. Again, Brian ended up in charge of the engineering there, designing cell phones. So, he was doing that. I went off to another company and designed another version of that phase modulator that was really quite exotic using vernier techniques for detecting phase shifts. It was really crazy. Anyway, that's one of the patents, probably the most exotic thing I ever worked on.

Spicer: Are you a ham radio operator, by any chance?

Sander: I am actually now too.

Spicer: I thought you might be because your facility with RF is unusual in a digital designer.

Sander: Well, I wasn't one then, though. What's strange is I wasn't...

Spicer: Oh, I see. Okay.

Sander: There's this whole story to that too.

Spicer: Yeah, please tell us.

Sander: Well, Tropian, that was what we did at Tropian and the next one, Amalfi, was also a variation of this. But I actually had a ham radio license when I was in high school for about a year. I was a novice. I never really followed it. But about last November, October of just last year, where I live at The Forum, they have an emergency preparedness committee because there are about 400 residents in a senior facility spread along a hill next to a park and there are a lot of reasons for worrying about emergencies. Anyway, as a part of that, they have a group of radio amateurs who coordinate with the Cupertino emergency services in Santa Clara County.

Spicer: ARES? [Amateur Radio Emergency Services].

Sander: ARES, absolutely. So, one of the people who are in that there came up to me and says, "Look, we need more radio amateurs. So, why don't you go take your test?" So, last like October/November, I took the first test, technician class, right?

Spicer: Good for you.

Sander: So, I took that. I studied for about a day and passed it, and I thought "Well, that was pretty easy, and I need something to keep me busy." So, I went ahead and took the next week and studied and got my general and extra class both.

Spicer: Nice.

Sander: So, I got all three licenses.

Spicer: That's great.

Sander: And then I decided "Well, jeez, I got those." If you're familiar, now, I could do HF.

Spicer: Yes.

Sander: So, I thought "Well, I ought to get an HF set." So, I got me an HF set and just a simple antenna, but I'm buried down in an apartment complex.

Spicer: Me too.

Sander: Where you can't get anywhere.

Spicer: I know. It's really-- HOA is a problem, yeah.

Sander: So, I decided "Well, okay, then I better get me a decent antenna." So, I did some research.

Spicer: It's all in the antenna.

Sander: I did some research and discovered that well, probably the best shot for me is a MagLoop antenna, right?

Spicer: Yes. Expensive, but very good. Yeah.

Sander: Well, I decided "Well, heck, if I'm going to do this, I'll just design and build one myself."

Spicer: Right. Oh?

Sander: So, that's exactly what I did.

Spicer: Oh, you built one?

Sander: So, that's what I'm working on still, just get it done. --So, I got the modeling programs and ran modeling programs and modeled up exactly what I wanted to try and so I built it up and I just in the last week or so got it functioning. It needs to be cleaned up, but I got it functioning.

Spicer: Wow.

Sander: The techniques I'm using are working extremely well. I don't know if I can really talk to anybody, but as a MagLoop antenna, my standing wave ratios are phenomenal. So, I'm really pleased.

Spicer: How's the reception? Have you picked up...

Sander: I...

Spicer: Haven't tried it yet.

Sander: I haven't tried a lot. I've tried some. I get SWRs below 1.1.

Spicer: Wow.

Sander: Just because I came up with techniques for tuning the SWR.

Spicer: That's basically perfect. Yeah.

Sander: Yeah. That's basically perfect.

Spicer: You don't need a better...

Sander: You don't need any better than that.

Spicer: Oh, well, that's fun. Good for you.

Sander: Yeah. So, anyway, now, I'm an amateur. But anyway, so, we got diverted at Tropian. I left Tropian and went to Amalfi, but basically did the same thing and this was really design of digital phase modulators for RF.

Spicer: Okay. What kind of products, end products, would these have gone into?

Sander: Well, cellular phones. There were certain cell phone types that potentially could use polar modulation, where you'd modulate the two and this is what it was aimed at.

Spicer: Did you reduce this to a chip or...

Sander: Oh, yeah.

Spicer: Yeah. Wow.

Sander: Both places, two different chips on this.

Spicer: Did they do...

Sander: They haven't gone anywhere.

Spicer: Okay. I was wondering if they would succeed or...

Sander: But...

Spicer: It's a tough market.

