Oral History of Robert “Bob” Miller

Interviewed by:
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Günter Steinbach: For the record: Today is May 7, 2015. I'm Günter Steinbach interviewing Robert Miller, Bob Miller, about his contribution to computer history, namely the development of the capacitive TouchPad pointing device. So welcome Bob to the Computer History Museum.

Robert "Bob" Miller: Thanks.

Steinbach: I know you have a busy life. I remember you telling me once that now that you have retired you are so busy you wonder how you ever found time for a fulltime job.

Miller: That's true.

Steinbach: So we appreciate you finding the time for the interview today. I'll be using my notes for the questions since I'm not a seasoned interviewer. For the start, can you tell us about your background, like where and how you grew up?

Miller: Okay. I was born in the Chicago area, in Skokie, Illinois and while very young moved to Des Plaines which is today right near the O'Hare airport. This was before it was built, about the age of five. We lived in a very rural sort of suburban area and it was literally forest and swamps and lakes around the area for many miles. And so I think that's actually what probably started me into science and such because I just spent all of my life outside exploring and looking at things and understanding things and I for many years wanted to be a biologist. I just enjoyed being out there and watching things and doing things. And then over time I just got into other sort of scientific things, chemistry and then finally electronics later on. And I was also very physically active. I just enjoyed being out and getting around, biking, running, whatever. So it was a great childhood for a kid. I would basically leave home at eight in the morning and come back after it was dark. What more could a kid want?

Steinbach: What pushed you towards engineering from biology?

Miller: I seemed to go through some phases. That was sort of the first thing and I would save up my allowance or do jobs, paper routes and things like that and buy books, initially biology books. And then I got into chemistry. That seemed to be the next phase. And then after that I think it was around fourth grade I was really just curious about the mechanics of things and how the world works. So I got into a sort of imaginary thing where I'd be doing these drawings or sketches of, you know, furnaces or washing machines and I'd sort of sketch out all of the components in it, things like that and that was sort of the electromechanical start of things, I guess. I was just very curious about how things were made and what made up things. And then I had some cousins and friends who showed me some high voltage electric coils and all of the effects you could do with that and that sort of intrigued me. And that was also about

the time, when transistors were first coming out. We had transistor radios. And electronics actually was starting to get some notoriety then. I think it was becoming a special thing and that really caught my eye. So I dug into that some more. I did all of the usual things as a kid. Well, not usual things I guess, but I wired my parents' stereo so we could have music around the house and I put in loudspeakers and various things like that. And so I was just starting to dabble in electronics then. Around seventh grade I think I was really starting to take off. I was in the 4H and I had to do a project so I picked the electricity group. You can raise sheep or rabbits or whatever but I picked the electricity group and did sort of a rudimentary calculator. It was a rotary phone input and a bunch of flip flops that were all individually hand wired from discrete components and it would count the number of turns and sort of be an adder kind of thing. Unfortunately, I didn't have very good debug equipment. So all I had was a soldering iron and a few lightbulbs and things but I won first prize and that got me all excited. I think mainly because they [the judges] didn't know what they were dealing with and didn't know how to deal with that so they just took my word for it. They were so blown away. Then getting into high school. At that point in time I was very intrigued by math and science in general and math became very interesting to me. I enjoyed the elegance and the ability to describe many things in nature and science. It was just mind blowing the things you could do with it and the exotic kind of things you could get into so I really did a lot of reading in that area and that got me started in high school then. I don't know if you want me to get into that part of it. But that was sort of the kickoff somewhere around middle school for us.

Steinbach: And you studied electrical engineering I assume.

Miller: Yeah, in college.

Steinbach: I saw from your résumé you went to Caltech and I remember it too. How did you choose Caltech? That's far away from Chicago.

Miller: Yes, at that point in high school I took all of the AP courses. I did really well and so I was very excited about science. Actually, more science and math than technology in particular, I guess, at that point. And I applied to MIT and was accepted there as well as Caltech and both sounded very exciting. MIT had a lot of variety, a lot of interesting courses. It was a much bigger place. But I guess what intrigued me with Caltech was the small size and this teacher to student ratio. And maybe a few other factors. In my last AP class we had a lab book which was written by a professor named Jürg Waser who came from Caltech and that sort of got me clicked in as well. So a lot of little factors as well as the fact that it was warmer. I was getting tired of the Midwestern winters. And as I always told my friends it was waves and babes. It was sort of like if this is California, this is Beach Boys territory. Although I didn't realize Pasadena was very far away from anything. But it was good. I think it was the best choice of my life. It was an amazing decision.

Steinbach: Yeah, that kind of thing got me to Berkeley. And actually I was just at Caltech last week. My son is there now as a post doc.

Miller: Oh really? Post doc.

Steinbach: So that is California.

Miller: Yes, so there's sure an allure there with California. But I think a lot of it really played out for me in terms of the teacher to student ratio. I mean the size. It was an amazing atmosphere of not only teachers, professors, but as well as the students. I mean it was a very close knit group because literally almost everyone knew everyone else because it was so small. Our entering class was about 200. I think there was about 700 in the entire school. One sobering thing: We had a frosh camp at the beginning of the year. As you came to school, one of the first activities where you just got to mingle and meet everyone and one of the professors came up and he goes, "Look to your left. Look to your right. One of you is not going to graduate." This is not a way to start it all. Unfortunately it was true because it was quite a pressure kind of place. But just the closeness and camaraderie across all levels, it was just phenomenal. And through the school that fed into everything I did after that in terms of my career and including Synaptics where the TouchPad was done. And before that as well as after that it was an amazing kind of connection.

Steinbach: So when did people start calling you Big Bob?

Miller: <laughs> Uh-oh. That was at Megatest. So there's the first connection to Caltech: Megatest was founded by my two roommates when I lived in Sunnyvale here. We had a house together on Mary Avenue. And Steve Bisset one of my roommates he was also my roommate at Caltech. We lived off campus for our last two years. And we had spent some time actually as a summer job at HP at the end of our junior year. And so we were very close and did a lot of things together so we moved up here after graduation. He had met a fellow named Howard Marshall at HP during that summer job. And so Howard was the third person in the house. And Steve and Howard created Megatest. I went with another startup company called CTC. I figured 24 hours a day might be too much. And I was real interested in IC design at that point. So I went in that direction. They had gone into IC testers at Megatest. And I went with a startup that lasted for about three years but unfortunately it wasn't as well managed as it could have been. Plus it's a hard business to be in. It was custom IC design, doing custom IC's for pretty much anyone off the street. It was just a hard business. So that company folded and then I went to Megatest and that's where I was for about fifteen years. I think my login was Big Bob at something or other because I was the biggest guy there. <laughs>

Steinbach: Okay. <laughs> So then what made you go to Synaptics finally after fifteen years?

