Oral History of Travis Blalock

Interviewed by:
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Steinbach: For the record, today is August 3rd, 2018. This is the oral history of Travis Blalock recorded for the Computer History Museum by Shelby Blalock in Charlottesville, Virginia. I'm Günter Steinbach and I'm in Silicon Valley in California talking to Travis on the phone. So welcome, Travis, and thank you for agreeing to donate your oral history to the museum. The reason I wanted to interview you is that you once designed an optical navigation chip that became the basis for the modern optical mouse but this interview is not restricted to just that; it is supposed to cover your whole life history up to now.

Blalock: Wow.

Steinbach: You're not that old yet - up to now! So let's start with your background. How and where did you grow up? Do you have siblings?

Blalock: Well, yes, but first let me just say thanks so much for asking me to do this; it's quite an honor. I follow the activities of the Computer History Museum and it's really making an important contribution and given the folks that are already in there I'm just delighted and honored to be invited to participate so thanks very much for that, Günter. Anyway, to your question, yes, I have two siblings, an older brother, Allen, and a younger brother, Ben. My father was an electrical engineer and all three of us are electrical engineers. My poor mother was just completely outnumbered and as we got married she was so grateful to have non engineers in the family to talk with, but yeah, all of us-- It's very interesting though; my father, he didn't say, "Hey, you really should be an electrical engineer" or anything like that, but what we saw was that he really enjoyed his work and really enjoyed the creative process of design and so I think that just sort of rubbed off on us and maybe we were genetically predisposed, who knows, but somehow we all ended up as electrical engineers.

Steinbach: Okay. And you mentioned that you kind of teach each other from generation to generation.

Blalock: Yeah. I took electronics, undergraduate analog electronics, from my father and then my son who's now at MIT, he took undergraduate electronics from me at University of Virginia. So it's been sort of a family story at this point.

Steinbach: Okay. And you also mentioned that you started early on with electronics and electrical things in the way of hobbies. What can you tell about that?

Blalock: Well, I don't know. I like to take things apart and sometimes I manage to put them back together, not always, but I-- yeah, I was always interested in understanding how things worked and I remember early on I worked out a way to get a direct patch of analog music from the radio so I could record directly rather than from the speaker. I was probably seven years old or something and to me that was an amazing piece of hardware that I created. But anyway when I would visit my dad at the university-- he was a research engineer-- I used to use large carbon resistors-- I mean when I was very, very young, probably six, I don't know-- and I would solder them together to build things. Some people used Lincoln Logs. I used one-watt carbon resistors to solder together houses and things so-- and then I would measure their impedance with the meters and stuff. So anyway, yeah, a little bit of that and a lot of normal stuff too, swim team, track, all those things.

Steinbach: Okay. All right. And you also mentioned rebuilding a car engine, wow, that's--

Blalock: Oh, yeah. Yeah, I had a '67 Mustang and it had been-- it had over a hundred thousand miles when I got it and so it was already pretty beat up and we got it running, did a valve job, did some other things but that was just work on the top end. Later on the bottom end failed and suddenly lots and lots of blue smoke started coming out of the back of the car. And so I went to a junkyard and found a '72 Mercury Montego that had been smashed in the rear end and so that had a 302 in it and it turns out you can bolt in a 302 directly in place of a 289 and so one weekend I rented an engine hoist and took the 302 and swapped out the 289 that came in the '67 Mustang and got it all up and running. The irony is that the only problem it had was electrical after I got it all connected. I connected everything, got it mechanically timed as closely as I could and I started it and it just ran horribly, I mean just absolutely horribly, I thought oh, my gosh, I got a lemon out of that junkyard but I realized I had swapped two sparkplug wires and so when I put those back in place it ran beautifully. Eventually I sold it to my brother and then he sold it to somebody else; I don't know where it is now but it was a great car.

Steinbach: Well, I have to mention here that I had a 1953 Citroën but I didn't ever work on the engine.

Blalock: Oh, that was a beautiful car though.

Steinbach: Yeah. The front-wheel drive, designed in '36 or so, they were revolutionary. Anyway--

Blalock: Oh, yeah, absolutely.

