Oral History Panel on the Development and Promotion of the Motorola 6800 Microprocessor

Participants:
Thomas Bennett
John Ekiss
William Lattin
Jeff LaVell

Moderated by:
David Laws

Recorded: March 28, 2008
Tempe, Arizona

CHM Reference number: X4584.2008

David Laws: This is David Laws. I'm with the Computer History Museum in Mountain View, California, and we're here today with members of the team at Motorola who helped develop and introduce the Motorola 6800, one of the first, and one of the most important microprocessors of the early 1970s. I'd like to start off today by asking each of the panel members to introduce themselves. Give a little background on their role at Motorola, and how they came to join the project. John, could we start with you?

John Ekiss: Yes, thank you. My name is John Ekiss. At that time at Motorola I was the General Manager of the MOS Products Division, and we were searching for new state of the art products, and the microprocessor arena looked like a good one, which we're gonna cover in a lot of detail today. My particular background, I started work in Motorola in 1970. I had entered the industry in 1958, which was ten years after the first transistor was invented. And I was educated at Carnegie-Mellon University with a bachelor's and master's degree in electrical engineering, which was kind of appropriate for the work I wanted to do. I started out as applications engineer. For a while I designed integrated circuits. I was involved in process engineering, so I had a fairly broad background. But I came to Motorola to start the MOS projects group. And found there were a lot of opportunities. It was a very exciting time in the industry. There was a lot of new technology coming out, and we wanted to be at the forefront of that, and build a whole new business for Motorola.

Laws: Thank you. Tom?

Thomas Bennett: Thank you. My name is Tom Bennett, and I graduated [in electrical engineering] from Marquette University in Milwaukee, and worked in the telephone industry on an all electronic telephone exchange in 1960. And then I worked in circuit design, hardware design in industrial control applications for controlling gas pipelines and electrical utilities. And from there I went into the calculator game, and started the first working electronic calculator for Victor Comptometer. And that took us into MOS calculators. We worked with various semiconductor vendors on designing custom chips, and that's where I got to know the people of the industry. In 1971, I joined Motorola to put them into the calculator business. And when I got there, they had like four chips working, or [were] working on four. (None of them, I don't think were ever delivered in volume.) In addition to that, I had the responsibility of quoting all these custom LSI chips for potential Motorola customers.. They'd come in through marketing first, and then marketing would say, "We should look at this." And so I got to see all sorts of crazy designs and things that could never be built. And then a custom IC CPU chip from Olivetti come in, and we quoted that and won that and did the design in PMOS and that went to Mostek because we could not process it. And that's the old Mostek PMOS three-level interrupt on the same chip system. And then after that we started on the 6800.

Laws: Bill, what was your role and background?

William (Bill) Lattin: Okay, I'm Bill Lattin. And actually in 1969 I just finished a master's degree at Berkeley, and my last year at Berkeley I was a married student. I was on a GI Bill, and so I was in a hustle to get through. But I saw this course called the Physics of Semiconductors taught by Andy Grove. And so I went to him and asked him if I could audit the class. And he hated auditors. And he grilled me and grilled me about why I was gonna audit, and I said, "I'm just finishing my thesis. I'm pressed here, but I'd really like to know more about surface devices." That caught him. He was a big surface guy. So he let me audit his class. And so I finished in that summer of '69, and got a job -- I had already interviewed and I was going to Motorola because I wanted to finish my PhD at Arizona State, and that's something that they allowed. And so I showed up August of '69, uh.. big beard, Berkeley beard, you know? I'd shave for interviews. And Jerry Fulton, he was the guy who he kind of told me to 'lose the beard.' And so I did a couple of rotations and I ended up in this new MOS group. And there was a guy there who was teaching how to design MOS, and actually I'm gonna donate this book to you, but this is the book we used. 1969 version of how to design. {insert book title here] But a spark tweaked with me right then that this is a bad way to do competitive designs. And Don Pederson [Donald O. Pederson] at Berkeley had done quite a bit of circuit simulation stuff, and so I put that in the back of my mind and said, "We need a circuit simulator." And so I chose the MOS group as my permanent slot, and I went into that group, and because I'd had some military experience, it seemed like I moved up pretty quickly, and pretty soon I was the Design Manager, and I also had all the CAD tools, so we did all the characterization, and all the design. And that was about the time that we were doing memory design, we were doing a copy of the 1102 first and then the 1103. And Phil Richards and I were kind of the experts on memory testers and memory design. And it was very difficult for Motorola to process this stuff. I mean, they had a lot of, you know, processing problems.

Laws: I don't think it was unique to Motorola.

Lattin: Well, it was challenging at Motorola.

Laws: Thank you, Bill. And Mr. LaVell.

Jeff LaVell: My name is Jeff LaVell. I came to Motorola in 1966 from Collins Radio Company. I graduated from the University of Arizona, went to work for Collins on their C8500 computer. And we had done the first prototype design with Motorola's emitter coupled logic, ECL. And then Collins wanted to standardize on a logic family that they could use throughout all their products. All their avionics as well. And so they ultimately migrated to Sylvania T-Squared L [Transistor Transistor Logic – TTL] And so Motorola got into the business of being the alternate source. And I developed a fairly good relationship with Motorola, and was very impressed with them, and had grown up in Arizona, and Iowa is cornfields and beet fields as opposed to mountains and...

Lattin: Dust storms.

LaVell: Dust storms, right. My wife and I had talked about coming back to Motorola as soon as we -- or coming back to Phoenix as soon as we had our kids. So we decided to come back in 1966. I came in as an applications engineer as well, John. And I was doing transistor-transistor logic for Motorola, and then they started forming [an] interesting marketing organization. So they took some of the applications engineering folks, and because I had some computer architecture background, I was assigned to the computer industry marketing organization, and we worked during those times with CDC and Digital Equipment Corporation and Cray. So part of our function was to go to look at the market opportunities where the growth segments were. And we'd done a quick analysis of the various industry segments in the computer marketplace, and found out that there were communications -- what we called communications-oriented peripheral equipment. And we did some analysis on that and decided that the biggest way we could impact that was to cram everything onto chips as much as possible. And so we designed a family of programmable building blocks, and did that in conjunction with Bill and Tom. And we coordinated software specifications for the architecture and the hardware systems specifications.

Laws: John, earlier, you were giving us background on the status of the industry at the time, and what was going on in the company. Could pick that up now for the camera?

Ekiss: And elaborate on that some?

Laws: Yes, we did not film any of that.

Ekiss: Okay. Well, the semiconductor industry grew out of the invention of the transistor in 1948, and by the time I got into it, it was 1958, and then fast-forwarding to the early 1970s when this project started to get some inkling of ideas. There had been an enormous amount of development, and a lot of companies had sprung up to attempt to get into the various segments of the semiconductor component business. Intel was started in 1968 to prosecute semiconductor memories. Motorola was -- had been started many years before that, and had started into a discrete component business, and were branching out rapidly into bipolar integrated circuits. Then I got involved with MOS products which is the subject of this video on the 6800. So it was very competitive. There were multiple companies working on their versions of microprocessors. Signetics I recall, was one. Intel certainly, I think, was out with the first one. And Motorola, it was timely for us to get our act together and get involved in that. We had the right technology under development. We had a good organization put together. There was a fair amount of turmoil organizationally within the industry because of the growth rates and people switching around, and some companies doing well, some failing. So there were always a lot of problems. Motorola among them. And we always fought to overcome these, and move ahead with our project. So it was a very interesting time for the industry.

Laws: And probably a particularly turbulent time for Motorola because of the loss of top management in the late ’60s that had to be filled somehow in the company.

Ekiss: Yeah, I’m sure that that-- I think there were eight-- a group of eight left, [Lester Hogan and his associates to Fairchild] and I’m sure that that was a portion of the problems caused by the lack of senior management who had the maturity to manage the kinds of things that were going on at that time.

Laws: Although, quite often that allows other things to bubble up

Ekiss: Opportunities arise.

Laws: Jeff, you mentioned about defining programmable building blocks in your area. How aware were people at Motorola of things like Lee Boysel’s work at Fairchild on multiple chip approaches to CPUs?