Miller: Yes, I was at Megatest for about fifteen years. It was a great time. It was a great experience starting as an engineer, hardware design engineer working up through the ranks, managing a group for another project which I think was sort of a lifetime kind of project, this Mega One project. It may not have

been the best project for Megatest at the time but it was an amazing design experience. There were probably 30 or so of us that just spent literally six months fulltime, 20 hours a day for over a couple of months just to get this thing out. But it was really another just amazing bonding sort of experience. So that was a real high point. After that point I was feeling like I was floundering. It's hard to beat something with so much energy. You just sort of start looking around. Towards the end of that time I volunteered for a customer support job in Southeast Asia and spent two years living in Singapore and supporting all of the customers in Asia. And that was not only taking a breather there but it also was a chance for me to get out and meet customers and interact and I enjoy that part of the business, not just the technology part. So I spent two years there. I got to see a lot of companies like TSMC starting up, help them start up and now they're one of the world's largest foundries. HMC and a number of companies in Taiwan, Thailand, Japan, Malaysia. It was just an amazing experience. But at the end of that time the story is always that as an ex-patriate, when you come back, the world is so different and you have such a different perspective that you have to do something big. You have to make a change in your life usually and that's exactly what happened to me.

Steinbach: Even after just two years?

Miller: Yes, after two years it was enough, when coming back to the same place, the same people. You had been through these incredible experiences and done all of this stuff. It was hard to explain to people and hard for them to even appreciate it. So about that time Steve Bisset had already left Megatest, I guess maybe a year before that. They [Megatest] had brought on a new CEO and they had gone public around that time. So a lot of changes and policy changes there and I was feeling adrift. So Steve was at Synaptics. I asked him and he said I should come over and take a look. At the time there was about, I think, it was 12 or 13 people there. This is another connection here with the past: Carver Mead and Federico Faggin were the founders of Synaptics. Carver was one of my professors at Caltech. He was an amazing guy. He was the guy that basically launched me into IC design because I took his class. It was his first IC design class at Caltech and I took that my senior year and just got very, very interested in it. So that's what launched me into IC design. And then Federico who had obviously come out of Intel prior to that and was one of the inventors of the microprocessor. And Steve [Bisset] had worked indirectly for Federico [at Intel]. He [Steve] worked for Ralph Ungermann at Intel when he graduated. So he had worked at Intel for a while. And then that's where he came up with the idea of this tester and developed Megatest because they needed a product like that. They [Intel] were exploding at that point in time with their 8080 and 8048 and all of those. So that's what started him down the track of Megatest. So there was all of these confluences again of all of these people from the past because Steve knew Federico and both of us knew Carver. And it was a very exciting, very high energy place. It was a lot of Caltech students, a lot of grad students out of Carver's labs. And it was sort of like a wonderland. They were working on neural network stuff. They were working on IC design projects, at one end neural network high level software type of stuff and at the other end very low level hardware type of design, the physics of the ICs. Carver loved to take advantage of some of the little side effects and physical sort of principles happening in a MOS device. And he would use those to his favor and create different functions and circuits and stuff. And they had just finished up a retina chip which simulated the retina of an eye and using the photon capturing capabilities of the CMOS. And that eventually spun off into another company later. But that was

one product they had. They were at that point a small company focused on a category of grants called small business. It was SBS or something like that, small business.

Steinbach: SBIR [Small Business Innovation Research]?

Miller: Maybe that was it, SBIR.

Steinbach: Innovation something.

Miller: Yes, research grants of some sorts. So they were getting a lot of those to keep things going. The thought was it was almost like technologies looking for a problem to solve. They had a lot of amazing technologies with the neural network stuff, with the tools they developed around it as well as the IC technologies and the compiler stuff Carver did. But they didn't have a problem to solve at that point. I mean they were looking at stuff. There was a lot of interesting stuff. They had a check reader that they just created. Tim Allen had created that. That was the MICR [Magnetic ink character recognition] code at the bottom of your check that normally is read by a mag [magnetic] reader. But they had done it optically and it wasn't competitive enough. People were so ingrained with the existing technology that they couldn't go anywhere with it but they took it quite far and it was an amazing feat of engineering just to do that. And that was a neural network combination design. And so all of this stuff was happening there. It was just very exciting. They were working on a configurable programmable analog neural network chip. The thought was they could build this general purpose chip and then reprogram it for applications, various applications and using again a lot of interesting tricks and components from Carver's toolkit in terms of making that happen. One of them that I really liked was this concept called an EPOT, you probably might remember that. It was a floating gate, sort of like an e-squared [electrically erasable] kind of floating gate but they used it as a programmable (pot [potentiometer]??) reference voltage. So they would set up…

Steinbach: Right, EPOT, yes.

Miller: Yes, they would set a voltage on it and then it would stay for life, basically, and that was one of the...constructs for this neural network chip so that you could program all of the levels in an analog fashion around the chip and then have it remember it and that would be how you would code it up, basically in the digital sense, how you'd code up this analog neural network. So there's a lot of amazing stuff going on so I just couldn't pass up the opportunity to get into that.

Steinbach: And then you recruited me.

Miller: That's right. Well, if I got sucked in I've got to…

Steinbach: So was the TouchPad your first project at Synaptics? Or did you work on some of those other stuff?

Miller: I think I spent a few months just sort of getting familiar with tools, helping out in a few areas, things like that. The company-- well it actually had been in two phases. There was a prior phase before Federico and Carver got involved, you know, it sublimated into this new form of the company where they're the founders. And it had been in this form for maybe two years or three years. And I think investors and also I think Carver and Federico were getting a little anxious to get a break into some things and make something happen. So I was a candidate for a new project. And I think it was Federico who was on the board at that time of Logitech and said, "Synaptics is a neural network company and we're dealing with sort of the neural part of it. Let's continue this. We have the vision part of it with the retina and things like that. What can we do in other areas, in haptics, touch kind of things?" And Federico was saying, "This track ball is just a big mechanical sort of construct and it's just really messy to build and sell. What could we do sort of supplant that?" And so he said, "What do you think you can do?" So he basically assigned it to me. And I went off. And Steve, I think he was COO at that time, so he was operations. So he and I worked on this a little bit together. And I went off and had some ideas-- basically there was a lot of possibilities. There was obviously the resistive devices but one of the requirements we put on it was we didn't want a situation where you had to actually touch something because we felt that was annoying, constraining. It was not a good user experience in the long run if people are using this for long periods of times, if they're having to rub their fingers hard on something. So that threw out all of the resistive stuff immediately. There were things like SAW devices, the surface wave acoustic devices. There was optical potentially. There were a few others. And then there was capacitive as well, obviously. And so I did research on those various approaches and decided the SAWs and the opticals and things like that were just either too expensive and also something that looked like it would be very hard to maintain and make very robust in a sort of a consumer environment. So the cost and the robustness was a big killer for those options.

