Oral History of Ray Holt

Interviewed by:
Steve Leibson

Recorded May 26, 2023

CHM Reference number: 2023.0092

Steve Leibson: Hello, I'm Steve Leibson with the Semiconductors SIG of the Computer History Museum and I'm here on May 26th, 2023, to interview Ray Holt who designed the first microprocessor chipset, which was used to implement the all-electronic Central Air Data Computer, or CADC for the F-14 Tomcat fighter from 1968 to 1970. Ray, thanks so much for speaking with me.

Ray Holt: Thank you, Steve. Nice to be here.

Leibson: Let's start with your childhood. Ray, where did you grow up and was technology your first love or was there something else you wanted to do with your life?

Holt: I was born in Compton, CA in the Los Angeles area. My dad traveled the Midwest a lot. He was an itinerant welder, pipe fitter. So, we moved a lot up until probably my 4th grade. Then we settled in Compton again. Technology definitely was not in my future. I loved baseball starting at age 8 and always hoped to be a professional ballplayer. Somewhere around when I was 12, my neighbor, who was, looking back, was some kind of radio technician, he offered me all his radios & cards and I said no. I didn't really care to have it all. It looked like junk to me and to my parents.

But he had this cool real high wooden chair. That I loved. And I used to go over and just sit in it. He said, “Take the parts, I'll give you the chair.” So, I took the parts. An easy decision. And then he told me this is really a major thing, he said, “Let me show you how to fix these radios.” And I didn't know what that meant, but what it meant was open it up, blow out the dust, turn it on. If there's any vacuum tubes that don't light up, go down to the store and replace them. And that was it.

Leibson: So you went to a store that had a tube tester.

Holt: Yes, at that time there were some small radio stores, they call them. They sold TV's and radios and they had tubes. So, I'd go down there and test them and of course, if they if they didn't light up, they were bad. Then I’d test them then I got replacements. And I started making five and $10 repairing radios. At 12 years old, it was kind of cool. I liked the money. I didn't really appreciate the knowledge at the time.
And I was also kind of big into fixing bicycles for my friends. You know, I'd line up their spokes and their chains and then I'd wash the bike and wax it and charge them $10.

So between the two, it was, it was enjoyable, I guess that was all technology looking back today.

Leibson: So, but you were interested in baseball, you said.

Holt: Oh, yes. Oh yes.

Leibson: So, did you play through high school?

Holt: I played through high school. I had some experience in college. And then as an adult I played fast pitch softball up until age 55.

Leibson: Oh, a long, long relationship with baseball.

Holt: So somewhere in college and we can hit this later, I realized that baseball wasn't going to happen.

Leibson: OK. Well, we'll get to that when we get to your college years, I guess.

Holt: OK.

Leibson: So, I believe that I guess towards your senior year you had a conversation with a guidance counselor who counseled you on your future.

Holt: Yes, and actually a couple of things came out in that. One was I asked him why I didn't get any scholarships, as a senior. And his simple answer was, well, you didn't apply. Well, that was a shock to me. No one told me I had to apply.

Then he talked to me about college and at the time the school, and I guess a lot of schools today still use the Iowa Aptitude test. And the test had four areas: English and Social, math, and something else. Oh, and mechanical aptitude. Well, my math was really high. My mechanical aptitude was very low. And he said, “Well, I can tell you right now, don't go into engineering.”

Leibson: Well, how does that square with fixing bicycles in your earlier life?

Holt: I don't know. I think of that a lot. I actually still have the test. Yeah, I look at it a lot. And, but you know at the time this is like the mid-60s, mechanical engineering was the big engineering field. If you went into engineering, you did that first and then maybe going to other disciplines. So that's really all he said.

He didn't give me any advice on what to do, I was confused because two or three of my friends who I kind of hung out with academically. One got into UCLA engineering on a scholarship one and the other into Caltech. One into Stanford. And here I was like, “How did they do it, you know?”

Leibson: They applied, I guess.

Holt: They applied, yeah. So, part of the essence of this story is that school counseling is important. And, that's why, I use that a lot today for counseling. So consequently, I really had no direction.
My parents, neither one went to college, but they knew I, I needed to go to college. And so, going to the local junior college was the next obvious step. Either that or go get a job. The local college was Compton Junior College. So, I made an attempt there.

Leibson: And did you? I mean, it's a junior college. Is, is there a, did you specialize in anything, or you just take general classes?

Holt: Well, I remember them asking me what do I want to study. I have no clue. They said OK, we'll just give you the normal classes. So, it was English and government and history. I think speech. Terrible, terrible classes for me.

I was typically a slow reader. So, all of them really bogged me down. I was so discouraged. I just quit and walked out. Which was a bad move.

Leibson: And what did you do then?

Holt: Friend of mine’s Dad was in construction. And he was one of my Little League advisors or coaches and he, he liked me and he said, “Yeah, I can get you a job,” right? So he got me a job. Watering garbage on a garbage dump.

Leibson: Keep the dust down.

Holt: Yeah, the dust down and to compact the material as the Caterpillar tractor goes over it. So, I did that every day for a semester. It was quite eye opening. I realized this is not a career. And as bad as college was, I was wishing I was back there. And also, baseball season was coming up just like the next semester.

So, I wanted to get back into college. I was offered, instead of watering the garbage, I was offered to be the front person to price the stuff coming in. So, he let me do that for another semester. Raise my pay, I think, from $1.50 to $1.75 an hour.

But I was able to study. So, my time was like 3 hours when it was open and then I had the evening, more as a watch guard. So, I had time to study the second semester. So, I could then, magically that worked out well.

In high school, you know, we were using slide rules back then. Calculators were not around. So, in high school we had a slide world class. And I really didn't get along with my teacher. So, I think I got a “C” or “B” in the class. I knew that wasn't right, so I retook it in college. Got a straight A.
You know, looking back today, it was probably not a big deal, but it was to me at the time, because that was an engineering class.

Leibson: But also speaks to the difference between one teacher and another.

Holt: Yes, great time. And your motivation in life at the time. I knew I needed to stay in for baseball. So here comes baseball season. I tried out, half of the team with my friends. Coach got us all together and said, “OK, this is a group that's made the team, and as soon as I do some academic checks, we’ll get back to you tomorrow and we'll start the season.”

Well, my academic check was all F’s the first semester, because I failed to unregister. Again, I was, “I didn't know I had to.” I just thought if I didn't attend, you know, they'd drop me. So, he said, “Ray, you can't be on the team. You gotta get your grades up.” So I went to admissions. I begged them and begged them, you know, let me in I can do this work and…

Leibson: Now is this Compton or is this a different school?

Holt: Now this is Compton, so it was the 2nd semester Compton. And I remember them saying, “As soon as you prove to us you can do college work, you can appeal and have them taken off.” That didn't happen until three years later.

So, I couldn't make the team and then a friend of mine was the quarterback on the University of Idaho team in North Idaho, Coeur d'Alene area. He just said, “Ray, Come on up. We can room together. And he’d show me pictures of the school. Just an absolutely beautiful school. So, I applied and within two weeks they accepted me, which was a shock because of the F’s. I just figured they're desperate for out-of-state students. And my parents said, well, if they accept you, you can go.

So, I started at the University of Idaho, my second year of college. And when I applied, they said because you're an out of state student, you have to declare a major. Well, here I was. I wasn't really quite sure. So, they just gave me a list. They said, “Well pick one that you want to do.” And since I like the outdoors, I picked Forestry. So, for the next two years I was studying forestry. And of course, I tried out for the baseball team. And again, I made the team. And then when they did the background checks, it turns out, transferring from the LA area to Idaho was a different conference, and any inter conference transfers had to wait one year. I played baseball, so I played intramural baseball, which is a lot of fun really.

And then come to the second year, I tried out for baseball, made it again. I mean, he was happy to have me back. Part of the deal was we had to get a physical, which was normal. Well, I had some pulled muscles in my lower abdomen and that requires surgery. And I was out that whole season again.

Leibson: The fates are against you.

Holt: It finally hit me. Maybe I'm not gonna make it. But when I was in high school, the summer before my senior year, I played on a team in Compton. Half of the players, by this time, they’d signed pro. And some of them became well known at that time. I just couldn't figure out now how can they make it and I thought I was just as good as them and maybe I was, I don't know. But if you don't play, you don't get watched. So, I guess my brain kind of kicked in and said “OK, Ray, you better start thinking of your career.”
And at that time, I was taking the, I was in my second calculus class. Oh, and the Dean of Forestry had called me in. Really cool guy. His desk was like a 10-foot tree cut in half. And all I remember him saying was, “Ray, Do you do you like forestry?”

I said, “Yes I do.” And it was the research arm of forestry. So, it was a little bit technical. He said, “Well, you need to do better in chemistry if you want to stay in the program.” Well, I never took chemistry in high school, and this was my first time. He said, “Well, why don't you next semester sign up for this class,” and he pointed to something. Turned out to be physics of electricity. I don't know why he suggested it. Maybe he saw I was good in math. I don't know. It was kind of shocking to me, but you know, he's a Dean and I just signed up and took it. Absolutely loved it.

