Oral History of Hal Feeney

Interviewed by:
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Recorded: June 6, 2004
Los Altos, California

CHM Reference number: X2809.2005

Gardner Hendrie: Well, we have here today with us Hal Feeney who is going to give us-- gracefully agreed to give us an oral history for the Computer History Museum. Hal, probably I'd like to maybe start with a little bit of your personal background, where you grew up and maybe a little bit about, what life was like when you were growing up, how many siblings you had, what your parents did, some of those details.

Hal Feeney: Okay. It's kind of interesting. It's amazing how far away and how different it is from what we're seeing today in the industry of technology. But I grew up in Iowa. My father ran a grocery store in Iowa in the 1930s, 1940s and 1950s, so I got to see the world from a little bit different perspective, from a very commercial perspective and also watching society evolve too in a totally different way. In Dad's case it was a business that probably didn't evolve with the time and at the time that he closed, it was one of the smaller grocery stores in town. But a very specialized store, he gave very specialized service. That in many ways kind of drives the kind of thing that we have to do today in our industry is provide a tremendous amount of service. I grew up in Iowa, went to grade school and high school there and then left and went to the University of Notre Dame for my college work.

Hendrie: Okay. When you were growing up what was the-- what's your earliest memory of what you thought you might want to do when you grew up?

Feeney: Oh, it's kind of hard to say. I guess in some ways I was always interested in electronics in one way or another. One of my neighbors was the chief engineer at the local television station and that gave me somewhat of an entrée. And this again takes you back to the days when dealing with a stereo system was a lot like dealing with computers today where you had to have somebody on your street that knew how to set these things up and put them together. And, my neighbor was the person that gave me the assistance. But, getting involved with probably audio at that time and then just being very comfortable with math and that experience kind of came together.

Hendrie: You liked math and science in high school?

Feeney: I did and then, at the same time, I had an opportunity when I was in high school. One of my other neighbors was the program director for the local television station, so it enabled me to get a position there during the summers and work the television station on a production crew. And then after I got into college I was able to work there one year with the engineering staff.

Hendrie: Oh, that's very good, so you've really had some-- technology was rubbing off on you all the way through.

Feeney: It was more of a rub-off too on what it could do as opposed to the pure theory behind it but what are some of the opportunities, what are things that could be accomplished with it?

Hendrie: Do you have any siblings?

Feeney: No, I don't.

Hendrie: Okay.

Feeney: I grew up as an only child.

Hendrie: All right.

Feeney: And I guess it's got the goodness and badness with the goodness, of course, is that you get to do almost anything you want to do and it gives you total flexibility and I didn't have a lot of companionship around the house.

Hendrie: Yes, exactly. All right, so you decided to go-- did you think about other schools that you might go to? How did you pick Notre Dame or was that sort of for ordained in your upbringing?

Feeney: I thought about a number of different schools and part of the tradeoff -- there were certainly very good engineering schools in Iowa and one thing that drew me to Notre Dame was the fact that they had an engineering school, but they also were a strong liberal arts college and I wanted to get a balance of the two rather than having something that was, you know, totally technically oriented.

Hendrie: Okay.

Feeney: It was more the influence of that. It wasn't-- at the time, Notre Dame didn't have a football team that would make it very attractive, but they finally grew back into that.

Hendrie: Okay. What sort of things did you study at Notre Dame? I mean do you remember any courses that you were really particularly interested in?

Feeney: I think…

Hendrie: Or teachers that influenced you?

Feeney: Everything in the curriculum was very fundamental, basic engineering courses, in electrical engineering, at that time and we were just going through the transition where we had one teacher who had his notes which were obviously very old, still teaching us about vacuum tubes and just as the transistor was coming in. Now this is in the 1960 to 1965 time frame, so we were going through a major change in electronics going from the vacuum tube to the transistor. And, of course, the integrated circuit had just been developed but that hadn't made it into any schools yet.

Hendrie: Okay. So, you did learn something about transistors. There were courses in basic…

Feeney: There were courses and what was interesting was is a close friend of mine now, who had gone through the same courses about ten years prior and essentially had the same set of notes and the same things on the vacuum tubes then. So, as I say, we were just right on the edge but did have… In the senior year there were some courses in logic and I don't want to call it pure computer design but just basic logic design that were kind of an introduction to some of the things to come and that's one of the things that got me interested in computers.

Hendrie: Okay, interesting. So, they were starting to teach something about logic design. Did you have to do any of the power engineering or any of that or could you finesse that by that time?

Feeney: There was no way to finesse that. The head of the department was also the person who taught power engineering courses and we had, in the engineering lab we had motors that were larger than these chairs that we had the opportunity to be very careful around.

Hendrie: Opportunity, yes, okay. That's a pretty broad range, transistors to AC and DC motors.

Feeney: Right. I have a tremendous amount of respect for the voltage and currents involved in the literal power that these things have.

Hendrie: Yes, okay. So, you know, when you came close to graduation what was in your mind about what you thought you might want to do?

Feeney: Well, I enjoyed the undergraduate part of it but I also knew that I wanted to get a little bit broader perspective and I decided to go to graduate school and there were several different choices. And, perhaps one of the major influences in coming to the West Coast was the fact that the weather was so bad in the Midwest that it made it very attractive to go someplace where we didn't have snowdrifts that were four and five feet deep.

Hendrie: Okay.

Feeney: So, I decided to come to the West Coast. I went to work for Hughes Aircraft in the summer and then came to Stanford the following fall to do my Master's degree at Stanford.

Hendrie: Okay, very interesting. Did you look at other schools that you might go to or is that really…

Feeney: I looked at some other schools but it was kind of a two-fold thing being able to have the package with Hughes and also going to Stanford on Hughes fellowship.

Hendrie: Oh, all right.

Feeney: That made it very attractive.

Hendrie: All right, so Hughes recruited you and said, "If you sign up for this package, we'll send you to school…"

Feeney: Right.

Hendrie: "…and you just are supposed to come to work for us after you get your Master's."

Feeney: It was a great opportunity.

Hendrie: Yes, exactly, okay good. Now do you remember were there any particular professors at Stanford at that time or what did you specialize in, in your Master's degree, maybe I should ask you that?

Feeney: Well, Master's degree, again, it was generally in electronics and logic.

Hendrie: Okay.

Feeney: And focused as many courses as I could in those areas. Again Stanford's program, the Master's program at that time was a very intense program of coursework, labs, and doing the degree in a year.

Hendrie: Okay. All right, so it was a…

Feeney: There really wasn't, there wasn't a lot of time available for going through and doing unique and interesting and different things but yet one of the lab courses I had… One of my lab partners had worked for GMe [General Microelectronics] in Palo Alto, so we had access to some chips and we were able to get, to do a lab project, we were able to get a number of chips and put together a small computer system as part of this lab and it just was a great opportunity there to get our hands on something.

Hendrie: And really build something, something that works.

Feeney: And really build something that works, yes.

Hendrie: Yes, exactly, as opposed to the theoretical…

Feeney: That's right.

Hendrie: Theoretical approach. Who were your best, looking back who were your best teachers in grad school? Or none of them really made a mark on your, in your brain?

Feeney: Well, I think a number of them made a mark. I'm trying to pull the names out right now.

Hendrie: Okay, all right.

Feeney: Gene Franklin in the controls course or Bernie Widrow and I guess it was a combination of logic and adaptive systems course.

Hendrie: Okay, all right, good. When you'd finished, got your-- now what year are we in? I need to calibrate the time every so often.

Feeney: Okay, I got, did my undergraduate in 1965 at Notre Dame and then graduate in 1966 at Stanford.

Hendrie: Okay.

Feeney: And, at that time, I was looking at doing further graduate work and I had an opportunity to go back to Notre Dame with an NSF [National Science Foundation] fellowship to do a Ph.D. in electrical engineering.

Hendrie: Uh huh.

Feeney: And I chose to do that and I got about well half or two-thirds of the way through the program and it was then that I began to scratch my head saying do I really want to cut myself off from the rest of society for another two years to do a thesis or would I rather go out and get a job and do something else? And that was the decision I made and it turned out in that area it was very good timing because I did that in 1968 and it turned out that some of my classmates that finished up in 1970 had a very, very difficult time in the marketplace…

Hendrie: Okay.

Feeney: …in 1970 where that difficulty didn't exist in 1968.

Hendrie: All right, so, okay, so you went back to Notre Dame. Now have you gotten married along the way here?

Feeney: No, not yet.

Hendrie: Not yet, not yet, okay. Have you met your future wife yet?

Feeney: I did when I was at Notre Dame.

Hendrie: In Notre Dame, originally or the second, when you were doing this Ph.D.?

Feeney: When I was in graduate school.

Hendrie: Okay. All right.

Feeney: So, I met her then although we didn't date and then I came back to Los Angeles, went to work for General Instruments in Los Angeles and a fellow that I went to work for at General Instruments was a fellow I had worked with prior at Hughes.

Hendrie: Ah.

Feeney: So, those kind of things tied together.

Hendrie: Okay, all right, so.

Feeney: And…

Hendrie: So what did…

Feeney: General Instruments at the time was the leader in MOS [Metal Oxide Semiconductor] processing technology.

Hendrie: Now this was a West Coast. General Instruments is based in L.A.

Feeney: It was an East Coast company based in Hicksville, Long Island.

Hendrie: Long Island, right.

Feeney: And they had a design office in Tarzana, California. They did the design office in Tarzana, California to recruit the fellow that I went to work for.

Hendrie: Ah.

Feeney: So, it was a small design office.

Hendrie: Okay.

Feeney: But…

Hendrie: What was his name?

Feeney: His name was David Callan.

Hendrie: Okay.