The capacitance looked very good. There was some prior art but most of it tended to be sort of single bit kind of stuff in the sense that it was sort of a button on a screen and you brought your finger near it and it detected you and it was sort of a yes or a no kind of solution or answer. That was sort of the typical thing. And in our first patent application I probably had 200 citations there. I spent a lot of time looking at prior stuff because I really wanted to make sure that we were clear because it worried me a bit because there was a lot of capacitive sensing stuff out there and I wanted to make sure we were very clear of that. The patent examiner wasn't very happy with that. But I did go through a lot of stuff and there were some other techniques where people used sort of resonant techniques and AC techniques but most of it tended to be very low resolution type of solutions. And I was talking with Carver on some ideas. In another aspect of the design it was, again, in the spirit of Synaptics and being analog based and neural network based this was going to be an analog design, a very low power analog based kind of concept where we could do a lot of the computation in the analog domain. So he was showing me some building blocks and interesting things on combining inputs and processing inputs in the analog domain. So I was keeping those in mind as far as building blocks. And even though I was still fairly new at the company, I was there for probably a

year, less than a year, it's probably less than six months at that point so I was just sort of learning what the strengths and weaknesses were there and what I was expected of.

So I remember a board meeting was coming up and Federico wanted me to demonstrate the concept to the board. So I created like a ten wire matrix, an XY matrix of wires on a PC board and hooked them up individually to charge integrator op amps [operational amplifiers]. I had a little array of those around the outside. And I could run my finger around it and you could see-- and I had LEDs [light emitting diodes] associated with each of the outputs so it was really just for show and for the board. And you could run your fingers down and you could see the lights get brighter or dimmer as you moved your finger down. And so it was obviously something that was feasible. With the fairly simple lab kind of demonstration I was able to show that even with this very rudimentary thing it was fairly reasonable. So that was the first demonstration at the board meeting. So I think they gave the go ahead.

Steinbach: What year was that?

Miller: That was like in late '91. I started in mid '91. That was probably late '91. And so the board gave the go ahead and Federico at that point... I guess in the spirit of Synaptics we were going to use our expertise, sort of sell our expertise, create a design and sell it to other people. That was how we thought we were going to take this on. So Federico went to Logitech and made a proposal to their president who he knew, I guess, because he was on the board and knew him personally. And Logitech said, "Yes, great." And the deal was at the time that as long as the price was reasonable Logitech would give us a 50 percent gross margin, so a 2X markup. So theoretically if the chip cost us 50 cents they would buy it for a $1. That was the deal.

So I then went off and at that point, obviously there was a lot of unknowns, to put it mildly. You know, we didn't know how the finger was going to react or the kind of noise environment. Obviously AC is everywhere from 60 to 120 hertz, fluorescent lights, all kinds of nasty things in the environment and computers. It's going to potentially be built into a computer. Who knows what frequencies are going to be running around there? And how the finger was going to act, was it going to act as sort of a capacitor to a virtual ground, a kind of a capacitor to space? Or was the largest effect going to be the coupling to adjacent traces? And if the former was true we wanted to minimize the coupling. If the latter was true we wanted to maximize the coupling. And, in fact, we could even do tricks like say a trace we want to sense on we could be moving it in one direction [voltage-wise] and moving everything else in the other direction to amplify the effect of the capacitance. And so we had all of these possibilities, ways to go. So what I did is... I was still sort of the person in isolation on this. I did a test chip. We had some tools and things there that you could do and manual layouts of chips and so I went off and manually laid out a test chip. Many of our designs were done through this I think it was the Mosis process, where you could go off and by 20 die. They'd stick your die on a larger wafer with 100 other projects and you could buy 20 die for $50 each or something like that. So I developed a design which allowed for scanning of both dimensions, the X and Y. And it was designed to be completely configurable so I could change the polarities of all of the scan

lines relative to any others and allowed me to check out all of those options that we just talked about because I really didn't have an idea of which was going to be stronger and which was not.

Steinbach: And you were the only chip designer on that?

Miller: I was the only one involved at that point. Steve was my boss, direct boss, and Federico was his boss. So I spent a lot of time talking with Steve but I was the one who designed the chip.

Steinbach: He does not have chip design experience?

Miller: I think he did some at Caltech, however at that point in time going through Megatest he was more of a higher level conceptual guy. So he helped me with a lot of making sure I stayed on track and stuff conceptually. But I was the one who came up with all of the detailed design and so on for it. And I put in a number of the components that Carver was recommending in terms of integrators. And there was an interesting weighted mean topology that was just pretty amazing and so I put in a number of these things just so I could test them and use them. And then the chip was, as I said, configurable I put in a number of probing paths and things so I could get at every voltage and every sampling point in there, so I could see what's happening and if it was doing weird things.

And then Synaptics had already developed sort of chip debug tools that I could take advantage of. There was this program called View I think it was that Dave Gillespie had created that allowed you to create interpretive sort of sequences so you could sequence the chip, that controlled IO and you could do things like that. So I could develop little test programs to sequence it and then read results. There was an interface board, we could analog measurements or digital probing, whatever was needed, and print out the results. So I'd create these test programs to cycle it through and look at the results, it was very powerful. Put them into matrixes and graphs and stuff so I could compare in various ways how it operated. So we got the chip out that was I think in early '92. Turned it around pretty fast. And started doing all of the debugging of the various issues.

Steinbach: So that was the chip that we later used as a pointing device, right? I thought that was the alpha chip that we turned into a TouchPad to use as a pointing device in designing the commercial chip.

Miller: I think it was. Yes, this was the very first generation. As it evolved later, moving the digital domain in closer to the front end, this allowed you to get at that point on the chip if you wanted to. And I think we tossed out a lot of those analog building blocks later. Ye—s, while we sort of threw a number of sensor designs in, debugged a number of approaches there. I remember Joel Seely was helping in that area. [This version of the touch pad that Bob Miller created was a prototype design that was used to demonstrate the concept, debug the issues and develop the approach later used in the commercial

version. The larger engineering group, led by Tim Allen and Dave Gillespie created the next generation, the “alpha” chip that Günter refers to, used in the commercial version – described below]

Steinbach: I remember helping you at one point too.