Aced every quiz, aced the homework, aced every test 100%, aced the whole class. I just couldn't believe it. And I liked it. I understood it. Maybe the early radio experience helped. But I just remember liking it. It was kind of a strange feeling. Then I remember thinking after meeting all my classmates, “Look, they're all engineering majors,” because it was a required class for engineering. I just decided I could be an engineer. It's really that simple. That was a good semester.

I aced calculus and a few other classes and made the Dean’s list, which was an absolute miracle. My parents got a letter saying I made the Dean’s list before I knew about it. My mom called me up and said, “Ray. I think they made a mistake.” Because I was like a low student before. I said, “No. No, I'm really doing good.”

And so, I decided to search around and see my options in engineering. Obviously towards the electrical end. And then I found Cal Poly at Pomona. They were starting a new electronics engineering program. It was in their second year, and it looked really good. You know small voltage electronics. It wasn't the power lines and stuff.

So, I applied, and they accepted me. I had to take a few classes over, like economics, and history, and stuff. So, I went three more years. I actually talked to the baseball coach there too. He was a real famous coach and he welcomed me to try out, but he said since you’re second or third year, even if you make the team, I probably couldn't play you much.

And so, I decided, OK, I'll work, and concentrated on the electronics. I loved it. The reason I loved it, and the reason I picked it was for every hour of lecture, they had three hours of lab. So, we had no spare time. We were always in labs. Every lab had a lab report every week, so I probably did 200 lab reports. Touched about every electronic part there was.

Leibson: So, at this time you're probably studying vacuum tubes and transistors.

Holt: The first half of the first semester when I was there, we did vacuum tubes. Which is kind of interesting because you know, as a 12-year-old, I was changing them and I didn't know what was going on. So now I learned how they work. And then halfway through, he says, “OK, all of you. You are in a major transition at the school. We are stopping teaching vacuum tubes and we are going to start teaching transistors.” He said the theory is very similar, but everything will be transistors.

That was kind of fun to be a part of the transition and of course touching little transistors is more fun than big tubes because they get hot. So, we got to do a lot of lab work on that, and we learned how, you know how they amplified. Kind of. That was it. I was, I was motivated, encouraged, just getting A’s and B's. One of my friends from high school, we were on the wrestling team together. He had also entered the school. So, we did most of our lab reports together and he was a little sharper than me. Taught me a lot. And he went on to be a major manager at HP in the instrumentation area, which doesn't surprise me.

So there at the end, my last year, I had to take an elective. And, also it was my choice, I looked at the list and I didn't want to take more electronic kinds of stuff. I really had a lot of that. So, there's a class listed. It was called, a theory of switching systems. And I read the description and it was kind of mathy and kind of electronic so, I thought, “This will be interesting.”

So I took the class and was absolutely amazed that I liked it. It was… today it would be called a binary arithmetic class. There's electronics, so we just learned all about the gates and the equations and it was fascinating because it wasn't analog amplifiers, it was on-and-off digital.

And what I really liked about it, it either works or doesn't work. If it doesn't work, you just trace your gates back or your equations and it was actually fun. It was a very fun class. So that's kind of how I ended my school.

The school had a career day. Like they still do, I guess. And I remember talking to several companies and three of them made me an offer. Let's see, Bendix, Garrett AiResearch, actually, I kind of forgot the other one. I think it's probably Aerojet general or Westinghouse. But they all have some kind of, it was either amplifiers or digital. And I remember I really liked the Bendix, because I'd had a side job at Aerojet General testing the computerized torpedo called the Mark 4.

Leibson: That's a famous one.

Holt: Yeah, that was that was kind of fun testing. And I kind of learned all the parameters of all. And so I would not have minded working for Bendix. It was not on the torpedo, but it was on other stuff in that department.

The third company, which I think now is probably Westinghouse, so I wasn't really interested. They weren't really motivating to talk to. For some reason, Garret kept pursuing me. I wasn't real proactive with them. But they just kept calling, and "come for an interview," and "come back," and all this stuff and they made the best offer.

Leibson: Where were they?

Holt: Torrance, California, and LA. The headquarters was in Los Angeles, but the AiResearch Division, which was the space and electronic division, was in Torrance.

The downside was, I was to design amplifiers. Which scared me to death because I struggled in college with them. I probably would have admitted I really don't know the theory that well. I could do it.
And the project was to be an audio multiplexer on commercial airplanes. So, they wanted to take all the wires going to all the seats and making it one wire, where the music is multiplexed and then they just select it. Which they ultimately did. But I got diverted from the project, fortunately.

Leibson: So, is that is this before or after you actually showed up for your first day?

Holt: On my first day was the life changer. You know, I walked in thinking I was going to be an amplifier designer. I had hit the books the month before and made sure I could talk the language. And here I am. I can still visualize it. It's a strong image in my mind. I'm sitting there next to the desk of the human resource person. He had me sign the papers for all the benefits, insurance, and everything. And then he said, "I see you've taken a computer class."

And my response was not positive. And I'm not sure why he continued to answer that. "Yeah, right here, you know." He pointed to Theory of Switching Systems. Oh yeah, yeah. That was that was about computer gates and stuff. You're the only one in your new department that's had a computer class. We have a special project for you.

And for a young graduate, young engineer, that was scary. For a company like Garrett that does military and commercial systems, we have a special project for you. So, he asked me to follow him down to the basement of the building and it was the manufacturing line. And at the time they were the main contractor on the F-4 Phantom jet CADC flight computer. So, he took me up to one and he took the lid off. And he said, "You know what that is?" Well, it was all gears and cams and wires.

Leibson: Right, not an electronic product at all. OK, so you went to see the CADC used in the F-4?

Holt: OK.

Leibson: I did a little research. The original CADC went into the Saber jet for the Korean War, and this is obviously a descendant, and it's a purely electromechanical device. No electronics, really. So, what did you think?

Holt: I just told him it looked like a transmission I had overhauled. I had an old car at the time in high school and I had overhauled the transmission and engine. But it was a bigger version. It was like three times the size.

He said no, that's this is a mechanical computer on the Phantom jet. And my first thought was, "OK, I'm low on mechanical aptitude, and is this the special project?" So, it wasn't making me all that more comfortable.

That was part of the project. So, I was hired on and the department, the people in the department, were just fabulous. I mean, these were top notch engineers. One of them, which became a good friend. He actually was part of the design of that mechanical computer, I've been told. Today, there's no one in our lives that could design one of those, much less troubleshoot.

Leibson: We should discuss what it actually computes, because it's a very specialized computer and it's important that I think people looking at this interview understand what the CADC was responsible for doing.

Holt: So traditionally, the CADC receives pressure input and computes it, and then calculates known equations of aerospace for vertical speed, horizontal speed, angle of attack. That's the main parameters. And then those parameters are fed into other systems that would be on the plane, like the weapon system. And it was transmitted to the ground, so the ground controllers know what's going on with the plane.

Leibson: So, I believe there are two pressure inputs, right? There's a static pressure input which is a hole in the side of the fuselage, and then there's the Pitot tube pressure, right?

Holt: Yeah, actually I have a Pitot tube, let me show you.
Yeah, I bought this at the Boneyard Museum in Tucson, Arizona. They're from the F-14. So, it's the same Pitot tube for both. So, one's facing the direction the plane's going. The pressure goes in and then gets converted to electronic, and that's the dynamic pressure. And then the same type of tube is in the middle of the body typically, facing backwards. And that pressure is what they call static pressure, as if the plane is standing still in the air. Every airplane has both tubes, commercial and military.
So those two pressures are used in all the equations for aerospace.

Leibson: And where does the attitude information come from?

Holt: From the pressure difference. Every equation has two pressure inputs and somehow it works it out. I didn't become an expert in the aerospace math. But we had one, and he convinced me that it all works. I just had to implement it.

Leibson: So, your job becomes, convert this electromechanical behemoth into electronics, right?

Holt: And one of my first meetings was with this applied mathematician Bill McCormack. Super, super guy. I've never met anyone so smart in math and just so nice. He convinced me, he said, "Ray, don't worry about the mechanical. The mechanical computer and this new one all run on the same math equations. We just have to implement the math in a way where it works, and it fits in the box, and is reliable.

So, he set me at ease. And he knew math so well, mainly polynomials, but a lot of other variables. And I understood that and so we worked together.

And then the company had hired another gentleman, Steve Geller. Steve was about 44 at the time. Had worked for a larger computer company and had worked on some mainframes. Steve was very unique.

Leibson: How So?

Holt: Unique in such a way. He did not like to talk about details, and he did not like to be around live electronics. But he's just one of these thinkers. You know, the typical aerospace company has this bullpen arrangement where everyone kind of sits in the middle.

Well, they put Steve's desk right in an aisle without a wall. So, everybody walking by talks to Steve. Drove him nuts. He ended up doing most of his work at home, because he, you know ‘cause he's a thinker, he needs quiet time.