Feeney: And he had done some system work at Hughes with the digital differential analyzer and when I went to work for Dave I worked on some of the test devices for the digital differential analyzer and also did some simulation with it and then he was using the analyzer or the goal at Hughes then was to take an analyzer and have it integrated. It was with General Instruments they were able to do the integration of the digital differential analyzer and, in that process, then Callan was hired from Hughes to GI to set up the design office and do the DDA [Digital Differential Analyzer].

Hendrie: And really run the project.

Feeney: And run the project.

Hendrie: Now what were they going to use the digital differential? I mean what was the market for it at this point?

Feeney: A very limited market but much of Hughes work was in the satellite business.

Hendrie: Okay.

Feeney: So, the simulation that I got involved in was basically de-spinning a satellite antenna array and using the digital differential analyzer as the control and de-spin the array such that the main signal power is beamed back at earth rather than being beamed out into space. So, it's off the antennas that surround the satellite being able to get the antenna power focused directly at the earth.

Hendrie: Okay. So, this is a flying digital…

Feeney: It was designed for flight, yes.

Hendrie: This is designed for flight as opposed to a, you know, a floor mounted one that's used to solve equations, design equations.

Feeney: Right, not a rack-mounted thing.

Hendrie: Not a rack-mounted thing for design. This is not for engineering use. This is a real time control device.

Feeney: Correct.

Hendrie: Okay. Well, that sounds pretty exciting.

Feeney: That was kind of a fascinating start. You know some of this came about during my first summer between Notre Dame and Stanford and as part-- I became familiar with some of the GMe parts because we were using the GMe parts to do the breadboard that we had at Hughes.

Hendrie: Okay.

Feeney: That kind of led into the Stanford lab project.

Hendrie: Yes and so then you knew the parts. Now what kinds of parts were these? Were these fundamentally, were these MOS gates or bipolar?

Feeney: These were MOS gates and flip flops.

Hendrie: My goodness.

Feeney: So, I mean the first, I mean if you think about it in terms of the TTL [Transistor-transistor logic] equivalent to MOS when they first became available in 1964, 1965, 1966.

Hendrie: Okay, where you might have one flip flop in a package.

Feeney: Right.

Hendrie: Or four gates or three, you know.

Feeney: Four gates, you know, NAND gates, NOR gates that type of thing.

Hendrie: Yes. Okay, it was in the early days of SSI [Small Scale Integration] I guess, yes. All right, very good. And the reason they were using this was power I assume?

Feeney: Yes.

Hendrie: Yes, so they were going to do it in MOS just to get them really low power.

Feeney: To keep the power as low as they could, because all the power from the satellite came from solar collectors.

Hendrie: Uh huh, all right. So, you're working on this after you're-- in 1968 and what happens?

Feeney: Well, when I went back to join GI in 1968, at that point it had evolved into a design office, design outpost if you will for GI corporate and we were doing a variety of different custom projects there.

Hendrie: Okay.

Feeney: So, some of them were military based. Some of them were designed for military backpack use and location positioning and, you know, the very, the very rudimentary designs for the stuff that is very commonplace and very sophisticated today.

Hendrie: Okay. All right, so it's basically all military oriented though, mostly?

Feeney: A lot of it was, not all of it.

Hendrie: Okay.

Feeney: And, you know, this is the market at that time. A huge part of the market was military because they were the ones that were willing to make the expenditures to do the significant things that were being developed and the products themselves were quite expensive at that time.

Hendrie: Uh huh, okay. So, how long did you work at General Instruments?

Feeney: I worked at GI for about, oh, probably almost three years and, as I said, GI was a leader in MOS at the time that I joined them and there was a downturn in 1970 and GI experienced a downturn almost before anybody else and they made the decision to close the design office in Tarzana at that time.

Hendrie: Uh huh.

Feeney: So, it basically gave the option of going to another GI facility in the west or going back to Long Island. I decided to look around and a number of good things happened.

Hendrie: That was a good decision.

Feeney: It turned out to be a very good decision and a number of good things happened and I ended up with a job offer from Intel.

Hendrie: Okay.

Feeney: And so GI closed its office down there at the end of February and I joined Intel about a month later in March of 1970.

Hendrie: Okay. Now how did you find Intel? I mean did you solicit them? Did a friend tell you about it? Or, I mean tell me the story of how you ended up there?

Feeney: I mean, this is one of these quirky stories.

Hendrie: Okay.

Feeney: You know good things just seem to happen and I was going to visit a GI salesman or former GI salesman at the time. I walked into his office. He happened to be on the phone with a friend of his who was an Intel salesman and we were talking for a few minutes and said send your resume up. Intel's looking for some designers and it was just that fluky.

Hendrie: Wow.

Feeney: One thing led to another. I did the interview with Intel and got the offer.

Hendrie: Do you remember who interviewed you?

Feeney: Interviewed and was hired by Les Vedez.

Hendrie: Okay.

Feeney: And so, Les went on, in fact he's probably one of-- next day Andy and Gordon, probably one of the longest Intel employees in terms of duration at Intel.

Hendrie: Okay.

Feeney: Les was running all of the engineering design activities.

Hendrie: Uh huh.

Feeney: From 1968 through the early 1970s.

Hendrie: Okay. All right, so you got hired. Now have you talked your future wife into coming out to California yet?

Feeney: Well, no. What happened was we were both living in Los Angeles at the time we started dating.

Hendrie: Oh, she came out?

Feeney: She was in California for another-- for a job. I was working in California. We started dating and we were planning to get married in that spring time frame and suddenly with the closure of the GI office at the end of February of 1970. We'd just picked out an apartment, we were planning to get married around the first of April and we were all set in Los Angeles and suddenly things got into a turmoil with that change.

Hendrie: Exactly. No job does not feel comfortable getting there.

Feeney: No job is not a good tradeoff and, of course, suddenly then the tradeoff became that I had a job at Intel and then she had no job. And we had set April 1st as our date to get married and so I joined Intel on the 9th of March and three weeks later I was taking a vacation to go off and get married.

Hendrie: Oh, my goodness, all right.

Feeney: So, but everything worked out well.

Hendrie: Okay, good. So, you joined Intel and walked in the first day and what did they-- what happened?

Feeney: Some of it is a bit hard to remember.

Hendrie: That's okay but just sort of.

Feeney: Well, the reason I was hired was that Intel had been talking with one of its customers about doing a custom project and trying to convert this customer's electronics into a single microchip.

Hendrie: Okay.

Feeney: And, in this case, it was CTC, Computer Terminal Corporation out of Texas, San Antonio that was a long time Intel customer for shift registers. Or I shouldn't say, a long time Intel customer in this regard was about a year. But was a major Intel customer for shift registers. And, as kind of a follow-on to some other work that the applications group at Intel was doing, the applications group, Ted Hoff and Stan Mazor had previously taken a look at the needs of a Japanese calculator company and the Japanese calculator company wanted to have a large number of custom chips built to enable a desktop calculator. Intel, of course, was quite small at the time with just a handful of design engineers.

Hendrie: Uh huh.

Feeney: And the solution that Hoff and Mazor proposed was implementing this calculator as though it were a computer and reducing the number of chips from about 13 custom chips down to four standard chips whereby a number of chips, ROM, stored program ROM, RAM and CPU could be used to implement the calculator. So, with this in mind, when CTC came in and was looking to perhaps expanding the relationship with Intel or Intel may have counter-proposed can we get more of CTC's business with implementing something special for them and it was with that that the single chip 8-bit microprocessor was proposed back to CTC.

Hendrie: Okay.

Feeney: So, the skeletal thing that was developed was a rudimentary spec based on the Datapoint 2200 terminal and that became the target then for a design for Intel to do, which would be an 8-bit single chip microprocessor implemented in MOS. And, at that time, it was planned to go in a 16-pin package.

Hendrie: Okay. Now when you-- I forgot to ask you while you were working at GI what kind of work were you doing? Were you doing circuit design? Were you doing logic design, systems design, a little bit of everything? Maybe you could clarify what you were learning to do really well.

Feeney: Basically chip design and circuit design. We would take things all of the way from the spec for a product all the way through to the layout of the chip.

Hendrie: Okay.

Feeney: And layout of the chip and the cutting of the Rubies and checking the Rubyliths and so forth.

Hendrie: All right.

Feeney: So, we had those facilities there and not unlike a lot of the fabless companies today then we ship to Rubyliths back east to have somebody do the processing for us.

Hendrie: I see, okay, so you didn't get into the processing but you got into all the design tradeoff.

Feeney: Got into all aspects of the design.

Hendrie: Yes, so you would design, you'd lay out the transistor dimensions and you do everything.

Feeney: Right.

Hendrie: Okay, all right.

Feeney: Part of it involved doing, at that time, very rudimentary simulations. We didn't have the desktop computers of today so we were using time sharing as basically the simulation tools or as the circuit modeling tools that we had available.

Hendrie: Okay. So, you would do-- so that was your exposure to computers primarily was as a tool.

Feeney: Yes.

Hendrie: To run programs, simulation programs both for logic and for circuit?

Feeney: Right.

Hendrie: Circuit analysis.

Feeney: We were not doing system design or system engineering at that time.

Hendrie: Yes, okay.

Feeney: It's been quite interesting just watching the changes in the industry because back in those days semiconductors were building blocks the system companies used to implement a whole variety of different functions.

Hendrie: Uh huh.

Feeney: And now almost all that system capability has moved into the semiconductor companies and the building blocks of semiconductor companies are substantially larger today than even some of the system products of years ago.

Hendrie: Yes, I agree. If you want to be a computer designer better work for a semiconductor company. <laughter>

Feeney: Well, one change it was difficult to, in hiring people it was difficult to sell them on the fact that there was a greater career opportunity at a semiconductor company than at a computer company.