LaVell: We had been tracking that information. But one of the things that we had -- where we had gotten most of our information from, our architectural information, from was a real requirement in the computer peripheral market. That was an era where you started first thing [with] intelligent CRT terminals, and so the various computer industry groups that built peripherals like that were some of the targets. Hewlett-Packard was doing a bunch of stuff. NCR, National Cash Register was doing point-of-sale devices. And so what the industry marketing segment did, at least the computer industry marketing segment did, was targeted -- we had the marketing guys, and Link Young was one of those-- we all worked for a gentleman named Doug Powell who had come from G.E. and was a crazy guy, but very, very highly motivating kind of guy. And so he had his interesting market folks to find the high growth rate segments of the market, then he targeted us, engineering -- we had two groups. I had a systems engineering group with probably about 15/20 people, and then there was an applications engineering group about the same size. And we targeted the high growth rate market segments, and we got their computer, and their equipment in. The high end, medium, and the low cost and tore them all apart and looked at them and said, "What levels of integration could make the greatest impact on cost in the systems?" And it became very clear that the higher level of integration was the key to that. That bipolar circuits weren't gonna get there, because you know, we were building T-Squared L gate arrays and you could put your finger on and burn your thumb off. And so the technology had to be the MOS-type technology where you could get the higher level of integration. What we did was went back to those various communications-oriented peripheral markets and said-- we hypothesized, block-diagrams, functional blocks, and said, "If you had something like this, would you buy it? Is this the thing you needed?" And they said, "Well, it's close, but we'd like to do this and this and this and this." So we did those market surveys, and came up with a family -- the original 6800 family was about 15 building blocks. And so it was a CPU core, but it had the memories, the ROM and the RAM, but then the peripheral circuits and things like keyboard controllers and modems and things of that nature. So the whole family was a pretty extensive family of products that were targeted at communications-oriented peripheral equipment, whether they were point-of-sale terminals, or smart CRTs, or pieces of test equipment that were communications oriented. So that was the general background on where the ideas for the functional building blocks came from. The reason we called them programmable is because after talking to so many various customers from the high technology ones to the low-cost ones, it became clear that we couldn't integrate all the variables into one fixed block. But you could come up with a variant of that, if you could make it "programmable." And so that was the architecture for the overall systems architecture. We also, that was the time of the PDP11, and it was the great hi-technology computer at that time, so a little mini-thing with a lot of switches and so that was a neat architecture and we liked that a lot. So we started with that architecture and built some variations on it, and the original product definition of the 6800 family was a 16-bit machine. And then we talked to Tom and he said, "Go away." <laughter> And then we evolved into the real world of what we could build. And so we did it over a couple years.

Laws: So part of the "real world," Tom, was the experience you'd had with MOS at GME [General Microelectronics MOS School and actual product designs at Victor Comptometer in Chicago] on building some of the calculator chips, and then the proposals you'd been making and some work with Olivetti. Can you tell me how you evolved then the core CPU for the 6800?

Bennett: I was basically introduced to the 4004 in like May of 1969 when Dr. Hoff [Marcian "Ted" Hoff of Intel] just had his sketches on paper and said, "What do you think of this? Would this solve your calculator problems?" And it looked good. And I had background in a 24-bit computer that we built out at -- Jeff mentioned SUHL - I worked with Tom Longo in the development of that, part of the early phases of those gates, and we built a computer out of that in 1964 for industrial control. So I had computer-type background. And then in the calculator game, we went in 1970; we started to use a Rockwell four-phase [logic] system that eventually developed into the PPS4. And so I had computer background along with putting random logic on chips and what a nightmare that was, before I come to Motorola. And so when the P-channel process was not there at Motorola--they couldn't make the memories with it--they couldn't make the calculator chips they were developing. It set about that we did need to have a new process to go along with it. And with all of the custom chips coming in, and the quoting of them, you could basically sit down and sketch out how these could be implemented with a microcomputer. And that led us to the point of where management could see that yes, there is, you know, more than the big mainframe or minicomputer-type thing. And then we took that, tried to start it. This was after we did [designed] the three [one] processor-type chips that went Intel, or to Mostek. When that failed, then we took off to develop a new process. And the new architecture. We really started in late '71, early '72, when marketing come back and said, "We can only sell 18,000 in five years." And it wasn't worth the investment. So then I found Link Young. And Link was in marketing and [had] come from G.E. [or] Honeywell?

LaVell: Yes, he did. He came from with Doug Powell.

Bennett: Yeah, and so, and he lived about ten doors down in a MOB [Mesa Office Building] building out here, at Broadway and Dobson. And so we spent a lot of time together, sketching these different things. And as other chips would come in to quote, I could take that and I could go down and draw them another sketch. And he was able to pick that up and probably from working with Jeff's group, went out and talked to a number of customers, and found that there was more of a market. And one day he came back with a potential order for 200,000 from CDC [NDC (National Data Corp)] in Atlanta. And what they wanted to do was they had a government contract to try to reduce [paper] checks from whatever [the quantity] was done in 1974. They wanted to keep that as the maximum, and get to electronic-type control. And they did all the credit card billing for the big oil companies and that. So they had a lot of terminals that they could use. And they really wanted Motorola to build it, but we backed away from that. But we did use that for, you know, the real hammer to get the product started.

Laws: So the conception then came out of this CDC [NDC] opportunity. Then how did you refine the ideas that came out of that? I think you said Link Young had a role in terms of paring down the features so it was reproducible?

Bennett: Yeah, Link went and found different applications that we could talk to him about, and get what the product could look like. We decided early that the, you know, that they were having trouble making NMOS memories. So we decided early that we had to go to a new process. And in 1963, I developed a five-volt only circuit family for GT&E that used the 2N708 transistor. And so I knew that with a little higher threshold on a device, we could make single supply systems. And make them work in high-noise environments. And so that's where we started, with three people. We got approval for myself, a circuit designer by the name of Don Hill and a layout man by the name of Don Craft. And we started the basic architecture of what the system would have to look like, and then key circuits to put on a test wafer. And that's where Bill come in with his M-time [timing] analysis. And at the same time, that's when Ed Armstrong and Jim Rugg come in, [I'd] go over and sit with them and say, "If you can do this, then I can do this!" And get them involved of how much it would save the customer if we could get this to five volts [power supply operation]. And between the two of them, they did it!

Laws: Bill, how involved were you in any of this activity? Was this a little side project done on the weekend, or was it a major project for you?

Lattin: We knew that there had to be a lot more precision -- you know, we're moving from 12- to 20-volt supplies to five-volt supplies. So everything had to be much crisper. And ion implantation was the thing that gave Ed and Jim the ability to control the threshold voltages very well. But still there were a whole bunch of circuit challenges, and what convinced me that this was a worthy program was this idea of a five-volt family. Because clearly, in my view, and even later when I was at Intel, I realized that they had no distinct strategy for the peripheral devices that go around the processor. They were good processor people, but they didn't really sense the whole idea of this being a system. So this idea that you're gonna build a microprocessor, there's a ROM, there's RAM, there's a peripheral interface adapter, and all of this is a family, it all works together, was the thing that really convinced me this was gonna be a winner. And then, you know, against the background -- before John, we had a rotating set of management, and nobody ever seemed to stick very long, and nobody ever understood the technology very deeply, and that was a real problem, because not only were implanters expensive. You needed clean rooms. This was a very expensive operation. Motorola wanted to get in, but they were, you know, didn't quite understand what it was gonna take to get in. And so I think, I'd come from a frustrating time of designing dynamic memories, and not being able to produce them in volume. And it was very frustrating. We actually took those -- we took our mask sets sometimes to AMS [Advanced Memory Systems], it was another memory supplier, and they could do yields for us that we couldn't do at Motorola. So this was kind of a new launch. And there were a number of people in the design group that were working to help Tom characterize these chips. Make sure the models, all the stimulation was right. We had a big challenge in circuit simulation, because an MOS gate is really two voltage controlled current sources, and the simulation program has to have the same current in both of these. So you've gotta get the same voltage conditions to get the same current. And then you have a loop of capacitors that are voltage controlled. So Frank Jenkins did a marvelous job on some of the analytical techniques of the circuit simulator. Later -- and I had a nice lab to characterize devices -- and later Kim Concannon came in and he did good modeling work.

Laws: What kind of computing power did you have to support the simulator?

Lattin: We finally went to big IBM mainframes.

Laws: 370 by then?

Lattin: Yeah, for years we would actually call them card decks, 'cause we actually submit it. We would go and submit cards that had a circuit description on it. Probably making sure the device physics was right. And that we could work in five-volts and get clean, clean accuracy was really a step forward for us.

Laws: John, how were you involved in any of this activity in the early conception and simulation.