Steinbach: So let's list your engineering degrees, when and where you got your degrees.

Blalock: A bachelor's degree I did at University of Tennessee in Knoxville, Tennessee; that's where my father was a professor and it seemed a logical place to go. And I then went to NASA. I had been an engineering co-op at NASA Langley Research Center for most of my undergraduate period, which was fantastic; you got work experience in between each quarter of coursework. And then when I was back at school I also worked at a nuclear instrumentation company part time while I was full time in school and then in between each of those quarters I was working at NASA Langley. After I graduated I went to Langley for a couple years and decided to go back to grad school. Went back to Knoxville to the University of Tennessee for my master's degree, and worked on a radiation hardened, very high-power radiation-hardened switching power supply for my thesis. Then I went to Auburn University to work on my Ph.D. where I specialized in-- the focus of my Ph.D. was very high-speed DRAM sense amplifiers, which sounds digital but it's actually a very analog sort of problem.

Steinbach: Right. Your time at NASA, I think that coincided with the Challenger disaster?

Blalock: Yeah, it was—

Steinbach: I--

Blalock: Yeah, it was a really difficult time. I'm sorry. Go ahead.

Steinbach: No. Go ahead.

Blalock: Yeah. I was actually working on a project where we were-- they wanted to launch the shuttle from California and to do that you've got to go out over the Pacific for safety and if you go out over the Pacific you're working against the Earth's rotation in terms of getting to orbit and so they needed to lighten the shuttle. So they decided they were going to try to make the solid rocket booster casings out of graphite epoxy composite to lighten it up. I was working in a group that was working on material characterization techniques for a number of things but one of the projects was to try to find out a way to test these booster casings before they were used, characterize the materials and make sure they were going to hold up. And then tragically that project wasn't too far along when we lost the Challenger and then NASA became very, very conservative of course. At that point the launching from Vandenberg and the graphite epoxy solid casings, that completely turned off at that point, but it was a great place to work and a lot of really outstanding people there, I learned a lot.

Steinbach: So after your Ph.D. you went to HP Labs, right, and I understand the path there was not exactly straight. So what year did you join the labs and how did you get there?

Blalock: I joined in '91, which if you remember that was-- it was early '91 when I was interviewing and that was during the first Gulf War and employers were very nervous; they were being very conservative and so there weren't many jobs. This was interesting because when I happened to be graduating with my bachelor's was a real boom time for electrical engineers and people would send you offers without even interviewing you but now suddenly in '91 it was a lot different situation. I really wanted to work at an industrial R&D lab; I thought eventually I wanted to teach at a university but I wanted to work in industry for a while first to get that experience and just to learn but none of those positions were available. So I was at an interview at UC Davis and I had an interview scheduled at UC Berkeley and I had some time off from Davis and so I thought I'd drive down and see what was happening at Berkeley and check out the department. While walking around UC Berkeley I saw a notice on the board about a job at HP Labs and so I wrote that down. I believe Joey Doernberg posted that note on that bulletin board. Do you remember Joey?

Steinbach: Oh, yes.

Blalock: He worked in our department and so thanks, Joey. I think he's the person who actually put that notice on the bulletin board at Berkeley. And I was just-- I just went down there on a lark to go explore and learn more about it before an interview and found that note and then made some calls and ended up having an interview with HP Labs. I had a great day interviewing there and ended up going to HP Labs. So even though it was a really difficult situation I ended up at just a wonderful place. It was a real blessing how it all worked out.

Steinbach: It is a good place to work, yes.

Blalock: But it was a little circuitous. Sometimes you just have to keep looking, keep trying, and you never know where you're going find a really interesting opportunity.

Steinbach: Now tell us about what you worked on at Labs, kind of in order maybe.

