Oral History of David Fullagar

Interviewed by:
David Laws

Recorded: September 9, 2014
Mountain View, California

CHM Reference number: X7263.2015

David Laws: Welcome to the museum, David.

David Fullagar: Thank you.

Laws: It's September the 9th, 2014. We're here in the Computer History Museum. I'm David Laws, a semiconductor curator here at the museum, and I'm going to interview David Fullagar on his life and times in the semiconductor industry. Perhaps we could go right back to the beginning, David. Could you tell us where you were born? You can tell us when you were born, if you wish, and a little bit about your childhood.

Fullagar: Yes, I was born in 1942 in West Kirby, right outside Liverpool [UK], and my parents lived in Liverpool, although my father was off in the war in the Orkney Islands. But they didn't have maternity wards in Liverpool because of the bombing, so they'd moved all the pregnant mothers out to West Kirby. And that was 1942.

Laws: And you lived in West Kirby through your childhood?

Fullagar: Only until I was about three or four years old. And then at the end of the war, my parents had dreamed of being in a place which didn't remind them of the bombing, and the war, and the cities, so they bought a country cottage in Yorkshire, and my father got a job in Yorkshire.

It was a very romantic little cottage on the edge of the moors, but it had no electricity, so in terms of my early electronics career, this was definitely a limitation! So I was somewhat restricted to crystal sets and radios that could be powered by batteries, which were few and far between in those days because of the vacuum tube consumption.

Laws: What was the town?

Fullagar: The nearest town was called Baildon, and it's sort of on the edge of Ilkley Moor.

Laws: OK. So what kind of school were you able to go to out in that part of Yorkshire?

Fullagar: Initially, a little tiny sort of kindergarten school. But then after that, I went to what was called in England a preparatory school, in Harrogate. And that was as a weekly boarder. The boarding school system in England is fairly prevalent, and there were no really good schools within walking distance of our

home because it was a mile to the nearest anything. So I used to get on the bus every Monday morning and go to school, and come back on Friday evening.

Laws: Did you enjoy school?

Fullagar: Yes. I did, yes, yes.

Laws: Any particular subjects that you enjoyed most?

Fullagar: I always enjoyed the science subjects, but at prep school I don't think I really had any preferences other than somewhat dislike of Latin.

Laws: Not a great disadvantage in the scientific area. But good job you're not a horticulturalist.

Fullagar: Well, that's true, right, right.

Laws: And was there a particular teacher or somebody that steered you in the science direction?

Fullagar: There was a teacher called Mr. Plummer that certainly was fairly inspirational but I think it probably wasn't until I got to high school, or public school, that I really got deeply into the sciences with a teacher that did inspire me. So that was 1955 to 1960 was the high school era.

Laws: Was there anyone in the family that was inclined towards science or engineering?

Fullagar: Not really. My father was very good mechanically. He wasn't really interested in electronics, but he was always taking cars to pieces and doing mechanical things, so I picked up on that from him. And then I was quite involved with construction sets, [something called] Meccano [Erector Set in the U.S.], which I'm sure you're familiar with. I used to build all kinds of machines out of Meccano, but that was probably partly because, as I said, we didn't have any electricity.

Laws: And you said you were building crystal sets. Any other electrical or electronic devices that intrigued you?

Fullagar: Well, there was quite a lot of war surplus stuff on the market. We used to be able to get these sort of microphone headset combinations which didn't require any power, so I would string those across the house and across the way to my friend so we had some communication that way.

Laws: I see.

Fullagar: And those didn't require batteries, so that was OK.

Laws: When was the first time you saw an electronic circuit? Probably in a crystal set?

Fullagar: It would be in the crystal set. The crystal set was a pre-packaged one with a little cat's whisker. You had to sort of twiddle the whisker onto the germanium crystal to make it work.

But then I read about a radio in a flashlight, or a torch, as we'd say in England, in Practical Wireless, I think it was. And this used a transistor, which I had never heard of, and when I went down to the local electronics store, the guy there had never heard of it.

He was willing to sell me an HL2 or a KT66, but an OC71-- never heard of it. So I used to devour the electronics magazines, but never did get to build a radio in a flashlight.

Laws: Did you get your OC71?

Fullagar: I did. In fact, I think I donated some to the museum.

Laws: You did. Absolutely right.

Fullagar: Yes, little black glass encapsulated devices. And if you scratch the black paint off, you've got a photocell.

Laws: OCP71.

Fullagar: Exactly, exactly.

Laws: And so you went to school in Harrogate. And from there, you went on to Cambridge University, I believe.

Fullagar: No, I went to public school in Shropshire, a place called Wrekin College.

Laws: Yes.

Fullagar: And that was from 1955 to 1960. I went through the O [Ordinary] level, A [Advanced] level, S [Scholarship] level, procedure at the time. And there I did have a physics teacher called Mr. Frost who was very inspirational.

And he and I just sort of hit it off in terms of the way we thought, or the way he taught worked for me anyway. And that's when I really got to be interested in physics. There wasn't really any electronics curriculum there. It was physics, chemistry, math; the standard sort of natural sciences program.

Laws: And you took A levels, presumably, in those three subjects?

Fullagar: Those three subjects, chemistry, maths, and physics, and then S levels in the same topics, and then sat the Cambridge entrance exams and the Oxford exams, and went to Birmingham and a few other places, in case it didn't all work out.

Laws: And you started at Cambridge, then, I guess, in what year?

Fullagar: 1960.

Laws: 1960. And you studied physics?

Fullagar: Well, yes. Ideally, I would have liked to have gone straight into electrical engineering. But for two reasons, I didn't do that. One was I had an industrial scholarship from British Petroleum that was paying my way. And I thought I might even want to be a geologist -- I mean, it was a genuine career possibility.

So I did take geology classes. I went to the Natural Sciences Tripos for two years -- physics, geology, math. I can't remember the other subjects. [Alternatively,] to get into electronics, you could go through the engineering school. But then you had to spend the first two years doing dams and sewer systems [because] there was no electronics until the third year. The other way to go was what I did, which was through the physics curriculum and then switched to engineering for the last year.

Laws: I see.

Fullagar: And then you could jump right into electronics.

Laws: Why did you switch from physics to electronics?

Fullagar: I think once I got to Schrödinger's equation, and they didn't know where the damned electron was -- it was only a probability of being somewhere -- I lost interest.

Laws: I gave up at Bessel functions.

Fullagar: OK, same sort of thing. I'm just much more of a touchy feely person than speculating about whether a black cat's in the black hole or not in the black hole, or whatever Schrödinger's thing was. And I just liked the practical hands-on aspect of electronics much better.

Laws: This was the early 60's. Did they have computers available for you at school?

Fullagar: No, not at all, no. In fact, they only had one person in the engineering school [at Cambridge] who knew anything about transistors. I mean, they were still teaching vacuum tubes because they were somewhat behind the times. And honestly, the electronics -- I mean, Cambridge was terrific for physics and natural sciences but for electronics, in hindsight, they were really very weak. We had a professor from Stanford, whose name I should be able to remember, because I think he was involved in the invention of the klystron.

Laws: Hansen?

Fullagar: No, no. It wasn't -- no. It was an Eastern European name. We didn't really get a basic grounding in electrical engineering but we did get all the klystron theory you could ever want! And I felt like I missed out on a lot of groundwork that I should have had because they were busy teaching subjects which they had an interest in for their post graduate programs.

[Note: It was Dr. Marvin Chodorow, who “deserves most of the credit for the spectacular increase in klystron tube power which was achieved during the 1940s from watts to megawatts,” according to a Stanford obituary. He was a visiting Fulbright Fellow at Cambridge 1962/63].

Laws: So there wasn't exactly a hands-on course. It didn't make you very useful when you walked out of the door.

Fullagar: And funnily enough, many, many years later, I ran into the same professor from Stanford, up in the Trinity Alps, having a birthday party with his family, and instantly recognized him.

Laws: Small world.

Fullagar: Yeah.

Laws: And so you graduated in '63.

Fullagar: '63, right.

Laws: And you chose to go where?