Ekiss: Well, let's see. I would say in the first couple years of the '70s, I wasn't involved really in it. I became more involved about 1973, I would say, 1974. And tried to make sure we had the right people, we had the right equipment. There was just an overwhelming amount of work had to be done, and I don't know that all of the management structure in our group even understood what it would take to do it, and how much capital would be needed. I think from a capital point of view, we were probably a little bit underfunded in terms of our look at where we were going and how much capacity we would need to do, and which ultimately got solved by creation of a whole new plant in Austin, Texas. But we struggled, and

I think a lot of the work that these guys have reported on are the kinds of things that went on to tie it to the marketplace through what Jeff has been talking about, and then bring that back into the reality of the design and implementation people, and do the analysis as to whether or not this could yield some practical products that were going to be made in volume for specific applications and meet the market needs.

Laws: So, Tom, you're at a point now where you've got a circuit designer, you've got a layout person. About when was this that you started actively laying out the design?

Bennett: Late '72-- or I'm sorry, '71, with the test vehicles and that. And it was about May of '72 when we felt that we had something that we could begin to go with and go out and propose to customers. And we went -- there was a team, basically what I remember is Mike Wiles from Jeff's group, was the software responsibility. Link Young was the marketing guy. And myself from representing the MOS part of it. And we went -- we selected a couple divisions of HP, and two divisions of TRW, and then one other, who I don't remember. But we had gone to like NCR. And NCR had quotes into us, chips. They had like 12 chips that they wanted to do for their calculator, or their terminal. And there was no way to get enough manpower to do that kind of chip design. And all of them seemed to have more pins than MOS could handle. They all wanted 64-pin or something like that. And so it was just a constant battle. So what we did is we went out and we explained to them our concept with the microprocessor: the 8-bit wide memory to fit with the 8-bit wide ROM. And then the PIA was the peripheral interface adaptor, and its flexibility that we had thought about putting into it. And then in addition to that, because of the terminal type market, we took the ACIA and the SSDA and the modem that Jeff's group had defined, and they had been trying to implement it in PMOS. So we took those and added to our bag of tricks, and went out and talked to these people. And this is where like CDC [NDC] ended up, and we had all these parts, including the communications thing, and you just plugged them in where they wanted us to go do the job for them. And that's what really began to sell management on the fact that yes, we did have something. And there was the process development had reached a point where we could start to see some of the test vehicles come out, and things were beginning to look slow compared to the multi-voltage, N-channel stuff. But we worked at it and developed techniques that allowed us to work with those slow chips. And the result was is that we ended up with a one-megahertz clock [device] that had the same performance as Intel did with their four megahertz part on the Intel 8080.

Laws: What were some of the tricks that allowed you to accomplish that?

Bennett: With our process, because we didn't have depletion load devices, we used the implant to adjust the threshold off of the basic substrate. So everything going to ground was nice and snappy. Everything going to the five-volt level was ugly. And this is where Bill mentioned before about the voltage doubler and that. I conned one of his memory designers to come over and work for me, and he was-- everybody said that you couldn't do this. And he was one of them that says, "Oh, I can do that."

Laws: And who was this, Tom?

Bennett: This was John Buchanan. and he was the driving force behind all the circuit design getting all of the M-time analysis run, and chip layout, and power and ground distribution and things like that. That was his job. And he had a couple other people to work with him, Rod Orgill, and.[Tony Kouvoussis]

Lattin: Bill Mensch?

Bennett: No, Mensch, I think, worked on the PIA.

Lattin: Okay.

Bennett: Not sure who. But Rod Orgill was part of that.

Lattin: That's the first time that the load devices to pull all the way as far as you can pull to five-volts had been done with on-chip voltage doublers. In the past, you just used another power supply, so that you could make those load devices work, and so it was very creative, and...

Laws: Was that a patentable idea?

Bennett: I don't know if that got patented or not.

Lattin: I don't know if it did.

Bennett: The bus architecture got patented. What we did in the bus architecture, we had latches. And the output of the latch was just the pull-down device. So in phase two of the clock cycle, we took every one of the bus lines, and pre-charged them to the five-volt level. And then those--during the phase one time was the active time--and that's when things would go like heck, so we'd just yank them to ground and send them off to the ALU. And we had the ALU set up so that it was pre-charged. So that most of it, if it had to do something, would go to ground. And that's where we got our speed. And we took, in the area of getting like the 16-bit program counter, and stack pointer and that, we had what we called an incrementer. And the incrementer would increment to lower-rate bits, and there was another one that incremented the upper eight bits. And then we made a decision based on the carry-out of the lower one of whether we took the old count or the new count. Because when we incremented the other one we said, "It's gonna increment one. And we made our decision after the fact of what the carry coming out of the lower one did. And that way we got our 16-bit increment basically in 8-bit time.

Laws: So this was mid-1972 to late '72 you were going through these development of the design techniques to get the speed.

Bennett: Yeah.

Laws: Were you in layout at this time?

Bennett: Layout probably started in late '72. If I remember correct. Went through '73, and our first working parts was in like February of 1974. And by the way, the first parts worked. We had two or three instructions that didn't function correct, but the people in the field could use those. We just told them what the bugs were, and they just changed their program a little bit and got around it. And three months later, I was invited back to look at their systems. And you'd be amazed what those young engineers ….

Laws: Let's get on to that in a few minutes, Tom. A little bit more about getting the mask designed. This chip came out at what size?

Bennett: 212 by 212.

Laws: 212 by 212 mils. How long did it take you to squeeze it down to that size?

Bennett: Our goal was 180 by 180. And the pressure got to a point where we couldn't spend any more time in the layout to try to shrink that down to that. And so it was--we just let the chip grow to get there.

Laws: Do you recall the minimum design tolerances you were working with at that time.

Bennett: Ooh. I know the pads were like ten mils.

Lattin: Yeah, but I think these were mil-and-a-half, must before the big conversions, the microns.

Laws: Okay, a mil-and-a-half is about...

Laws: It's about 3 micron then, is that right?

Ekiss: 40 microns per mil.

Lattin: When did you see your first RAM?

LaVell: RAM was-- the 128-bit RAM was the first product that we saw out from Bill's group.

Lattin: Yeah, and I think it matched -- I mean, my memory may be-- when you're behind schedule, you erase that part of your memory -- and I've had a few of those in my career. But I think the ROM and the RAM that came out of the memory group were kind of right on schedule.

Bennett: I think they...

Lattin: It was a nice static RAM. And of course, the ROM was fairly easy to do. But the-- it's on the boards here. You've got what, two 6810s?

Bennett: It was a 6810. No these are PROMS.

Lattin: Okay.

Bennett: They emulated the ROM. And two PIAs.

Laws: So the 6810 was the RAM?

Lattin: Yeah.

Bennett: It was the RAM, yeah.

Laws: Okay, and that was an eight-bit wide RAM?

Bennett: Yes.

Laws: That was pretty unusual in those days.

Bennett: Very unusual.

Lattin: Family -- I mean, you have to really understand that this was a complete shift to a family of products! And that was a very clever...

Bennett: If you took a point-of-sale system at that point in time, the 128 by 8 RAM was sufficient memory for them to put together their minimum system. And the key was to give them the minimum system and then allow them to grow. And that's what really made it work. Now we did a number of things inside the CPU that these things interfaced to that was critical. We had to speed up time in like the branch instructions and that. We assumed that there was not gonna be a branch, and went ahead and fetched the next instruction. And then we made a decision when the -- at the end of that time of whether the branch -- if it needed to branch, then we used the new data. If it didn't, we already had the next instruction. And there were times we put addresses out there that were meaningless, but we needed them to get them around the chip. And so we had a separate pin called VMA that said the valid memory address. And this would only come true during the phase one time. And it was used for all of the other memory systems.

Ekiss: Let me just insert a piece of business reality in here. In this timeframe of 1972/1974, while all of this-- the new product stuff was going along, and it was, you know, speculative as to how it was all going to hang together, etcetera, we had pursued a business relationship with National Cash Register, which was one of the target customers for these kind of products. And we were fabricating read only memories for them, for their point-of-sale systems. And we were making quite large volumes. That was kind of how we generated some of the money to feed all of this other engineering effort, but it was very lucrative for us, and we had a good relationship with them.

Laws: And those were tough times in the industry, ’72 or so. An important customer for you.