And then, oh well, first, the project didn't begin for two months. So, they just told me just take the time, learn all you can. Design, build stuff up. And that was really comforting.

Leibson: So, what did you build?

Holt: I went to a class at UCLA. And the guy that was teaching it, it was his first year, but he ended up becoming the Dean of the computer department, I've learned recently, doing research. I've actually communicated with his daughter, who is a PhD in computer science. So after 2 months, you know, I was pretty comfortable. I built up some adder circuits and shift register, all kinds of stuff.

Leibson: Did you use ICS at that point? Did you use integrated circuits at that point? Like small scale integrated circuits?

Holt: So I used the off-the-shelf stuff. So there there was like packages with four AND gates in it and flip-flops and stuff. There was some CMOS just coming out. But the best part was, I could physically test my equations.

Holt: So finally, they said, “OK, we got the contract.” And they said it like they could not have gotten it, which I had no idea. I thought it was, we're just waiting for paper paperwork. But it was a fight between them and Bendix. But they finally got it. I don't know on what basis, probably cost and delivery, which is always a big deal. So, then we had to start the project.

And working with Steve was fascinating, because I don't think he trusted me, because I was new and young. But he only thought on big scale, so he would draw blocks on paper and give it to me and said, “What do you think?” You know, it's like data in here and data gets done here, and all this stuff. So, we had these weird conversations at the beginning. I don't know for sure, but I think he finally realized he was forced to work with me.

And then one day I took one of his blocks, just in block diagrams I guess, and went into the lab and with the help of the technician who was fabulous, Lynn Hawkins was his name, we actually built up some of the circuits. And I said, “Steve, yeah, it works.” He goes, “Well how do you know it works?”

Holt: I said, “Well, we built it up.” I said, “Come on down and see it.” “No,” he says, “No, I don't go into labs.” So, we brought it up to his desk with a little power supply. He was impressed. He was impressed. I could take his idea and put it into actual working logic.

Leibson: So, I'm going to guess that you were Wire Wrapping at the time.

Holt: Yes, yes. Wire Wrapping. Great technology.

Leibson: Yeah.

Holt: So, we became best friends after that. I mean, he really opened up to me and started throwing all kinds of ideas out. So, I was working with the applied mathematician and Steve and then the technician and we were going back and forth. We were not too concerned about packaging at the time. We just wanted to come up with a system that would perform the equations and perform them in the time frame required.

That took about three or four months to come up with even one architect that we thought would work. And it was more of a traditional von Neumann style architect, where the one processor was doing all the work. So, at that point we touched base with a couple of semiconductor companies. The three we talked to was American Microsystems, General instruments, and North American Rockwell.

Leibson: Now, before we get into those, there is something unique about the F-14 that made it unusual compared to previous CADCs, and that's the swing wing.

Holt: Yes.

Leibson: And you might want to talk a bit about how that complicated the design.

Holt: Well, it was a new concept. First, there was not a lot of history on it. So, there was a lot of discussion, a lot of changes on how has it’s to be implemented. The equation for moving the wing was changed a lot. In the end, it turned out to be pretty simple, just Mach number versus wing sweep. Oh, angle of attack was in there a little bit. And Grumman was still experimenting with the wing, too. You know how far it's going to move forward and back and what speed. Some of that did not affect us, but they didn't know that.

So, it got to the point where we thought we could implement whatever they wanted. Then early on, we just kind of left it at that. So, they were confident that whatever speed, whatever angle, whatever limits on the angle, that we were OK. So, we didn't really hear from them probably for a year later.
So, our main concern was just implementing the processor and can we do all the equations? And I think it ended up being like 5000 multiplies and 3000 divides. And also at that point, early on the applied mathematician decided it had to be a 20-bit operation. So obviously that affects the speed of the computations also.

Leibson: Right, so, so the thousands of computations, that was per second?

Holt: Yes, yes.

Leibson: The 20-bit resolution now, were the pressure transducers able to produce readings at that resolution or just the math had to be that way to get the precision after all the multiplications and divisions?

Holt: Every math operation was 20 bits. And because of the range of the pressure input, we had to do, and this I learned at Garrett. I didn't learn this in school about scaling. So, take a small number which might have been 8 bits, and you scale it up, so when you multiply or divide by another number that's not scaled you get a more accurate answer apparently.

Leibson: OK.

Holt: I tried to go through all that math, but the applied mathematician assured me he was right. So, there was a lot of scaling done. Actually, those numbers I gave you was 5000, like, multiplies per equation. So, all the equations were repeated 14 times a second.

Leibson: So, it's 5000 times 14.

Holt: Yes

Leibson: OK. And I believe you had some software simulation programs to reassure yourselves that the design was right?

Holt: Yes. And that was really all, they just kind of gave that all to me. Really it got to a point where nobody knew what I was doing. It kind of scared me. You know all these brilliant engineers were around me and I would ask them, you know, this and that.

We hadn't done a computer before. So, from my Cal Poly days, from my hands-on I've learned, you have to simulate. You have to test everything. So, the first thing we did was to build a full working prototype out of standard ICs, and so that was one of our test models. Then we got to a point where we needed to really test the math more exhaustively. And so, what I needed was a programmer.

Well, backing up a little bit, my brother graduated from Stanford the same time in math. And he hired on at Garrett also. We both knew we were interviewing, but we didn't consult each other on accepting the offer. We both accepted Garrett offers. He worked in Los Angeles in the math programming area, and then I was in Torrance.

So about a year into the project, I needed a programmer and they said well, call the programming department. My brother had just finished a high-tech searchlight project for helicopters. And they said, "Well, Bill can work with you." So it was great. I mean two brothers. We fought all of our lives. We get to work together on a project like this. We got along great.

Well, he ended up writing the software simulator for the chips. Fortran was the only available language, and it wasn't designed for simulating. But he got all the chips simulated and we used that also.

Leibson: Do you recall what computer he was using for the simulation.

Holt: It was the business computer of the company. Let's see, the 1104, 1108.

Leibson: Yeah, that makes sense. A Univac 1108 would have been in the right time frame.

Holt: Yeah, I think that was it. I mean that was the only computer in the company that could do it and they, you know, they were programming with the card decks and everything and paper tape outputs sometimes.

So, we had those simulations and we just kept running them back and forth. You know, if it works on the hardware, then we should get the same answer on the software. Probably took four or five months.
But in the meantime, the first… So backing up just a little bit, once we got the first architect idea, we decided on American Microsystems because they were willing to work with us. And so, they looked at our concept, our design, and they came back in a few weeks and said they'll never work. Chips will be too big. They'll run too hot. We can't drive them that fast. So, we have to go back and redesign again. And Steve mainly did the high-level redesign and I would look at the details on how much logic that would take. And so, months or so later, we go back to AMI and again you know, too many wires between the chips. The packages are too big, and we only had 40 square inches to put the whole thing on, and this wasn't going to work.

Leibson: Now, were they targeting bipolar? Were they targeting bipolar or MOS for this?

Holt: No, it was N-channel.

Leibson: N-channel, NMOS.

Holt: NMOS, which is, like, brand new. You know, almost, they've made calculators out of it for a year, but…

Leibson: Yeah, for HP.

Holt: Yeah, HP and Burroughs. So, they suggested a few changes and of course, Steve Geller resisted their advice. But we go back and another month later we came up with another, and AMI finally said, “Yeah, I think this is possible.” And it was the architect we finally ended up with, with a single CPU and coprocessors doing the math.

Part of the problem was the single CPU just couldn't do all the math at the speed the chips had to run, which was 375 kHz. Super-fast at the time. Today, when I talk to students, they just kind of laugh, you know. “You mean it wasn't gigahertz?”

But we had temperature considerations, package considerations, and mil-spec considerations.
So, we moved forward with that architect and probably six months I've spent a lot of time at AMI in Santa Clara. And I'd help them. Not necessarily layout of the chips, but suggested things that might go together to minimize wire lengths and stuff like that. And we made a few minor changes, but eventually they laid out all the chips. And I'm sure you know back then it was all laid out by hand in Mylar, on a very large wall. And so here every chip was like on the wall with different colored mylar.

And the next step for them was, OK, we had to point-by-point verify everything works. So, I think it took about two or three weeks for each chip. I would be reading the logic schematic and the layout person would be on the ladder. “OK, we got that wire. We got this wire.” It was an amazing manual process.

Leibson: How many chips?

Holt: Six types.

Leibson: Now, do you remember what they were?

Holt: Yes, the CPU. RAM and ROM. ROM to hold program storage. And then one chip, which today would be called a digital multiplexer. It directed the data between the chips. I should know. I actually have them right here. Oh, then the multiplier and the divider coprocessors. So while we're talking about it, here, I have all this. [Shows a notebook with mounted chips and photos.] The first six chips off the production line. So, the multiplier chip, it's a 24-pin package, you know. This chip’s 150 mils by 150 mils, 3,063 transistor devices.

Leibson: Right.

Leibson: Now were all six chips in 24-PIN CerDIPS.

Holt: Actually, only two.