Miller: Okay.

Steinbach: Since you mentioned fluorescent lights we had the effect where if you were too close to a fluorescent light and you put your finger on it the chip would kind of die.

Miller: Yes what was amazing about the project is the evolution of it because every step along the way was needed to make it successful and I think in that case you were involved in doing some common mode rejection circuitry there, doing two quick successive measurements and canceling them out, doing one in a negative direction and one in a positive direction so you could cancel out slow moving, slow frequency stuff. And every one of the steps it wouldn’t have been a success without. It really was a group project in a lot of ways. And then you did a lot of the analog stuff later of the A to Ds [Analog-to-Digital Converters] and that performance stuff, the high performance stuff there. I think I sort of got through the basic functionality and got it to a point of showing that we could do TouchPads. I mean the point where it was time to rethink things, so I took it all the way to the point of being a TouchPad. You could actually move cursors and things like that. However, there was a lot of built in calibration stuff, in fact, using these EPOTs to cancel out background. So early on the assumption was: Okay we have a PC board. You know, there’s going to be some background capacitance. So let’s calibrate that out and so I don't know algorithms for doing that. And then that would involve programming in some EPOTs and putting in some thresholds for canceling out this background stuff, background capacitance, background noise and so on.

And so I was able to get to a point where it was workable and demonstrating it to Logitech. We had a Logitech engineer there for a while. He was checking on things and monitoring things and he was giving his input based on their perspective and so on. His name is Bernard Kasser [ph?] which, unfortunately, had a spinoff issue later because they later competed with us after we didn’t come to an agreement and Bernard was the head of that group. So he was already taught up and everything since he had sat down with me and Steve on this stuff.

But so I got it to the point where it was actually a finger pointer. It was a TouchPad device. You could use it. You could walk around with it and use it on devices. But in the end it was fragile. These EPOTs, you know, you could calibrate it, do a good job for the next fifteen minutes or half hour, an hour it worked great. But we found out there’s the first order effects which is the finger and it’s how it reacted. And whether there was this space capacitance or whether it was this trans-capacitance we called it, the coupling, which phenomenon was stronger? And it turned out that both phenomenon were fairly strong so we tried to take advantage of both in the way we laid out the sensor. And so we made some great

progress there. We discovered a lot on how it worked. However, the next level we ran into was then the second order effects of moisture, that was the next big sort of killer situation. Even in a basic way of, you calibrate a PC board in the morning and it sits around in a humid environment all day and by the end of the day it's not calibrated in the way it was originally done at least.

Steinbach: I don't remember that but it makes sense.

Miller: And then we ran later into other cases, just moisture on fingers. And somebody dragging their finger across the pad and leaving a ghost of a finger print there. So that was still another phenomenon. And then the sampling: On the original one we did sequentially because we were trying to optimize the trans-capacitance to the adjacent traces as well. So it sampled one at a time but because we had the phenomenon of the 60 hertz issues and stuff that showed up then. So we went to sampling it all at once and so on. So it was about that time when I had with the prototype demonstrated it. I think that was about the same time that we were pushing Logitech to... We must have done some initial design on the next generation because we had enough of an idea of the die size that we gave them a quote on what the device would cost. And so we said it looked like it would be like 50 cents for the packaged device tested and everything. We could sell this to you. And they said, "Well, that's pretty expensive if you're going to charge us $1. We'll give you 55 cents." And it was literally like that and so we all came back from that meeting and everyone was ticked off.

So we had a big group session because this was a major —issue. We still had a lot of SBIR projects, side projects going, but it was starting to feel like the company was going to depend on this or it was starting to be something significant for the company. And we were not just going to fall over and give it all up and turn into another SBIR kind of project where you'd give it away. So we had a really tough session but in the end the decision was, we're going to go it on our own. We're not going to sell them that. We're going to build our own. And so I think that was right around the time when we felt pretty good. So I think probably just prior to that was the point where we were starting to run up against the wall with moisture and calibration issues and the comfort of having this analog design. I think it was shortly before that maybe three or four months before that the programmable analog neural network fell out of favor and we sort of discarded that. That was going to be another sort of 8048 kind of product for the neural network community and at that point we decided this isn't happening. This is just too fragile with all of the analog components. And so that momentum was starting to build up in terms of analog. Maybe this dream of an analog world, the ultra-low power, subthreshold pico-amp kind of analog stuff isn't necessarily the answer for everything.

I know Tim [Allen] and Dave [Gillespie], they were involved definitely in the periphery there and I was going to them for advice too. And they got to the point where they said, "We think we can do this better with a digital back end, taking it back to a certain point." And that really is a much cleaner way to do it. Then you can do your calibration on the fly continuously. You can just have so much more flexibility. So basically taking it back to the point of the output of the A-to-D converter and letting some software

takeover from there and apply what other algorithms are necessary. So I think you were on board probably just before that point because you were basically in that transition. So you then dove into that whole redesign effort with Dave and Tim and took off from there.

Steinbach: Right.

Miller: I sort of actually backed off at that point and hand it over to them.

Steinbach: Okay. I was just going to ask you about your involvement in that second chip.

Miller: Yes, I was involved with you guys sort of in the beginning and just the transition of information and so on.

Steinbach: I think you sketched the successive approximation register for me.

Miller: That's right. Yes. Because it was sort of a backwards design. It wasn't the classic having kind of successive approximation register. Yes, I did a few things there. So I helped with a little of the digital transition and some of the concepts there. All three of you guys are brilliant guys. Those guys-- Dave is amazing in software and Tim Allen was amazing in chip compiling and design. So he basically compiled up the back-end from what I remember, the digital portion, and got that built up pretty quickly. Dave created the algorithms and things that ran in the processor for that and those guys had something running pretty darn quick if I remember right. And so that was the second generation of the product. So it turned pretty quickly. Again, it was an amazing group effort because everyone was applying their specialties and their expertise and it was incredible.

I really enjoyed going back to the fundamentals. I mean that was always something I enjoyed in engineering, dealing with first principle kinds of things. And so that is what really drew me into the project, which was okay we have a finger here and we have these phenomena happening and how can we measure it and take advantage of it. And I really, really enjoyed that part. And those guys, everyone, you guys all contributed to different parts of it and taking it the next step. At that point it worked very, very well. I mean there's still-- it's one of these things, there's third order phenomenon and fourth order and it was an evolving product over at least the entire lifetime when I was there. It was between one quarter and the next there was several version of firmware passed but it was all good stuff because we're learning a lot of stuff. And the fact it was a programmable device made a huge difference because we could make those evolutionary steps.