Sander: in the early 2000s, Brian decided… Tony had gone off starting the iPod and Brian and Tony talked to each other a lot. They were friends. So, Brian decided to go to work for Tony at Apple. So, in the early 2000s, he went to work at Apple, and I was at Amalfi. That wasn't really going very far so I decided to join Brian at Apple. In 2005, I went to work for Apple. Brian was in the iPod group, and I went to work for him, and about that time or shortly after, he became the director of iPod hardware. So, he was in charge of the hardware for iPods.

Spicer: Was that Jon Rubinstein's old...

Sander: Well, it was, but Jon had just about left about that time.

Spicer: Okay. Yeah.

Sander: That was right about when he left and Tony took over all that and about that time., I came there, and Brian was already there and took over the design group and I worked for him for several years.

Spicer: How nice.

Sander: One of the public things that I did there was if you remember the earbuds they had, they had a volume control on the earbuds. I was largely responsible for the volume control design.

Spicer: Neat.

Sander: It wasn't trivial because the wires coming out of the earbuds where you had two stereo audio lines, you had a microphone line, and ground. That's all you had. So, you had to run a signal from the button up to there and what do you put it on and so, what we concluded, we put ultrasonic pulses on the microphone line. So, we literally made a little ultrasonic generator in the buttons that sent it up to the microphone line to go into the computer or into the iPod and then put a detector in the iPod and...

Spicer: That's incredible.

Sander: It was kind of...

Spicer: So, that little inline thing that you'd hit with your thumb...

Sander: Yeah. It has a little chip in it.

Spicer: That's what you're talking about.

Sander: Yeah.

Spicer: Wow. I never realized it was so complicated.

Sander: Yeah. That's what you had to do. You had to do it with ultrasonic pulses.

Spicer: That's fascinating.

Sander: So, that's what that was and it was interesting because it had a receiver on it up there and actually, we did that… it was remarkable. We worked with a little group with TI and Brian said, "We ought to try to do this," and several of us got together and worked out a strategy and I made it-- I worked with them, and we got it working and we did that in like six months. We had products using that within… so, like, one Christmas and by the next Christmas, we had those in products. It was really amazing.

Spicer: And those were made in the tens of millions, probably.

Sander: Oh, yeah.

Spicer: Maybe more.

Sander: Well, in particular, the ones in the host, iPod host, those chips also had to be in every Mac because those earbuds worked in everything. Everything it worked in had to have a chip in it. So, yeah. that was a high-volume design chip.

Spicer: I always remember when you used to plug in a plug into a jack, there was a mechanical break-before-make kind of thing and now, it's just like I don't know what's going on. There's a microprocessor analyzing this input, right?

Sander: Well...

Spicer: Is it an input? Is it an output? It's quite remarkable what they can do now with that one jack.

Sander: Not only that, but it didn't matter which way you turn it.

Spicer: Oh, there's that too. Yeah.

Sander: I mean, that's...

Spicer: USB-C. Very nice.

Sander: I think the first one was the lightning. It was before the USB-C.

Spicer: Oh, yes. That's also nice.

Sander: The lightning was where that started.

Spicer: Yeah.

Sander: I got some patents on that too. Some of my patents are...

Spicer: Oh, my gosh.

Sander: Those connectors.

Spicer: Once you left Apple, did you finally retire?

Sander: Yes. Well...

Spicer: Are you still working?

Sander: No. Actually, I-- see, I went to work there in 2005, and I was 70 years old. So, I was probably their oldest hire ever and I became a DEST, Distinguished Engineer, Scientist… anyway, but when I retired, I was 75. My wife had Parkinson's disease and so...

Spicer: I'm sorry.

Sander: And macular-- she was not well. So, I was a caregiver for seven years. She passed away about three years ago and that's when I moved from Morgan Hill to The Forum in Cupertino.

Spicer: Yes. Right.

Sander: That's where I'm at now.

Spicer: Good. Well, anything else you want to say before we sign-off?

Sander: I think that's probably pretty good. I'm surprised I talked so much.

Spicer: You've been wonderfully forthcoming and thank you so much for taking the time to stop by today and telling us the amazing story of Wendell Sander. That was really cool to hear your adventures.

Sander: That's my adventures.

Spicer: Thank you, Wendell.

Sander: You're welcome.

END OF THE INTERVIEW