Hendrie: Yes, okay. So, you had, you got assigned to this project. Tell me a little bit about what the certain design parameters were that you were working with. What process was this going to be?

Hendrie: Feeney: Well, Intel built its entire start-up plan around silicon gate MOS.

Hendrie: Okay.

Feeney: And so this was, this would be p-channel silicon gate MOS.

Hendrie: Now, n-channel had not, they did not have an n-channel process yet?

Feeney: N-channel process, the process had not come along. That was a couple of years away.

Hendrie: Okay, somebody was probably working on it but it wasn't there.

Feeney: Oh yes, it was not at the point where the designers would be using it. In fact, a very good example, I think probably 1972, would be the first n-channel chips coming out of Intel and those were the static RAMs at that time.

Hendrie: Ah, okay. Okay, all right. So you had p-channel silicon gate.

Feeney: P-channel silicon gate and we also had a constraint that was put on. I'm not sure if it came directly from Andy Grove or it came from the packaging group, but it was a constraint to minimize the number of pins on a chip. As an example, when I worked with GI, we were doing things with 44-pin flat packs and so that was like kind of harnessing a spider and an octopus together to try to get control of all of these leads. And, in general, the largest packages that Intel worked with were 16-pin packages at the time.

Hendrie: Uh huh.

Feeney: And then they grew to 24-pin packages but, you know, it was not-- it was far, far different than the thousands of pins that we're seeing today on packages.

Hendrie: Yes, or even the much larger number of pins in military applications where probably the cost wasn't important.

Feeney: That's where the 44-pin flat packs came from.

Hendrie: Yes.

Feeney: That was military. Cost was not a significant-- I mean cost was an object but it wasn't the significant driving force. It was more the functionality.

Hendrie: Uh huh.

Feeney: And in the case of Intel the thing Intel was driving for and I think some of this came out in their history moving to Fairchild. They often had difficulty getting products to market in a timely fashion and one of the things that Intel was stressing from a marketing perspective was to deliver.

Hendrie: Uh huh.

Feeney: And they knew they could deliver packages with low pin counts. Delivering packages with high pin counts was certainly far more difficult.

Hendrie: Okay.

Feeney: And as good fortune would have it as we moved through this design, we started out with a 16-pin design, but we desperately needed at least one more pin and we at least had-- as the 1103, the 1102 moved to the 1103 in terms of the DRAM, we then had an 18-pin package available because it was the RAM part of the business that drove high volume manufacturing.

Hendrie: Ah, okay.

Feeney: And the 1102-- the 1101 was the first DRAM design that Intel had, a static RAM, 1103 was the second. It was a product that was, it was the first-- it's either a three or four transistor cell. That particular design did not go to production but then the follow-on from the 1103, the three transistor cell did go to production.

Hendrie: Yes.

Feeney: That device had an 18-pin package and suddenly 18-pin package and a slightly larger cavity was available to us.

Hendrie: Okay.

Feeney: And so a lot of things came together at the same time.

Hendrie: But you had a clear die size constraint, if nothing else the cavity.

Feeney: The cavity and the margins and negotiating, or the space around the chip, and negotiating with the packing group on how much space we could steal was a constant challenge.

Hendrie: A constant challenge, okay. Well, so, you know, what were the-- maybe you can go a little bit through the history of the design, you know. You just started and started…

Feeney: Well, the history of the design going back to the time when there were meetings in 1969 and early 1970 between representatives from Intel and CTC, it was through these meetings that the two companies decided what the principal form of the specifications for the device would be. Again, CTC was building their device out of TTL. TTL was fairly expensive at that time and there was some attraction that if they could get on the learning curve with MOS that they might see prices or costs for the device begin to fall, especially with higher level of integration and with as a result lower system cost on the board itself.

Hendrie: Uh huh.

Feeney: So, and so the application group at Intel, mainly Ted Hoff and Stan Mazor put together a specification based on the Datapoint 2200 original specifications and worked out a way that the design could be implemented as a parallel design in MOS.

Hendrie: Uh huh.

Feeney: And so, at the time that I arrived, Stan had developed a spec that laid out the instructions for the device, laid out the basic machine cycle for the device and there'd be a certain varying machine cycles depending on the instruction or instruction type.

Hendrie: Uh huh.

Feeney: In terms of how the registers were being handled, how the interrupt was being handled passing through.

Hendrie: So, he figured out the algorithms for executing them, yes.

Feeney: So, the basic instruction or basic things that had to be done in the machine cycle were defined at the system level.

Hendrie: Uh huh.

Feeney: At the time that I arrived, my job was to take the instruction set itself, implement that into logic and into the 1s and the 0s and the gate level translations that we had to make, figure out how the control signals would work on a chip, figure out how the registers would be set up and laid out on the chip and what kind of registers or any intermediate registers we needed and how we could basically convert the whole thing into an MOS design.

Hendrie: Okay.

Feeney: And deal with timing and other aspects of it. As I noted we were short with one pin. We got partway through the process and knew that we needed to interrupt the processor. We also needed some additional handshaking with the outside world to be able to handle and store away the processor states and the extra two pins gave us the signalling that we needed to be able to move things back and forth.

Hendrie: Okay. So, you had an issue about, yes, being able to store the processor states when you did an interrupt.

Feeney: But it was interesting at that time with the amount of memory we were addressing that we really only needed to use, as far as CTC was concerned, you know, a very limited amount of memory was okay as far as they were concerned.

Hendrie: Really, like what kind of memory, have any idea?

Feeney: I'm scratching my head back right now, I think it's around 32K.

Hendrie: Okay. All right.

Feeney: Absolutely, absolute, I mean nobody really needed more than 16K.

Hendrie: Yes, okay, all right, so that was okay to just have it…

Feeney: That was okay. That was okay at that time because, again, memory was, as you recall memory was very, very expensive.

Hendrie: Yes, exactly.

Feeney: And, you know, the dynamic RAM hadn't taken over from core yet.

Hendrie: Lots of base mini computers, the 32K was the highest they would go and they'd sell lots and lots of 4K and 8K machines.

Feeney: In fact, it may have been limited to 16K.

Hendrie: Yes, okay.

Feeney: I'd have to go back and take a look at the specs on this but, again, relatively small but designed to be stored program and share and permit any mix of stored program ROM and RAM in the memory space.

Hendrie: Okay.

Feeney: So, it could be set up with RAM at the beginning, then stored program, and then more RAM as an example.

Hendrie: Okay.

Feeney: It was completely left to the system designer.

Hendrie: Okay. Was this, now was this a completely static part or was this, you know, was this a dynamic part?

Feeney: No, this was dynamic.

Hendrie: This was a dynamic part?

Feeney: Yes.

Hendrie: So, you could not single step the clock.

Feeney: No.

Hendrie: And it wouldn't work if you tried to do that.

Feeney: No and, again, this becomes a power issue.

Hendrie: Okay.

Feeney: If it were static you'd end up with a device that would be too big and too power hungry and one of the things that we wanted to do was to use the cell for the 1103 DRAM design and use that cell effectively as a register storage and be able to use the off cycle from the clocks to refresh the registers.

Hendrie: Ah, okay.

Feeney: So, we could-- as we were going through and stepping through, in this case I believe it was five different machine states, we could take one of those machine states and very predictably refresh the memory every time through so we wouldn't have any issues about doing special refreshes or anything else as long as the machine was running at a reasonable frequency.

Hendrie: Uh huh.

Feeney: We could easily refresh it.

Hendrie: Okay, so you really made use of that wonderful feature of MOS of being able to store with a past transistor.

Feeney: See, this was part of it. You scratch your head at that time and say, "How do we put this much functionality on a single chip?" And, you know it's an evolutionary type of thing and, if Intel hadn't done the 008 at that time somebody else would have done something equivalent in the near time thereafter.

Hendrie: Uh huh.

Feeney: But, you know, in contrast to today, we were putting 3500 devices on a chip but we were doing that with the process technology at the time. We were doing it with the design tools at the time and today we're putting hundreds of millions of devices on a chip but we're doing it with totally different design tools.

Hendrie: Different set of tools. It was just as challenging to do it with a 3500 in those days is it probably is to do a million transistor design today.

Feeney: Well, I mean today we've got huge teams working on chips…

Hendrie: That's true.

Feeney: …and at that time one or two individuals.

Hendrie: Yes, okay. So, it was a dynamic chip and you tried to use dynamic registers as opposed to static registers for all the registers?

Feeney: Yes.

Hendrie: Same in-- wasn't there a stack, a built-in stack for the program counter stack on the chip?

Feeney: Well, there's a built-in stack for the program counter and there was also a built-in set of registers on a chip.

Hendrie: Yes, okay.

Feeney: And we could go effectively, I believe it's eight levels deep, it's either seven or eight levels deep on the program stack.

Hendrie: Okay.

Feeney: And, in fact, one of the levels, I believe was the program counter itself where it just went in and out of the stack, occupy the one level and then we just kept moving the pointers on the stack to get to the other levels.

Hendrie: Okay, and that was all dynamic too?

Feeney: That was all dynamic.

Hendrie: Okay, well that would make it very efficient, yes.

Feeney: Again, half the number of transistors.

Hendrie: Exactly.

Feeney: Half the number of transistors and smaller transistors.

Hendrie: Uh huh.

Feeney: Both of those kind of went hand in hand.

Hendrie: Yes, okay. What were, you know, were there any, you know, what were some of the challenges that you discovered in the design? I remember talking to Joel Karp about when he was doing the 1102 about the difficulty of the way the design was done and the intermediate voltage generator that had to be on chip and, you know, that was a real, that was a real design challenge. Were there particular design challenges you sort of remember or was it just lots of hard work getting everything right?