And so I stepped back. One of the things I had wanted to do when I was coming on to Synaptics was actually be involved in a business unit and sort of take a product line. So this was my chance to take that

next step. So I got the concept and a working product or working prototype handing it off. And then I got involved in the sales and marketing and manufacturing of the product at that point. The first thing I did was, we needed to go out and sell this thing now that we were a real company doing sales.

Steinbach: And not to Logitech. Or did you try Logitech?

Miller: Well, that was a side story. It was about that time I think Steve had a falling out with Federico and he left the company and I think there was a bit of bitterness and competition there. So he went to Logitech and started up a touchpad group there. And that other fellow Bernard and he started up this touchpad. And unfortunately they were already very well trained up in all of the issues and problems. But at that point they were really trained up in sort of just the second order problems. I think he left about the time that you guys were spinning that first prototype of the next generation. And so they knew a lot of the issues to stay away from but there was a lot of other issues that were waiting for us. And I think our group was much more in tune with the momentum of it and where we're going and what the problems were. So that helped a lot. And I think Federico mentioned at one point the fact that we chose a path with one time programmable parts whereas they went directly to a ROM. We knew eventually we were going to need to go to a ROM to get the cost far enough down. But we felt like we didn't know enough about this solution yet and what laid ahead that we could commit to that. And that was one of the big differences. So they committed. They took the big step and they got sort of like a 95 percent solution. They were impressive enough to get in the door of many places and they got in cheap and being the usual Logitech sort of competitor they cut prices down to costs for a while so they could buy the market. And they hurt Synaptics for a number of years until Synaptics was able to turnaround and really get the cost down further. But we ended up ultimately with the better solution because we were able to iterate and iterate and fine tune it.

And that was part of what I took on next, was going out and working with manufacturers, finding sources for printed circuit boards, cheap ones, testing, assembly as well as working up contracts with folks like Microchip. We're looking at in short order being almost 100,000 units a month, 50 to 100,000 units, and we got the attention of the president of Microchip and he'd visit a few times and wine and dine us. So I sort of moved into that side of it and set that up, also because of my manufacturing background with Megatest and testers and high volume manufacturing and so on. So I could contribute a lot in that area. And then I went out with our sales guy Bob Somes [ph?] I remember this one trip to Japan. We didn't have working units yet but... So what I did was glued a bunch of components to a PC board and made it look like the size it would be and the number of components. And people were awestruck that we were so far along. <laughs> I was saying to Bob, don't they realize these are only glued to the back. So we did a big song and dance kind of thing going through Japan. It turned out there was one company in Japan. I keep wanting to say Acer, but I don't think it was Acer. There was another company there that was doing components, touchpads and things.

Steinbach: I dimly remember something - was that Alps?

Miller: Oh, that's right. It was Alps and they were very happy to receive us and looking at our product yes, we could maybe use your stuff for our future devices and things. Well, it turned out they were just feverishly taking notes and asking lots of questions about the technology and they were working on something in parallel too. You run into those kinds of things. And then as it turned out later, Japan was a fairly closed market at least in laptops which was going to be our target market at that point. And since Alps was a Japanese company they basically had full access to everyone there and we had very little access. So for a long time we got no Japanese market because of Alps. Now in Taiwan, it was Logitech we were competing against, so it was nasty, just bloodletting going on there.

And well in parallel with this, Federico is very clever about all of this. We created the touchpad peripheral which was basically to replace a trackball. And that was one of the original concepts, could this replace a trackball? And so we developed one of those devices. We got in partnership with some manufacturer in Taiwan and they manufactured these for us and we did a little bit hands off. That was his strategy because I think he was having second thoughts about whether this really was the right market [trackball substitute]. But it was certainly a great test market for us.

Steinbach: As a standalone device.

Miller: Yes, as a standalone unit because we could get a lot of feedback in terms of usability. I mean that was the next level which I think Synaptics excelled at, usability and performance. Because there was a lot of parameters just in terms of responsiveness, its lag, having multiple fingers on there, what the effects of that might be. This is before a lot of the gesture stuff. So this was a way to really get out there and get a sense of whether people liked this or not. Whether this was a compelling technology or whether it was just a pain for people with their fingers. And as it turned out the response was fairly lukewarm for the standalone units and we never made a business out of that. Its main application was built into a laptop. And I think in the order of usage sort of priorities, the mouse still stood out. If people had a choice they seemed to prefer the mouse. This was, again, focusing on just the laptop market or the PC market, home computers. In those markets people would prefer the mouse if they could. If they couldn't then the TouchPad did a pretty good job. There was still some comfort level with moving the finger. There was some issue with just it's tiring sometimes.

Steinbach: In the very beginning you talked about not having to touch but you ended up you really have to touch.

Miller: A little bit, yes.

Steinbach: Lightly, but still.

Miller: You always felt something. You can imagine if you really had to push hard... But even touching lightly was annoying over a long period of time. And this marketplace is interesting.You not only have your kinds of solutions, various competitors in those areas like Logitech. Well, there's another company called Cirque out there and then there was Alps. Cirque had come out with a TouchPad-like device in parallel with us. They were off in Utah or somewhere. This was a guy, sort of a lone inventor. But it was much more complicated and it required multiple chips like four or five chips in this solution. But it worked pretty good. He sold his rights to Apple, I think, at some point because he couldn't afford to continue on and couldn't compete with us as a business, certainly not Logitech. At that point in time we were selling to Apple and that's another whole story. Apple is ruthless with their procurement people. It's knock down drag out…

Steinbach: Was it you who sold to Apple?

Miller: I accompanied our sales guy, Bob Somes, there and he was the master sales guy. He could sell refrigerators to Eskimos any day of the week and he was very good. But Apple was just... it was a battle. I mean there were times where I thought these guys were going to just go at it over the desk and just punch each other out. And they would play tricks and, "If you could do that, well then why can't you do that? Okay, then we'll cut the price there and this and that. And then we want to throw this in too, we need this." And they were very demanding, as well, in terms of quality obviously. So we were going with Apple for a while there and then we were actually, I think, their first TouchPad installation. But then they bought these rights from Cirque and they came up with their own design in house. So I think they might have used us for a year or something in that order, and then they went with their own design for a while. So there was a lot of business sort of coming and going there, where things would look great and although it seemed like the Apple business wasn't in the end necessarily great business because you didn't get much margin out of it.

But then the other thing was the IBM Stick. That seemed to be a significant competitor to a TouchPad technology for a while with the little…

Steinbach: Yes, but not anymore.