Blalock: Okay. Well, when I started it was very interesting. Tom Hornak, wonderfully brilliant, clever, just a real gentleman, he ran the department-- the high-speed electronics department-- at that time and he had hired me under the auspices of becoming another designer on the GLink chip; this was a project of Rick Walker and Cheryl whose last name escapes me and some others. They had been looking for a long time to find somebody and by the time I was hired the project was essentially finished. And so when I got there, in August I believe, Tom revealed his secret plan and his secret plan was for me to actually start a CMOS design effort because the group had not done any CMOS design up to that point and my background was CMOS. I had wondered why is he hiring me for a bipolar design position but it turned out he had a secret plan and so Tom had me start looking-- start developing and putting the tools in place for us to be able to do CMOS design within that department. And then I kind of went around Labs looking for opportunities that might make sense for that technology, that our department could contribute to, and the first I actually encountered-- the first sort of major project was-- Well, as an aside Tom and I spent some time looking at analog neural network architectures but at the time it was sort of a hammer looking for a nail and CNNs and other things hadn't been developed like they are today. And so believe it or not we had trouble finding the right application for that and so we didn't pursue it. Hearing that it's sort of surprising because neural nets are everywhere. Well, I found that the storage technology department was working with the disk mechanism division in Boise and I started working on some circuits and techniques that could be used in disk drive read channels. And just to give you a little background, at HP Labs we sort of had a couple of missions. One was to help evolve existing technology in product groups; the other thing was to also just create entirely new businesses sometimes. Maybe hopefully create new technologies that could lead to entirely new business groups. The storage technology department had been working closely with the product division in Boise, the disk mechanism division, and this was the time that disk drives were transitioning from the old technology into partial response, maximum likelihood channels and Labs was trying to get the product division to shift to this new technology. So we decided to try and build a sort of a demonstration chip to help move that process along. It was a big project. It ended up having some issues and unfortunately the disk mechanism division ran into a lot of headwinds because disk drives at that time were really becoming commodity items and HP previously had been very vertical. You need a computer, of course you build your own disk drive, right, that was the thinking but of course nobody does that now, and so unfortunately the disk mechanism division ended up being closed and that project ended but I had a lot of exposure to and learning of a lot of great technologies.

Steinbach: And you got some patents out of it.

Blalock: Yeah, we got some patents out of it and actually one of the most important things that came out of that within our department, within the design group, was that we ran into some big problems in that prototype chip and one of those problems was that we weren't accounting enough for the variability of CMOS circuits. I got bitten pretty badly by that and I just realized we did not have the tools in place to predict, model, and analyze the effects of variability very well. And so I set about building some tools and we released test chips so that we could gather the necessary statistical data for the parameters to put into those models. So from that point on any design that we did, we used these tools to do good statistical analyses of what the variation was going to be in the worst case and standard deviation, those sorts of things. Now that's a common thing in any decent analog tool set but at that time we didn't really have that.

Steinbach: So that came from you, right? When I went back to HP Labs that was established and I said, "Oh, this is great!"

Blalock: Yeah, it was part of-- and really with CMOS it just has to be part of the design process and it is commonly in tools now but at that time we just didn't have anything for that and I sort of learned the hard way with some circuits that had some real issues. So I thought okay, never again! I'm not going to be bitten by that one again; I'll make some other mistake next time.

Steinbach: Okay. So what next?

Blalock: After that came the hand-held-scanner project which led to the optical mouse, which is I think your primary interest today. I think Bill Holland you interviewed earlier, he mentioned that Joel Birnbaum had sort of started this ultra portable peripherals initiative and the idea was hand-held devices to do sort of fulfill the roles of peripheral functions for computing and other activities. Ross Allen in the printing technology department, he formed a little ad hoc group called the Nude Couch Potato Office of the Future Task Force which-- It's a very strange name but the idea was, if you had no pockets or backpack or anything else, what would be the one or two sort of handheld devices you would really want to have and so that's where the name-- the moniker came from, Nude Couch Potato. But what would be the must-have things you'd want to carry with you? They thought that a handheld scanner would be one of those items you'd like to have. They had been thinking about this and how to do this and developing some architectures. We ended up having some conversations and I had CMOS analog signal processing background and they described to me a little bit of the work that Bill Holland and John Ertel had done in using imaging and cross-correlation to measure movement over surfaces, paper in particular. So I kind of took that back and thought "well, is there a way that we could integrate that onto a single chip and do it in a way that would be really low power so that you could reasonably put that into a handheld device?" I proposed an architecture that could do all of that and then we ended up formally starting a project which was initially-- The device was called Swipe, which I think was a much better name than the final product name of "CapShare." I don't know who came up with "CapShare"; I guess it was-- sorry, marketing people, but it didn't--

Steinbach: Fort Collins actually called it "Zorro."