Feeney: A combination of both. I mean that's the first time we were putting both logic and dynamic memory on the same chip.

Hendrie: Uh huh.

Feeney: We were dealing with some of the voltage generators and that technology or that approach had been figured out almost in parallel Federico Faggin was working on the 4004 and he developed a voltage pumping scheme that was able to get and use on the 4004. We used that on the 8008 also.

Hendrie: Uh huh.

Feeney: And also another interconnect. Interconnect became a real challenge because in the memory side of things and the work Joel was doing you've got very, very regular arrays where you're running things around and on logic you've got a whole myriad of interconnects using the metal layer and silicon layer. Of course we didn't have multi-layer metal or anything at that time.

Hendrie: Yep.

Feeney: And one of the other schemes that worked out extremely well was developing what they called a buried contact which again gave us a different interconnection scheme between metal and silicon that we were able to again move signals around the chip more effectively, more efficiently, and in different ways. So there were some circuit designs, circuit processing techniques that were done. And the other part of it was just getting the whole thing put together and laying it out, because there was just so much random stuff involved.

Hendrie: Yes, okay. I think we need to change the tape.

Hendrie: We wondered what other details of the design might be interesting to our future viewers. Did you do any logic simulation to try to make sure the logic was going to work before you actually built the chips. There's always the question did I make a logic error somewhere here?

Feeney: All the way through there was always that question and that challenge, and this is kind of what came first, the chicken and the egg. Because the tools that we had available, for the most part we had to build ourself in terms of both simulation tools and also circuit design, circuit response type of tools in modeling the circuits. And in looking at something this size, basically we had to take certain areas that we believed were critical path areas, simulate those. We did some simulation on the instruction set, but again you can only take it so far. And the only computer tools that we had available, I believe it was GE Time Share, so you're working with a teletype over an acoustic phone line at, I guess it was 300 baud. And trying to do things back and forth at fairly expensive rates, also, in terms of the cost of simulation. So there were cost constraints. There were time constraints in doing it, and we simulated as much as we can, but it wasn't a lot. I mean, by today's standards, not even close.

Hendrie: What were your most difficult timing problems? Do you remember?

Feeney: One of the timing problems was in the decoding in the instructions, and trying to get through the decode fast enough to set up everything so that for the most part it all had to be set up in, I think, the first clock cycle, or the first half of the first clock cycle, to know what we were going to do, or how things were going to be routed around the chip as far as the data was concerned.

Hendrie: Yes, okay, to set up all the data paths.

Feeney: Basically to set that up. And we used an 8-bit bus on the chip, so we were basically moving stuff onto the bus, moving stuff off the bus, and sending it out, bringing it back.

Hendrie: It was basically just one 8-bit bus?

Feeney: One 8-bit bus. And so we used it in both directions.

Hendrie: To do the transfer you put on one clock cycle, put the data onto the bus. Get it. And then in another register, clock it into the register.

Feeney: Right. As an example, in the first clock cycle, we would draw in the 8-bit instruction.

Hendrie: Uh huh.

Feeney: And that instruction effectively would tell us whether it was a one-byte instruction, a two-byte instruction, or in a very few number of cases, a three-byte instruction. And so we would then decode that, and then handle the setup for either bringing data in from memory, bringing data in from the registers, and having everything set up and ready to go either for the next cycle, or just to complete an arithmetic operation, and put the result back into a register.

Hendrie: Back into another register.

Feeney: So basically just 8 bits of data handling back and forth through the five separate clock cycles that were there.

Hendrie: Is that how many there were? There were five?

Feeney: There were five cycles, and we used a two-phase clock.

Hendrie: Okay, <inaudible> five cycles. Were there problems with the carry propagation in the add, or did you have to do anything special but make sure the adder could get its job done in the clock cycle it had?

Feeney: I don't recall anything special there, because we set up a carry look-ahead.

Hendrie: Oh, so you already had -- designed it with carry look-ahead?

Feeney: And so everything was- that pretty much propagated through and worked out during the clock cycle time available. And basically again with two-phases and five cycles, we basically had ten different opportunities to do something. And in general, very often on the first phase we'd be pre-charging all of our buses, and the second phase would be moving something from one area of the chip to the other.

Hendrie: Okay, alright, was the control logic, was that basically random logic or did you have some concept of microcode or state machine that stepped through, you know, the order, told you what gates, what paths to open and what paths not to open in a given cycle. Or was it mostly just logic?

Feeney: In general, everything was random logic. But in terms of what to open and what not to open, we had a lot of parallelism in the instructions, parallelism in the way the different instructions were executed, so that we could treat one class of instructions in one way, another class of instructions another way. In other words, any of the instructions dealing with the accumulator were all treated in a similar fashion and all the logic for that full set of instructions was a random logic, but it was all basically in one place.

Hendrie: Okay.

Feeney: And basically I think, if I recall, the way we set it up was through our instruction decoder. We had all of the similar instructions at various points through the instruction decoder, and then the logic associated with each of those, was pretty much the same, except for the one unique difference. If you're moving something from register A to register B, you may always end up moving it through the accumulator, so it looks just like an add, or just like a subtract, or an increment or decrement.

Hendrie: It would be fixed like that.

Feeney: Yes.

Hendrie: To simplify the control.

Feeney: Exactly. Then again, with this it was more a matter of laying it out and getting all the control logic jammed into the space available. It became-- the greatest challenge, I think, was just the floor planning of the chip, and squeezing everything in that had to be there.

Hendrie: Now who did the layout? The actual chip layout?

Feeney: We had two designers, two layout designers, that went through and put this altogether, and did a very, very fine job. You've got to realize, at the time that we did this, as it turned out the 8008 was the last chip that Intel did without any kind of - I don't want to.. necessarily computer aided - but CAD type design tools. In other words, when we did the layout for the 8008, it was drawn at 500 times the actual size. And then the Rubyliths for the chip were cut and it was peeled by hand, and checked by hand, and all of this. Later on they were able to digitize the entire layout and then it was actually cut automatically at 200 times the actual size, peeled and the Rubyliths then went into the mask making. But in this particular case, at 500 times the actual size, cut and peeled, but 500 times the actual size put us at the point where we could only do one-half of the chip on a standard width Rubylith that was available. So we had to draw the chip on two different halves, cut the chip on two different halves, and then basically paste the Rubyliths together on what would be the equivalent of a ping pong table in terms of size.

Hendrie: Oh my.

Feeney: So you've got the Rubyliths stretched out on this ping pong table sized area. Imagine the opportunities for failure with either peeling or not peeling the Rubyliths, but then getting the Rubyliths onto the table, and getting perfect alignment, not just in one layer, but trying to get it all squared up and lined up for the five different layers that we had.

Hendrie: Okay and this was a five-layer process.

Feeney: This was not what you would call, in any way- this is something that would not fit into the elegance that we see today with the designs. But trying to get the alignment marks set. That was part of the goal, too, was to have appropriate margins in the design rules that would allow us to do something that by today's metrics would be quite crude.

Hendrie: Yeah. That's pretty interesting that this was the last one that was done totally manually.

Feeney: Well, we were suddenly getting just- at 500 times the actual size, you're getting to just totally outgrow all of the capabilities that you had. And, again, it's one thing leading another in a chicken and egg situation, where we had to move on. We had to invest in better tools, more effective tools, to be able to develop the chips.

Hendrie: At least somebody was making them.

Feeney: Yes.

Hendrie: You have to be able to buy them certainly. Intel can't do it themselves. So about how long did it take to do this design, and get to the point of the Rubyliths are ready?

Feeney: Let me go through the time cycle a little bit with this, because with the 8008 basically, conceptually it was started in early 1970, before I joined the company. I joined in March of 1970, and by the summer of 1970, the industry was in one of its all too typical cyclic downturns. And some priorities were being reset at Intel and at the customers. And by that time, CTC was backing away in terms of its, how shall we say, the priority that it wanted to put on this chip. And Intel was at the point where it had to also use its engineering resources in a slightly more effective way to get things out. So I ended up never being totally taken off the 8008. But as an aside, at the time that I joined Intel, the 8008 really was called the 1201, which is basically the first custom, random logic device that Intel did. 12- the "1" meant the p-channel MOS process. The "2" meant custom device. And the "01" was the sequence number on the devices. So did the 1201. And I kind of split my time on that with the 1201 going to a lower priority during the summer of 1970. And I did some work on characterization of the 1101, the static RAM that Intel had. The part had been in production quite some time, but we had not gone through a totally full characterization of the part, worst case voltages, worst case temperatures, and that type of thing.

Hendrie: Uh huh.

Feeney: Again, Intel was a small company, and had not instituted the rigor that they have with their products today. So got involved in that. And then I also got involved in- Federico Faggin joined Intel about three weeks after I did. In fact, you asked about getting married. I got married on April 1st, and when I came back from my honeymoon, Federico Faggin was sitting at my desk, and we ended up sharing the pullout trays on these old metal office desks for about a week or two until more desks arrived, and there was more space for the two of us each to have our own desk. And he joined around the first of April to take over the development of the 4000 Series, the 4004…

Hendrie: And it's companions.

Feeney: …and all of the ROM, the RAM, the IO shift register that went with it. And so he started that, and he made very good progress with those devices. There was quite a bit of pressure from Busicom, who was the customer for the 4000 Series, to get products out. So I spent some time working with the development of the test equipment for the 4000 Series, with the thought in mind that that same test equipment would also be the test equipment that we would use for debugging the 1201 when it came out.

Hendrie: Okay.