Miller: Not anymore I. think it went to the wayside but Synaptics eventually sold the combination TouchPad and Stick where they integrated both of them into one design many years later. So there was a competition there for a while with them. It was not easy even though if you felt you had a great design, in spite of that there were difficulties in the marketplace, you know, of closed markets, dealing with Logitech and price gouging or cutting and then other technologies that you had to compete with. So I helped Bob with the sales there. I helped set up manufacturing in Taiwan from the U.S. We did initial prototypes and moved to Taiwan and set up there.

Steinbach: So even back then you had to go to Asia to do the manufacturing cost effectively.

Miller: Yes, I would say that was in probably late '93, maybe '94. Yes, it's probably '94ish, '95 in that range even, where things were starting to ramp up but yes, we had to go to Asia. Yes, we set up initial manufacturing locally in Milpitas. I had picked a vendor there and ran for a while and, in fact, the reason we chose that vendor is because they had connections to Asia. It was pretty obvious we were going to need to go there so we chose a vendor that had a partner over there so that we could easily move and transition the material over. And that helped a little bit. But it turned out in the end we just had to go over and pick someone. And then we had to send someone. And later we sent someone from Synaptics, who lived over there to manage and monitor it just for quality reasons and staying on top of things in terms of inventory and such.

Steinbach: So that was the competition, basically Alps and Logitech and Apple.

Miller: Yes, and then a lot the stick, the IBM stick. So there was very strong competition there. And that lasted for many years, actually surprisingly. We were surprised because it had an entirely different feeling, but there seemed to be just two distinct camps. One just loved it and others hated it. And the people that loved it, for some reason you couldn't convince them. To me it was like steering a boat or something. You basically point it in a direction and it would start driving that way and eventually it would go to wherever you wanted. And then you'd have to back off and do things. I thought it was maybe for a very loose kind of pointing situation it might be okay but for anything that required any delicacy it was hard. And the TouchPads, I was always impressed because the resolution we got out of it compared to a device like that…

Steinbach: With only a dozen traces.

Miller: Yes, four bits of traces [16 "digital" traces would give 4 bit of information] and you got ten bits or eleven bits of resolution and that really impressed me, that we were able to get to that point. But it seemed I was able to simulate a lot of that initially by making estimates of what we might see and then doing those measurements and using those tools to lay up graphs and do geometric means or weighted means and stuff. If I remember right we were literally detecting down into the femtofarads, half a femotfarad kind of resolution on some of these Gaussian curves basically you got out. And that just always amazed me that we could find that amongst all of the noise and garbage in the world that's flying around, and able to filter all of that out and make it happen. It was just a great show of design technology all the way through the design.

Steinbach: We filed a lot of patents on it. Do you remember about any patent fights?

Miller: I think there was. That's a good question. I think we had some issues with Cirque but we were able to pull our way out of that. I think we were able to differentiate ourselves enough there. With Logitech we had to keep a real close eye on what they did. I know for sure in the gesture area when it got later in the life of the product, when we were getting into gestures there were some fights there because Logitech patented some gestures, Steve and his group there, which always really frustrated me because I am 100 percent certain we talked about all of those things at Synaptics ahead of time before we he left. And however…

Steinbach: He didn't have a non-compete clause or anything?

Miller: No. And I know we talked about that stuff and I remember talking with a number of people, Steve as well as Dave and you and Tim, and making sure we always had that provision, the ability to do that. In fact that was one of the reasons-- one of the nice things about that next generation approach is, it allowed you to look at the raw data a lot closer and you could do a lot more with it then, things like gestures and other stuff. And Dave was really into creating some interesting side benefits of that. He had a development kit for a while where you could partition parts of the pad to be a relative coordinate system and other parts of the pad to be an absolute coordinate system. So you could put buttons and things around the perimeter and virtual buttons and such and make that all programmable. And all of that was sort of the same concept of, it's a variation of a gesture in my opinion. And a lot of that we talked on about I'm sure before he left, but unfortunately we didn't put a patent down and Logitech did. So this is after I left the company. I heard there was a number of battles in that area because Logitech sold a lot of the rights to Apple and then Apple obviously has all of their gesture stuff. I think there was some deal eventually made with Synaptics on that, that allowed Synaptics to do some of that same stuff. So that particular issue is one of the sadder parts of it all, that it happened that way because I felt like that was our domain and our ideas.

Steinbach: Yes.

Miller: But I mean still it was an amazing progression.

Steinbach: Ye. Do you own a computer with a Synaptics TouchPad now?

Miller: I don't own any laptops but many of my friends have them with Synaptics TouchPads.

Steinbach: Actually, I just checked and my wife's laptop has a Synaptics TouchPad.

Miller: Okay. Every time I see one I do a double check and I would say most of them are Synaptics. The sort of third generation was integrating the processor into the TouchPad IC itself. So it was a one chip

solution. So when it went to the second generation it was a two chip solution. A microprocessor, a Microchip solution and the T-1000 chip, the TouchPad chip. And the third generation was a single chip solution. So they started working on that pretty much right away, knowing that Logitech was going to be killing the market in terms of price. So that one I think took a year or two-- it was probably two years before it hit the marketplace but that's what saved the day for Synaptics because we were slogging it out with Logitech, price dropping. We were sort of winning on the fact our performance is better. But it was a hard battleto get good margins because Logitech was dropping the price so much. So Synaptics was squeaking by. I don't know. It might have gone unprofitable for a quarter or so in there somewhere. It wasn't too bad but it was tight times. And so this third generation just took it over the top. So that was another very impressive engineering feat. I mean I think Dave and Tim compiled up a processor design. Were you involved in the OTP stuff?

Steinbach: No, only analog. I left when I was the only analog designer left in the company. <laughs>

Miller: Look to the left, look to the right. <laughs>

Steinbach: I didn't have anybody to talk to.

Miller: Yes, I guess, the company was making that transformation.

Steinbach: And it makes sense, right. You have the programmability and small analog, big digital is the way the world is going, has gone.

Miller: As much as the company was originally trying to push it in the other direction, the forces just overtook it all and the logical minimum was over in the other area. So there was Ting Kao. She did the OTP section. So we actually built a one-time programmable processor. At that point I think I was no longer with the company as well but they built the one time programmable processor single chip solution and then we had complete control of everything. We didn't have to deal with a Microchip and it was an inexpensive solution. They designed it so they could take it to a couple of fabs. So they had complete control over where it went. Then they could drive the price down. I remember the first couple we sold to Taiwan - I think it was Compal and a few other companies. I was going over there and doing the negotiating with these laptop manufacturers. It was interesting because at that point in time laptops were not that widely distributed and not widely used and some of these designs... I got a free design out of one because they gave us a number of samples to run the TouchPads in and play with. And god, you dropped these things four inches and they just exploded. The designs were really pretty basic back then, pretty immature. So we were selling them TouchPads for like $12 or something like that. And I would say…

Steinbach: That's the complete thing with the pad?