Fullagar: I chose to go to Ferranti, because frankly, they offered the most money. And a friend of mine also graduated at the same time. And we both accepted jobs at Ferranti, so we shared an apartment in Edinburgh. My first job was designing this range gate for a terrain following radar system for the TSR2 nuclear strike bomber, I guess is what it was.

Laws: What skills did you have to acquire to do that?

Fullagar: Just about everything. You know, I was working for a fellow called Brian English. He was a very, very good engineer, and taught me a lot. And so he helped me. And the first thing I was working on really was basically an integrator: it was just a fairly high gain amplifier circuit with a capacitor around it, and we'd create these ramps for the range gate for the radar system.

Laws: Transistorized?

Fullagar: Transistorized, yes, yes, yes. The idea of the TSR2 was it was terrain following and it would fly at 200 feet off the ground at Mach one point something or other all the way to Moscow. So they used to take the design engineers who had designed this radar system over the Highlands of Scotland.

So it really made you think about what you were doing. But we weren't going at mach 1.2; we were just going in some fairly slow aircraft.

Laws: Were there any integrated circuits?

Fullagar: No, no. It was all discretes.

Laws: I was selling Fairchild products to Ferranti in Edinburg in '66 and '67. And my biggest order was, I think, 1,000 burned in 709s at $900 apiece.

Fullagar: That's a good price for a 709. I think that's a very good price!

Laws: So this was all transistorized.

Fullagar: All transistorized.

Laws: Did you design the complete product?

Fullagar: No, I designed this one little radar range gate thing. And then, the project was canceled pretty much right after that.

Laws: OK.

Fullagar: It was sad to see the project go, but that's the way it was. So then Ferranti made an effort to turn that division into a commercial enterprise. And Brian English, the fellow I just mentioned, came up with the idea of having an automated vehicle location system, which you could sell to police and ambulance [organizations] to know where vehicles were.

And of course, this was way, way before GPS. They used the police radio to radio back to headquarters the position of the vehicle, but you had to manually say which sector of the city you were in by dialing little thumb wheel switches.

So you had one out of 99 positions with two thumb wheel switches. And as the police vehicle moved from one sector to the other, you dialed in a new number and then it would show up on the big board. It was potentially useful because the police used to complain they have no idea where their cars were.

Laws: At the pub, probably.

Fullagar: What?

Laws: At the pub.

Fullagar: The pub – could well be! So that was a project I was working on when my roommate that I mentioned from Cambridge got married, so I had to move somewhere. And another friend of mine, called Wadie Khadder, also from Cambridge, had come out to Transitron the year before and was writing me these letters about how beautiful it was, and how great the girls were.

And I thought, OK, why not? So I interviewed with Tom Longo in London. And that was it.

Laws: Was there a particular skill set he was looking for that time, or anybody who could speak transistor?

Fullagar: I think probably anybody who could speak transistor and had a reasonably good educational background. I don't even remember what questions he asked me at this point. I just remember sitting outside the room, hearing him interview somebody before me, and kind of getting a little nervous, because he had this very low rumbling kind of voice.

But obviously, it worked out. Of course, at that point in time Transitron got me the green card. The whole process was very easy [back then] so I had the green card even before I left the UK.

Laws: And so you moved to Transitron in-?

Fullagar: 1965.

Laws: 1965.

Fullagar: Yes, fall of '65.

Laws: And Transitron was located in Massachusetts.

Fullagar: Wakefield.

Laws: Wakefield, Massachusetts.

Fullagar: Wakefield, Massachusetts. They made me this offer letter; and the note paper had this incredible line drawing of this futuristic building, stretching into the distance, on the top right hand side of the note paper.

So on the Sunday night before I was due to show up for work, I went down to Albion Street and walked up and down the street, trying to find this building, and I couldn't find it. And I walked several times past this rundown old brick mill, and eventually realized that was it!

Laws: And Transitron, in those days -- were they still a very successful company? Or were they in a decline at that point?

Fullagar: In my opinion, they were at that point in decline. But they had been the number two semiconductor company after Texas Instruments throughout the late '50s and part of the early '60s. And when I was at Ferranti, we were buying PNP [silicon] transistors from Transitron: they were the best available. But somehow, the transition to integrated circuits -- they had a hard time with that, partly because, I think, when you're in an old mill and every time you walked on the floor boards you'd get these puffs of dust coming out, it's very difficult to make a clean room!

Laws: I'm sure. And Tom Longo -- was he running the whole company then?

Fullagar: He was running the company for the Bakalar brothers. So the Bakalar brothers were the owners of the company, but Tom was very much CEO.

Laws: We actually did an oral history of David Bakalar just a month ago.

Fullagar: Oh did you? OK.

Laws: I haven't seen the transcript yet. But I'm looking forward to it.

Fullagar: So he's still alive?

Laws: He's still alive. He went on to a second career as a sculptor.

Fullagar: Really? That's amazing.

Laws: He's an internationally renowned sculptor.

Fullagar: OK.

Laws: Interesting character. And what did you work on at Transitron?

Fullagar: TTL. I mean, basically they were second sourcing Sylvania, who I think were the originators of TTL. And they [Transitron] had a number of TTL designs that they were second sourcing. But they also

had a contract, I think from the military, to do a 16-bit RAM, which was at that point the biggest RAM that had ever been built.

And certainly I wasn't that active in the design details, but I was involved with that. The rubylith was bigger than any table we had in the building, so it was spread out all over the floor, and pieces were glued together to make this immense memory of 16 bits!

Laws: How many designers were working on the project? Do you recall?

Fullagar: Three or four. I think the lead was a guy called Manhah Shah.

Laws: S-H-A-H.

Fullagar: S-H-A-H, I think. TTL had a problem and that is that when it switched, it took an enormous glitch out of the power supply -- I don't ever remember how many milliamps it was. But it was quite a big hit.

And we were looking at could we design something which would take less of a hit from the power supply. And so I got involved with doing a circuit simulation. SPICE didn't come out until 1973, so this was back in '65 and six.

Laws: So circuit simulation on a slide rule?

Fullagar: No, it wasn't There was a fellow called Nat Sokal who had a company called Design Automation; and he advertised an ability to do circuit simulation with a program called Sceptre.

Laws: Sceptre?

Fullagar: Sceptre which is different from Cadence's current Spectre, which is a whole different ball game. So for Sceptre we would give him the net list, and he would come back with an IBM printout, fan fold about 2” thick. It had every picosecond of every node, no visual, no GUI whatsoever-- this huge stack. And you had to go through and plot out whatever node you wanted. It was an interesting exercise.

Laws: Was it useful?

Fullagar: Well, it was useful in that it taught me something about what simulators could do for you. I think what happened realistically was that Schottky TTL came out and solved some of the problems of the big power glitch. But also by that time, I'd realized that Transitron was underpaying me.

And they were somewhat in decline, but most importantly, they were just taking advantage of people from Europe. It was a stupid policy because it took me a month to realize I was getting screwed and two months to find a decent job. And that happened to so many people.

Laws: Now, because a lot of people moved to the West coast from Transitron for the same reason --

Fullagar: Exactly the same reason.

Laws: Did you work with any of the [later Fairchild people], Corrigan?

Fullagar: No, they didn't overlap with me.

Laws: OK.

Fullagar: I don't think there are any other people who -- like, George Wells, I didn't know him, if you look at the time period, because none of us stayed very long, so we didn't overlap very much because it was a very narrow window.

Laws: OK. So you stayed at Transitron how long?

Fullagar: I think I probably went there in about September, and by May or June I was driving across country to Fairchild.

Laws: Less than a year.

Fullagar: Less than a year, yes, yes.

Laws: OK. And well, I guess, output switching is a linear problem, as much it is a digital problem. Did you do all digital work at Transitron?

Fullagar: I did. They bought a 709, and we looked at the 709 and tried to work out what it was all about. But I really didn't get that involved in analog circuits until I got to Fairchild.

And Fairchild tried to recruit me into two different groups. One was an applications group under Murray Siegel and the other was an R&D analog group under Marv Rudin. I ended up picking the R&D group and so that's where I reported to work.

Laws: And so you were in the building out in Palo Alto.

Fullagar: On Arastradero Road right, yes.

Laws: That was probably bigger than the whole of Transitron, right, just the R&D building?