Blalock: Oh, Zorro too, yeah, because—

Steinbach: --because of the motion--

Blalock: Yeah, that was good.

Steinbach: The people who wanted the handheld scanner, did they know that they wanted a free-form movement and so they needed a navigation chip?

Blalock: Well, sort of in a general sense. I mean they knew that Bill and John-- Bill Holland and John Ertel-- had done that nice work with a CCD and off-the-shelf DSP and so I thought well, that would probably allow us to track motion. And so yeah, I think they felt like they wanted to get away from-- There were a couple of handheld scanners out there that had the rotating balls or rotating wheels and you could move across and they would encode the motion of the wheels but they really wanted to make it a much more freehand kind of system but they didn't know how to get there in a practical way, right. They said, "Well, we ought to navigate somehow optically." Unfortunately I just moved, we moved out to a farm and I cannot find my CapShare. It's somewhere missing but you may have— actually very few people have seen this thanks to HP stealth marketing. At any rate, this is what the device looks like. It's a handheld device. You had a little very crude 1990s LCD screen but the action happens on the end. There's a linear imaging array to gather the actual image, the scan data, and then there are these two little optical navigation modules and these tracked position as the scanner moved in a freehand across the paper so you're gathering stripes, 1D stripes of data as you move the device and then these two are measuring the X, Y position as it moves across the paper. If you're going to stitch all that together of course you need to encode position very accurately and so I proposed an architecture that we could put in a single chip to build a-- basically an optical cross-correlation processor and--

Steinbach: And that needed to be in 2D, right?

Blalock: Yes—

Steinbach: --because Holland had only a 1D paper advance encoded.

Blalock: Right. They had prototyped a 1D system and like I said it was sort of an off-the-shelf DSP and used CCDs, a lot of power and area. Okay well, at that time people were beginning to build CMOS imagers. That's when a lot of that was happening, the very beginnings of CMOS cameras, and so I thought okay, we can integrate a CMOS imaging array and then if we really want to make this low cost and low power we need to somehow on chip do these cross-correlations, on chip. And so we actually did-- in the first prototype, the Magellan chip-- this is the actual prototype chip from the MOSIS foundry service. It's an HP process. This chip if you could zoom in there's a compass logo on it, for navigation. Anyway, it had an optical imaging array; Dick Baumgartner and myself did the bulk of the chip design. Dick primarily focused on the optical imaging array, very nice work. And then the image data would be transferred in the analog domain from an imaging array down to a computation array and the computation array had analog storage for the entire array plus it had storage for a reference image. And so what would happen, as it started you would acquire a reference image and then you would continuously acquire new images as the device moved and what was neat about the architecture was that it enabled-- each array element had nearest neighbor connectivity so you would calculate nine correlations, an autocorrelation and eight cross-correlations, with each of your eight nearest neighbors, the diagonals and the perpendicular, and then you could interpolate in correlation space where the best fit was. And so the trick was you had to do that very fast so that you never moved more than one pixel; otherwise you could get lost, right. So you've got nearest neighbor connectivity and you've got a reference frame. Imagine you take a picture and then as you're moving you take more pictures, you compare them and you say, "Okay. Now I moved far enough. Now I'll build-- create a new reference frame" and it would keep going like that. A couple--

Steinbach: So--

Blalock: Okay. Sorry. Go ahead.

Steinbach: So you talked about interpolating so you had sub-pixel resolution for the correlation?