Feeney: So through that summer-fall timeframe, there was a little bit of work being done on the 1201, but not significant work. And never had much contact with CTC as far as what their intents were, anything else, in terms of using it, but as we went through those times with the downturn of the semiconductor industry, it typically is the fact that you also see a downturn in pricing, and the logic that…

Hendrie: It was the competition.

Feeney: The logic that CTC was using from TI also went down in price significantly, and went down in the dollars-per-gate down to cents-per-gate over that time. And there wasn't as much of a motivation then for CTC to go to a single chip implementation, because at that time bipolar logic was substantially faster than MOS logic. So MOS would have less power consumption, could achieve greater densities, and as an integrated device, be less expensive, but it didn't have the performance. And so CTC was making its trade offs as to whether it wanted to go forward or not. And so that pressure was gone.

Hendrie: Okay.

Feeney: But anyway, we decided to, sometime around- and I'm not sure of the dates on this, but it was either late in 1970 or very early in 1971, we decided to turn up the pressure again on the 8008 to get that out the door.

Hendrie: Do some more research or something.

Feeney: To put my resource back on it full time.

Hendrie: Put re-resource back on it.

Feeney: Full time. And it was either late 1970, early 1971, that the designers were assigned full time to that task, the mask designers, and got the devices out. Again, snapshot overall time frame, the 4004 was announced in November of 1971. The 8008 was announced to the market in March or April of 1972. And that meant with each of those chips about six months before that time, that the devices were functional and were being characterized.

Hendrie: So you went back on it full time. And do you remember when you got to, you know, went out to make masks for the first device? Is that one of those things? Sometimes these dates just…

Feeney: Dates on that I can't remember. I could probably look on some timeline information that I've got. But it would be in that early 1971, or second quarter 1971 timeframe most likely.

Hendrie: Okay, so you managed to finish it up as something you thought was…

Feeney: We got it finished. We got it functional.

Hendrie: What sort of design reviews did you do before you sent it our for mask <inaudible>. Certainly, these days it's a big deal to try to get it right and not have to happen mask <inaudible>

Feeney: There's a huge difference in the size of the wafers, the cost of the masks, and everything today. And the number of masks. In those days we were talking generally about five layers. We did all of the fairly standard things in terms of peer reviews on the overall design, and the concept of the design itself. Also, at the mask level, just very, very intense review, checking, rechecking, of the mask, checking of the alignment, having process people involved that would check on design rules, design rule violations.

Hendrie: Do all those spacing checks.

Feeney: And these are all of the things that are being done today by computer, where the design rules and everything are put in. And in those days, some of these checks would go into the very early hours of the morning. And I recall coming out of the building, and everything looked pink after looking through the Rubyliths for that long a period of time. No matter what you looked at, it was pink.

Hendrie: It was pink, wow.

Feeney: With the 8008 I think the first time through we did not have full functionality. We had some things that we had to check on, but we were able to get into the device and literally, at least the devices were large enough at that time, that you could actually put jumper wires on. You could put a probe down on a metal scratch. Either have something made without passivation on it, or scratch the passivation, and get through to a metal line, and be able to connect a wire or two on the outside, or break a metal line if you needed to reverse the level of logic from a one to a zero, or zero to a one. So those were times you would put on your resume that yes, integrated circuit repairman. But for the most part, it was just a matter of getting the most able people involved for checking, rechecking, and there's never enough checking.

Hendrie: Okay. Do you remember what the clock rate was on the thing?

Feeney: I would have to look it up.

Hendrie: I am sure it's in the spec.

Feeney: But it's something like 200kHz sticks in my mind. So it's just, by today's standards, quite slow. Again, the real objective at that time was to have something that would be fully functional and implemented in MOS technology.

Hendrie: So, you go back and fix the chips, and turn them, and spin the mask another time. When you finally got fully functional parts, and you started thinking about would they actually produce this, how would you do the checking of that. Did you do any set it up or any probing at the wafer level?

Feeney: Oh, absolutely. We want to do as much probing at the wafer level as possible.

Hendrie: How did you go about checking this very complex part. Or are you just looking to see if the process works, looking at the test devices?

Feeney: No. The way we set this up, and this is where the work on the 4004 was quite important, because what we did was we designed a memory and we designed the memory to be basically 8-bits wide. Didn't use the whole thing for the 4004, but we designed an 8-bit wide memory in using Intel's bipolar memory devices. Put a tape reader on it. Basically wrote a program to check each and every instruction, and set it up as a program load for the computer device. As in the case of the 8008, we'd interrupt it, have it go through it's startup sequence, which is built into the chip itself, and then just start presenting it instruction by instruction, not at full clock speed, of course. But going through all the logic.

Hendrie: And you could do this at wafer probe.

Feeney: And we could do that at wafer probe.

Hendrie: Oh, wow. If you get enough probes down.

Feeney: Right. You're only talking about 18 probes. <laughs>

Hendrie: That's true. And it's pretty big of an area.

Feeney: Right. Big probes, big pads. So from a logical functionality point of view, we were certainly able to test the whole thing. From a dynamic functionality we did get into some tweaks and some enhancement even after the part came out to be able to enhance its performance. It originally came out at- again trying to think of the parameters, but it originally came out at one level. Our target for enhanced performance was about 50% higher. And we had to do a little more work to get that next 50%. And we did achieve that.

Hendrie: That's looking at where the slow paths are.

Feeney: It was looking at slow paths, and it turned out in this case there were some issues with the refreshing of the dynamic RAM that became an issue. And this was kind of in parallel with work that was going on in the 1103, in terms of either how often we had to refresh it. And there some issues also with the refresh where, because of the refresh, the entire memory array of voltage was being shifted some way or another. I can't recall the changes that we had to make, but there were some detail things that had to be done in the refresh circuit designs.

Hendrie: Electrical engineering things, circuit design things to get it more stable.

Feeney: These became yield issues. They were not functional issues on the part. Now, going along with this, I made some comments about Datapoint, or CTC at that time, having some reluctance to use the part. The good news with this particular part was that our contract did not commit us exclusively to CTC for the part. And we were able to talk with other customers as we were going through the development. And one of the closest customer relationships we had was with Seiko. And Seiko was doing a very specific calculator similar to the Wang, Hewlett Packard devices of that era. And they were working very closely with us, and they decided as soon as we had the 8008 available, they wanted to put it in their calculating device. And they did. There were either one or two other terminal manufacturers available that were looking at using it.

Hendrie: So you did develop some customers other than…

Feeney: So we had people that were ready to use it as soon as it came out of the box.

Hendrie: Oh, that's good. Great to have some early customers. Get a little volume?

Feeney: Well, two things. One you get a little bit of volume with it, and you also get tremendous customer feedback on what works, what doesn't work. And that becomes both a very effective tool for you to use in marketing the product. And also then becomes the most effective tool you can possibly use for developing your following product. Now from a career point of view for myself, we got ready to announce the 4004 in November of 1971, and then we're ready to market the 8008. And the question was, who was going to market this, and how are we going to handle it? And it was at that time that I moved them from engineering to being the first microprocessor marketing person at Intel.

Hendrie: Is that right? Okay.

Feeney: And did that in January of 1972. The real significant thing there is that you suddenly get a chance to look at a design that you've done yourself, instead of just looking at through your own two eyes, you're looking at it through a thousand pairs of eyes of all of these customers that are out there, that are trying one thing and another. It's just amazing how many different customer approaches there were to working with these devices. And they were creative enough that, well, what if we did this? What if we did that?

Hendrie: Do you remember any of the ones that stuck in your head? Tell us about particular ones.

Feeney: Well, of course, the Seiko situation, and then Sycor was the terminal manufacturer. And so those were the first two customers on the product. And then beyond that, we just had a whole myriad of customers doing anything from traffic control. There were some other- I'm not sure if Beehive worked with that product, or with the 8008. Communication companies using it. Small do-it-yourself computer companies. I think even some of the early Altair stuff may have been, at least bread boarded with the 8008, and then moved to the 8080 when the 8080 came out. So there were a lot of customers ready to use the 8080, the follow on product from the 8008 in 1974 when that product came to the market.

Hendrie: Because had some enhancements and it really was a lot faster.

Feeney: Exactly. It was a lot faster. And the other thing that was significant was that there was some of the external logic that was required around the 8008 was already taken into account and integrated in the 8080. And this is again just the evolutionary process that was going along with these devices from day one. The instruction sets, the instructions for all of these devices really have their roots in that CTC instruction set, and then the implementation of the 8008.

Hendrie: That's interesting. And you started out with a parallel approach, and you never went back.

Feeney: Right.

Hendrie: So CTC had been…

Feeney: CTC was doing everything in serial.

Hendrie: Yes, it was implemented in a serial machine.

Feeney: It was a complete shift register machine. And I think that was part of the discussion also, well, again, I didn't get involved in it. But I think it was part of the goal was how does CTC get transformed as a customer from a serial approach with shift registers to a parallel approach that would enable them to use RAM chips instead of shift register chips.

Hendrie: Shift registers- I've worked with them. I wouldn't go to RAM.

Feeney: Right.

Hendrie: They're more expensive.

Feeney: Shift register was so inexpensive. That's right.

Hendrie: Exactly. They're harder to deal with.

Feeney: But, again, this was the whole thing of, yes, if you're thinking truly in a serial nature you'll take one approach to a design. And the parallel approach gave us a way of really not being as hard pressed for the speed of the device, because we had again in MOS we had limitations for speed, so if we're doing it in parallel, that gives us at least one-eighth advanta- or an 8x advantage in the speed we'd have to be doing in a serial design.

Hendrie: Were you involved in the work, the characterization of the 8008, the work to speed it up? Figure out what the problems that were limiting the performance or did you move right into marketing and start working on that?