Lattin: Then we’re -- I’m trying to remember this exactly, but I know it started early ’74 in the middle of all this, we started making -- the management was making decision about moving to Austin, Texas. Moving the whole group to Austin. And Jack Henneshen ,it is claimed that he wanted to move down there because he wanted a windmill on his property.

Bennett: I thought it was the Texas football games. <laughter>

Ekiss: I don’t think he ever wanted...

Lattin: I don’t know if that’s true or not, but what -- for me, I was trying to run a design group, and then start going down to the University of Texas, understand whether continuing education would be available for our engineers, what kind of supportand we were heading into a slow recession. So it was a very frustrating time. And I remember going back couple times to management and saying, “Listen, you know, conditions are worsening in the environment here, and this is our last time to call off this move. I don’t want to get half-way down to Austin and have this thing blow up on me.” And, “No, no, no. We’re committed to this.” And so by then we had Jack-- not-- Bob Heikes, I think.

Bennett: Yeah, he’d come in after Henneshen.

Lattin: He’d come in after Henneshen was removed. Now remember, it’s a chore to remember all these names.

Ekiss: Now there was a gap in there between when Henneshen left and Heikes came in.

Lattin: Okay, well...

Ekiss: Yeah, there was a gap.

Lattin: I remember getting an affirmation that we’re still moving, because I had a lot of concern about it. Then, chips all come out, and I think end of ’74. I remember taking a long European trip with Wes Patterson who I was giving all the hardware information, and he was doing all the software. And then a long story short, by mid-’75, we moved. A number of people, including Tom, dug their heels in and said, “We’re staying in Phoenix.” The only guy -- and there was a guy that I thought could do this microprocessor management job, his name’s Bob Foster, but he was in the government electronics division, and he didn’t want to move. So I went back, trotted right up to the top and said, “If you guys are asking us to move, you need to have the impact to get Bob Foster to take this job.” Well, Bob Foster took the job for about three months, because I went -- I moved, John changed jobs, and then I left and went to Intel. And Bob Foster said, “If Lattin’s not gonna stay, I’m not gonna stay,” and he came back too-- so it was a real lot of turmoil.

Laws: Meanwhile, you’re bringing out this extra -- what turned out to be an extraordinary successful family in spite of all this. So a little bit more on the team that actually completed that first chip, Tom. You said you had a circuit designer, a layout person. How many people physically did the layout, did the circuit design? You had simulation help from Bill.

Bennett: With the five chips I had, I think, 17 people total. That included all the layout people. And the chip designers for each of the chips. And the one thing I did -- at that time, it was hard to hire people. Particularly from the East Coast, where there were some companies that had laid off in the ’70s, or had closed down. But try to hire those people and get them to come to Motorola was an impossible task. And so we picked up a few from the memory group, and then some others that had come in. But the logic design, the whole chip layout -- or I mean, the state diagrams and the flowchart of that, I did all by myself. And I did that at home at night. And then we’d come in and work on the other stuff during the day. And the simulation, the logic simulation of that was done with putting stuff into the CDC computer at MOB, through...

Laws: MOB is?

Lattin: It’s a [Mesa] office building, which is this Dobson and Broadway plant.

Bennett: We could put it in there, and they would take it from there and send it over to GED [Government Electronics Division], and then from GED, send it to Chicago to the 370 for simulation. Well, I was dealing with, you know, decks about three stacks of cards like this [approximately three IBM card boxes]. And by the time you’d get the stuff in there, and put them in, maybe three days later, you might see it come back, because the main computer was used for accounting. Like Wednesdays and Thursdays, forget it. <laughter>

Lattin: That’s right.

Bennett: Never existed [no processing on Wednesdays and Thursdays]. But so we did work our way through that. And Buchanan and Rod Orgill did an awful lot of the circuit analysis. My original plan for it was to basically use a PLA-type control. But we couldn’t get enough speed out of it. So if you looked at the chip, the top part of it is all ROM, which does the initial decode of the instructions, and then after that there was a state counter, and that state counter cycled through, depending on how many separate steps it took to get the instruction completed. And then they had to go back and start over again. So they were working on that part of it. And the voltage doubler, I’m sure that was Buchanan that created that sucker, or he got it, and so that’s where that worked. And then we got the bus layout (we had pretty much arrived at back in the test vehicle stage, because we developed that latch), and that with the ALU and so we could characterize it. And the way we did that is we characterized an output buffer, and then we allowed the switch end of each of the other elements one at a time, so we could see exactly what each one was doing. And so they worked on that part and on the basic layout of the chips from-- I don't know, maybe Buchanan come in and late '72?

Lattin: Probably about that time.

Bennett: And we finished it and had parts in February of '74 that we built and showed it on …

Laws: Why don't you hold that [demonstration board] just so we can get a shot in the camera?

Bennett: This is the chip system that Chuck Peddle and John Buchanan wired up and put together and programmed it. And all it did was say: "Hi, John" or "Hi, Bob," and "Hi, John."

Laws: John and Bob were...

Bennett: Bob was Bob Galvin. And John was John Welty at that time.

Lattin: Yes.

Laws: These were senior managers at Motorola?

Lattin: Yes, they were.

Bennett: Yeah, he was the general manager, and Bob Galvin was CEO, right?

Lattin: Yeah.

Bennett: And interesting. The only one that really asked some questions which I thought were important was Bob Galvin. And his comment was when he looked at it he says, "You understand that you're putting our customer's chip -- or system -- on one of these little boards?" He said, "What's that gonna do to my other products?" But that's where it was at that point in time. The other thing...

Ekiss: Yeah, HP really recognized that, because I had called on them as a customer, and they quizzed me up and down about the implications for the semiconductor company to be able to make products like this. Because we were now right on their turf.

Laws: We did the recording of the 8008 oral history several months ago, and listening to the tremendous battles that went on in Intel between the memory people who were terrified that processor people were going to be treading on their [customer's] turf and taking away their business. So it was not unique to Motorola.

Bennett: I think we had some of the same.

Lattin: Yeah, but I was just thinking as you were talking, we were very collaborative. I can remember loaning people to Tom, and even though I had primary responsibility for the memory, we were shuffling people back and forth as the needs were. So it was -- at the worker level it was a committed program. It was...

LaVell: Very much a team.

Lattin: Yeah.

LaVell: Yeah.

Bennett: There were a lot of people, and I don't think you could say that you could drop any one of them out, including Lillian Morales, the digitizer. She was accurate, and she did one super job!

Lattin: Well, I'm thinking about people who have gone on out of that group. Clare Webb [ph?] was in that group, he's an Intel fellow. Paul Madeline [ph?] was-- he's a retired Intel fellow. He was in that group. So there was some-- I mean, these were guys who went on to do...

Laws: Great training ground for the industry.

Lattin: Yeah, yeah.

Laws: Just a couple more questions, then we'll take a break for a few minutes and assess where we are. So 17 people, five chips basically came out. About when were all five working so you could start going to customers with them?

Bennett: We had customers that had their systems built by June of '74.

Laws: June of '74.

Bennett: Yeah, we had worked with them, and you know, sketched out what it was gonna look like. And any changes gone back to them, you know, so that they knew what the things were, and what the performance might look like. And in June, I went to HP in Loveland, I think, and saw a system on a Friday afternoon. And this thing was just amazing what they had shrunk that thing to--because they had their before and the after. And they were getting ready that night to go up to a park up there, because there was a Coors truck sitting there loaded with beer for them. And then we got on the airplane to come back, and they went on. But they had it going that quick. TRW in, I think, San Diego or Southern Cal there someplace, had a terminal. And they had basically used two of these processors running in parallel in a common 4K of RAM. Because the RAM was faster and they could share it. And so they were really popping that thing, and they run the RAM on one system (was on the phase one), and they inverted that to phase two on the other system. So there was never any contention for that memory. And that was another one that -- and then I had one in Houston that had one running by July, I think. So it went before we got all the bugs out of it, or time to recycle, they had systems working. [They changed their program to work around the bugs.]

Laws: I'd like to get a bit more background on customers; on some of the work the sales and applications people had to do to sell the product; some of the kind of tools that were developed, software tools, emulators, assemblers, the like. And then any other stories you think you would like to tell us about the products and the people. And I'd like to pick up now a little bit on more of the kind of applications the product found, the kind of volumes it grew into, and why you think it was such a fantastic success as a product in the marketplace. Who would like to pick up? Jeff, you had some role here with developing tools, the applications people I mentioned.