Blalock: Yes. The chip actually output the nine correlation numbers for the eight nearest neighbors and the autocorrelation and then you would interpolate off chip. We didn't do the interpolation on chip on that first prototype. In later devices the interpolation was moved on chip. So that little chip running in the 0.8 micron CMOS could do the equivalent operations per second to 1-1/2 giga operations per second and it was doing this for under 200 milliwatts, nothing you could have approached at that time in the digital domain. A couple of neat tricks we did: As the optical images were being transferred down to this computation array we would do local differencing on two axes so there were buffers, analog buffers in between the two arrays, a little 2D FIR, and we would calculate local differences so that we were correlating on the gradients rather than on the absolute response. And that really is huge because it wouldn't work otherwise. I mean just processing absolute response could swamp out the correlation because we were looking for very, very small signals. So it had a little differencing engine. And then the other neat hack: After doing a lot of system simulations and looking at the accumulated error-- we wanted to have close to 300 DPI accuracy at the end of the page. And so the accumulated error goes as the square root of the number of times you acquire new reference frames. It's a square root N sort of error accumulation, a random walk problem.

Steinbach: Yeah.

Blalock: Yeah, and so-- but we only had nearest neighbor connectivity and so I tweaked the architecture, adjusted it so that you could drag the reference frame along as you moved so you'd grab a reference frame and you'd realize oh, we moved to the upper left location, now we're getting a strong correlation there, so we would analog-shift this entire reference frame to that location, we'd move it up and to the left, right, and so now we do nearest neighbor cross-correlations with the same reference frame and then we'd move it again, do nearest neighbor calcs again. So by introducing this reference frame translation you could-- If you dragged the reference frame four pixels you would get a factor two improvement, square root of four, you get a factor two improvement in the accumulated error. So it became a trade-off of how many extra cells you had to allow you to drag this reference frame versus the accumulated error but we could drag it maybe six pixels before we would then acquire a new reference frame.

Steinbach: Okay. So you used one reference frame multiple times.

Blalock: Yes.

Steinbach: Okay. I thought you might just each time the pixel you have becomes then the reference frame for the next step but that's not what you did.

Blalock: Well, you would except that your error accumulates faster, right, and so to make it—

Steinbach: Okay. Yes. It's--

Blalock: Yeah. It's like when you're climbing on this cliff and at what point do you let go of the wall, right, you want to-- And of course to do all that you had to have very low-offset amplifiers and be able to shift analog values-- because this was all in the analog domain at the time and you would shift this reference frame over but that was an important part of improving the overall accuracy, that reference-frame translation. And then later when it became a product the process technology had marched along and so a lot more of that was done in the digital domain but at the time we were initially prototyping to get to the form factor and power that we wanted to really demonstrate the technology we did a lot of that in the analog domain. By the way, that device ran at 25,000 frames per second so we were doing 9 full cross-correlations of these arrays at that rate and acquiring images and most of the time was just waiting for light to integrate, waiting for photons to integrate and then we would do these cross-correlations. And another-- Bill Holland mentioned that we had analog multipliers and it’s interesting. We didn’t actually do multiplication, we did a difference-squared correlation instead of a multiplication, so we were looking for a low correlation, Low correlation values because when you have good correlation the difference-squared term is zero. Right?

Steinbach: Right.

Blalock: So were looking for this sort of bowl-shaped correlation space to fit that. And the reason we did difference squared instead of multiplication is because in the analog domain I could implement a difference-squared circuit with six transistors and so I was like “Okay, six transistors. I can’t do multiplication that cheaply so sold, difference squared, that’s how we’re going to do it.”

Steinbach: What resolution did your array have, what X by Y number of pixels?

Blalock: It wasn’t that big; it was 32 by 64, which wasn’t huge. I’s not that big but we looked at a trade-off between silicon area and how much we thought we could fit in these elements and then how sensitive you wanted the detectors, and ultimately it came down to the resolution of the optics and that related to the surface. We were actually navigating on the texture of the paper. And so, if you’re going to sample and see the texture of the paper, you’ve got to obey Nyquist in the spatial domain. You’ve got to obey that. And that ended up driving the size of the pixels. We made them as big as we could and still capture that texture. And we ended up with thirty-two by sixty-four on a reasonably sized chip. It was actually a photo transistor, not a photo diode. The optical current was the base current for a photo transistor, and then we were integrating the emitter current as it turned out, interesting little structure there.