Leibson: Now there's a small one.

Holt: Yeah, that's the RAM.

Leibson: So, the RAM is so small.

Holt: I have more. I have more detail on this on my website, [firstmicroprocessor.com].

Leibson: So, the RAM is so small, with so few pins, I'm guessing that we're talking about a serial bus to connect these chips together.

Holt: Yes, that was the suggestion of AMI to eliminate the pins. And at first, we didn't like it. But after doing some calculations with coprocessors running in parallel and we added pipelining. So, while the last instruction was being performed, we would shift in the next instruction. And that helps speed up the whole processing a lot.

Leibson: So, pipeline execution, that's a relatively new concept for the time period we're talking about. Where did you get that?

Holt: Most of my ideas came from Gordon Bell's book of architecture. Wonderful, wonderful book. And I got to meet him in person the day I introduced all this [at the Vintage Computer Festival]. It was a great day.

Leibson: OK, now since you have gotten pretty deeply into AMI, as I understand it, they were not initially a willing partner.

Holt: They were not, and it was a shock. You know, we got to the point where they agreed the chips would work. We were happy with the architect, and the speed, and all that. And so, part of the process of a Navy contract or a military contract, he had to get multiple bids. And AMI helped us prepare the chips back, and then we had to add other stuff around it.

So, we sent it to General Instruments, North American Rockwell, and AMI. Waited a few weeks and all three of them said, “We're not interested.” That was a shock to my department managers. Then they started asking questions. “What are you guys doing?” You know, I thought, “This is all going to work.” So, they actually stopped me working on the project. They stopped the whole project, obviously, because what if we can’t do it you know.

And a few days later, my manager came to me and said if he had to pick one of the three sources, which one would you pick? I said, well, obviously AMI. They worked with us. They helped us do everything and he said, “OK.” So, a week and a half later, he came back and said, “OK, we're going with AMI. Get on the plane tomorrow and fly up there and start working with them.

I did not know for another year and a half what went on. And the reason I got to know was when this project was over, and I didn't know this happens in military, but like everyone disappears, you know they all leave and go work in other places. And so, I stayed another year and worked on the technical manual. And then I said, “Well, maybe I can work for AMI,” you know. So, I called them and they said, “Yeah, Yeah. You need to get approval from Garrett.”
I said why? “Well, they're part owner of our company.”

Leibson: And that's when you found out.

Holt: Yeah, I went to the president. Well, I went through my manager, and they said, “Sure, Ray can interview with them.” Then when I got up there, I got the whole story. And the story was the president of Garrett, Mr. Harry Wetzel, flew up to AMI, and talked to the two owners, and made them an offer they couldn't refuse, to buy 51% of their company at a very high price, make the chips, set up a second source company, which was called Garrett Microsystems, at the time in San Diego, and then when all that was working, we'll sell the stock back to you at a very low price. Well, the AMI owners became multimillionaires just out of that deal.

So, Garrett owned AMI and we got a lot of attention, and the chips were made.
The big moment was, you know the first set of chips, are they going to work or not? We had the programming patterns. I had to program in binary. I think it was 63,000 bits, and of course we simulated all the binary. The chips still had to work.

Leibson: So, there was no assembler?

Holt: No assembler, no time. Would love to have one. But the project was a two-year project. We were already well past halfway. But I was happy with the simulations, the hardware and the software simulation. And the day we got the chips, we were all ready to plug them into like a motherboard. It all worked. It was absolutely amazing.

And I think I was too young to appreciate all of that because of the pressure of the project, and like what if they didn't work, it'd be a three-month delay. We might lose the contract and all that stuff.
I just remember going to my boss, who was completely clueless on what we were doing, because he was a program administrator.

I said, “The chips work.” All he said was, “OK, ship it.” That's all he cared about. But I'd like to back up. There was another interesting part of the design. We delivered the chips to Grumman in March of 1970. But about 3-4 months earlier, they had come to us and they said, “We need your MTBF report.” Which I had never heard of, but of course my managers had. And they came to me and they said, “Well, can you help us prepare a MTBF report?” And I said, “What is it?” and all that stuff.

“Well, that's a history of the devices you're using. We have to prove to the Navy that they're reliable and won't fail and all that.” I guess for the first time, that's when they realized the N-channel process is less than a year old. There's no history. There's no report to make. They went back to the Navy and said that we have no history on these chips. The Navy was clearly upset. They formally stopped the project. They contacted Bendix, to see if they would pick up the project. Bendix said, “No, it's been too long. We're on to other stuff.”

So, for two weeks the project was formally stopped from the Navy, which made the department atmosphere pretty quiet. And then my manager came to me and said, “Ray, the Navy has asked If it's possible we can self-test the chips while the plane is flying.” Now I, I kind of knew what diagnostic was, but I didn't know what in-flight diagnostic would look like. So, my brother and I and a couple of other people, we kind of brainstormed for a few days. And then it dawned on me. Well, if we tell the chips to multiply 2 by 3, and if we get 6, they're working. But if we get 5, they're not working.

So using that basic concept, we came up with a set of bit patterns to run through the whole processor that tested every wire and every transistor on or off. And except for the multiplier and divider, we were 100 percent, and we ran it through my brother's simulation. And, so, he forced the failures in the simulation. And so, except for the coprocessors, we 100% could test all the other chips for single failure. And for the coprocessors, it was like 98%. It would take a lot more bit patterns that we didn't have room or time for them. And so, we went back to the Navy, and they said, “That's OK.”

Leibson: So let me see if I've got this right. You implemented a built-in self-test. How often did that run?

Holt: Every 14th of a second. Every major cycle, all bit patterns. So, well, I just programmed them in like normal equations, because the original set of equations, we used about half of the processing power. So, we had time left. So, in those open times, I just programmed these self-tests. And any single failure, I just had to turn on an output port.

So, part of this deal was, and the Navy said OK, we'll accept this. But we want you to put two computers in the plane. And if the first one says there's a single failure, switch over to the other one. Well, that doubled the cost for the company. But they had no choice. Looking back, it was a wise decision on the Navy. You know, having redundancy. And so that's how we implemented it. And so, they had to design some reliable switchover circuit, to switch the power and everything over. I never got the exact, how much time that took, but it was fast enough. It did not interrupt the operation of the plane.

Leibson: So, I think this is the first time that I've heard that the F-14 CADC is a dual-redundant design.

Holt: And what's interesting is, they said, “If you switch over, give us an output, and we're going to turn on a red light on, the display. And they did. And then in the pilot training, they were trained that if the red light comes on you can abort the mission and come back, or you can continue. It’s the pilot’s choice.
I thought that was pretty risky, yeah. So, moving forward, just a little bit, then we'll come back.
See, ten years later, I had a retail store in Santa Clara close to the University of Santa Clara. And in walks this guy about 28 years old. He wanted to buy a computer. So, we were talking and I finally asked him, “What do you do?” He says, “Well, I'm an F-14 pilot.” I said, “Oh boy, this is going to be good.”

And I had a display of the chips and everything, so I took him over and I told him everything I did. I said, "Oh, I have to ask you about this red light." And I told him this whole story and he just looked at me and said there's not a pilot in the US that would abort a mission for a red light. We took it out. So, at the time that's, you know, he said we took it out and that was it. So, later on, I'll tell you the final part of that story. So, we implemented the built-in test that was really good to help us diagnose the hardware prototype we have. And we of course, we use the software simulator to do it. So right before we release the chips to AMI, we wanted to do a complete exhaustive test. Not only the diagnostic patterns, but a set of patterns to simulate the flight and the angle and everything.

So, we went to the computer department, the IT department today, and said, "Well, we need to run this simulator. It's going to take a couple of days." And he said, "No, we can't do that because payroll's on Monday. Blah, blah, blah." Well, my department manager was pretty upset. He said, "Heck with payroll. We've got to release these chips." He goes to the President of the company, who now knows, you know, he's the owner of AMI. Told him the story and he said, "Well, I guess we'll make payroll on Tuesday." For the first time in history, they delayed payroll.

And our simulation ran Friday, Saturday, Sunday, and part of Monday. 100%, everything worked. So, we released the bit patterns for the ROMs. Now I think it was, it took 16 ROMs for the whole program. So, then we had to generate ROM patterns for each of the ROMs. And at the time, you only transmitted patterns on paper tape. So, we did punch it out on teletype. Of course, we did it three or four times. Sent them two sets. And that's what they used to make the ROMs. And we had to wait two or three months to see if everything was right.

Leibson: So how big was each ROM?

Holt: Have to look it up here. Was a 24-pin package also. 143 by 150 mils, 3200 transistors.

Leibson: How many bits?

Holt: Oh, it was 128 20-bit words.

Leibson: OK.

Holt: 2560 bits.

Leibson: So, the CADC is not only a 20-bit data machine, it has a 20-bit instruction word.