LaVell: Yes. I had -- there were two organizations that worked for Doug Powell. Systems Engineering Group, which was mine; and the Applications Engineering Group worked for a guy named Lloyd Mall [ph?]. Tom mentioned what he was doing at the silicon level. What we had done was literally go off and we built a bread board. It was CMOS breadboard of this chip, this great big blue box! <laughs> And we developed all the software for it. We developed a family of system development tools. The concept was not only to come out with a family of chips, but to come out with a box, if you will, and individual boards, so you could very quickly implement a system and test it. So we did a box that was called "The EXORciser." Then there was a computer board, memory boards, parallel interface boards, serial interface boards, motor boards and so on. And then we had written a little executive -- it wasn't really an operating system. It was just a little controller system that would allow you to interface with that, and so on. As we were refining the architecture, we were building this huge CMOS breadboard and trying to keep it up and running. We put it in a room up in front -- Tom used to laugh about this-- we were in a building over in Hohocum [ph?] Park over here, and we leased a building, and it had really nice carpet in two display rooms up in the front. And then there were the engineering groups behind there. And the trouble was CMOS didn't have very good ESD devices on it in the early days. So what you had to do was you come into the room wearing these grounding strips, right? And we would continuously do demos, have customers come in, or senior management. And they'd come up and say, "Well, what about this?" And you'd say, "Don't touch it!" <laughter> Because you got enough static electricity from the carpet that you could sit there and zap the thing. So we had to trade off between the customer presentation environment, and the reality of life. And we did our software development, our assemblers, there was a single board version of this called-- that had an operating system on it, or an executive on it called MICBOG [ph?]. Mike Wiles developed that. Funny story is when we saw the first chips that came out were the memories, the RAM and ROM. And they were -- and they came out a month or two before the microprocessor. Because the microprocessor was a lot more touchy, more sophisticated circuit in order to get the performance out of it. And the techniques that Tom was talking about were very clever things, and they were done based on, not only the architecture, but also how you would then implement the systems. And we memory mapped all the peripherals, and he built the bus structure so you could -- for its time it was very high performance from the system's standpoint. It was pretty impressive. We were even impressed on it, so we then used the breadboard to develop the software on it until we actually saw the products. I can remember the first time we saw the MPU chips. I think we got three of them, didn't we? You gave us three of them?

Bennett: I don't know.

LaVell: Yeah.

Bennett: They were allocated.

LaVell: Yeah, and so we got three of them over in Engineering, Applications and Systems Engineering Group. And we had built this box-- this breadboarding system, not the CPU breadboarding system, but how you breadboard a typical system using those products. And you had the various RAM/ROM, parallel, serial, interface boards on them, but we had an extender board. And we'd made a fatal architectural flaw. We didn't key the extender board, so you could take the extender board and put it in upside-down, or right-side up. So we get these three, where everybody's anxiously waiting to see the first processors come out. And if they, as Tom said, "Boy, the first batch, they just came right out," and we were ecstatic. And one of the key guys that was doing the hardware, he was a software guy, but he was a hardware guy, so he did the hardware/software interface, the microcode kind of stuff. And he got one of the processors, and he was out in the lab, and everybody was all excited about it, and then he takes it and he plugs it in. He plugged the board in upside-down. And so he fries this one of the first three units. And you hear this scream throughout the whole building! "Ahhhh!" And everybody goes running out there to see what happened. And he's a relatively young engineer, and he says, "Oh, no! I just burned out the first part!" And just -- so we had a lot of things to learn from that standpoint, but we did the software, the development systems. There was a family of boxes that were done, EXORciser series that were done to do system implementations and software, and terminal interfaces. Those boards in there were used then to start another business which was called-- we called it the "Board and Box" business. It was Motorola Microsystems that was somewhat competitive with a group that Bill ran up at Intel. I was the Operations Manager for that at Motorola, so we were selling, trying to sell into various customers doing that. But we started this Board and Box business as a result of that as well.

Laws: Selling tools like this is very different from the kinds of products that Motorola salesmen traditionally we used to help promoting. How did you go about training salesmen to sell a product as complex as this? And charge for development tools. It must've been quite a challenge.

LaVell: We had -- our manager was Doug Powell, and as I mentioned earlier, he came out of General Electric. He had the ear of Tom Connors who was the...

Lattin: General Manager at that time.

LaVell: General Manager for the Semiconductor Product sector. And so he, because of his strong computer background came up with a marketing plan that would go in and as -- we were the engineering guys, and Tom's stories and some of the others, I've told you where we go in to customers -- we were the engineering grunts, right, that were talking about...

Laws: Experts from the factory.

LaVell: Yeah, yes, right. "Those guys from the factory." And Doug Powell had, along with his -- Link Young was one -- he had three key marketing guys, and they'd done a market analysis, and he'd gone to the customers and he'd said, "If we had this, can we sell it to you? Not only the chip set, but the support products and the documentation?" The Applications Engineering Group generated hundreds and hundreds and hundreds of pages of manuals. Because, as I'd mentioned earlier, there were fundamentally 17, some number like that, in the family, different products. And each one had to have its own manual. And they had have the overall systems manual. And we went in to the customers and asked them, "Hey, if we come up and do a good set of documentation, will you buy the documentation as well?" And they said, "Yes." And so Doug went back to his management and did this total marketing plan, including sales of chips, selling of boards, selling of implementation boxes, selling of documentation. And it was pretty aggressive for the industry at that time, as you're suggesting. But I think because of his computer marketing background -- and the objective was to go in and say, "Here, we'll help you get up into up and running very quickly. We'll try to reduce the cost by at least 50 percent," some number like that, "And here's all the manuals. Not only that we'll supply...," we had a big team of applications' folks that went out and trained people to use it, and help them write code, and help them optimize and things like that. So it was pretty much a total, what we really called a "total product offering." Trying to bring the customers up as quickly as possible. Part of it was to keep from getting, you know, get the funding cut off.

Lattin: I did a couple of stints in the field, maybe two-week periods presenting to customers. And I remember, it dawned on me in this process that when we would hand out the lists of independent consultants that could help you develop your code, that was what kind of just flew out of our hands. These bunch of TTL designers kind of saying, "I'm intrigued. Is there somebody I can go to that'll hold my hand through this process?" So you just couldn't keep enough of these lists of independent consultants who would help you do your code.

Laws: Typically a product like that is driven by just a few champions like that. Are there some that you remember who really made a difference in the success of the product? Either the application engineers in-house, or these outside consultants?

LaVell: The ones that Tom mentioned, the customers, NCR, HP, TRW and some of the gaming companies.

Bennett: Yeah, we had an old buddy of mine that worked for Bally, I think, back in Chicago was one of them. And that one was one of the most interesting ones, because you went and looked at the system, and there were wires that would run, and there was no connection. And it turned out that they were depending on crossover, crosstalk to trigger that, so that other people couldn't figure out how to copy their machine, 'cause they could -- with the microcomputer, once you got it there, you just make the little board, and plug it in, and write your code. Well, if they could copy the code, here we are! And so they did funny things. One of the other things that I think really helped was the fact that we did our specifications TTL compatible. We measured our times, our propagation times...

Lattin: That's a good point.

Bennett: To the actual noise level. If it said that the output needed to get to 0.5 volts [0.3 volts or 2.4 volts], we measured that time. And we wouldn't start it until the input reached 0.8 [volts or 2.0 volts], which was the minimum input threshold. So we took into account all the timing functions that the TTL designers had to worry about, and anybody using CMOS in that, where all the memories and everything were basically just spec'd at 50 percent [voltage level of 5.0 volts]. When something got to 50 percent level, and go from there to when the output changed [to 50 percent of 5.0 volts]. But we did it taking into account the other stuff. And this was a great comfort - particular to their quality people - that, "Yes, indeed, if they did design to that, it would meet that timing spec."

LaVell: Yeah, your point, Dave, it's amazing, because the industry, the guys that we worked with were not computer guys, right? I mean, they didn't think in terms of microprocessors. So the thing that Tom is saying was part of a really important marketing strategy, practical engineering strategy as well, to try to get guys who'd never worked with this kind of stuff before comfortable with it instantaneously. And it worked well, don't'cha think?

Bennett: Yeah!

LaVell: Those were good strategies.

Lattin: And there were two or three independent guys that wrote little books on the 6800.

So I think that's the question you're getting to. But there were -- I'm just trying to pull up a name or two. But I remember seeing independent consultants, who would work with the groups and write a book, and Motorola wouldn't have to take any responsibility -- it happened at Intel, too. There're a number of little books that came out by independent guys that sold -- and I remember interacting with some of these guys when I finally got to Intel, and they made a nice little business of doing these books on the processors.