Fullagar: You know, the R&D building wasn't huge. It was a single story building. It wasn't a huge. I mean, Transitron had this big old mill. I don't know what they did with the rest of it, but it was actually quite a big facility.

Laws: Sure. And you came in to work for Marv Rudin with a particular assignment?

Fullagar: I worked actually for Garth Wilson, who reported to Marv Rudin, and then I think Marv reported to Gordon [Moore]. My initial assignment was -- [Bob] Widlar left [to join National]

on Friday, I showed up on Monday -- the yield for the 709 was one die per wafer. Could I fix it?

So I spent some number of weeks sort of analyzing the 709, trying to figure out what was going on, and came to the conclusion that there was nothing wrong with the circuit. And it turned out the yield problem was that they'd switched DI water suppliers at the factory, and the new DI water they were using wasn't of the appropriate purity or something like that, so it was an entirely independent problem.

So then I got assigned [to design] the future successor of the μA709, which was defined by marketing as 'take every spec on the 709, and make it twice as good,' a typical marketing approach. That was the μA725. So that was a three stage amplifier. And I worked on the initial version of that, got working silicon. But by then, National had announced the LM101. I'd look at that. I thought we could do better or do some things differently, and proposed the μA741. So Marv Rudin said, you know, you'll never get that into production out of the R&D group. There was this sort of competitive barrier between the R&D group and Mountain View.

“Why don't you move to Mountain View, get that thing done? And we'll have George Erdi (who was my office mate) pick up the 725.” So that's what happened. He completed the 725, did a very good job, probably better than I would have done. And I went to Mountain View and did the 741 down there,

Laws: That was unusually magnanimous [for R&D], to suggest taking away a competent designer.

Fullagar: I don't know, actually, why there was even an analog group in the R&D building, because in Mountain View, in what I would call the production building, or the production facility, Widlar had been there, Darryl Lieux, Jim Giles. There were a bunch of people there, designing linear circuits.

Why was there a competitive group set up in the R&D department? And the only reason I can think of -- and it would be easy to confirm it, if I was to call Marv Rudin -- was Marv had more of a systems background. He came from North American Rockwell, or TRW, or somebody. And I think he understood and sold maybe Gordon Moore on the idea that there was a generation of circuits, like multiplexers and A to D converters, that the people at Mountain View didn't understand: They were just thinking in terms of the component level.

So for whatever reason, there was a so-called advanced analog group created in the R&D department. They pulled off the 722, that was a D to A, [for example]. But it always seemed a bit arbitrary to have two groups. But it was interesting, because I got to know Andy Grove fairly well. I took that semiconductor device physics course, which you’ve probably heard about.

Laws: People reduced to tears.

Fullagar: Well yes, it started at 6:00 in the morning, which was enough to drive you to tears in the first place. And then Andy was a fairly tough taskmaster, as you well know.

Laws: Right.

Fullagar: So I took that, and then actually was a teaching assistant for it in subsequent years. So that was a worthwhile thing to do.

Laws: So you had good grounding in analog, then, after a year. How long, do you think, until you felt comfortable with what you had designed was going to work, as long as they made the process correctly, of course?

Fullagar: Yeah, I think pretty well. It's self-taught. I mean, there weren't a lot of people who had the skill anyway, so you didn't have to know very much to be the leader of the pack. I've got to give Widlar credit for what he did, because he did what he did almost in a vacuum.

I mean, there was nothing there. And I think Dave Talbert deserves as much credit for creating a 40 plus volt process, [and] the ability to put down lateral PNPs, which, I guess, had been invented by H. C. Lin at Westinghouse. But still, Widlar put the whole thing together from a circuit point of view. Talbert put the whole thing together from a process point of view. And it was an amazing tour de force. And that really set the stage for all the rest of us.

Laws: So you were able to look at what he had done.

Fullagar: Look at what he had done, analyze his layouts, look at how they structured vertical PNPs, and pinch resistors, and isolation resistors. There's a whole cadre of components that they developed between the two of them.

Laws: And the unique feature of the 741 over its predecessor, the 709, was the addition of an internal capacitor?

Fullagar: The internal capacitor. I mean, honestly, I drew a lot from the original LM101, which is differently from the LM101A. Widlar redesigned the 101, made it into the 101A. So some of the front end parts -- I mean, he really pioneered the idea of a two stage single pole compensation amplifier.

And then the rest of us kind of really made use of that concept. And then George Erdi, of course, took the 725, went to PMI with Marv Rudin -- and maybe I'm jumping ahead a little bit here -- and developed the OP 07 which was a three-stage internally compensated amplifier, which is a whole lot more difficult to do.

Laws: How difficult was it to bring up the 741? Was it fairly straightforward?

Fullagar: Once I was in Mountain View, they really had quite a good machine, better than many subsequent companies. So once you had done the design, it would go into the production group. And three or four weeks later, you would get 100 pieces back from 10 different runs. So you had a lot of parts to characterize, and I would say it went relatively smoothly.

Laws: Were you working alone? Did you have a particular process engineer that you think made a difference?

Fullagar: Yes, well, I was working, I think, with a guy called Sam Yawata who was the fellow who felt that we could put the capacitors down and make them reliable. And he did some experiments to show that it could be done, because there was always the concern that the oxide defect density could be so high that we'd never get the capacitors to yield in production. So I will give him credit for working on the process end of things.

Laws: That's been an important contribution to analog through the years, hasn't it?

Fullagar: It has.

Laws: A certain engineer and designer working together.

Fullagar: Right.

Laws: You mentioned Talbert and--

Fullagar: Dave Talbert and Widlar.-

Laws: Are there other teams like that that can think of in the industry?

Fullagar: Well, I think the bi-FET process that came out of National certainly revolutionized some of the FET kind of amplifiers. That was at a later date. And jumping ahead a little bit to the Analog Device Intersil days, that was a good combination, because Analog Devices had some design expertise and we had the process expertise and the IC design expertise. We'll come to that maybe when we get to that point.

Laws: OK. Interesting sidetrack there. So after the 741 at Fairchild, that was a single op amp. You did a dual version of it?

Fullagar: Dual version of it. And by that time, Jack Gifford had left to form AMD with Jim Giles, Larry Stenger, Frank Botte. It seemed like everybody was going somewhere to form a company. I thought why am I getting [left behind]?

And then I got the offer from Intersil, went over and interviewed with Jean Hoerni and decided that was a good choice for me. I talked to Andy Grove about going to Intel. You know, I just wasn't [really] interested in the digital side, but I asked him how much stock he would give me if I went to Intel, and he told me a

number, and it was the same amount that they'd offered me at Intersil. In hindsight, I would've done better with Intel stock! But who knows what would have happened?

Laws: Sure. You were waxing fairly nostalgic about Fairchild at the Fairchild at 50 talk, which you gave about the changing of the guard and what a difference it made to the company. Have you had any other thoughts about what was going on at Fairchild at that time, why everybody was leaving to form their own companies?

Fullagar: I've thought about that, because when I was at Fairchild, we still felt like we were kind of the king of the heap. I mean, there was nobody really close to competing with us on the analog side. So why did people start leaving?

I think it was just maybe the frustration that Noyce and people felt that they were all being controlled from the East Coast by Sherman Fairchild. Maybe that filtered down. Maybe it was the fact that they weren't giving stock options, and everybody else was offering options. And it seemed like, why not?

But I mean, I had no complaints [at Fairchild]. But there was a fellow running the analog group at the time when I left, called Len Ornick. I don't know whether you've come across his name.

Laws: I know the name.

Fullagar: And he made a half-hearted attempt to persuade me to stay at Fairchild, and then a week later, he was gone to ITT in Florida. Everybody was jumping ship.

Laws: Interesting times. Were there other competitors appearing on the horizon in the analog business in those days? Obviously National.

Fullagar: National.

Laws: Anything coming out of TI, or Motorola, of note?

Fullagar: No, probably Radiation, in Florida, had a dialectically isolated process. It was producing some nice looking op-amps because they had decent PNPs as well as NPNs.