Holt: Yes. Yes. And because we implemented serial, the instruction of 20-bits is divided into controlling the RAM, the ROM and the CPU, constants. So just one word controlled the whole cycle, what everything does during that cycle. It was really kind of… Looking back, I thought it was pretty clever. It turned out to be conceptually simpler, I thought. Because it was synchronous, it was straightforward to program. I don't know at the time if I'd say programming binary is straightforward, but you know, looking back, you knew what you had to do at each clock cycle.

Leibson: Right, it, it's basically it's a RISC machine, right?

Holt: Now at the time, I didn't know what RISC was, but...

Leibson: Yeah, that term had not been invented yet. However, I'm suspecting that the multiplier and divider, they did not do their work in one cycle?

Holt: No. Well, one cycle was 20 clock bits, so every clock, the multiplier and divider would like add, shift, add, shift, add, shift. The tricky part was every time you add, the carry had to ripple through all 20 bits. And that's called carry lookahead. That was a huge design effort. Probably 90% of my design on those chips was on that carry lookahead because there's a lot of propagation delay.

And I work with AMI a lot on that, you know. How fast are these gates going to be and can we do it all in? Bottom line is that we proved it should work and it did work.

Holt: And I had implemented the hardware prototype exactly with the same gate structure as the chip. So, we had a comparison there. So, for me personally having those work was just the thrill of my life, you know, because I'd spent so much time on them.

Leibson: Now, one of the reasons that people don't know very much about this chipset is it took you another 20 plus years to get it declassified. You want to talk about that?

Holt: Yes, 30 years. So, when the project was over I wrote a paper. As a young engineer, I thought that'd be kind of cool to write this up. And I submitted it to Computer Design magazine. Just on my own. And they liked it. They accepted it. And they said, "Well, clearly this is a military project. Send us the military approval and we'll publish it." This would have been late 1970 or early 1971. And I went to my manager or the department head at that time and I said, "Well, I wrote this paper." You know, I was excited. It got approved. We're going to be known and all this stuff.

My manager said, "No. No Way" And he was the nicest. But I remember him being real strong, "No way." I said, "Well, would you ask the Navy?" "Well, I know their answer, but I will ask them." And they came back, "Absolutely not." So that was really disappointing. Then maybe a few weeks later, someone put into my head, hey, you know, hey, you should patent this.

So, I went through the same process. The proper manager says no, I don't think the Navy would approve the patent on this. Would you ask them? And so he did. And they said, "Absolutely not." I did not understand. Well, I knew the secrecy of it all, but I didn't understand why they wouldn't work with me a little bit on it. Well, I found out about 20 years later that at that time patents were all public. Whereas today you can apply for a private patent that will be released down the road. So had that been in place, I probably could have patented the concept. But I just had to accept it.

You know you work for an organization that controls your life and your design and all that and I just set it aside and they didn't tell me how long to keep a secret. I kind of knew the typical life of a plane was maybe 5 to 8 years before they replaced it. Well, the F-14 just kept going and going and every 10 years, for the next thirty years, I would call the F-14 office in Washington, in the Pentagon, and explain to them, "I got this paper, blah, blah, blah." They said, "No, we don't want you talking about it."

So finally in 1997, I called again. They transferred to the captain who was in charge of the F-14 at the time. I explained it to him and he said, "Now tell me that again. What are you asking me to do?" So, I told him, and then it was like he held the phone far away and he just was laughing. I thought, "This is not funny." He came back and said, "Oh, I'm really sorry. I'm really sorry. I realized I wasn't even born when you did this." He said, "Yeah, send me the paper. I'll approve it."

So I did, and on my original copy up in the right hand corner is a little stamp, "This is approved for publication." That was 1997. Then, in 1998, in Santa Clara, a gentleman by the name of Sam Ismail was running a Vintage Computer Festival. So, I contacted him and asked him if I could meet for lunch. I wanted to tell him my interest. I gave him the whole story over lunch. I didn't have any artifacts with me. Super nice guy, but he said, "I don't believe you." He says, "There's a lot of people said they had stuff early, but I don't believe you."

I said, "Well, if we meet tomorrow and I show you all the stuff, would you believe me?" He said, "Well, let's meet tomorrow and bring it." So, I brought the chips, I brought my technical manual, my engineering manual, everything. And he was dumbfounded. He goes, "I guess I have to believe you." And by then the plane was well known, and so he said, "Well, would you be my keynote speaker at the conference?" I said sure. And so, we introduced it at the Vintage Computer Festival.

So, two things came out of that that were nice. I got an article in the Wall Street Journal, and I got to meet Gordon Bell. He was speaking at that conference also. And Sam just walked him in and surprised me.

And I was like, “Wow! Here's Gordon Bell.” So, I told him the whole story, how I used his book and I have referenced him in the paper. And I had the paper there. So, he signed the paper for me. That was nice, you know?

Leibson: OK, so now we'll go back 30 years into the past again and talk about what happened when you left Garrett.

Holt: So 1971, late, I joined their engineering department.

Leibson: This is AMI now.

Holt: I was working with AMI in Santa Clara. I was working with the engineers that laid out the chips. I already knew them. You know, we got along well. I knew the manager, Ken Rose. And they were very heavy into calculators. So, my first two projects were to design a calculator. My first one with, partnering with Brian Schubert, who became Intel’s graphics director later on. And then the second one for Burroughs, I did on my own. One of these 100-key calculators.

Leibson: Are these still NMOS chips?

Holt: They have a lot of logic, huh?

Leibson: Still NMOS chips.

Holt: Yes, NMOS and single chip. And calculators are just, you know, a keystroke, a sequence, a keystroke, a sequence. Store data. Use it on the next sequence, and stuff like that. That was really fun. It was a lot easier than the F-14 design. And so, they showed me internally, you know, how to, what gates to use, and you know the whole process. And I worked with the layout engineer, circuit layout engineer. Both calculators just worked. I mean it was kind of fun. Then, so Intel was starting, I think they've already announced their 4004.

Leibson: That's November, ‘71.

Holt: Yes, they had. And I don't know how AMI became convinced. I’m sure I was part of it. But I know Ken Rose was convinced that they'd need to start doing their own processor. So, they formed a microprocessor “division,” that was more of a department. Eventually, after a year, there was 25 of us in it. They hired two other engineers besides myself, Gaymond Schultz and a guy named MacFarlane. He came from the DEC world. And so we did an AMI 7200 microprocessor, which was really a faster, more instructions than the 8080.

Leibson: It's an 8-bit machine?

Holt: 8-bit, yeah, 8-bit.

Holt: And that worked. Then the next year, 73, we did the AMI 7300. Now Gaymond wanted to get a little more exotic and convinced me it would be really cool, and I thought it would be too. So, we designed it where the instruction set was downloadable. So, we had a micro instruction set that configured the main instruction set.

Leibson: It's a micro programmable microprocessor.

Holt: Yeah, I mean, technically it's really cool. And the breadboard worked and the chips, you know, we got some chips working. That about that time, AMI, I mean, Intel announced the 8008, the 8080. And apparently AMI got a little nervous because they had a meeting of the managers and the marketing department, nobody from the microprocessor department. And they made a final decision that there was no future in microprocessors for AMI. All 25 of us were fired.

Leibson: Oh my. And AMI is, the one I know of is in Pocatello, but I suspect you are not in Pocatello.

Holt: No, I was in Santa Clara, and they had started the Pocatello Division, I think to make LED's. And I think they were bought out by Monsanto, probably. But somehow the Santa Clara division went away. Only because the cost of land was getting high. The cost of people was getting high.

Leibson: So, there you are in Santa Clara without a job. And then they… What did you do?

Holt: Well, part of the microprocessor department, we had hired a gentleman by the name of Manny Lemas. He was a programmer. And Manny and I got along very well. He had experience on General Electric mainframes, working with Chuck Peddle from Commodore. This was before his Commodore days, and he knew Bob Schreiner, who started Synertek. But they also knew Gene Amdahl. No, Lowell, who is Gene Amdahl's brother. So, Gene Amdahl started Amdahl Computer. Lowell Amdahl ran a consulting firm in Palo Alto. So, Manny talked to him and he agreed to hire us. And then we approached Intel to see if we could help them on their microprocessor. And it turned out they were open to some training.

So, we did a little bit of training. It was a short contract, but we did some local training of engineers on how to program. But that model did not fit into Lowell Amdahl's consulting firm. And Manny and I approached him and said, "Well, can we approach Intel to get our own contract and then break away?" And he said, "Yeah. That'd be fine. I'd support you." So we went back to Intel. And they were looking at that time for a bigger plan for training engineers. We were part of a marketing meeting where it was said that the President of Intel gave them an edict: "Figure out how to sell this thing in six months or I'm going to drop the line." He loved memory chips, going out at 10,000 a month, but he did not like microprocessors going out at a hundred a month.

Leibson: That's a perfect description of Andy Grove.

Holt: No, the other guy.

Leibson: Bob Noyce?