Laws: So we're now probably in 1975, 1976. When did you start to see the first volume orders come in, and where did they come from?

LaVell: I don't know the answer to that. Here, you want to hear a copout? That's an applications engineering marketing problem. <laughter>

Bennett: That was Austin's problem.

LaVell: No, I don't know the answer to that.

Laws: I was at AMD during this time. And there were tremendous battles going on inside the company as to whether they should second source the 8085 or the 6800. The sales force absolutely wanted the 6800, 'cause they saw it everywhere they went, compared to the 8085 that was a few places in high volume. We know which won for AMD, but you guys did a great job in terms of getting out there, spreading the word, and getting a huge number of applications going. How about Europe and Japan? How did you handle those? Tom, I think you were in Japan for a while, right?

Bennett: Yeah. Growing up in the telephone industry, it was critical that there were second sources for products, and so we worked -- we had different companies here in the US come in, and wanted to see what we had, to make a judgment on second sourcing. And they'd bring in the people that they had doing their own design. And we'd go through the 6800, and it was really interesting to watch the designers, because all of a sudden when you went through and showed them how you accomplished something, their heads just went, "Hm." And they knew that they were gone. [Motorola's product was far ahead of theirs.] And we had picked up Fairchild as a second source. And then in Japan, we had Hitachi. How that relationship developed, I'm not sure. But Hitachi come over and fought, and management decided that, "Yes, we should at least investigate doing--using them as a second source." So a number of us -- you [Ekiss] were on that trip, I think.

Ekiss: Uhm hm.

Bennett: Went over there, and we were royally entertained by the Hitachi management. I mean, that was the first time I went to places I never thought I could get to.

Laws: I'm not sure I want to hear all these stories, Tom. <laughter> This is for public consumption.

Ekiss: And ate things he doesn't want to remember either.

Bennett: It worked well, because they come back in what? '78 or something like that? After they were in Texas, I run into them down there where they had come in and were getting all the details of the chip and that. But we had established some very good relationships with them. Every now and then I'd get a call from the Hitachi people asking about this, and when they were sort of confused about what was happening. And so I'd go through how it worked, and they'd, "Okay," and so they did it. And who else? Fairchild? Picked up on it.

LaVell: AMI picked up...

Bennett: I don't know if it was AMI or not. I don't think-- I don't know.

LaVell: I know that we had a fairly reasonable size design center in Geneva, Switzerland. And it was headed up by -- I think the names-- the guy that we worked with, a guy named Arturo Kruger and Nate Finkelstein.They picked up on the parts. They were very technical. Very technical guys. They picked up all on the parts, translated a lot of the documentation into the local languages. Then worked very specifically with a lot of customers, and got the products designed in, I think there were five or six major high-volume European customers. I don't know who they were off the top of my head, I don't remember. But that was primarily driven out of the Geneva Design Center, at least for Europe.

Bennett: Japan, I don't know how much we had over there. We had a design center in Yokohama.

LaVell: We did in Hong Kong, and we did a lot of stuff out of Hong Kong. But the trouble was, I think, in that period of time, the culture was more towards taking a design and mass producing it rather than doing the design themselves. And it wasn't until late in the game where they developed the engineering skill level to be able to do unique original designs, and so early on there was -- able to take it and mass produce it for half the cost, or whatever, some number like that. So, the automotive things in Japan were probably first major alternate source activities.

Bennett: We made a trip in '78 in late April, early May, to all of the automotive people. This was after we had pretty much secured the GM business.

Laws: Let's back up a little bit. When did you first start getting the 6800 involved with automotive applications? And how did that happen?

Bennett: In, I think, 1974, the US government said that, "You're going to have to meet these emission standards by 1981, which stirred up everybody." We had quotes coming in, or people coming in at GM it was Packard Electric, AC Spark Plug, and Delco Electronics. Now Packard Electric was the wire harness people. AC Spark Plug did the emission system. And Delco had the radio. And we always internally joked about the fact that each of them, Delco wanted to put it all on the radio. AC Spark Plug in the spark plug part. And Packard Electric all in the wire harness. And so these people would come in and you'd begin to look at what they were coming with, and they all began to look the same. And we got --I had gone when MOS moved to Texas; I moved into product planning. And when that request come in, they were going to make a presentation to Delco. And Jack Morgan was the leader of that. He was the automotive application person. And so he had his whole presentation put together. And went through it, and I just sat in the back of the room, and I watched as Jack was talking about different things. I watched faces, and you could pick up on areas where they didn't agree with him at all. And so at the end of it, I told him, I said, "Well, after the meeting, if you get a blackboard, I can sit down and tell you another way that it might look." And so I started drawing with one hand, and erasing with the other, as I went around the blackboard, and brought up the things like the noise immunity, and the time, you know, the AC measurements, how it was done. What the architecture looked like, and why we could get away with these different things. And it turned out that that stimulated them enough that they decided to put a computer in the driver information system -- or a trip computer.

LaVell: Trip computer.

Bennett: What it was first called.

Lattin: It was an electronic engine control or the trip computer first?

Bennett: It was trip computer first. [Used as a learning vehicle for operating a computer in the automobile in a non-critical function]

Lattin: Okay.

Bennett: For the ’78 Seville. Well, things went along, but they had field tests going on, and all of a sudden they would be driving along, and the computer would reset and start over, because it had its main function that it would work at. But then if there was an interruption, you could punch a button and go to like mileage, or miles per gallon or whatever. And if it hiccupped, it’d go back to this other “normal” state. And they’d be driving down a country road, and it would change, and they didn’t know why. And so -- the purchasing man at Delco called Motorola, and I don’t know what -- maybe Welty --at that level they’d come, asking for help. And so I was chosen to work on that. And we got a car down here in Phoenix, and put it in the garage, and first thing I did is I took a high energy ignition system, and I stabbed the car with it to see what was gonna happen, and the computer stopped working. So I went in and took it apart and looked at what was going on. And fixed that part. Go ahead and start jabbing again. And before we were done, we had it corrected so I could take the 50,000 volts and jab it all around the car, and the computer would keep going. And it turned out to be just some simple grounding problems. And I cleaned those up, and went back into Delco, and that system was done, part of it was done by AC Spark Plug, and part of it was done by Delco. And the Delco guy says to me, he says, “You know, make sure you highlight all of those problems with the AC Spark Plug system. Keep ours to a minimum.” So I did that. And we were back there working with them on it. As they were developing it, I could go through stuff if they had questions, and tell them how it was working. And I didn’t have to call the factory or anything. Just pull it out. And so I become a valuable tool to them. And with that, the ’78.5 [model year] they put the system in there. But at the same time that was going on, I was working with Ford on their driver information system. I called both of these “rich-man rally pack”, because they were sort of useless functions, but they really did get the computer in the car. And I’d never tell each other what they were doing. And Ford came out with their system, and I knew it was working. And about a week later, I get a call from the Delco guy saying, “Bennett, you knew all the time what was going on there.” “Yeah.” And that relationship developed into the engine control part, and that was the biggie. ’Cause they put it in the closed loop carburetor in ’81, and we took that up to 25,000 [computers] per day, starting in the second half of 1980. [Each computer consisted of seven 6800 family LSI parts.]

LaVell: Yeah, that was about ’80.

Bennett: And we did that. And we made it successful. There were times that I would be called 5:00 at night, and be on the airplane and in Milwaukee the next day by 9:00 [AM]. If they had a problem, you jumped. And that’s how we developed that relationship. And I have some drawings over there that I can’t leave, but they’re the original architecture for the GMCM chip set, where I took the 6800 and modified it to meet their [requirements]-- it was just a couple instructions added.

LaVell: Wasn’t there a multiplier and stuff like that that...

Bennett: Maybe a multiplier, yeah. That’s what we did.

Lattin: Became the 6801, right?

Bennett: GMCM? Yeah. Well, a modification of the GMCM chip became a 6801.

Lattin: Okay.

Laws: So that was a derivative product for that application.

Bennett: Yeah.

Laws: Any sense of what the total number of chips sold in these applications by Motorola was over that period of time?