Feeney: It was right in that timeframe. I was involved in some of that, and then when I moved into marketing Ben Warren and Federico Faggin did some of the finish up work, and the next spin of the 8008 as far as getting into the market.

Hendrie: Did they have a new number? Was it its performance improved enough to call it something else? 8008A or something?

Feeney: The 8008 was the initial product that was released in the market. And then we did an 8008-1. And Intel used an approach of dash one, dash two, dash three, as special binning, or special specifications on all of their chips. So it was part of a standard numbering scheme.

Hendrie: And so when something had a spec that really made a difference to a customer…

Feeney: Correct.

Hendrie: An improved spec then.

Feeney: Well, an improved spec, or just a bin split. And there are a variety of different ways you get bin splits. One is just to sort them at speed. The other is to actually make a change in the mask set itself to enhance it. And another marketing approach that we used that was interesting- again, I noted that the performance of the processor was somewhat limited. In general, our memories were substantially faster than what we needed or would be dealing with with the 8008. So we actually did a separate bin split on the memories, and selected slower memories that could be used and would be quite compatible with the 8008. And we were able then to attractively price them because they were slower. And match up sets. We began selling kits of parts, where we would have EPROM memory, and generally static memory, because the memories were smaller, so we'd use static RAMs with the 8008. And have a set of parts the customer could use to keep the pricing under control and be able to balance the pricing between the processor and the memories that were involved.

Hendrie: Right. And probably shift memory chips that there might not have been any market for otherwise.

Feeney: In this case, these would have been down-binned chips.

Hendrie: Exactly. So, what happened next in your career?

Feeney: <laughs> I think the real next is that we did the initial marketing for the 8008, for the 4004.

Hendrie: Now, who were you working for when you are doing this? You moved into another…

Feeney: I was working for Federico Faggin and Les Vedez when I was doing the design work with the 8008. And then when I moved into marketing, I went to work for Mike Markkula, who later went to become one of the founders of Apple. And with Hank Smith. Hank Smith later went into venture capital with Venrock, but Hank was running the product marketing group at Intel. And a very short time after we started marketing the microprocessors, we broke off a totally separate microprocessor group that was focused just on the microprocessors, just on the development systems that went with the microprocessors. And so that was in the 1972-1973 timeframe, where we had a focus in that area. And that grew then, especially after the IBM selection of Intel as the microprocessor vendor for the IBM PC that Intel became a microprocessor house and not a memory house. So that genesis started back there.

Hendrie: When you did the split, who went over? Who was heading up the microprocessor marketing at the beginning? Do you remember?

Feeney: I was heading up the microprocessor marketing. And then Hank Smith was heading up a combination of marketing and the development systems. Let's take a step back for a minute. In some of the documents that I've shown you, we start out with a single page spec. Here's the single page spec on the 1201 and by Intel custom, everything about the device had to be in the single sheet of paper. But we all know from a computer point of view that it's almost…

Hendrie: That would be unreal.

Feeney: It's almost impossible to have everything in an entire book, let alone on a single sheet of paper. But Intel being a semi-conductor company was very focused on having the single sheet of paper. And, in fact, so focused on that and data sheets, that even when we brought the 8008 to market, the very first question Bob Noyce asked, was you've got the user's manual here for the 8008, but where's the data sheet? Shows the pin-out, shows the timing signals. And that's basically the things that are on the data sheet. And we were more focused on having the user's manual ready so people could program it and begin planning for it, than worrying about all of the timing diagrams and wave forms and all of the things that would take it to worst case characterization type of thing.

Hendrie: Okay.

Feeney: So in a way, it shows you a little bit of the mind set, going from one type of company to another. And, of course, if Intel had been in a position, or had the foreknowledge of how all of this would work out, the fact that you need a 100-page user's manual, and you give away tens of thousands of these, if you need some kind of a development board, you need the software for it. You need to develop an assembler. You need to develop debuggers. You need to develop tools for the customers to use. If may have certainly delayed their entry into this type of business since it was a business that was so foreign. But we got in there and boot strapped our way into the business. And in doing that boot strapping, we learned a lot about the business, and it was the foresight of even somebody like Dr. Noyce to go through and when the 8008 was ready to come to market, we didn't even have an assembler for it. And he happened to meet an assembler writer, and funded- you know, it wasn't one of these things that went through channels or anything else. It was the president of the company saying, here's the money, go write an assembler for a microprocessor.

Hendrie: Yes, we need this.

Feeney: We need this. It's a tool that we need.

Hendrie: Who was that <inaudible> Do you remember?

Feeney: I just remember the name was Michael Grey(???). And he had an office in Palo Alto on San Antonio Road. And he wrote the original assembler back in 1972 for this device.

Hendrie: Oh, my goodness.

Feeney: Trying to remember these names is extremely difficult.

Hendrie: That's anomia. Inability to remember proper nouns.

Feeney: Right.

Hendrie: Comes with age.

Feeney: This is the foresight that Noyce had. And he just did it. And it was things like that being done at the right time in the right way, and what Intel did was create the environment for these things to happen. And so all of these tools and everything were built around the microprocessors, because we found out that we need them. We had conducted seminars to teach customers how to use the devices. We then built up a training program and taught- had formal training for customers on how to use and how to program Intel microprocessors. Each step along the way was kind of a peeling of the onion and learning more about how to do all of this.

Hendrie: I think we need to change the tape.

Hendrie: What I think I'd like to do is continue with your story and, you know, maybe we can work through and get up to the current time. You want to try to do that? You're now in the marketing department at Intel and you're going out and talking to people and trying to explain how this works and write articles and do all the things that marketing people do.

Feeney: The real challenge of marketing at that time was that we were trying to teach people how to do things in a way that was totally different from the way that they had basically done design in the past. It's more getting people to think in terms of either using software to control their tasks as opposed to just using gates and signals and flip-flops to capture things and alter their design. So, that became a major challenge during that point in time and it was also a difficulty from selling semiconductors where you would go through a huge initial rise with putting chips into the marketplace and then basically never market lull for about 12 to 18 months where customers are developing their designs, developing their products. And then after that point, volume would take off and that was in some respects a difficult concept again for Intel to grasp because it was a company that was accustomed to putting memory chips out into the market, having memory chips designed in over a six-month period and then having volume take off.

Hendrie: Yes.

Feeney: It was also a challenge with the companies that we were dealing with in general. The marketing, the companies that became memory customers were generally selling larger systems, larger computers and they were well known companies. Given that we had this opportunity or should we say a dislocation in terms of the way the design were being done, small companies had just as much of an opportunity as large companies to develop new designs and bring products into the market. In fact, small companies often were a bit more flexible and a bit more aggressive in getting products to the market. So, I recall in one occasion standing(???) with our vice president of marketing and he was trying to counsel me a little bit from a marketing perspective, telling me that if we look at Intel's customer portfolio, it kind of reads like who's who. And then he would look at the microprocessor portfolio customers and it kind of read like who's that?

Hendrie: Yes.

Feeney: Again, a cultural thing that the company had to get through and, of course, as we look back at history today, Intel has learned very, very well how to deal with developing markets, designing products and managing and monitoring design wins, not just the amount of products shipped out the door. Developing the, nurturing of new customers of new markets, which the company is very good at today and all these things have their roots going back to the early 1970s and the first, released the first microprocessor products.

Hendrie: Uh huh.

Feeney: And many of the things that we started at that time were a bit difficult. They've all been institutionalized. If you look at any of the Intel microprocessors coming out today, they've got a number of volumes in terms of books written about them. There is no such thing as a one-page data sheet anymore, so cultural changes all the way through.

Hendrie: Wow, yes.

Feeney: But in my career went through with the initial marketing, all of the marketing of the 4-bit series and the microprocessors that became the path for microcontrollers for Intel and then the path that became the microprocessors for Intel would be 008, the 8080, the 8085 and then after the 8085 was launched, I moved into some other area at Intel and other groups came in and launched into the 8086, which then became the genesis for the IBM PC designs of the future.

Hendrie: Uh huh. Okay. All right, good. So, you moved, when you moved out of marketing what did you end up? You stayed with Intel for a while?

Feeney: Yes, I stayed with Intel. I was with Intel for about 14 years.

Hendrie: Okay.

Feeney: So, I still stayed in marketing but I got involved in business planning, forecasting and more of the business aspects of things as opposed to the market development side of things.

Hendrie: Okay.

Feeney: And…

Hendrie: The promotional and market development.

Feeney: Yes, I got involved very heavily in business development, in forecasting and planning with both our development systems and with the microprocessor side of the business.

Hendrie: Okay.

Feeney: So, got a system feel and a chip feel out of the whole thing.

Hendrie: Good.

Feeney: And then I left Intel in 1984 and Intel was in the early 1984 time frame, basically Intel was going through another huge boom. Everything was sold out and…

Hendrie: Really?

Feeney: Things were just growing like gangbusters at that time. I left in the fall of 1984 and decided I wanted to get involved in the-- I had an opportunity to really manage and run my own business and I had that opportunity with a business or a marketing research company called Dataquest.

Hendrie: Yes, I know Dataquest.

Feeney: And Dataquest was starting a group to focus on technical computing and I went to Dataquest, started the technical computing service or joined with Brad Smith who was already there. We started a technical computing service and then I ran that for a couple of years and this was just right on the heels of workstations coming up and making them work, the Suns, the Apollos and all of the other workstation companies.

Hendrie: Yes, exactly.

Feeney: That were driving the market at that point in time. And so it gave me a chance to run my own business and have a lot of fun doing it. In the late 1980s, Dataquest reorganized and I ran the-- moved the technical computing back into the semiconductor industry and ran the semiconductor market research, which was really the largest group at Dataquest and the original technical group that was formed there and we had a number of groups all over the world focusing on the semiconductor marketplace, all of the different users from European semiconductor service, the Japanese semiconductor service, an Asian semiconductor service that we were just taking into China at that time and then the entire group that was here in the U.S.