Holt: Yeah, Bob Noyce. I never met Noyce, but his words were everywhere. Andy was in his position, but he wasn't watching. He was doing the memory mainly. So, we had a couple meetings and we decided that the problem in marketing these chips is that engineers don't know how to program. They're trained to design fixed logic and programming was not even in their thinking. So, we came up with a set of training courses: two days on the 4004, two days on 8008. Later on, we integrated the 8080. And then the last day Gary Kildall came in and taught PL/M. You know, Gary did CP/M later for Digital Research?

Leibson: Right.

Holt: And so, for two years we were out on the road. All over the place. Lugging six teletypes. Big, big, heavy. We had to pay a lot of money to get people to move those for us. In Chicago, they refused to move them because they were too heavy. We couldn't pay anybody to move them up to our conference room, so we had to do it ourselves. It was a strange two years.

Leibson: What is the name of your company at this point?

Holt: Microcomputer Associates. We started in '74, and ultimately we sold it in '78. So, one interesting story. Somewhere in the second year, a gentleman…Oh, two stories. My professor from Cal Poly that taught the switching systems class, walked in one day and he signed up to take this class. And we looked at each other, I was like, "I'm supposed to teach you now?" We had a great time. We had a great time. That was just an honor, to teach your professor, you know, how to program those microcomputers.
And then the second year, this gentleman walked in. And he turned out to be the Vice President of Engineering for NCR, National Cash Register, one of the largest users of electronics in the world. He had 1000 engineers working for him. He really didn't want to be there, but he was told to come.

And so, in the class, we would do two days of programming the 4004 to read a switch and turn on a light, and then the next two days, the 8008, do the same thing. Well, he had trouble with the 4004, but on Thursday of the, that week, he threw the switch, the light came on, the guy jumped in the air, and he goes, "Hallelujah!" You know, that was a light-bulb moment for him. Went back and retrained all these engineers how to program. Converted everything over to Intel products and became their largest customer for many years. And that's probably why Intel is still shipping microprocessors.

Leibson: Well, we could discuss that. I think the IBM PC is why they're still ship shipping microprocessors, but…

Holt: Oh yeah, that helped too. But you know, initially because Noyce says, you know, "Figure out how to sell these things in six months, or else." The picture on the front of my book is the picture from that meeting of myself and my partner and Phil Tai from Intel and one of the other engineers. So that we took that picture for the brochure of the class. And I just ended up using it on my book.

Leibson: So at this point, I know there are two different directions you're going to end up going in. First of all, I know, you're going to have a publication, and secondly, you're going to hook up with Synertek. Which would you like to talk about first?

Holt: Yeah, let's do the publication. That was kind of a wild idea. So, we realized in 74 when we started Microcomputer Associates, there was not a lot of knowledge out there easily available. So, we had this crazy idea: "Well, let's start a little magazine to summarize all this stuff." Well, our technician, Darrell Crow, had a journalism background. So, we asked him if he would part time do a newsletter digesting all of this stuff. Well, he was a good technician for us, but he also loved that.

No, micro…, no word processor. Back then everything was typed, cut and paste. And we call that the Microcomputer Digest. Yeah, so this is Volume one, Number one. And there were 16 pages. And ultimately, we ended up with 1000 subscribers at $60.00 a year. And we did it for two years. Believe me, after two years, it was much more work than what we thought it would be. And we realized that we have to decide, do we want to be computer people or publishers? We decided not to publish anymore. So, we wrote three major publishing companies. The only two I remember is McGraw Hill and Macmillan. Both of them wrote us back. This would have been '76, late '76 probably. They almost said the same thing. It was, "We're not interested. We… there's no future in this field."

We just couldn't figure out why people weren't getting this, you know? Yeah, to them there probably was no future. You know, they probably hadn't even heard of it. We were offering them, almost dirt cheap, probably $5000 you know, a $60,000 a year subscription base. Now, a third of them were probably in libraries, in colleges, but still, you know. There's a good base. So, we ended up dropping it. And then two years... We were making products by then too. So, while we were working with Intel, we introduced our first product called the Jolt. The Jolt card. It's a single-chip, I mean single-card computer. I referred to that as the first home computer.

Leibson: What is it based on?

Holt: The 6502.

Leibson: So, you're teaching Intel, but you just based your first card-level product on the 6502. Why don't we discuss that?

Holt: Clearly more powerful. And they were they were being sold… I think by then, Synertek had second-sourced them. It was like $10 a chip or something. And we liked it. It was a good instruction set. So, we decided to do that. So, we advertised this. We found a marketing company. They went with us to advertise it internationally. We sold about 5000 of these in about two years. And backing me here [pointing to bookshelf behind him], there's other cards. So, they're I/O cards, RAM cards, music cards. We had a whole set of cards to go with it. I think you can see that. That's back right there. That was my prototype stack. Testing all the cards and typically that's how they built it in their home. They stacked them and then ran a ribbon cable between them.

But somewhere in the second year, which would have been ‘76, companies were… Oh, and that that was sold as a kit. Mainly as a kit. But we offered to solder it ourselves at a higher price, but most of them are sold as a kit, because at the time, Heathkit had created a huge market of “build your own radio, build your own TVs,” and all this stuff. But then companies would approach us and say our employees don't solder. Would you sell us a bunch that you soldered and tested? And would you make it a little more powerful? So, then we came out with called the Super Jolt. So more I/O, more RAM, more ROM. And still 6502-based. However, during this timeframe we made an 8080-based one too. And we sold tons of these, 30,000 maybe. Down the road when the… I'll tell you that story in a second.

So the reason we called it Jolt is because Manny Lemas and I, we went out to have lunch, and we had to come up with the name for what we were doing. Manny had a Hispanic background and was always calling me Jolt, which is Spanish for Holt. And after two hours, we couldn't come up with the name. And he says, “Oh, we got to go. Let's just call it Jolt.” And that was it.

Leibson: So, it's named after you.

Holt: Yeah. So, we have Holt and Super Holt. Probably ’76, ’77, there appeared to be a market for training programmers. Commodore had come out with the KIM: Keyboard Interface Monitor board. It was good for software training, but it was limited in I/O, and limited in RAM and ROM. And we knew Chuck Peddle, who was the engineer on it. So, we approached Chuck and said, “What are your plans with the board? Do you, are you going to make more?” And he said, “No, no, that's it.” We said, “Well, would you mind if we kind of copied it and enhanced it because…” “Oh no, go ahead and do that.” Because he was involved in selling 6502s also.

So we did that, and we came up with our own board. Initially it was called the VIM, the Versatile Interface Module. So, it has a keyboard, a display, microprocessor, RAM, ROM, speaker, lots of I/O, probably 64 I/O lines. Usually popular with manufacturing companies. They would build it in as an OEM board to control their machines. And I’m quite sure we sold probably 70 thousand of these. So that was a big kicker.

Now the most famous customer was in 1980. Or at least the most famous that I'm aware of. There was a gentleman named Bart Everest. He was a naval postgraduate student out of Monterey, CA. He was building a robot for a project. And when he found this board, it was perfect for him because it had a lot of I/O. And he wanted a lot of sensors. So, he built it in. It was the main controller of his robot Robart. The robot was called Robart I and he graduated with that as his project. Got a lot of attention commercially and military wise. And the Navy hired him as the first Commander of military robots around middle 80s.

Leibson: Now you said the board was originally called the VIM-1, but that's the SYM-1 board, isn't it?

Holt: Yes. So, a year later, because of our success, we did not have the cash to cash flow all the inventory and everything. So, Manny knew Robert Schreiner who was president of Intel, I mean, Synertek. We approached him and it turned out he was looking to start a systems division. And everything we did was exactly what he wanted. So, they bought us out, pretty much for nothing, just paying our debt off and raising our salary a little bit.

But he said, “You're going to be happy, because a month after we buy you, another company is going to buy us.” But he couldn't tell us. But we were just happy we were being bought and we can continue. A month later, Honeywell bought them. So, we became the smallest separate division of Honeywell. And the highest tech division of Honeywell. That was really interesting.

So Honeywell dealt with us separate from dealing with Synertek. Probably good or bad. Large companies have the mythology of meetings, meetings, meetings, reports, budgets. That's kind of wearing us out. But that's when we changed the name of the board to the SYM, Synertek Module. And that's when the volume increased. We probably had only sold about 5000 up to that time and then our company of 6 probably grew to 70 within Synertek. And they kept it, well, Honeywell kept it going for about four years. I ended up leaving in 1980, and I think around ’82, Honeywell dropped Synertek. Basically, they had driven it into the ground with their meetings and policies. Most of the founders had left, and it wasn't worth it to them.

One thing interesting out of that is, soon after they bought us, we were working on an electronic microprocessor control terminal. And ours is called the KTM, keyboard terminal module. So, it was the whole terminal on one board, and the keyboard. So, we ended up on our own simulating Honeywell's most popular terminal on our board. And we proved that it worked. Honeywell was divided into the control system and the information system [groups]. The information system [group] was selling that terminal, and we were part of the control system [group]. So, the control system [group] manager was excited. He went to the board meeting of Honeywell and said, “Look, we can make this terminal for $300. You're selling it for $3000 from the information system [group]. We think you should buy our board and save money.” And the information system people were furious that we were, that they were even working with terminals. And I heard it was a major Honeywell board discussion. And they voted to tell us to quit developing it. They didn't want to change anything. It was a high profit item already.
That's kind of discouraging, you know. But then we concentrated on the on the SYM and Super Jolts and…

Leibson: So eventually you left Honeywell.