Steinbach: So, something that comes to my mind is: It seems kind of risky or expensive to move the data out of the array into a second array for the correlation. Did you consider having it all in one pixel?

Blalock: It came down to, we wanted to have good fill factor and resolution in the optical imaging. And if you put in all the computation circuits, the spacing would have become too large. And you wouldn’t have had the right-- Nyquist would have been unhappy about that. The Nyquist suggestion would have been disobeyed, I guess.

Steinbach: Suggestion?

Blalock: Yeah, yeah.

<laughter>

Steinbach: So, was there an optical magnification involved that--

Blalock: I was trying to remember that the other day. Barclay Tullis, I think, designed the initial optics. And it was either one to one or two to one. But I just don’t quite recall. It may have actually been one to one optics. I’m not certain.

Steinbach: Okay so, your pixels were basically the size of the irregularities that you were looking for?

Blalock: They were certainly similar. And I-- sad to say, I can't believe that I don't remember that number. That's used to all be top of mind, but[1]--

Steinbach: It's been a while.

Blalock: It's been a while.

Steinbach: Okay, and yeah, you mentioned it was 0.8 micron CMOS in an HP process.

Blalock: Yes, yes.

Steinbach: Okay.

Blalock: For HP people, that was CMOS 26B.

Steinbach: Ah yes, and you got some patents out of that, I saw online, right?

Blalock: Sure, and then--

Steinbach: Okay.

Blalock: I guess we haven't gotten to the mouse though. Go ahead.

Steinbach: Well, the mouse came after that, of course. And did you actually already think about what else could we do with this now we have navigation?

Blalock: Yeah, I mean there were lots of people-- a lot of us were thinking about different applications-- and the mouse had come up several times in conversations. The real question was: Could we do this inexpensively enough to make it work in a mouse. And Gary Gordon, he came by, and he wanted to do initially this "flying mouse", is what we called it. We took a Magellan and put a lens on it. And it looked out into the room, and you could wave this thing around and it would move a cursor. Gary was thinking about interactive TV applications and things like that. And then Gary also became very interested in turning it into a mouse. And I think-- so, when the handheld scanner product was created, the Magellan prototype and sort of that core architecture of the spatial differencing, the acquisition, the cross-correlation surface, all that stuff was carried forward. But they moved it to a finer line process which became available-- it was more digital. You know if you can do it in digital, you're certainly going to do that for manufacturability and things like that. And they did a fantastic job with that. I think that was Rajeev Badyal, Derek Knee, Mark Anderson, Charles Moore. I actually made a list. I didn't want to miss some of these. Tom Walley perhaps was involved in that and probably other folks I'm forgetting. But anyway, they had built this cross-

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[1] [Editor's note] During the editing process, Dr. Blalock recalled that the y were 60 micron.

correlation engine, the Magellan follow-on, for the scanner product. And I think they were very interested also in looking at “okay, where else could we sell this?” I know Gary had interest in a mouse and a mouse had been discussed. And I don’t know exactly how it came to be, but they thought “well, we can probably take the navigation chip that we did for the handheld scanner, kind of dumb it down a little bit, make it smaller, make it less precise because, of course, with a mouse, it doesn’t need to be that precise.” If the cursor doesn’t move far enough, you just move your hand a little further. If you get a little bit of mismatch, you’ve still got the human as part of the feedback system, and it’s okay. So they put together a sort of a stripped-down version of the navigation chip. And then I guess it was OED, the Optical Electronics Division. They had done other position encoders. And so, they took it on and made a complete module. And yeah, it ended up in hundreds of millions of optical mice for quite some time. So, it’s typical: What something’s invented for, it doesn’t necessarily mean that’s where its primary use is going to end up being. It could be different.

Steinbach: Okay, anything else about navigation, or should we move on?