Hendrie: Oh, that's fascinating, from chip design to market research.

Feeney: Chip design was kind of the cat bird seat of everything that was going on in the semiconductor industry and Dataquest, as its name implies, was into data. When I first joined Dataquest, we were not too heavily into data but we got more and more involved in that area and so in 1990 when I left, I joined another colleague of Dataquest, in fact the fellow who started the semiconductor service at Dataquest Fred Zieber and we developed a company called Pathfinder Research and spending more time focusing on what the data means, what the information means and looking at strategy, looking at emerging companies in the semiconductor industry and consulting to a number of these companies.

Hendrie: Uh huh, okay.

Feeney: So, it's been a pretty wide range going from….

Hendrie: It sure has.

Feeney: Designer of the chip side to basically dealing with large companies now who are driving, building, growing the semiconductor businesses and, at the same time, going from 3500 transistors on the 008 to 300 million or more on the newest microprocessors that are on the market.

Hendrie: Wow, that's true. That's pretty amazing for an industry to have that much change in so short a time when you really think about it.

Feeney: In a way it's really scary because, I mean you can draw the curves, you can follow Moore's Lay through all of it, but to be able to deal with it and to be able to-- I think the wonderful thing for all of us in the industry right now is to be able to utilize the tools that we've worked on or the outgrowth of those tools. In the early days, you pointed out, a lot of things were oriented at military systems and most of us can't have military systems in our homes but to be able to have the computers, the settop boxes, the audio gear, the printers, be able to have the cameras and do our own photographs, having all of this come out as a result of some of this early work I think is, to me it's exciting.

Hendrie: Yeah, it really is. Well, that's wonderful. Thank you very much for going over your career in this oral history for the museum. I really appreciate you taking the time. What I would like to do is maybe we'll turn off the camera and, if we could just maybe have you go through some of the materials you have, so we can sort of hear your comments and, you know, that's a lot better than that part of the tape we can bring out if and when they arrive at the museum at some later time and we'll have you talking about them on tape, all right?

Feeney: Very good.

Hendrie: Good.

Feeney: Thank you very much.

Hendrie: You're welcome.

<Camera shows framed Intel 8008 photomicrograph>

Hendrie: All right, we're on. Well, why don't you tell us a little bit about what we're looking at here and then maybe you can go over some of the different pieces and where the data path, the main data bus is, et cetera.

<Camera pans around the photograph>

Feeney: Okay. Well, this is a photomicrograph of the 8008 chip and we took this and blew it up to a large size and our intent was to be able to use this as a marketing tool to show customers or prospective customers exactly what some of the elements or some of the functions were that were included on the chip itself. Now, this being an 8-bit chip and with having the constraints that we had on the pins of the device, we've got an 8-bit data path that runs all of the way around the device and gives us a path from our memory, in this case our register memory, our instructions or our program counter stack, our decoder for our instructions and our instruction register and our adder. All of these elements are carried or tied together with the 8-bit bus. At the same time, we've got the 8-bit pins coming to the outside world indicated by these pads around the outside of the chip. And these pads or the pins to the outside of the chip were bi-directional, which means signals came in and came out relative to external memory. The signals to external memory had to be controlled by certain clock cycles and the clocks coming into the chip were a two phase clock, shown down here in this corner, and also the information coming in or going out had to be controlled and had to be known to the outside world, whether it was going in or going out with these particular state pins around on this side of the chip. So, the whole purpose of this drawing was basically to show the instruction register, the instruction decoder, all of the random logic that is used to control the arithmetic unit, all of the random logic that is used to control the registers in the chip. These are, again, 8-bit registers and there are eight of them and the program counter stack also under the same control .

Hendrie: There's also some-- you used carry look-ahead logic did you to…

Feeney: Yes, we did. We built the carry look-ahead logic because we needed the speed as far as the processor is concerned so carry look ahead seemed like something we could integrate and have fairly low real estate overhead and, as you see, the whole carry look ahead is just a very small portion of the chip.

Hendrie: Uh huh, very good. Now you had mentioned something that the original spec you had made a couple of changes in this from the original spec that there weren't as many, there was one less output pin, is that correct?

Feeney: Well, in the original specification for the chip we were working under a constraint in 1970 of only having 16-pin packages available for this particular device, so that put us under constraint both in terms of chip size and also a constraint in terms of number of pins. With the advent and the planning for the 1103, which went into an 18-pin package, again the goal was to work with high volume Intel packaging and that gave us two more pins available, which we desperately needed. One was an extra pin, an extra state line that would be available and the other was a synchronization line with our clocks. Again, we had two phase clocks but we had five states to deal with and we needed to know in terms of the clocks, we needed the synchronization with the clocks to know what part of the states we were in at any given point in time.

Hendrie: Uh huh.

Feeney: And, again, this had to do with the handshaking with the logic on the outside of the chip and realize now at the time that we were doing this we were using SSI logic outside of the chip and so we had small 16-pin packages with flip flops and gates that occupied the same physical side on the board that our entire microprocessor did with its 3500 transistors in the-- implemented in LSI [Large Scale Integration].

Hendrie: Okay. Now you had mentioned that one of the things that at this period the chief designer of a chip managed to get his initials, figure out someplace to put his initials on the mask? Are yours on this and, if they are, can you show us where they are?

Feeney: This was an opportunity for a number of us when we were doing chips and, you know, this is, again, in contrast today with the large teams of individuals that are involved in doing chips today, in those early days generally it was one designer, one chip. And, in this case, I had the opportunity leaving my initials on this device and they're up here in the upper right-hand area of the chip itself.

<Camera zooms in>

Hendrie: Oh, okay, there they are, good, HF.

Feeney: Okay.

Hendrie: And we also, this is an early, relatively early mask before marketing had figured out how they were going to market this, so I note that it is listed, shown as a 1201.

<Camera zooms in>

Feeney: That is correct. The number is right here on the side, 1201 is etched into the mask and in later implementations, later mask sets 8008 was etched in as the number for the chip.

Hendrie: Okay. All right.

Feeney: And, again, this is undoubtedly one of these that photograph or photomicrograph that came from the very first run of wafers. So, we had our wafers, we had everything available and we wanted to get it out and get information in the marketing hands as quickly as we possibly could.

Hendrie: Very good. Yes, I notice the date is before the formal announcement of the chip too.

Feeney: Right. The data, there's a check. Okay, I think this is something that we put on for the marketing side of things and later on the-- someplace implemented on the later mask there would be a copyright. Here we just show a trademark on the device, but and that's why we put it on this print so that we could do prints of the photograph and get those out.

<Camera zooms in>

Hendrie: Okay, very good, excellent. All right, thank you. Let's move on and look at a few more other things.

<Camera shows Hal Feeney seated>

Hendrie: All right, good. You have some things that, some treasures from history that maybe you can show us.

Feeney: I'm not sure if we can call these treasures but they're certainly a few unique things in my collection. This is my engineering notebook.

Hendrie: Okay.

<Camera zooms in>

Feeney: Where I had all of the historical stuff that we did for what was the 1201 that became the 8008. But the one interesting thing in here happens to be a specification that was written on the 4th of March in 1970. I joined Intel on the 9th of March in 1970 and the specification was written by Stan Mazor in the applications group to basically implement the specification for the Datapoint 2200, which is the CTC machine that the 8008 was being patterned after.

Hendrie: Uh huh.

Feeney: And so, here we've got the specification. This happens to be clearly pre-word processor days and written…______.

Hendrie: In pencil.

Feeney: Written in pencil by hand and…

Hendrie: That's a company with no secretaries.

Feeney: The entire spec is laid out and there were two or three secretaries in the company at the time and obviously none of them had time or the inclination to take all of this verbiage and put it into…

Hendrie: They probably all worked in sales.

Feeney: I think the one that was available for us was actually working directly for Andy and Andy was running the manufacturing at that time, so it was a very, very limited resources. But this became our first spec and it was from this spec after I joined Intel that I was left then to develop or move from how we would develop and take this spec into the implementation in silicon .

Hendrie: Okay, very good.

Feeney: So, we started out with the handwritten spec. We went through about a year, a year and a half of design, development and planning. The outcome of that, of course, was the 8008 chip itself and the spec then became the 8008 user's manual. As I noted earlier, we had historically it was the goal to have a single page data sheet available and it's very, very difficult, of course, to characterize the computer within a single page data sheet. So, the 8008 was completely characterized with this user's manual and provided information both electrically on how to hook the device up and also information from the point of view of instruction set on how to use the device. So, we put one big data sheet with features on the first page and then we came in with the full table of contents and basically how to use the 8008 and we always spent a lot of time in that era of showing people what complexity of what we had and, of course, the complexity just keeps getting to be more and more complex along with following the pattern of Moore's Law. So, this was designed as marketing collateral but went into the hands of hundreds and hundreds of customers and all of these books at that time were given out. Now it's interesting how the entire microprocessor business has developed into not only the giving out of books but sales of books. And, I'm not sure how well you're going to be able to see this. Here we've got a collection of 8008 chips and a few of these in this box have the lid off. It was designed, these are some rejects that we were able to get just giving us an opportunity for some show and tell within the package itself.

Hendrie: Uh huh.

Feeney: So, we've got the ceramic 18-pin package with the chip inside and then the one next to it is completely sealed, bonded and marked.

Hendrie: Okay. Can you just-- let's see. I'm just going to bring.

Feeney: How can you get these best?