Holt: Yeah, I left Honeywell in the ‘80s.

Leibson: And what did you do then?

Holt: I consulted for a while, which went pretty well. I ended up being a… getting the license on some video store software and some business medical office software. So, I was… I did the whole package, the hardware, the software installed, warranty. And then I started a retail store. The one where the pilot walked in. I did that for 10 years.

Leibson: What was the name of that store?

Holt: Cornerstone Computers. It was right across the street from Santa Clara University. That's where I've got my masters. And my theory was, I'll get orders from all these students. That was false.

Leibson: You forgot students don't have any money.

Holt: Yes. But they always walked in and took my time and asked questions, and then they go home, and they say, “Oh, I'll tell my parents to buy this.” Somewhere else. And I was building IBM clones at the time. So, I just used the storefront to continue my business operation. And then I got into the Internet and Web page design and I just I closed the store, I didn't need it.

Leibson: And, somehow, you've eventually ended up in Mississippi. How did that happen?

Holt: Well phrased. “Somehow.” Yes. When I retired in 2000, I left California. I went to Oklahoma. My dad was part Cherokee Indian. He talked a lot about it, but we never went there. And I knew I had tie-ins, and he was part of the Cherokee Nation, and so I spent four years in Oklahoma researching my Cherokee background. Which was very thrilling. I found grave sites of like five generations of Cherokees. Everyone in the backyards of people, because pre-statehood, everyone had their cemeteries in their backyard. And met some relatives. And just, it was just really nice.

Then I had to decide what to do. You know, I was, I had retired a little bit early, so now I was like late 65, 66, maybe. I decided it would really be cool to buy a motorhome, sell everything, and travel through the US. And stop here and there and do some computer consulting.

I did that. And I was sitting in my driveway, in the motorhome, ready to leave, kind of deciding, do I go East or West? And a friend of mine called from Mississippi and touched base, and eventually said, “Well on your travels, why don’t you come through and stay a while.” So, I decided to go east. I went to San Antonio for Christmas to see the River Walk there. And went on to Mississippi. And he said, he ran a Christian Ministry, and he supported 12 other small rural ministries. He said, “All of them are having computer problems. Would you stay a few weeks and go to each one and fix their problems?”
And I did, and they're all mostly user problems. And then we went on to lunch, he said, “Well, what do you think?” And I said, “What do you mean, what do I think? I'm ready to go.” He said, “Well, if you'll stay two more years, I'll cover your salary.”

Well, that was pretty tempting, because, you know, I was mainly on minimum retirement and trying to travel and I agreed to do that. And part of the agreement was that I would set up Web pages for each of those ministries, which I did. But the amazing part was all of them dealt with rural students.
And so, while I was there, I started teaching the students some STEM stuff: math, electronics, robotics. You just fall in love with that. It's, it's hard to get away from it when you know you can help them.
And so, after two years, I worked with one particular ministry. Taught a Saturday programming class, robotics, we went to world competition. It was fascinating. These kids from a town of 800 in rural Mississippi going to world competition.

Out of the 10 students, eight went to college, one became an EE, a girl. Two went in the military, and none of them dropped out of college. I mean high school. And so, I decided to start a nonprofit. And it's called STEM Advancement, and we operate as Mississippi Robotics within Mississippi. So, it was 2014, and I've been doing that since. So, we do after-school programs, camps, a lot of teacher training competitions. We've trained about 500 STEM teachers so far, and work directly with them, and with about 3000 students. I think I'll be there a while. My vision is to build a school. This is a rendering of the school. [Holds up rendering of a large campus.]

Leibson: That's quite the rendering.

Holt: It’s to be on 300 acres. We'll teach all aspects of STEM from 4th grade to 12th grade. It will be industry requirement driven. In other words, the skills that industry needs, we will make sure it's integrated into the program. It'll be kind of like a Cal Poly. A lot of hands on. So that's my vision. Like it kind of got the vision the first year I was there. But lately I ran across a gentleman who said he thinks he knows some supporters. So, we had the rendering done and now we're walking through the long process of “Where do we put it?” and “Who supports it?” You know, how do we make it work?” Nothing to do with engineering, but well, the teaching does, but you know it's just there's 200,000 low-income, disadvantaged students in Mississippi. It's a very unique culture. I think there's 500 small towns. They're an hour or so away. Every village or town has their own culture. Every local school department is run by local people, so they're all run different. Yet as a state, they're the lowest in the nation. And even though they graduate students, most of them don't have opportunity. It's, it's a long-haul thing, but I, we're just trying to change the culture and education.

Leibson: Well, it's quite a vision, I commend you for it.

Holt: Yeah, that's interesting. I think it's harder than making chips.

Leibson: Working with people is always harder than making chips.

Holt: There's one thing I wanted to talk about. During the design phase of the [F-14] chips, it was so sensitive, you know on package size, and power distribution, and speed, that I actually had to measure the distance of all the wires on the PC board, measure the capacitance of every wire, and we even did it internally on the chips. So, in my engineering notebook I ran across, this was in July of ’70, the diagram of where, this one was for… the loading on the outputs of all the chips. [Holds up engineering notebook.]
So, we had to go through every output and then I had to measure the capacitance out of the chip and then the capacitance on the PC board. And then AMI had to say, well, that is too much or too little, you

know, because the wave form can't curve too much. You had to stay pretty straight. And I remember that taking quite a while.

Leibson: So, is this a two-layer PC board?

Holt: Six-layer.

Leibson: Six-layer PC board. OK so…

Holt: Very major at the time. We had to find a certain manufacturer that was willing to do it. It has three ground layers and then three trace layers.

Leibson: So, it's going to have extra capacitance.

Holt: Yes. So, we had to measure all that and then make sure it was within spec. And I was really nervous about that when we got the chips, because what if we did that wrong and one of the waveforms, you know, wasn't right.

Leibson: So, I'm familiar with…

Holt: It's kind of fun.

Leibson: I'm familiar with the need for one and two ground planes, but three?

Holt: Yeah, that's three.

Leibson: Why?

Holt: Just to minimize the ground paths.

Leibson: Well, that'll do it.

Holt: And we figured the current on each output, you know it's in microamps. We figured how much was dumping into each ground plane. Just to minimize. The military people are quite good at analyzing ground noise and stuff like that. It was really fun, working with these engineers. They're like analog experts. I learned a lot. The main circuit design engineer was Tom Redfern, and he went to National Semiconductor after the project, and he became their CMOS expert, and eventually was the first National Semiconductor fellow. Tom was very good.

Leibson: So, you spent 30 years getting this declassified, and since then people have been talking about the CADC for well, for the rest of this period. Why do you think they're still talking about the CADC?

Holt: Well, I don't want to be too Smarty here, but many believe it's still not true. “How could you do that, and no one knew about it?” And those that do believe we did it, “Are you trying to make trouble?” One professor said, “Ray seems like a good engineer. Why would he do this? Why would he try to change history?” Nothing to do with engineering interest. And, of course, my whole purpose was just to reveal that we did it, and it worked. But very few are looking at it from an architect point of view. You know what we had to go through with that technology to make it work at mil spec.

It's been interesting, yeah. I talk at universities a lot. I never charged for that. I never made a penny off of this. And it's fun because the professors that know about this time period, they're excited. And the students are completely clueless. You know, they couldn't believe we had paper tape outputs and stuff. So, it's been enjoyable speaking on it.

How it's labeled in history is not up to me. I just want to make sure that it was known that we did it.

And of course, the plane is well known. And with the second, you know “Top Gun” that featured the plane, that's the first time I saw the plane fly, by the way.

Leibson: In the movie.

Holt: And when “Maverick” came out this year, last year, there's more talk about it.
And two years ago, three years ago now, I got to speak to the F-14 Pilot Association out of Pensacola. First time I've formally spoken to pilots. It was like 50 of them, and it was a thrill. Thrilled because they had no clue of what was controlling their plane. Their wives were more intrigued than they were, I think. But they really enjoyed it. And while I was speaking, I talked about this red light for the switchover. And the lady in the back who was a, now the army has master sergeants, but she was that level in the Navy [Master Chief Petty Officer], and her job was maintenance on the CADC. And when I mentioned the red light, she yelled out, “We changed it to amber.”

Because the first pilot I met early on said they took it out. But they put it back as amber. And then she said, “And we added a reset on your computer.” Now, that stunned me and it's embarrassing to a designer, that you had to reset. But I didn't question her during my talk. I talked to her afterwards. I said, “Tell me about this reset.” She said, “Well, it was on the third model of the plane. And they added a lot of other electronics and more stuff. And so, the airplane’s power source started getting noise, and it triggered the switchover in the CADC. And so, the light would come on falsely. And instead of redesigning the CADC, somebody decided, “Well, let's just reset the computer. See if the light goes out. And if it does, you're OK.” Well, I guess if I was in their position, you know, after 20 years, that would be a good choice. And so, after I talked, I went back here. I went back and I was sitting next to a pilot. I said, “Tell me. Are you really up there dogfighting, hitting reset all the time?” “Yeah, no problem.” It's just it's crazy.