Miller: Yes, a board. Yeah. Sort of a little module which was the pad, the sensor and behind it was the two chips and the peripheral components and things. So they could buy that module and plug it into their unit and with a little software could be up and going. And we were selling them for $12 each. I remember the manufacturing because we were doing it locally then. We'd have a test, a final QA in Synaptics, there was a couple of us. And I was running manufacturing at that point, the operations and had a test set up there. We'd set up the testing. We'd apply the labels, the Mylar covers because we found out every manufacturer wanted a different color or they liked different textures. So we had to leave that for last and so we'd have an inventory. Although at times we'd build up a bunch and then we'd find out that guy canceled and we'd have to ship to this guy so we'd have to remove all of the Mylar. And that was bad. and then apply a new Mylar. So we were doing 5,000 a month, they were $12 each of something. That was our first level of manufacturing. And then I think it [price] really was an exponentially decreasing thing where I would say by moving offshore we went from $12 to about $6. And it also meant volumes were going up. So it went from like 5,000 to maybe 20,000. So not only the offshore but the volume got us a halving in price, almost. And then we'd go from $5 down to $3.75 or something like that by getting the volume up still further. And I think it was when we finally got to the single chip solution we were down to like-- again, this may be a second person here, a third person-- but I think they were down to like $1.50 or $1.75, sort of in that range.

Steinbach: Well, several years ago I heard they sold a billion total but it's probably five years ago so already…

Miller: It's like McDonald's you've got to have a little sign up there. Five billion sold.

Steinbach: Yes. It is amazing.

Miller: That it is, yes. And it just shows that once you sort of hit the sweet spot and have factored in all of the issues there was, and you've got the right product, it just takes off. And Synaptics was able to just squeeze around the others. And I think it shows a lot all of the design capability there as well as the managerial focus was: We need this here. Absolutely, the single chip solution if we're going to succeed. We're going to have some rough times between now and then. But as long as we can maintain that focus and not have to give up on that we'll succeed in the end. And the others-- Logitech there was no chance they were going to get a single chip solution. They just didn't have the capability. And we had a very special group. That, again, was the whole reason I went there is just the people around there are just phenomenal folks. And just being able to do things in days that would take others months. So yes you could suggest something and it wasn't just absurd. You could actually do it.

Steinbach: What made you leave Synaptics?

Miller: Well, I had taken manufacturing to the point where I had set up a manufacturing group. I don't remember what the volumes were at that point. We were overseas. It was probably 20,000 a month kind of thing, maybe 30,000 a month sort of at that level. At that point that was like '97, late '97. I had been doing it for probably two-and-a-half or three years. And it was getting to the point where in some ways it was sort of beyond my capabilities in terms of needing some real high volume manufacturing guy who knew how to run Asian plants and things like that. And Synaptics was not a nurturing kind of environment. <laughs> You either could do it or you couldn't. And no one was going to help you do it. So anyhow, up to that point I could do it or I could learn it on my own and I did most of that. I enjoyed that part. But there was a certain level beyond that where-- and it also maybe wasn't in my nature. You had to become sort of a ruthless manufacturing guy where your whole life was spent with your finger on your manufacturer or wherever and you had to be on them every minute. And that was not sort of where I wanted to go. I loved the energy and the excitement of making things happen but it was starting to get to a point where it was in a lot of ways reaching some kind of maturity and requiring some skills that I didn't think I was interested in learning or interested in being a part of. We had a guy living over there most of the time [in Asia, Thailand in particular] and it was twelve-hour days. You'd be calling him in his time zone and you have to come back and do your stuff and then you'd be dealing with Europe.

And again, I think the company was sort of looking for some other person at that point to take it to the next level and I could feel that. So it was time. And the company had changed a lot too. I mean well, there was still a bunch of research stuff going on and I loved that part and just going to lectures from other parts of the company or going to presentations and the work they were doing and the stuff you could learn. It was just incredible stuff. And I enjoyed that sort of physics and electronics aspect of it. I enjoyed learning the manufacturing and doing that. It was a new experience but it was that it started getting a little bit old at that point. So it was sort of time, I guess, to move on.

Steinbach: What did you move on to, briefly?

Miller: Well, I went off on my own and in short order met up with a guy that I used to work with many years ago. He had a small consulting company. So I went in partnership with him at his consulting company. It was called 3rd Rail Engineering and we did prototype development for companies. So we would take a concept. It was…

Steinbach: Chips or…

Miller: Actually typically embedded systems. At this point it was embedded systems. So say an irrigation company wanted to build an irrigation timer and they didn't really have a department to do that. We would take their concept, work with them, work out the specifications of it and develop a design for them and build the first prototypes so they could then take it around and sell the concept and maybe get funding. We provided them with all of the documentation and tools to take it directly into manufacturing. So we took it to that point and would release it. So I think we might have done an irrigation project. We did

electric meter projects for the smart meter, the precursor to the smart meters. I worked with [Hitachi] it's now Renesas]. It was the big IC manufacturer. They had a number of processor designs, embedded processor designs. And we developed a number of development boards for them, for their entire family. They probably had four or five designs and that was very fun because I would learn about the processors. I'd develop a design around it. And I got to do some tricks that really caught them off guard and impressed them. I used some of their high speed designs and how to get more out of it and doing some multiple stepping of time cycles and things in the background and stuff. And so they were very excited about that stuff. So I got to do a lot of system designs at that point, embedded system designs and smaller stuff too, hearing aid products, tools for managing hearing aids. And eventually got into some RF stuff as well. So I really enjoyed that.

Steinbach: That's quite an arc.

Miller: Yes. Well, then at Socket, the next place, I got into more RF designs.

Steinbach: Because I saw on your résumé at Megatest you were involved in 100 kilowatt power supplies.

Miller: Or systems, yes.

Steinbach: That's an amazing variety. And I was going to ask you, but I guess it's kind of pointless, whether it was just serendipity that got you into all of these different things? Or were you always looking for something else? But from what you're telling me it's more like that's just kind of it happened that way.