Hendrie: I'm going to just bring it forward a little bit and maybe we can get a little close-up here. We don't want to lose it. I will pick that up. Okay, let's see what we can see here. The editor will have fun editing this.

Feeney: Right.

Hendrie: Okay, good. All right. There you go and let me give you these two. Fortunately we don't have to make them work, so the fact I don't have a static wrist strap probably is not important.

Feeney: And then with that the other thing that's striking we made strides also from the manufacturing side of things and we've gone from basically the size of wafers that were like large mints and today's wafers are the size of pizzas. This is an original 8008 wafer, probably an original 1201 wafer and it was a two-inch wafer.

Hendrie: Very good.

Feeney: And later on the 8008 did move to three-inch wafers and that's maximum size that it went to in its lifetime.

Hendrie: Do you remember about how long the 8008 was manufactured and offered for sale?

Feeney: It was-- we had a number of customers that were using it and, again, the volumes of the 8008 were somewhat limited. Kodak was using it, as an example, in a copying machine and it never had very much volume but became a controller for a copying machine. And I know that that was sold up through the 1970s.

Hendrie: Okay.

Feeney: And I believe the manufacturing of the 8008 in limited fashion went up sometime through probably about 1978.

Hendrie: Okay. Was that-- that was during the transition. Eventually you must have shut down the PMOS [p-channel MOS] line.

Feeney: The PMOS was shut down. I think it was a PMOS line that was probably more of a control on the manufacturing of any of these products than it was the success of the product itself.

Hendrie: Uh huh, okay.

Feeney: But certainly the average selling price in the 8008 stayed up somewhat higher than the microprocessors of that time because it was made in such low volume and was really for the most part being manufactured just to meet specific end of life customer needs for some period of time.

Hendrie: And the customers were willing to pay because of the redesign cost.

Feeney: Yes, the redesign cost would be extraordinary and a little extra cost in that processor was insignificant in most of these designs.

Hendrie: Do you remember what the average selling price was of the, you know, in modest quantities in that era of the 8008? That's probably a memory feat that may be too difficult.

Feeney: Yes, that's scratching back a little bit but to kind of characterize this the 8008 was originally announced somewhere around $120 for the 8008 itself, 8008-1 then it went to $180 and these were, this was for sample quantities.

Hendrie: Uh huh, yes.

Feeney: Very likely that we're talking about prices in the $30, $40 range for these products. Again, that's kind of a guess.

Hendrie: Okay.

Feeney: But when the 8080 was announced the sample quantities of the 8008 were at $180 for the 8008-1. The initial 8080 pricing was at $360 because it was substantially better, substantially higher performance, a matter of 10x performance higher, so some of these devices did relate to each other in price and, of course, then the 8080 became a very, very high volume microprocessor and the chip prices on that got down into the $10 to $20 range.

Hendrie: Okay.

Feeney: In bulk.

Hendrie: But the initial pricing, we see Intel's pricing today and strategies even back in the mid 1970s.

Feeney: Yes, well, and that's one of those things that Intel learned as it grew and developed as a company that it became very comfortable with pricing on value not just pricing on cost. There was a great propensity at that time to drive semiconductor prices based on the cost of the chip for the cost of the silicon when you got into high volume. In low volume it was a totally different story.

Hendrie: Uh huh.

Feeney: In low volume it was strictly a matter of looking at what the costs were, what the special handling was and not necessarily pricing what the markets would bear because in low volume there was never a good market model to use. But in high volume, there was a good market model and the theory always was that if you drive the price down, you expand the market dramatically more than the difference you'd take in lower average selling price. So, at Intel, the average selling prices were drifting down in the tens of dollars during that time frame and what Intel and its competitors wanted since is that there's so much on the silicon now that there is a certain amount of pricing on value as well as pricing on just the pure cost of the silicon.

Hendrie: Uh huh. Okay, good. One other thing. You had indicated that stored away those are-- that your notebook has some fascinating things in it. We've had, you and I had an opportunity to go through some of the other things but you said you also had a significant number of documents relating to the patent litigation that occurred in, was it the 1990s?

Feeney: Yeah, it was around 1990, 1990 through about 1991-1992. There was significant patent litigation between TI [Texas Instruments] and a number of microprocessor vendors and the patents at the heart of this dispute were patents that were related to an implementation that TI did on a variant of the 8008 design.

Hendrie: Uh huh.

Feeney: And, all of that litigation was settled without going to court so there never was a settlement but there were a certain number of depositions taken, depositions of Vic Poor, of Ted Hoff, of Federico Faggin, of Stan Mazor, of myself, I believe Gary Boone and several other CTC designers. And, it's just squirreled away in my archives I do have some of these depositions.

Hendrie: All right, well we hope that at some point you will be inclined to donate them to the museum. They would be a wonderful treasure trove of documents that you have here.

Feeney: Well, I think this is a wonderful treasure trove and the one thing that we should take a look at is to make sure that there is nothing that is in any way of a restricted nature.

Hendrie: Uh huh.

Feeney: But there certainly should be a home for these documents and they'd be much better in a museum than in my barn.

Hendrie: All right.

Feeney: And, also coupled with that, by the way, you have got those documents but there are also a substantial number of documents and exhibits that were pulled together by the attorneys. And again, I believe almost all of these have no restriction on them whatsoever.

Hendrie: Okay.

Feeney: And so, I leave it to the attorneys associated with the Computer Museum to figure out what they should accept and what they should not accept.

Hendrie: All right, very good. Well, thank you very much for your time. It's been a pleasure, very enlightening. It's wonderful to have an oral history of the designer of the first of an incredibly long line of 8-bit microprocessors, Hal Feeney.

Feeney: Well, I certainly appreciate the opportunity of being involved and assisting the Computer Museum with this.

Hendrie: Thank you very much, Hal.

eeney: Thank you.

<Next recording>

Hendrie: You were mentioning some of the people that were involved in the applications in marketing.

Feeney: Yes, one thing I was thinking in our discussion about how pervasive some of the microprocessors have gotten. There are so many different applications running the gamut from microcontrollers on out that it may be very worthwhile for you to contact the very early marketing people that were involved at Intel getting the microprocessors into the market.

Hendrie: Uh huh.

Feeney: Ken Mackenzie is one name that was one of the very early folks that I hired as a product marketing engineer. And another one is Dane Elliott. Dane was actually the first marketing person I hired at Intel, worked for me in the microprocessor area and Dane and Ken also had a lot of involvement in the early seminar times and working and doing handholding with customers as they were designing the products. One other name that comes to mind is an engineer at Unisys or it was Univac at the time in Salt Lake City. His name is Ron Bell.

Hendrie: Uh huh.

Feeney: I believe he's now with a small consulting firm here in the valley but he was one of the very early users and might shed some light and some perspective on how a user looked at using the 8008 system.

Hendrie: Do you know what product he was doing?

Feeney: No, I don't.

Hendrie: Okay.

Feeney: Part of his work was in the labs of Unisys.

Hendrie: Ah, okay.

Feeney: Or Univac and I'm not sure the path the 8008 took into products.

Hendrie: Okay.

Feeney: But I did see prototypes of terminals at the time.

Hendrie: Okay. So it might have been terminals. That would a natural application. Okay.

Feeney: Essentially the terminal was the most natural because it was a character-oriented device or character-oriented screen and the 8008 was designed as a character manipulator.

Hendrie: Yes.

Feeney: This is the big gap between the 8008 and the 4004. The 4004 was really oriented handling BCD [Binary-coded decimal], handling numbers, and the 8008 was oriented handling characters. That put them in two totally different realms as far as the way the devices would be used.

Hendrie: Yes. One thing I did forget to ask you was the names of some of the other people that sort of worked on the project. You had mentioned you had a couple. Did we cover the names of the two layout people? You said that…

Feeney: No, we did not.

Hendrie: Yeah. Do you remember their names?

Feeney: Julie Hendrix and Rod Sayer.

Hendrie: Okay.

Feeney: Were the two folks who were involved.

Hendrie: You probably spent lots of long hours with them.

Hal Feeney: We spent lots of long hours together. Rod I haven't seen since the time of that project. Julie I've seen from time to time and she is up to at least five or seven years ago and still been involved in doing designs.

Hendrie: Is that right? Oh, wow, so she made a long career with that.

Feeney: Certainly Ted Hoff, Stan Mazor in the applications group who were two key individuals and of course Federico Faggin.

Hendrie: Uh huh.

Feeney: All his guidance and help were incredible critical.

Hendrie: Okay.

Feeney: And the finish up phase and getting ready for market Ben Warren.

Hendrie: Oh, okay and Ben worked in the...

Feeney: Ben was an MOS designer at Intel also.

Hendrie: Okay, all right, he's…

Feeney: He worked with Federico.

Hendrie: Okay, so he did some of the-- and did he work in some of the characterization work and things like that?

Feeney: I'm not sure who did, whether-- I'm not sure where the full characterization was done.

Hendrie: Yes

Feeney: Whether that was done, I'm not sure whether that was done by…

Hendrie: Yes, you were off in marketing by this time.

Hal Feeney: I was off in marketing by that time.

Hendrie: Yes, somebody had to do it because of all the drive to get the yields up and you aren't going to get the yields up unless you…

Feeney: Yes, I'm not sure whether it was done...

Hendrie: Figure it out there.

Feeney: ...in engineering or in product marketing.

Hendrie: Yes, okay, good. Well, thank you.

Feeney: But I'll certainly be happy as we go beyond this, a number of us can put our heads together and come up with names of people. Because, as I said there were so many people that were involved that really made it a success.

Hendrie: All right. That usually takes a team to do these things.

Feeney: Yes, it does.

Hendrie: Thank you.

END OF INTERVIEW