LaVell: Well, the next derivative, and there's a whole series of the base architecture, because it was targeted for different types of application, there was the - the software model was relatively the same, so it was consistent from a software standpoint, various instructions, various functions were added. The next big variant on that was the 6805. And that was slightly different architecture. Some architectural enhancements. But then the paging products group came in as I mentioned offline. They came in and they said, "Hey," -- this is '77-'78 timeframe -- they came and said, "Hey, we'd like to have a CMOS version of this 6805 variant." And so they were very, very power conscious. And the fellow, the systems architecture guy that drove that was probably one of the smartest guys in Motorola, a guy named Walt Davis, and he brought his design team to Austin and worked with Gary Daniels with -- and you'd hired Gary, right?

Bennett: Yeah.

LaVell: And then they worked on this implementation of this, what ultimately turned out to be the 68HC05, which is a low-power variation of the 05. And that was designed into pagers. They shipped that in December of 1979, and the production rate went to the millions. I tell ya, we were shipping a lot of pagers. And the cellular phone guys picked that up. So these were all internal products. But they jumped up in the multi-millions very quickly. So you link the automotive stuff together with that, and I was talking to Walt Davis last night, and we were trying to find some articles, published articles on the volumes of the 6800 family variants. And the published data is around eight to nine billion units that have been shipped in total. It depends on how you group things together. Walt thought he had seen some numbers in the 12 billion range. But there have been quite a few units shipped.

Laws: Extraordinary numbers. A long way from the initial forecast of 18,000 units, I think we started the conversation, what in 1970?

Bennett: In 1985, I think about that timeframe, Delco Electronics alone was using 105,000 microprocessors per day.

Laws: Extraordinary.

Bennett: That was like 25,000 of the engine control systems, and the rest were these smaller, 6805-type products that the automobile people wanted as individual controllers. They don't want things lumped together, and stuff going to them. So, they'll design this little thing, and maybe the part's only 20 percent efficient, but that's the way they want it.

Laws: Average car today has how many controllers, 40, 50, 60 probably?

Bennett: Probably at least. But no, it -- once we got in there with that Seville, it showed them that that product would work, and they understood what the architecture of the chips were. We pretty [much] in my mind we had the next generation pretty much locked up. Because I had the key people at GM helping me. That's the way I felt.

Laws: Sure. So Bill, you had left Motorola, I think you said about '77, '78?

Lattin: No, end of '75.

Laws: End of '75. And so now you were beginning to see some of this from the Intel perspective?

Lattin: Yeah, I went to Intel as managing a couple of microprocessor products, but the key one was this -- we called it at the time "future" system. But to give you a kind of a flavor, when I went to Intel end of '75, of course I met Ted right away, Ted Hoff, and I said, "What're you using for circuit simulator here?" And he had a little teeny home-brewed thing, but none of the other engineers were using it. And so luckily for us, we went out and hired Frank Jenkins [ph?] to bring in Aspect. And then I hired a couple guys right out of Motorola who came and did the modeling. And so surprisingly enough, though, spending that kind of money to go -- Intel management understood that you need tools! I mean, Gordon sometimes argued that ten percent of the engineering budget should be spent on increasing engineer's productivity. And that's -- that kind of stuff never happened -- it was always a ground-up kind of swell at Motorola. There was never this management, you know, making it happen. So I just saw a very different style of management. And I think to some degree, I can remember a discussion with you down in Austin before I left. I'd hired Tom Gunter to come back to Motorola before I left. And we were having discussion about the Next Generation -- do you remember this? And there were none of us could see where all this was going. Jeff argued for a very vital 8-bit market that you could do -- and of course, my bent was let's go to 16-, 32-bit, you know? Let's just ride this thing up. And surprisingly enough, the market's gone both ways. And even ways that when you look at ARM - where they sell you a synthesized processor, I mean, I just never envisioned all those. Microchip is a latecomer into this market, and it's almost a billion dollar company now.

Laws: Over a billion.

Lattin: Well, there ya go. And I especially remember that meeting, because it caused me to sit back and say, "Where are the margins gonna be, because if this market goes both down and up, where is the money, you know, how could you follow the money?

Laws: Both ways apparently.

LaVell: And it turned out it was always in the ROM and the RAMs.

Laws: And John, you followed Bill to Intel?

Ekiss: I followed Bill to Intel, and ultimately got into running the microcontroller business.

Laws: So you saw both Intel, and what was going on at Motorola.

Ekiss: Right. And it was a very exciting time for me, because the microcontroller business was just nothing. It was just starting, and it subsequently got to be very, very large, and very quickly.

Laws: And again, automotive played an important role in that, an 8051 product?

Ekiss: Well, in the first half of the ’80s it was not a big part of the Motorola business. The Motorola business was suffused in a lot of different other applications. Keyboard was one of them.

Laws: You said Motorola, did you mean Intel?

Ekiss: I meant when I was at Intel, yeah.

Lattin: But Intel had an interesting-- there was a time when the 860 was going into laser printers in Boise, Idaho as a-- and it was huge volumes, but almost a silent...

Laws: Application.

Lattin: Yeah, and so some of those, there were a number of those that shocked me with the size of-- with the volumes that they ended up with. I mean, just incredible.

Laws: Just no way of anticipating that. There’s some folklore about a group that left Motorola in the mid-’70s, went on to MOS Technology, I believe. And they did a derivative of the 6800. Has anyone any background on they can fill in?

Bennett: Yeah. <laughs> It was people that worked for me. Chuck Peddle, Rod Orgill, Bill Mensch, Ray Hirt, and Terry Holdt, for the process.

Lattin: Terry Holdt is the one I remember.

Bennett: And they amazingly came out with a part that was very much like the Motorola -- what eventually was Motorola 6802 in zero time. And so it involved a lawsuit and some change in direction, but they got to make that part. And I don't know what the final settlement was on that thing.

LaVell: Which is another interesting number. The 6502 family, I think I was reading something that Bill Mensch was talking about, that they had seen about five billion of those devices ship, so you know, the architecture impact. And Tom had hired -- it's kind of interesting that -- probably shouldn't say this, but Chuck Peddle claims to be the father of the 6800. Tom hired him in relatively late in the game. And we had been working with Tom for what? Almost a year-and-a-half, almost two years before Peddle ever showed up. So if there is a father of the 6800, it ought to be Mr. Bennett, rather than Chuck Peddle. And Chuck did-- when he went to-- he went to Commodore?

Bennett: It was MOS Technology, and then to Commodore.

Laws: MOS Technology was purchased by Commodore.

Ekiss: Valley Forge, Pennsylvania.

LaVell: Yeah, that's right. And came up with a variant, and that made him successful and I think that was probably part of his basis for saying, you know, "I'm the father of that architecture." But I read -- I think I read something from Chuck, and he said, "Of all the people in the industry that didn't get credit, it was you. And Tom, he said, "You ought to be the -- should've gotten credit for being the Father of the 6800." That's really true. That's unfortunate that didn't happen.

Laws: Well, we're recording that today, so maybe history will...

Lattin: You know, but it's interesting if you think about, I think it's the turbulence in the Motorola whole thing that caused the history of 6800 to be kind of, oh, maybe shoved off the edge, because later, you would, you know, when you would see somebody write something on the history of microprocessors, clear discussion of what happened at Intel, and a very fuzzy discussion about what happened at Motorola.

Bennett: If you look at some of the magazines, one of the articles that I have there was, I think, written by Cushman from EDN. And he wrote that, you know, when he first looked at it, he didn't think it was anything. But then when he come in and we sat down with him, and explained to him how it worked, and he got a better idea of it. And everybody in the industry at that point in time looked at clock speed as the key factor. And here's Intel with that 8080, 4-megahertz clock. Using the instruction execution time, we beat them in many applications with our one-megahertz clock. And so we sat down and went through that, and how to get, you know, how it fit together. And in his article, he mentions that he was extremely surprised that the performance was as good as the 8080. So, you know, another thing that happened at that point in time, when we were first going out with it, is we were a paper tiger. And Intel used that to no end. Never make it work at five volts! Well, some believed it, and some didn't. And so from that standpoint, we really drove -- and I have to compliment Mr. Ekiss for making the decision. At one time when I came back from a trip, I was told that, "We're gonna drop the three-voltage [power supply] N-channel process, and do everything in five volts." And that made me happy!

Laws: How did you make that decision, John?

Ekiss: Well, I think it was obvious. It was a five-volt world at that time, and single supply, and that's partly what drove the economics of it.

Laws: Was there any cost in the process to do that? Certainly, ion-implantation it took, right?

Ekiss: Well, I think if there was, I just never paid any attention to it, and we just went straight ahead, and you can see-- you've heard some of the inventions that were made. And ion-implantation came out right at the right time.