Motorola had, I think, second sourced the 741 at some point. I don't remember historically quite when. And I hope I have my facts correct here. I think they used a 100 orientation of silicon and it didn't lend

itself to building a 44 volt process, so they were having some reliability problems. And we could look at their part and see the problem. And you could tell that it was 100 material, not 111.

Laws: Sure.

Fullagar: So we didn't tell them about that.

Laws. How about in Europe? The consumer business must have had demands for analog parts in Europe. Philips, probably--

Fullagar: Yes, but at Fairchild, anyway, the consumer products, and the linear group, and then there was a consumer group. So there were people doing circuits for —

Laws: TV circuits

Fullagar: Zenith, and Dave Bingham, and people [like] Larry Blaser -- there was a whole other group that was doing true consumer products for TVs, radios, and so on, and I think Philips probably had products in that marketplace, but we didn't see any competitive op-amps for the industrial marketplace out of Philips.

Laws: So in '69, I guess it was then, that you talked to Intersil. Who did you interview with at Intersil? And what was their strategy at the time?

Fullagar: Intersil was primarily a matched low-noise bipolar transistor and FET company. Jean Hoerni loved FETs. That was his love. So I was the first analog IC designer.

They had a contract from NASA to build a low power comparator, so that was my first project. So that, basically, probably paid my salary for the first year. So it didn't cost Jean anything to bring somebody over from Fairchild.

And I worked for John Hall, who was sort of a thin film expert. And we did that product for NASA, and then we did a custom circuit for Canon camera, which was really an interesting project. So the first two circuits I worked on at Intersil were custom products. And I went to Japan and worked with the people at Canon for a while.

Laws: So you stayed in Japan while you were doing the work?

Fullagar: No more than about three weeks at a time.

Laws: OK.

Fullagar: But it was still an interesting experience for a young kid suddenly to find himself in, because I was always a photographer, so I loved being around the camera company.

Laws: And what was the product you were designing for Canon?

Fullagar: It was an electronic shutter. The problem in the single lens reflex camera is that you're measuring the light when the mirror is down. The mirror goes up, and the source of light to drive the shutter, if you have an electronic shutter, goes away, so you have to memorize what the light was before the mirror goes up, and then you've got to do a computation for the exposure based on the film speed, aperture [and light intensity], so for that circuit, I had to take the log of 3 things, do a computation, take the antilog, and then derive a shutter duration. It was fun. I mean, it was an interesting project. I did the whole thing with about 30 transistors. Now today, you'd throw half a million transistors and a big CPU at it. In those days, it was different.

Laws: Interesting you mentioned log and antilog. I believe that was something that you enjoyed, designing other circuits.

Fullagar: Later on, I did those.

Laws: That was your first introduction to that [topic], at Canon?

Fullagar: Yes, there was a paper by a guy, I think, called Paterson, who showed that a good silicon transistor had a log characteristic which was damn near perfect over about 10 decades [of collector current]. It was amazing, so that's where the log antilog interest came from.
[W.L. Paterson: Multiplication and Logarithmic Conversion by Operational-Amplifier-Transistor Circuits. The Review of Scientific Instruments 34 (1963)]

And then you see, after that, our biggest customer for the low noise FETs and low noise transistors, and so on, was Analog Devices [Inc. in Massachusetts].

Laws: Ah, so they were making modules [in those days]?

Fullagar: They were making modules. And we went to Analog Devices, talked about what their needs were, talked to them about their products, and had a pretty good relationship with Analog Devices in the early '70s. And so what they decided to do was form a relationship with Intersil.

They hired a design engineer called Hank Krabbe, out of Zeltex in Concord. And he worked in my office; we shared an office together, so my role was to teach him integrated circuit design; his role was to interface between the design engineers in Massachusetts and us.

And we agreed to do seven, or eight, or ten new circuits based upon market requirements which Analog defined. And then Hank Krabbe had experience at module design, so he knew of some techniques I didn't know about, like feed -forward amplifiers and things, and my role was to turn them all into ICs. So that's what we did.

And then we jointly marketed the products under different part numbers, so we went independently to the marketplace with different part numbers, but we shared the fruits of our labor, so to speak. And that was the beginning of Analog Devices' IC business -- were products we designed at Intersil that they sold.

Laws: Were you the only analog designer at the time?

Fullagar: I hired a guy from Fairchild, called Bill O'Neil, and he'd worked on the 733 at Fairchild. So he and I were the only analog designers. And then Hank Krabbe was -- the guy from Zeltex that worked for Analog Devices, he was a fast study. I mean, he picked up very quickly.

Laws: And you were reporting to Jean Hoerni

Fullagar: I was reporting at that point still to John Hall, I think.

Laws: John Hall.

Fullagar: John Hall, yes, yes.

Laws: Was Jean Hoerni very involved on a day to day basis?

Fullagar: John Hall?

Laws: No, Jean Hoerni.

Fullagar: Not at the IC design level. He wasn't really interested in circuit design as much as he was in device design. I mean, he would have his head in a microscope, looking at a new FET topology, measuring the characteristics of an FET, but he didn't really get involved in the IC design that much.

Laws: Had he started Eurosil at this time?

Fullagar: No.

Laws: That came later.

Fullagar: He had got a contract from OMEGA, through his Swiss contacts, to build a watch chip. And they did that. So in parallel with the analog effort and the discrete effort, there was a watch circuit effort going on at Intersil.

And there's a funny story. Because the very, very first prototype [digital] watch, we shipped the chips off to OMEGA, and they bought the product back in the form -- this is, like, the big announcement. This is the first [digital] watch in the world.

And they [Jean Hoerni and the Omega folks] went off to lunch. And it was on Jean Hoerni's desk. And when they came back from lunch, it had gone. Someone had taken it. And they announced over the intercom system, no questions asked, you know, the company is in dire jeopardy if this watch gets stolen. Please put it back. It reappeared!

Laws: Interesting. And so what else did you do at Intersil? What expanded your analog horizons?

Fullagar: I did an FET amplifier. The original one we did with Analog Devices. We didn't know how to match the FETs that well at that point, so we took two of the matched FETS as discretes, and bonded them into a chip, which was the rest of the amplifier circuit.

So the joint venture circuit was really a little hybrid. And then I went ahead after that and did a truly monolithic one, which became a pretty good seller, and then the log-antilog amplifiers. And at some point-- by now we're about 1973, I'd had this ambition to go sailing, so I took off for a year's leave of absence, and went sailing.

Laws: Where did you go?

Fullagar: Mexico, Marquesas, Tahiti, Hawaii.

Laws: Your own boat?

Fullagar: Yeah, yeah, yeah.

Laws: Did you build any special electronic gear to take along with you?

Fullagar: You know, actually I did. I needed a chronometer, and because Intersil had these watch chips, they also came up with a stopwatch chip.

And so I took this stopwatch chip and turned it into a chronometer, so I could do the celestial navigation. But other than that, we had nothing. We had no radio. So we set off across the South Pacific for 3000 miles.

Laws: You and your wife?

Fullagar: Yes, well actually girlfriend at that point in time, yes. There's a much longer back story there that probably shouldn't be part of this discussion.

Laws: Any particular adventures on the way?

Fullagar: We had all kinds of adventures along the way, yeah. I think one of the things in sailing is you don't say that you're going to go from here to Tahiti. You say I'm going to go from here to San Diego.

And then when you get to San Diego, you say, OK, I'm going from here to Cabo. And then I go from Cabo to Acapulco. So we just took it one stage at a time, and then made the big jump across the Pacific. That was a 30 day passage, so that was a good adventure.

Laws: And this was a year you were gone.

Fullagar: Basically a year. When I started the trip, Intersil stock was at $22. This was the fall of 1973. And I got down to Mexico, and I called Jack Gifford, and said How's it doing? And he said, “Oh, the stock's at $9. But it couldn't possibly go any lower, absolutely impossible.”

I got to Tahiti and opened the Wall Street Journal, and it was $1 3/8.

Laws: Goodness.

Fullagar: So then I kind of knew the trip was over.

Laws: What was going on at Intersil at this time? Do you recall?

Fullagar: I mean, there was a recession: there were hard times. But Intersil had been through a series of managers. Jean Hoerni stepped aside. Jim Reilly was there. Marshall Cox was there. Bob Freund was there. It was kind of a sad situation, because the company had some good technology.