Miller: A lot of it happened that way but I mean I had choices along the way. And one thing I enjoyed most in my career was the variety. Talking about Synaptics. If I got to a point where I was sort of getting bored then it was hard for me. Then I didn't enjoy it anymore and I felt the need to look elsewhere. So to me the variety was very important. And also a lot in the design area I enjoyed,- if you could say it this way, sort of the first 80 percent of a design where you got all of the amazing first order and second order kinds of effects and you got everything sort of working. But then I wasn't the one to squeeze out the last one percent or two percent out of a design because at that point in time I was starting to get sort of wanting to look elsewhere because it wasn't as exciting for me anymore. So that's partly what drove me into, I guess, moving in to other areas. Much of it may have been serendipity because it just happened that the timing was right for different things. But I had choices on things and I would choose the things that looked the most exciting. I worked actually at National originally almost right out of school and worked in their calculator group. And I was the guy cranking out sort of block circuits and simulating them for shift registers and various things. And the first few were fine and after that I asked for other stuff. So I got to do some oscillator designs, one-chip oscillators and various sort of unique circuits and that was very fun. But I was in the hardware group and I was this one guy in the hardware group and they were a

very regimented sort of company, so that only lasted nine months for me there at National. And then I joined this custom design IC company which was very exciting because I got to do lots of different designs and not only full chips. I probably designed ten or fifteen chips there plus maybe another ten later. But I got to help do troubleshooting of other people's chips. We sort of teamed up with this company AMI, American Microsystems Inc. or something.

Steinbach: Yeah, they do BIOS, I think, nowadays.

Miller: That was a different company, actually. This is one of the first companies that commercialized MOS design and built products. They were trying to be a little more standardized but they did a lot of custom stuff. But they would have these problem chips every once in a while so they asked us to look at it so I'd go over and that was very fun for debugging those things. And I remember one of them there, you'd appreciate this, but they had some switched phase capacitor thing where they'd be shifting the logic through. And the way they designed it they had too much load on an output so they had to beef up the drivers. And it was a downward spiral. Well, now we've got bigger drivers and then we've got to put bigger capacitors here because we're sharing capacitance and everything was going to hell quickly for them. So I came in and used a clocked load type of design and did some other tricks for them. And they went from this chip at that point was probably their rev. 10 and was burning a couple of watts It was a modem chip for this company called Paradyne and it was destroying their modem. And so when I finished it with this clocked, this phased and clockwd load design, this thing dissipated about 50 milliwatts and was faster than what they had already had and they were just-- ooh. I loved that part of it. It was just the ability to solve problems. That was sort of what happened at Socket with a lot of the RF stuff. I had no RF experience but got to go in there and nowadays these designs are less interesting because so much of it is you basically buy a chip and you get their reference design and you build it up and there's your product. You miss out on a lot of the detailed stuff. And so I got to do a lot of that but with RF and actually solve a lot of interesting problems there so that was fun.

Steinbach: Great. You brought some samples. Can I get them and you say a few words about them?

Miller: Okay. You asked about some samples. And things I brought with-- these are the first chips, the prototype ones. I guess you could call them the alpha units. So this is out of the Mosis run, these four of them. I left most of them at Synaptics for their lawyers and their whatever but I kept a few for myself. In fact, I see dates and they're 7-17-1992. So those are when these samples came out.

Steinbach: That's just about the time I joined Synaptics, I think.

Miller: Okay, yes. I mean I'm sure you were right in the middle of all of the debugging as well and helping with that, coming to speed. I think you were also involved with some of the neural network stuff too weren't you?

Steinbach: Yes.

Miller: So you were probably initially way later… [???]

Steinbach: I found my way.

Miller: I wish I had schematics of these, but anyway, this is the first units, the first TouchPads. Well, actually, this was one of the-- we were talking about the TouchPad being used as a trackball replacement like on a PC or a desktop kind of situation. This is the product that Synaptics sold for a while and this is what it looks like on the inside. And this was the TouchPad module. So this says the TM1002 and the chip on there is the T1002. So this is the Mylar on the surface and the back side is the two chip solution. So the TouchPad device IC and then the Microchip controller there and that was it. And then a few peripheral chips. A lot of empty space on this one for tuning various features and such. But this was the design. So it was quite a stripped down product even at that stage. And you can imagine later with a single chip solution there was nothing left on here, just maybe an oscillator and the main chip. So yes, this is what they basically tested the market with. And then this was another one they had tested the market with.

Steinbach: So that would have been around ’94?

Miller: I saw the date code on here was ’95, October ’95. So still in ’95 this two chip solution. And then as a going away present, as a little bit of a practical joke, they made me a gold TouchPad. This shows the sensors. This is where the rubber meets the road. So yes, this is another one. They didn’t sell very many of them so they had a lot to give away as gifts. <laughs> And basically the same chip or the same chip set and the same board design. This one just had a few more-- was it Silitech . I remember this. This is a company we sold the rights to for the standalone unit. They could go ahead and manufacture as many of these as they want and sell them on the market so they went out and tried. It was Silitech was the name of the company. So they built this one. I don’t think it went very far, especially the gold ones. <laughs> But you can see the sensing technology here for posterity. It’s a number of diamonds. We were trying to maximize the capacitive coupling to the finger. And there’s a horizontal row here of lines. This is a multilayer board. So horizontal row on the surface and then a vertical row underneath. I think that was sort of the general-- that’s, at least, the set up here. And the vertical row going down was an internal layer that ran a via up to the surface pads. So basically we went to minimum spacing on pads and just put as much copper on the surface as you could, just to maximize the capacitive coupling to anything out there.

Steinbach: So it always had to be a multilayer board, I guess.

Miller: Yes. As far as I know. I mean with this basic X, Y system it had to be. I don't know if there’s any technology now that they’re using with some of the clear traces and so on. I mean that’s another area that

I wish we had talked about. I should say I wish we had documented better back in those days but we had talked about the logical progression going from an opaque sort of surface, I guess, on a PC board to a transparent surface. We, in fact, even looked at some of these indium-tin [transparent conductor] sort of conductors and transparent devices. And even talked about potentially using it on an LCD screen where you already have traces running across co-opting those functions and maybe multiplexing in the TouchPad which I think is what they do today. I'm, again, certain we talked about that at that time but unfortunately never documented it. And that's another thing that would have been a major key feature for later. Yes, in the patent we did put a number of things in terms of trying to broaden it. It doesn't necessarily have to be a flat surface. It doesn't necessarily have to be a linear system. So looking at other applications outside computers, the computer industry, but looking into who knows what automotive, other kinds of video systems, control panels for things that aren't necessarily a classic sort of XY coordinate.

Steinbach: Okay. Well, thank you very much.

Miller: Alright, well, thank you.

Steinbach: That was very instructive for me too.

Miller: Was it?

Steinbach: Yes. Yes. Very interesting.

Miller: Anything I left out?

END OF INTERVIEW