Leibson: It is crazy.

Holt: That was near the end of the life cycle of the plane, probably around 2000. But I did ask her, and I really wanted to know this, “Were there any deaths of pilots due to the CADC?” And she said, “Absolutely not.” Most of them were pilot error or mechanical or hydraulic problems.

Leibson: That's a relief.

Holt: One more quick story, if you don't mind. Late ’70, December, the first F-14 did a test flight. That was successful. On the second test flight, as they were landing, and this is a movie that's all over the Internet, the F-14 was coming in and it started wobbling. And pilots ejected and it crashed. And the exact motion, in my opinion, it was, could be caused by the CADC. And I was just visiting my parents and my Dad said, “Look, come in, come in.” They were showing on the news the plane crash and, oh, I was just dumbfounded. So, I went in to work the next day. For two days, completely silent, nobody knew what happened. They said it could have been the CADC. We're all talking then. You know, what could it have been? Well, it turned out it was a hydraulic gasket leak. And in that movie, you could see the fluid leak before the plane crash. So complete relief. And all these years, I think about the designer of that gasket. What he was thinking and then, when he found out it was his problem. I have great sympathy for him.

Leibson: So that's actually something we didn't cover, and that is that the CADC, the original mechanical one, was just driving indicators. This one is actually moving control surfaces.

Holt: Yes. There is what they call maneuver flaps, which are kind of on the wings, going up and down, that control angle. In the front of the wings, they had these little wings that would come out called glove vanes. And that was what stabilized the plane as it went through Mach 1. Those were added at the last minute. That was the last math equation to be added. And it's pretty simple. You know when you get to 0.9 Mach, they go out. When you get to 1.1 Mach, they come back in. Eventually they took those out because they redesigned the front of the wing a little bit. And then the actual sweep of the wing, and that it had an automatic mode, which is controlled based on airspeed and altitude and angle. So, we would automatically move them back. So, when it was moving slow, and like landing on the carrier, they would be all the way out for maximum lift. And then they were, for high altitude, high speed, high end, they'd be all the way back. You know, to minimize the drag and to prevent the tips of the wings from burning off. So, the computer did that automatically, but the pilot did have a mode where he can position the wing any place he wanted. But the computer limited him to within the safety range, so when he, mainly when he's at lower altitude, he could move them out more or in, you know, somehow they had to feel for all that. That turned out to be very successful. The mechanical designers on that wing were up for many awards in the mechanical area.

Uh, the one thing interesting is that the near the end of the design cycle for us, I received a request from those mechanical engineers, and it was like this: “When you move the wing, would you move it at the same time slot within the 14th of the second? So within the 14th of the second, don't move it here and then next time, move it here.” In other words, they wanted to eliminate the harmonics.

Leibson: Right. They wanted a smooth actuation.

Holt: And not knowing how we designed the computer, you know it could have been asynchronous. Since we were a synchronous computer, wherever the program says to move it, it's going to be the same every time.

Leibson: Right.

Holt: Like within days, we just wrote her back and said, “Done. We fixed it.”

Leibson: Yeah, got you covered.

Holt: I heard that they were happy. I actually talked to one of them about 10 years later. He remembered that. He was, he said, “That made us very happy.” Because, had we not been able to do it, they would have had to beef up some of the mechanical and it would have been heavier, and they were trying to make it lighter.

Leibson: OK. Anything else you want to talk about before we end this wonderful conversation?

Holt: Recently, a gentleman from the University of Boston, he's a biology professor. I won't mention his name. But he contacted me, and he says programming in C++ is my hobby. Can I write a software simulator on your old computer? So, I gave him copies of the technical manual. For the last two years, he's been doing it. He's already simulated three of the chips. The whole instruction set. And our goal is to, I don't have copies of the final program, you know. I wasn't bold enough to take that out of the company, but we'll figure out how to program it to simulate wing movement and stuff like that. So, we’re both quite excited about that. It's the first person approached me on that. And then based on that experience, I would like to find maybe a graduate student in computer science program that would simulate the hardware in current technology? And my goal would be to run it at the same speed as the original and do some benchmark testing. Like you know, some fantasy math equations and see how that compares to the 8080 and the Pentiums, and…

Leibson: That sounds like a potential project for Nvidia's Omnivision, which is a big system in the cloud for building digital twins of electromechanical systems and entire factories.

Holt: I just saw something not too long ago on that that would be interesting. One thing about the CADC architecture was we did not know if they were going to have us upgrade as the plane upgraded. They did ask us to leave quite a bit of extra space for upgrades. So, when we built the coprocessors, we built them where you can add more on. And it's really unlimited, so you could have five multipliers and five dividers. So, if we rebuild it up, I would like to add more of those and see how it affects some of the math we run through it. Now, it still has to be binary programmed, so somebody will have to come forward and attempt a compiler for it. Which is possible.

Leibson: Yeah, I mean one FPGA could implement the entire machine at this time. So, you know the hardware could be replicated exactly. The logic could be replicated exactly, including the RAM and the ROM, all on one chip at this point.

Holt: Yeah. Yes. Oh, yeah.

Leibson: A field programmable chip, right? So, there's a company called Digilent, for example, which makes FPGA boards for students. One Digilent board could replicate, I think, the entire CADC.

Holt: Well, maybe somebody would take on the project. I mean, I'd work with them. I have all the specs and…But it's been interesting, nobody has approached me technically on the on the chipset, except, well, except this Boston professor. So, most of the interest is the fact it was done in ’70, and “Are you sure it really worked and all this stuff?”

Leibson: The plane flew. Yeah, we're sure it worked.

Holt: Can't deny there's movies on it and…Now, I've had several people, including yourself, write nice articles. And the Smithsonian magazine wrote a nice article. And they wrote it as if they believed it, so that was nice. And they did request if I would donate the chipsets to the museum, and I won't. I'd rather sell them and finance my new school.

Leibson: That's a good idea.

Holt: With the follow up the last 20 years, you know presenting it, talking to museums, and talking to schools, it's been fascinating. And I like the fact that I could have students touch it. You know, I show them this chance to touch them, you know. So, you touched an early microprocessor. It just seems to be encouraging to them that they can touch history like that. And the boards you know…Another interesting story is I think it was around 2002. I was asked by an IEEE group at Cal Poly Pomona to come and speak, which is really nice. One of my professors was there. They didn't tell me till afterwards. And when I told them about the SYM board, it was dead silent. I mean, they're like, “Wow! Wow.” And a student walked up to me afterwards and said, “I'm from Compton. I'm majoring in electronic engineering like you. I graduate this year. Tell me about that board.” And I told him. He’d never seen one. How's that possible? How do you learn design?

Leibson: On a keyboard.

Holt: We do it on the computer, we send it to China, they make it, it comes back encapsulated. And it works or doesn't work.

Leibson: Right.

Holt: That's when I first realized that the design technology’s really changed.

Leibson: I'm afraid so. Yeah, it's all done by keyboard jockeys.

Holt: Yeah, well, he was fascinated. You know, “What are these wires, and the chips?” One other interesting story on the SYM is that Bill Gates had introduced his BASIC language around the time we made this. And so, we contacted him and wanted to license the BASIC. So, he was 18 years old. He came to our office and slapped the contract in front of us to sign the contract, and you can license the BASIC for $25,000. And no negotiation, no nothing. So, we were his fourth customer. And so, we bought the BASIC and we put it on the EPROM and then it plugged in one of the sockets. And so, when the board powered up, it would start right to BASIC, if you wanted it to.

Leibson: So that had to be translated, right? He originally wrote the BASIC for the Altair.

Holt: Right.

Leibson: So, it was in 8080 code. It was not in 6502 code.

Holt: But he wrote it in a compiler where he could switch the language. And so, we were one of the first ones, I understand, for the 6502. But he had to manually program our input-outputs, and apparently there was a big problem. My programmer kept saying, “It doesn't work, it doesn't work.” And she would go back to Bill, and he would say, “It has to work. It has to work.” After about 3 turnarounds, we quit getting support. So, we ended up changing the hardware a little bit and made it work. But overall, it was successful as part of the board.

Leibson: Well, that's an interesting side story that I hadn't heard before.

Holt: Yeah. If you go to a computer-museum or, yeah, computer-museum.org or com. Look up the SYM. She has her story there.

Leibson: OK.

Holt: Name was Bonnie Sullivan.

Leibson: OK.

Holt: Really great programmer. There's a lot of hidden stories in this industry.

Leibson: There are indeed. I have tried to write up quite a few of them, but there's always more to write up.

Holt: Yeah, you do a great job. Keep it up.

Leibson: Well, thank you. Thank you and thank you very much for this interview.

END OF THE INTERVIEW