Laws: Right.

Fullagar: But the management, in my opinion, left quite a bit to be desired. And I think that was the root of the problem. And on the digital side, by then, they got into digital circuits: at one point, they had 60% of the PROM market. They had what's called AIM technology.

Laws: AIM technology.

Fullagar: [AIM stood for Avalanche Induced Migration,] which was shorting reversed biased diodes [to program PROMs].

Laws: Bill Sievers worked on that?

Fullagar: Yes, yes. And somehow they lost it. Then they jumped into the CMOS version of the PDP8, and really, that was a product too late. It was piggybacking on an old instruction set, didn't make a lot of sense.

Laws: So in Tahiti, you discovered you no longer had the wealth you thought you had.

Fullagar: Exactly. So I called Marshall Cox and said, “what have you got?” And he said, “what we'd really like you to do is go to Europe and set up an applications group in Europe for a year.” And that kind of appealed to me because it was a chance to go back home and live in England, and see what I thought of it, and yet I always had the freedom to come back to the US. So that's what I did. I went to the Reading office. --

Laws: And what year would that have been?

Fullagar: And that would be 1974, fall of '74. And I stayed there until mid '76, so almost two years.

Laws: And what was the focus of the office? Was it analog?

Fullagar: No, it was a sales office. So I was basically applications engineer for the whole product line, including the CMOS version of the PDP8 and the whole works. And then I had to hire applications engineers in the different countries, and we gave a series of seminars. That was the big thing, presenting the product line through seminars, organized typically by the reps.

Laws: Sure. Had you hired people very much before?

Fullagar: Not really, no, no.

Laws: So it was your first experience?

Fullagar: Well, yes, other than Bill O'Neil, I'm trying to think who else I hired before moving to Europe. Probably not.

Laws: Interesting learning experience.

Fullagar: So yes. And then eventually, I hired my own replacement in the UK, a fellow called Dave Watson, who I'm still very friendly with and in touch with.

Laws: So you can't have made too much of a mess of it, then.

Fullagar: No, exactly. He was out here only a couple of weeks ago for a barbecue.

Laws: OK, good. So '75, you returned, then.

Fullagar: So in '76, I returned.

Laws: '76, OK.

Fullagar: When I left, I was actually working for Roger Smullen

Laws: Yes.

Fullagar: And then Jack Gifford took over the analog group, so when I returned from the UK, I was working for Jack Gifford.

Laws: So you returned to Intersil [headquarters] in '76 to work for Jack. And what was the role you were in?

Fullagar: And Jack basically said, I'd like you to run the engineering group. So he gave me responsibility for not only the analog engineering group, but also the whole of engineering. And I don't think it was a VP position initially, but it became a VP position.

Laws: OK, it had digital--

Fullagar: Digital and analog.

Laws: Logic and memory.

Fullagar: Yes, yes. There wasn't honesty, much memory at that point.

Laws: Right.

Fullagar: And then the other big change at that point was that Ori Hoch became involved. I don't know whether you've come across Ori Hoch's name.

Laws: Did they merge with AMS [Advanced Memory Systems]?

Fullagar: Yes, Ori Hoch was hired or became CEO of AMS, and he used to be CEO of Litton Industries. And I think he just wanted to have a change from LA, a change from big defense companies, get involved with a small company, so AMS made him CEO of that company. Then we merged with AMS, and Ori basically was a very mature, very sophisticated manager. And he, I think from day one, had in mind polishing the company up and selling it.

So I give him credit for lifting the stock from $1 3/8. It was down here [pointing towards the floor]. And we sold the company to GE [for $35/share] in, I think, roughly 1980, 1981. I'd have to find that exact date.

But Ori did a good job of managing the company, compared, certainly, with the predecessors that had been there. And then when GE bought the company, Ori [returned to Litton and] recommend that Jack take over as president, and that's what they did.

Laws: And what was the company predominantly at that point, digital, analog, mixed still?

Fullagar: Both of the above, yes, mixed. In our view, analog made all the money and the digital people spent it all, which is part of the origins of Maxim. And there was an exact parallel going on at National. National had a very profitable analog division, and a number of missteps in the digital area. And I think that was the genesis of Linear [Technology Inc.].

Laws: Yes, very similar story.

Fullagar: Yeah, of course, having GE step into Intersil initially appeared to be OK, but that didn't work out.

Laws: One other analog circuit that you mentioned, I believe, had a band-gap reference you designed at Intersil-- that must have been an important stepping stone to other products later.

Fullagar: It wasn't, actually. Really, when I got back from Europe and was managing the group, it was by then about 75 engineers, and it was a fairly flat structure, so it was pretty much a full time job managing the group.

And there were a lot of successful products that came out of the group. The 7106 digital volt meter chip became very successful, and there were whole range of industrial timers, and counters, and display products that came out of the group. So we continued to proliferate the products, a huge range of analog switches that were designed by a guy called Dick Wilenken, who lived up in Yreka. He was a very good, productive engineer.

So just managing the group, frankly, was a full time job, even though when Jack told me that he wanted me to take over the engineering group, he said, “Dave, it will only take you 10 minutes a week. Don't worry about it.” And somehow, I fell for it.

Laws: Not a detail man. How did you go about choosing the products, David? You obviously had important customers. Certainly, the relationship with Analog Devices must have been very useful, in terms of understanding what kind of products to build. And how did you continue that after Analog Devices was no longer there?

Fullagar: In the early days, certainly, we could look at the module products and say, OK, this is one we can bite off and make it into an IC, and basically wipe out the module product, like a log amplifier. There were a number of log amplifiers from Analog Devices and Burr-Brown. And Analog Devices was smart enough to realize that was going to happen, so that's why they created the interface with us to learn IC design, and eventually, they went off and started Nova Devices, which was a semiconductor facility in Massachusetts.

And then Hank Krabbe, who was the fellow I shared an office with and taught IC design to, then went to Limerick in Ireland, and became general manager of Analog Devices, Ireland, and did a very good job. I mean, they have a scholarship in his name. He died some time ago but Hank was a first rate manager and a first rate engineer.

But I think the product definition came from really just listening to customers. And I think we put a lot more value on the applications engineers to look at how the customer was using the existing products. And then how can we sort of bring in more and more [functionality onto the chip], rather than just having a marketing guy say oh yes, take this op-amp, but make all the specs twice as good.

And there were actually two competing groups, in a way, at Intersil, one run by Murray Siegel who I mentioned before. He had an Industrial Products group. And they did the timers, the counters. There were about 15 or 20 quite successful, what we called Industrial products.

And then Jack had the Analog Products, which are the amplifiers, references, regulators. And that's really how the product line got created. And we followed that same concept at Maxim -- of relying heavily on applications engineers to define the products.

Laws: Did you have the application engineers in the factory or in the field?

Fullagar: Both.

Laws: How do you go about hiring a good applications engineer? What criteria did you look for?

Fullagar: Anybody that seems to understand what the customer needs. I mean, the most successful applications engineer I've ever met was a fellow called Charlie Allen that we hired at Intersil just before we started Maxim. And then as soon as I could get him to Maxim, I got him over there. And he just has a brain like a sponge: I mean, he could just absorb so much information. He could walk in to a customer and just understand the whole picture, and those are the guys you're looking for.

Laws: Absolutely.

Fullagar: And Dave Watson, who I hired to replace me in England when I left there, is the same way. He understood what the customer needed, and he understood the whole system, so he could pull in peripheral bits and pieces, and put them on the chip. And we can jump ahead to the Maxim days when the RS232 product was exactly that kind of thing.

Laws: Did you still have to work very closely with process people at that point? Or were the processes pretty much defined and this is what you had to work with? You had to come up with any new structures?

Fullagar: No, there was quite a lot of process development going on. The CMOS process really made a big difference to the analog business at Intersil. And we had Dave Bingham, a very creative design engineer, who said anything you can do in bipolar, I can do better in CMOS, period. So we developed CMOS processes to suit, partly, his needs, to design the products he was designing.

Laws: And his claim was true?