Blalock: I don’t know. It was a lot of fun. I saw Dick Lyon’s interview and his oral history. And he ran into some of the same problems we did in that typically, when you test a chip, you have a bunch of electrical inputs, and you have electrical outputs. And you measure things. And you measure performance. But we didn’t have electrical inputs other than clocks and some control signals. And so, it was sort of fun to build a test platform for an optical system and basically ended up with a microscope with a little thirty-five-millimeter slide attachment on the top, except we were using it backwards. We designed test images. And we would project those test images down onto the imaging array. And some of them had very specific test patterns and things like that. And you could measure the accuracy of the array and the different analog components. So, it was a fun project in terms of the scanner, in terms of the team. And it also actually had some very interesting testing challenges as well, which is kind of fun, having it cross those disciplines.

Steinbach: Yeah, I hadn’t thought of that aspect. But now that you mention it, yes, Dick mentioned that too that--

Blalock: Yeah.

Steinbach: --you have a chip without inputs. How do you test it?

Blalock: Exactly. Well, it has photon inputs not electron inputs, just a different part of the spectrum.

Steinbach: Okay-- all right, then let’s go on to the next project.

Blalock: Well, the last major project I did at HP Labs was optical in nature again but in the other direction. It was an optical display.

Steinbach: Okay.

Blalock: This was for a heads-up display, and we built a primarily analog chip again. How do you describe this? So, we created a XVGA, “big” resolution, XVGA 1024 by 768 array that was used to control individual pixels of the liquid crystal display. And the display was a little small, an inch on a side or whatnot. And it was put into a pair of glasses for a heads-up display. And we did this in 1997-- ’96, ’97 or so. And you would put on this very lightweight set of glasses. And it would look like you had an XVGA monitor out in front of you. And that project was very interesting in that what the chip was doing was controlling the electric field across a little small vertical cavity of liquid crystal. And we were getting a wide color gamut by using pulse width modulation. So, you would say “okay, I want this value of red.” And that analog value would go into the pixel. And then you would use a ramp, basically a ramp and a comparator. And you would end up with a pulse width modulated electric field on that little metal reflector. And you had 1024 by 768 of these little metal reflectors on top of a tiny chip. And so, on each frame, you would wash in all these analog values. And then you would run this pulse width circuit. And sort of the nugget of how we made that work with high precision is interesting. These comparators were incredibly tiny for this pulse width modulation circuit. They’re sitting in, at that time, what was a small pixel. It was twelve microns by twelve microns. And so, these comparators are just incredibly small. And they’re double buffered comparators because you would bring in one set of data while you’re pulse width modulating with the previous set. So, you would double buffer back and forth. And so, of course, the offsets were horrendous. These things were biased at a nanoamp or two, deep subthreshold. Offsets were horrendous. And so, the fixed pattern noise would be really bad. And so, what we did was, because of this double buffering, we took advantage of that. And so, every other frame, you would apply your ramp signal and your analog voltage on the opposite sides of the comparator. And if you do that fast, every other cycle, you get a little positive offset, and the next time you get a little negative offset-- so, then every other cycle, the pixel will be a little too bright, then it will be a little too dim, a little too bright, a little too dim. And then you let the retina average, and so I called it retinal averaging offset correction because we’re using the retina circuitry to average, to time average, those errors. And if you do that fast, it looks like a high precision display. And so, we were running that display at a very high frame rate. You would do red, green, blue, red, green, blue, red, green, blue. And each time the red would be of opposite polarity. And green would be of opposite polarity. And the blue would be of opposite polarity. If you slowed the frame rate down, it was a lot of fun. You could slow the whole thing down, and you would see all the fixed pattern noise moving back and forth and see how horrible it was. And then you’d speed it up, and it would all just go away because your brain-- your retina would average-- time average all that. So, a lot of fun.

Steinbach: What was the frame rate?

Blalock: That was sixty frames a second, yeah.

Steinbach: Okay so, that’s fast enough to-- yeah, I guess that’s faster than a movie, right?

Blalock: Yes, and but the-- remember, we were doing red, green, blue sequential.

Steinbach: Oh, yeah.

Blalock: So, at a sixty hertz rate, we were actually doing six frames. We would do-- I believe that's right. We'd do red, green, blue, red, green, blue within that frame rate.