Bennett: We did the ion-implant only of the substrate. There was an extra one or two process steps to do the depletion load. And it was determined that, you know, that might be a little risky. That's why we went to all these other, you know, hardware extremes to get around that. And so we compensated for it with design. But it was a major boost as far as I was concerned for the microcomputer when John made the decision for the five-volt process. That opened up a lot of things.

Laws: If you could just summarize, Tom, why do you think the product was so successful in the marketplace? There's a lot of different factors here. Are there three or four reasons that made the difference, do you think?

Bennett: Probably the key was our AC and DC specifications for it. The fact that the parts fit together to those specs, and they knew if they plugged them in, they would work for them. The instruction set was sufficient to solve many problems. And we had support people there, in the field, in Jeff's group that could help.

Ekiss: That's the total product. I mean, that was the key. The key, having the total product.

Bennett: And when we went out on our definitions and that, Mike Wiles, I don't know how many miles he put on, but probably almost as many as I did during the definition part of it to get the product (and use [brief] the customer)--so he knew what we were thinking. And there was one other comment at that point in time, we were ahead of the universities, and I remember making trips to University of Cincinnati, John Hopkins, MIT, Caltech and some others, where I explained to them what we had done. Because we had, in the industry had jumped over the top of the universities at that point in time. We did that, and then they took off. But at that point, we were ahead of them, in getting that out to all those people like that. And I think, didn't you also have a University thing that you did?

LaVell: Yes, we did.

Bennett: And so that got more people familiar with it. But it was one heck of a big effort out of a small number of people that made it happen.

Laws: Now I'd like to ask each of you if there's any sort of special memory of the time that you spent on this product and what you took with it on into your later career? Jeff, can we start with you?

LaVell: I had an interesting experience. I had worked in the semiconductor products sector for quite some time. Tom didn't go to Austin, neither did my organization. We went into a group called MICARL, which is called Motorola Integrated Circuit Applications Research Lab, which is the acronym, MICARL. And what we did then was support the equipment divisions, and then we would be the customized design group for the various equipment divisions. I ultimately wound up going into the equipment division. And I was laughing with the -- in oh, 1993, I went to Florida for the paging products group. And started working with them on some of their system architecture stuff, and design productivity. When I went there, there's -- it's a tremendously successful product group, but there were rooms full of guys writing assembly language code for the 6805. For the 68C05. And it's just like déjà vu, you know? You say, "Whoa! Wait a minute! I've been there and done that a long time ago, because the industry is now the 16-bit larger, more sophisticated microprocessors. But there's this story that's behind the scenes that just consumed these little cheap things, right? And used them all over the place. That was just one of the projects I worked on. I ultimately went to Motorola Labs. And one of the things that we were working on was a communications protocol, implemented on the 68C05 for toys, and so that toys could come up in the same room and they'd wake up and there was little protocol, communications protocol where they'd acknowledge each other, and then the toy would say, "Oh, I know you. And I know you." So if some child had a doll whose name was Mary, then somebody else came in to the room with another, and whose Betsy, the toys would communicate to each other. And they were using these same processors that are -- and the reason we did them is because they were a buck, right? A dollar-a-piece. They're dirt cheap. And so a lot of the new communications protocols, I heard of some of these projects called "smart dust" and whatever, used these 8-bit chips all over the place. There's a hidden story behind all those things that are just all over the place. And they aren't as exciting, right, as very sophisticated, larger systems, but you sure make a lot of money on them.

Laws: Another story we should probably capture.

LaVell: Yes, there are some amazing things that're hidden. And I think Bill's comment, those were hidden in Intel as well. Because they're boring. I mean, who cares about 8-bit microprocessors, right? But if you look at the volumes that are associated with the moneymakers, a lot of them are down at those levels. So I think from a summary standpoint, it's interesting to look back, and you keep running into those products over and over again throughout your career, and see their impact. And that all came out of that early period, early '70-'75 timeframe. '70-'79 probably timeframe.

Laws: Bill, any last minute thoughts from you?

Lattin: Well, the amazing thing is that it succeeded as well as it did. Having gone to Intel and seeing a very -- a company that does a very structured strategic plan every year, and knows where to focus the resources, Motorola was a bottoms-up. A strength of an idea would get sold, and or Doug Powell would get it and he would push it. And then Tom would get it, and convince everybody, you know, we want to work on that. And it was, you know, having now been in management, and looking back I kind of say, “What could have happened here with 6800 had there been strategic direction from the whole company, you know, moving down this way? And so it was a phenomenal success. I’m privileged to have worked with really bright guys pulling it off, and against chaos that was put in everybody’s way!

Laws: Tom?

Bennett: I guess probably the biggest thing is the volume of the microcomputers that are sold today versus what people thought about to begin with. The number of people that I met, head of companies, big companies that because of the microcomputer and the work with them, I got to be introduced to them--including the Senior Managing Director of Toyota, Mr. Toyoda. When you come in as an outside supplier, like we were, Motorola, and make a presentation to him, and then they -- couple of the guys disappear, and in about ten-fifteen minutes come back in, and say something in Japanese, which you don’t understand, and then you look at the looks on the people, and then find out that you’re invited in to see the head guy. A foreign company brought in like that. And told we did a very good job. So things like that that stick in my mind.

Laws: John, any thoughts from you?

Ekiss: Well, I think one thing I learned, and it stuck with me for a long time, is when the conditions are right, when the iron needs to be struck, and if you make the right decisions, and if you have very talented people who can overcome the technical barriers, and make the right inventions, and decisions at a point in time, you can be very, very successful. Even with the existence of the kinds of barriers we were talking about existed at that time. Certainly a small number of people -- I mean, the implementation of the design, the layout group, I mean that he’s talking about is very small, I mean, relative, but yet it was leveraged via some really close working relationships that didn’t come from management, it came from the people, okay, that just got interested in the project, and wanted to make sure it was successful. And it was successful. And that can be done in any company. It wasn’t a top-down ever.

Bennett: No.

LaVell: Even if some of the guys did bail ship, right?

Ekiss: Yeah, but that was just a minor detail that you guys overcame.

Laws: Out of chaos that existed.

LaVell: It broke our hearts! “Oh, Bill, don’t leave!”

Bennett: I bailed when I looked at my calendar in Japan on May 10th, and found out that I’d been on the road for 110 days. And I said, “You’re not paying me that much.” So I quit when I was in Tokyo. But...

Lattin: You were straight gone 110 days?

Bennett: Yeah, well...

Lattin: Or had you come back for clean clothes?

Bennett: No, I'd get home every now and then. But it, you know, I had trips from starting off in Houston, give a presentation in Dallas, a presentation in Chicago, and be in Millsboro, Delaware that night for a presentation at 8:00 the next morning. And things like that got tiring. But that's the way we sold it. We went to those people and showed them what they could do.

LaVell: It's interesting, too, you know, we're the engineering grunts, right, but from management standpoint have folks like yourself, John, who would say, "Five volt," right? That decision was phenomenal! And you had the wisdom to be able to do that, and it's amazing how things -- people in the right place at the right time to just make critical decisions that in the long term are -- were probably unpredictable on the total impact.

Ekiss: But we had a few guys in processing that assured me that they could do it.

Bennett: Yes.

Ekiss: And why. And Bill Lattin was in there selling also.

Bennett: Yes, he was.

Bennett: Well, I know that the microcomputer carried Motorola through the 1981, '80/'81 recession. Because I was stopped in the Dallas airport one time by that memory manager thanking me for pushing the GM stuff because it kept them employed during that downturn (because of going from zero to 25,000 a day was a big boost to production). And it supported the memory group at that time. So that sort of balanced that out.

Laws: Okay, thank you all! This was another product that was inspired by a few hard-working bright people that fought against all odds, came up with a design that was very well thought through as one of the first processors that was designed with the total system in mind. I think that's what's unique about this compared with some of the other products we've seen. And then the dedication, hard work and determination of people to make it happen. So thank you all very much for contributing. It's been fun.

Ekiss: Thank you, Dave.

Lattin: Thank you, David. Do you collect things like this?

Laws: We do collect things like that, Bill. Thank you.

Lattin: <holds up the book> This was the way Motorola taught all their designers at the beginning before they had simulation. You solved these equations for every capacitance load you were driving. By hand. <Bill holds the book up-- then puts it back down> And I'm not studying those equations anymore.

END OF INTERVIEW