Fullagar: Yes, absolutely, yes. Yeah, I mean, he and Lee Evans, another person from the Intersil days who came with us to Maxim, were designing chopper amplifiers, designing DVM chips, designing a whole range of products in CMOS, which hitherto might have been done in bipolar. So when we started Maxim, it was 100% CMOS, basically.

Laws: Interesting. And what was the genesis of Maxim? You said that you were getting a little frustrated with the GE bureaucracy.

Fullagar: Yes. I think, first of all, the idea of starting a purely analog company had nothing to do with GE. It had to do with the experience we had with Intersil being partly digital, spending all the money, and partly analog, making all the money. But then when GE came along, Jack Welch said all the right things. -

he said we're not going to touch you. We're going to let you do exactly what you want to do. And we had dinner with him in the city one night. And he was saying don't worry, Dave, it's going to be fine. Do exactly what you want to do. And you can create stock option programs. You can do this, do that.

But a month later, two months later, the guys with the green eye shades moved in, and we got allocated to -- allocated is not the correct word -- we got put in the light bulb division, which probably isn't the most creative division in GE, working for a guy called Jim Baker. And Jack and Jim Baker just did not hit it off.

They felt like we should be on the same salary structure as their people in Poughkeepsie. And they didn't understand that house prices are three times as much as blah, blah, blah. So the relationship started to fall apart. And I was really only a very partial witness to this because Jack was trying to interface with the GE people to get decent compensation for the employees and it wasn't working out. And eventually, he had a big blow up [with Jim Baker] and they fired him, basically. I mean, he just was so adamant that he wanted these things and they said you're not going to have them: out of here!

And that was December of '82, I think. So Jack went off to do his tennis, and farming, and various things.

Laws: That's right. He had an apple ranch.

Fullagar: He had a pear ranch and a tomato farm at different times. Then sometime around March of '83, I got a call from Jack, saying why don't we start a company. I said sure, let's do it. So he and I and Fred Beck got together in a coffee bar in Woodside, and decided to give it a shot.

Laws: That was not a difficult decision for you, then?

Fullagar: Not at all, no. I don't know that I really fit into huge companies.

Laws: What was the process of getting Maxim up and running? The three of you each shared different pieces of the puzzle?

Fullagar: Yes, I wrote the original business plan. Jack and [Fred and I] -- we'd get together and talk about what the business plan should say and I was the only person with a computer -- I had an Apple II at that point with a little Epson MX80 printer -- so I'd go home and draft the thing. And then we'd bring it in and we'd critique it, and then I'd go back home and draft it again. We did a VisiCalc spreadsheet and four pages of write up about what we were going to do, and that became the business plan.

Laws: I seem to remember it was posted in the lobby [of Maxim headquarters in Sunnyvale]..

Fullagar: It is, yes. I've got a copy here, if you want. So that was it. And then we set about raising the money. And Jack had, because of his AMD days, I think, he had contacts in the VC arena that I certainly didn't have. So we floated the business plan to five or six venture capitalists.

And I mean, Jack had this really good intuitive understanding. He said, as soon as you get guys that look negative, back away -- never get a no, because if you get a no from somebody, they're all a bunch of sheep that will all say no. So you work around the different groups until you get someone that's really biting. And once one guy bites, they all want in because they're a bunch of lemmings. And he was right.

Laws: Do you remember who the first bite was from?

Fullagar: I think it was Kip Hagopian at Brentwood Securities.

Laws: Not familiar with them.

Fullagar: I remember going down there. Kip had a big sort of partners' desk and there was a stack of business plans, very thick business plans all on one side. And our little four page thing was sitting on his desk and he said, "at least I read yours -- I haven't read all these [pointing to the big stack]; this is way too much." And ours was basically, "here are the people, this is what we're going to do." And he agreed to invest.

Laws: How much money did the first round come in at? Do you recall?

Fullagar: It was a commitment for $10 million total, $5 million initially. And then the other five predicated upon announcing 14 or 15 circuits.

Laws: OK.

Fullagar: So we had a fairly aggressive plan to get 14 or 15 circuits out within the first, roughly, 18 months.

Laws: That's a lot of circuits.

Fullagar: We hired a lot of people. I mean, my job was just to hire as many people as I could, as many consultants as I could, as many layout people as I could, as fast as I could.

Laws: Where did you find them? Was there a particular hunting ground?

Fullagar: Well, we had a lot of people at Intersil that were equally unhappy. So the initial team was all from Intersil, except one fellow called Sam Ochi who was from Teledyne. And he was our sort of token non-Intersil person, so that Intersil wouldn't sue us based on the fact that we'd stolen a lot of their people. But they sued us anyway.

Laws: Of course.

Fullagar: Of course.

Laws: Well, these [people] were known entities.

Fullagar: Exactly.

Laws: So it's a lot easier, isn't it?

Fullagar: It's a lot easier. And the initial plan was to do second source circuits, because we needed the immediate revenue. We couldn't afford to have the time for people to design them into their equipment, and then their equipment to get accepted in the marketplace. So we picked 14 to 15 of the most popular circuits that were out there, and did them.

Laws: What tools did you have? SPICE? Anything beyond that?

Fullagar: There were versions of SPICE. We had Calma. We rented time on Calma's machines for doing the layouts. But since most of the circuits had already been designed once, we were second sourcing them for the initial round of products. It didn't need a lot of simulation because we knew exactly what we were doing. We knew what the process was. It was just a question of getting them done.

Laws: Now, did you have your own fab?

Fullagar: No, no, so we were using foundries.

Laws: Local foundries?

Fullagar: Yes, primarily local foundries, and some pretty shaky operations, when I think about it. I mean, if ever the company was vulnerable, it was in those early days when some of the foundries were distinctly shaky.

There was one I can think of that was in Scotts Valley, where the fellow running the foundry hadn't paid his air conditioning contractor. So [when] he came into the building one Monday morning, there was a huge hole in the fab area because they had taken a crane and they just pulled the air conditioning system right off the roof. Yeah, those were shaky days.

Laws: Interesting. Were there one or two particular foundries that really came through for you and made the difference.

Fullagar: You know, I wasn't directly involved with the foundries, per se. I mean, all three of them came through in their own way, in the end. But we had a fellow called Robert Scheer, who was responsible for qualifying the incoming wafers, so we did a very, very analytical job on the incoming wafers to make sure that they were processed correctly. And then we'd burned in every product, so we had a massive investment in burn-in racks and ovens. Because I mean, we said we were doing it because that gave us better reliability. And it did.

So our big sales pitch to the customer was we can prove, because we've analyzed it, that Intersil, and Analog Devices, and these other people have a failure rate of x. And we have a failure rate which is down here. But we did it partly by burning in every part.

Laws: And most of these were CMOS parts?

Fullagar: Yes, yes.

Laws: Was CMOS a stable process by then?

Fullagar: Well, we were using metal gate CMOS, which was a pretty old fashioned process. So it was certainly stable. But if the foundry misprocessed it, it wasn't stable. So the irony is that GE sued us for stealing their secrets and the only secret they could identify was the CMOS process that had been around for about 12 years!

Laws: So what were those first couple of years like? Were there times of particular concern and worry about whether you were going to pull this thing off?

Fullagar: No, it went fairly smoothly. I was under a lot of pressure because of course, Fred Beck was in marketing, saying get me some products. I need the products. I can't do anything until you get me the products. And the market, when we first started the company, was fairly hot for product.

By the time we had got the products out, there was a sort of mini recession going on and there was a certain amount of, oh, if only we'd had the product six months ago, we could have sold XYZ.

Laws: Sounds like a standard salesman's complaint.

Fullagar: Yes. But then when we did have the product, we actually started by going to market in Europe, because there was sufficient demand for these products, that, if we'd gone worldwide, we wouldn't have been able to satisfy the demand. So we announced the first products in Germany and France. And then once we'd ramped up production to satisfy that need, we announced the products in the US.

Laws: That's unusual.

Fullagar: So the first purchase order was from Germany.

Laws: Did you have any challenges with getting qualified in some of those big German companies. I remember Siemens was always a really tough nut to crack.

Fullagar: Yes. We certainly did. Because actually, I remember going to Siemens personally, and making a presentation about the reliability of the products. And you just had to convince them of the facts. We showed them the burn-in data. We showed them the reliability data. We showed them the statistics. And we had a believable story.

Laws: That experience you had running the applications group in England must have come in very useful.

Fullagar: Yes, you learn very quickly in Germany [that] if you're not there 10 minutes before the meeting, you're late.

Laws: It's like deliveries in Japan. They open the gates for three hours. And if you're not there, the order's cancelled.

Fullagar: Right.

Laws: When did you start looking at proprietary products at Maxim?

Fullagar: Almost immediately. I mean, we knew that we needed proprietary products to build up the image of the company, so Dave Bingham, in particular, was thinking about proprietary products. And by then, we had Charlie Allen on board. And I think the first proprietary product was the MAX 610, I think [that] was the part number.

And it basically took the line voltage in directly through a capacitor, and pumped out 5 volts DC. It was an interesting product, and it actually worked most of the time [but] it wasn't one of our most reliable products, probably.

But we got a lot of customer interest because it was huge. Because here's a tiny little chip and all you need to do is add a capacitor in series with the AC and you get 5 volts out.

And we had interest from people in microwave ovens, for example, for the display, and interest from people doing power meters, who needed smart power meters. But it wasn't one of the better selling products. The RS232 product is the one that really hit the nail on the head in terms of proprietary products.

Laws: How did you come up with that idea?

Fullagar: That was really Charlie Allen's idea of realizing that all the RS232 products -- they [the customers] basically, typically only had a 5 volt power supply on the board, and they had to generate plus and minus 12V to do the RS232. And he went to Dave Bingham and Dave Bingham said I think I could design that.

But doing a charge pump that goes both ways in CMOS is kind of tricky because you have a latch-up problem potentially. So you really have to do a pretty weird looking layout to prevent minority charge injection that can cause latch-up. So this thing had what we call the racetrack around it, which was a big sort of peripheral thing that sucked up all the floating minority carriers.

It was very successful but it's not a product that we would normally have thought of doing because RS232 was not considered to be an analog product. I mean really, it typically fit in on the digital board. It's not something we'd ever notice if we look at what's surrounding an op-amp or an A to D converter, you wouldn't see it.

Laws: Did that generate a whole family of similar kinds of products?

Fullagar: Yes, yes, a whole series of different numbers of inputs and outputs, and different combinations of them. The second proprietary product was, again, Charlie Allen's definition of a microprocessor supervisory circuit, so that you could watch what the microprocessor was doing. If it got into some sort of an endless loop, you could detect that and issue reset signals. And that became very successful as well. And so, those were the two which started generating a lot of revenue.

Laws: Did you look at particular market areas and say we want to focus on this, that, or the other? These sound like two just sort of bright ideas.

Fullagar: They were. The early days were bright ideas.

Laws: Right.

Fullagar: Later on, we became a lot more organized, if you like, where all the applications engineers had a charter to bring in so many new product ideas every quarter. And then we'd had this sort of massive session where we tried to sift through them and pick the winners. But the early ideas were really just bright people coming up with bright ideas.

Laws: And you were VP of engineering at this time.

Fullagar: Yes.

Laws: And so you had design and applications.

Fullagar: I had design, applications, and layout.

Laws: And layout.

Fullagar: Right, right. And originally, I had test engineering, but we realized that didn't make any sense -- test engineering needed to be in manufacturing.

Laws: Tell me about number two sailing sabbatical. Where did you go this time?

More

Fullagar: I've always had the sort of horror of you retire at age 65, and the next year you get a notice from the doctor that says sorry [you've got a terminal illness]. So I've always had this idea of sort of packing it in. Not packing it in. That's not the correct term-- putting in periods of doing what I want to do.

Laws: Good for you.

Fullagar: To the extent that I could do it without jeopardizing my career too much. So in 1990, I decided to take another leave of absence and go sailing. And by then, it didn't make a lot of sense to have the whole engineering operation under one person, because we started thinking in terms of market segments and having each market segment have its own entity of marketing, design, even manufacturing to some extent.

So I went off for a year sailing, and then came back and did another of these application stints, setting up Worldwide Applications Engineering. Because by then, we had totally autonomous divisions within the company: engineering was split up between the divisions. There were about six or eight different segments.

Laws: How big was the company by this point? Do you remember?

Fullagar: It was between $50 and $100 million, I think. Because by the time I retired, it was about $500 million.

Laws: And who were the real competitors, then? Linear Technology, I presume.

Fullagar: Linear Technology, Analog Devices, and to a lesser extent Burr-Brown, Texas Instruments, National. Those were the real competitors.

Laws: Any one or the other that you'd meet more frequently, do you recall?

Fullagar: In the bipolar arena and the standard components, like the op-amps, regulators, references, Linear Technology was the biggest competitor. In more of the CMOS subsystem products, it was probably TI. And they had a pretty good organization at turning around products fast. And certainly, we got ourselves competing on a couple of custom circuits against TI and they were pretty effective.

Laws: OK. Now, didn't Maxim purchase Dallas Semiconductor at some point?

Fullagar: Yes.

Laws: Were you involved in that process at all?

Fullagar: No, I wasn't. Actually, I may have been even partially retired because I remember Jack telling me about it at a cocktail party. And I don't think I was even working full time at that point.

Laws: OK.

Fullagar: The first acquisition that I was involved with was the Tektronix fab. We purchased the Tektronix semiconductor operation, which turned out to be a very good deal because they had a semiconductor operation which was first class. But they had almost no volume because it's not that kind of company.

Laws: Right.

Fullagar: And they needed it for a very, very limited number of small circuits and hybrids and specialty products. So we came up with a deal with Tektronix, where we would run the facility and we'd continue to provide the specialty products for them.

Laws: Was Barry Gilbert at Tektronix?

Fullagar: Yes [many years prior to the purchase by Maxim], but by then he was with Analog Devices.

Laws: That was a manufacturing arrangement?

Fullagar: That was a manufacturing arrangement. We had design up there as well, though. So we inherited their design team. We inherited their CAD team. So I would spend a day a week up there.

Laws: So they'd report to you.

Fullagar: Yes. So I would spend a day a week up there, interfacing with the design team up there.

Laws: Did they focus on a particular area?

Fullagar: You know, at this moment, I can't think of the product line that they were working, actually.

Laws: What did you must enjoy about your job at Maxim? You had two quite different jobs, in a way, the engineering job, which is very structured. Applications engineering is a lot less structured.

Fullagar: Yeah, I think the engineering job probably. Because the company was really successful and the stock was sort of almost doubling every year, and everybody was pretty enthusiastic.

Laws: Right.

Fullagar: So I mean, the whole time was actually good. I have to say, I have no complaints. It was fun. It was fun.

Laws: How did you and Jack work together? Did he just say hey, go do this? Was he involved in the day to day business?

Fullagar: Jack was involved in every microcosm of everything. So I kept thinking each time the company would grow, that he would have to sort of run out of steam in terms of his ability to control every detail. And he didn't. So yes, he was involved intimately.

He would run the company by a series of meetings. So he'd come into work in the morning and there'd be a meeting, a meeting, a meeting, a meeting, a meeting. And it was on any topic. And there were some routine meetings -- you know, how many products are we going to get out this quarter, manufacturing starts, marketing reports.

But anytime he'd sense something was not quite right, he'd call a meeting. And then he'd just wade into it. He had an amazing ability to get down and find the weakness in your argument or your presentation. A lot of the strength of the company was just his ability to control that level of detail.

Laws: Yeah. I had a couple of bosses like that. And they were the most successful ones, for sure.

Fullagar: Well, yes, yes, yes. I think it takes attention to detail. It takes attention to detail. And he wasn't always kind in his assessment of what you were doing, but honestly, I'd known him since the early days of Fairchild because he was running the linear marketing group. And we're going back in history now. But Mike Markkula was in that group. Mike Scott was in that group, who became briefly CEO of Apple. Len Brown was in that group, Jerry Zis who was marketing for PMI and Analog for a number of years.

And so I'd known Jack from way back when. And we used to go on seminar tours together at Intersil, where we'd be presenting the products. And you know, we were personal friends as well.

Laws: Any big differences in terms of how the company should be run between you and Jack?

Fullagar: Yeah, in the early days of Maxim, yes, we used to have some discussions about do you really have to be that hard on everybody all the time? And Fred Beck and I would sort of compare notes at the end of the day and say, we're going to lose our people if he keeps on doing that. So one or other of us would take turns trying to moderate him.

Laws: But successful nonetheless.

Fullagar: But successful nonetheless. And I think it takes that kind of personality, actually, and not unduly different from [Bob Swanson, CEO of Linear Technology] -- Swanson's a hard driving guy. Charlie Sporck was a hard driving guy. I mean, that's maybe what it takes.

Laws: So you ran the applications group for quite a few years, six or seven years, I guess.

Fullagar: Yes, I tried to retired a couple of times, and then I would have this plan to go in two days a week. And then I'd show up to work Monday morning and wouldn't get out till Friday. I think it was Len Sherman that said I'm the only guy he's met who'd failed retirement three times.

Eventually what happened was I said OK, I'm going to retire: I really am this time. And my wife said OK, I'm going to book enough travel to keep us completely busy for the next six months so you can't go back to work. And that's what she did.

Laws: And so 1998, you retired.

Fullagar: The end of '98, yes.

Laws: And the company was how big then?

Fullagar: $500 million. I actually had to look that up, because I didn't remember it. But yes, it was $500 million. So now they're about $2.5 billion, I think.

Laws: And other than sailing and traveling, you were a board member, a consultant for a company for a while.

Fullagar: I still am, actually, yes.

Laws: For--

Fullagar: For Genia

Laws: What does Genia do?

Fullagar: There was a fellow in my applications group called Roger Chen, who was an MIT graduate, a bright engineer. And then he left Maxim and went back to college, and went to UC Santa Cruz to study microbiology and DNA and so on under [Prof.] Deamer, who was one of the early people in the Human Genome Project.

And then he thought well, I've got these two skills. I understand the biology, and I understand electronics. I think we could develop a chip which would do genome sequencing. I ran into him in Radio Shack about six years ago and he said, come to my house, I want to show you what I'm doing.

Of course, it was in his garage -- all the best companies have to start in a garage. He had his little refrigerator there and he had a little circuit board there with an op-amp and some other stuff on it. And he felt like he could design a circuit that would do DNA sequencing.

Laws: How does that work? What's the basis of it?

Fullagar: There are certain biological, let's call them, things. I mean, they actually bear resemblance to the tuberculosis bacteria. But anyway, there are certain things that you can insert into a cell [wall] which have a very specific orifice size, and that's how maybe tuberculosis invades a cell.

So given that you have an orifice in a cell of a very specific size, if you put a single strand of DNA through that orifice, the bases are all very slightly different. The four bases, CATG, are very slightly different in magnitude. And they will constrict that cell differently, so if you flow current through that cell [immersed in a saline solution], you can modulate the current -- if you put a voltage across the cell -- you can modulate the current as a function of what's in the cell. And this is nothing particularly new, but I think what Roger understood was that with IC technology, you could create a circuit that would measure 100, or 1,000, or a million of these at one time. So that's what Genia is doing.

Laws: Create a chip where you physically place the cells on the chip?

Fullagar: There's an array of measurement cells. And then you create what's called a lipid bilayer, which is like a simulation of a cell [wall]. So it's a bilayer of a lipid substance. And then you can actually take alpha hemolysin, which can be inserted into the lipid bilayer.

And now you have the lipid bilayer and you've got this thing inserted in it, which has a hole which is about 1.4 nanometers across. And now you're in a position, if you can make [single strand] DNA flow into that hole, you can measure the base that's in the hole at any given time by the extent to which the current is modulated.

But the trick is you're trying to distinguish currents down to the femtoamp level, so it isn't a trivial analog exercise to do this fast.

Laws: It's an analog exercise.

Fullagar: It's an analog exercise, exactly. It's a very analog exercise. So Roger developed a prototype for this and got some funding. And the first chip was a 264 array. And the chip we're working on now is a 128,000 array. And the next one will be a million or 10 million. We don't know which.

It's a completely different business model to Maxim, where in Maxim's case, we were doing something everybody knew how to do, we just have to do it better. In this case, it's a breakthrough. Nobody's done it before, and it's not entirely assured that we'll get there. I mean, we believe it's a high probability. But it's been fun. It's been interesting to stay in touch with the technology.

Laws: Yeah, to keep the technology moving.

Fullagar: And, yeah, stay in touch with the technology. And my role -- it really is on the intellectual property side, because one of my roles at Maxim was to make sure that we were patenting things as we went along. So I'm watching out for their patent portfolio.

Laws: Interesting.

Fullagar: But they just sold the company to Roche for $350 million, so from starting in a garage five years ago --

Laws: Another great success story.

Fullagar: Well, yes, exactly right. Right. So I go there a couple of times a week when I'm in town.

Laws: Where are they located?

Fullagar: They're on the corner of Middlefield and Whisman in Mountain View .

Laws: So you come over the hill.

Fullagar: Yes, I come over the hill.

Laws: So outside of that, you've been a photographer for a long time.

Fullagar: Yes. I had an uncle when I was young who was a photographer and sailor. So I learned my best, most compelling interests in life outside of work from him. And so I've been doing photography and sailing since I was 10 years old.

Laws: Photography has changed a lot in that time —

Fullagar: It has changed a lot. The only thing that hasn't changed is can you see the photograph? Whether you take it with film or digital, it doesn't really make any difference.

Laws: Do you do much post processing?

Fullagar: I do quite a bit, nothing extreme. If you can see I worked on a photograph, [then] I've failed. Now, there are some people who will go to extremes and make something that doesn't look like reality. And that's fine, it's just not my style. So we're going to a photographic group going to Santorini end of next week.

Laws: Santorini is in --

Fullagar: Greece.

Laws: Greece. That will be a wonderful trip.

Fullagar: I did one in Tuscany earlier this year. So it's just nice to be with a bunch of other photographers who have the same interest.

Laws: Sure. Any other things you've got set for the future that you want to accomplish?

Fullagar: I've got my bucket list. But it involves mainly traveling, just see a few parts of the world I haven't seen yet before I get too decrepit to see them.

Laws: What advice would you give a young person entering technology these days? I won't say integrated circuits. It's so vast now. When we started in semiconductors, you knew what a diode was and you could build on that.

Fullagar: Right.

Laws: I don't know where you'd start today.

Fullagar: I'm not sure I do either. I mean, I think the only advice I can give is follow your interest: see where your passion leads you. And make something useful. I mean, that's one of the satisfying things about Genia is if we pull this off, the goal is a $50 complete human genome.

Whereas, the first time they did it, it cost, I think, $20 billion and involved 40 academic institutions. And we'd like to be able to do it in an hour or two, and do it for 50 bucks. Now, we're not there yet. But that gives you the ability to go into a doctor's office and get a pretty complete diagnosis.

And so there are cancer treatments possibility, and that kind of thing. So I would just advise somebody go where your passion takes you. I noticed at the end of Mike Markkula's oral history, he talked about advice from Bob Noyce, I think, who says create value -- don't just shuffle money around.

And I like that advice. Because my economic model for countries is very simplistic. A successful country is one which is creating value by manufacturing stuff. And I'm a little concerned the US, if all the manufacturing goes to China and all that happens here is we shuffle money around --

Laws: UK, even more.

Fullagar: UK, even more. And that creates a disparity of wealth, especially in the UK, where you go to London and there are Lamborghinis everywhere. And you go to Liverpool and it's pretty sad. So I'm not quite sure where that train of thought was taking me, except the idea of creating microprocessors out of sand is adding value. Creating cherry jam out of cherries is creating value.

Laws: Sure.

Fullagar: But shuffling money from one lawyer to another lawyer isn't creating value.

Laws: Anything else you'd like to go on the record here with? Your career?

Fullagar: I'll probably wake up tonight and think of all the things that I missed out.

Laws: Well, I really appreciate you spending time with us. It's been fascinating hearing your career.

Fullagar: Thank you. I appreciate it. I appreciate the opportunity.

END OF INTERVIEW