Steinbach: Oh, within sixty hertz.

Blalock: Yeah, so we were moving because we had to do all three colors because you would illuminate with a red LED, then a green LED, and then blue LED. And again, your brain is averaging those things together to form a full composite image. It did form some interesting motion artifacts if you had a fast-moving ball, you would see this multi-color little trailing bit. If you looked closely, you'd see some of those artifacts. But it was unfortunately sort of ahead of its time. There was no-- there were no smartphones, no tablets. There wasn't a big market of things to put images into a heads-up display at that time.

Steinbach: Was that supposed to be see-through or above your direct line? Or was it just covering your eyes so to speak.

Blalock: Yeah, a lot of discussion about that. This particular one, it actually was a little below. And it was not see-through. So, you would sort of look down and see the image. But you could still look up. A lot of people were very nervous about people getting seasick and having motion-- from being too immersive. And so, we kind of intentionally made it-- it wasn't completely immersive. It was a little set of glasses. It sort of looked like reading glasses set down on your nose a little bit. And you could look down, and you would see the image. And if you looked back up, you would just see what was around you.

Steinbach: Right.

Blalock: And anyway, I wish I had one of those prototypes to show you. But that was a great deal of fun. I just found it sort of interesting that it was optical-- this mixture of optics and photons and electrons, just like the Magellan chip, except it was in the other direction. It was sending them out instead of bringing them in.

Steinbach: Right. Now, you said it didn't get used. But the Google Glass is also gone now, right?

Blalock: Yeah.

Steinbach: They-- even they couldn't really find the market that was worth it.

Blalock: It's probably going to happen, it just has to. Somehow, you've got to figure out how to deal with-- I mean there were a lot of issues. But what's interesting, it was sold for a while actually. It was used in camcorder view screens in the viewfinders for a little while. Some camcorders had color viewfinders that used that technology.

Steinbach: Okay.

Blalock: So, it didn't completely-- it had a little life.

Steinbach: Okay so, I saw some patents that were awarded, that eventually were assigned to Avago which split off from Agilent, that mentioned finger recognition. So, was that a fingerprint sensor?

Blalock: I was doing a little-- I had gone to the university. So, I had left to go teach. I was doing some consulting still back with HP, and so I had a little bit of involvement. And they were driving towards a fingerprint recognition sensor. And I don't know, it just never quite came together. But the idea was we would-- this one was going to be, you would sort of drag your finger across this sensor, and it would track. Similar to the way the handheld scanner worked, you're dragging this thing across and navigating across a paper surface. Well, this was going to navigate across the finger surface, accumulate an image. And then you could get a fingerprint. And the thought there was if you did it that way, you could make the sensor very low cost because you didn't have to have a large area. You would just have this little thin-- and I think since then, some companies may have done that. I think I saw one on a laptop. But that was the idea. And it just never quite-- everything didn't quite come together.

Steinbach: Was it supposed to be optical?

Blalock: Yes, at that time, it was going to be an optical. OED, the same group that did the little module for the optical mouse, they were interested in trying to move into that market.

Steinbach: As I guess today the iPhone also, that's probably capacitive, right?

Blalock: Yes, yeah. And there are a lot of great characteristics of capacitive sensors, obviously. And but yeah, today--

Steinbach: I worked too--

Blalock: What's that?

Steinbach: I worked on the capacitive sensors.

Blalock: I know. I know you did, good stuff.

Steinbach: Not on the optical. Okay so, you said you left HP. What made you leave HP at the time when you did?

Blalock: It was hard. It was really hard to leave. I-- geography mostly. And I still kind of wanted to teach. I wanted to go to university and try that. But I was just having so much fun at HP Labs. And the people there were just so fantastic and so great to work with. I kind of started to think if I don't leave now, I'm never going to leave. It's not going to be possible. And an opportunity opened at the University of Virginia here in Charlottesville. And that was in between my wife's parents in Newport News, about three hours one direction, and then my parents were about six hours in the other direction. So, we kind of wanted our kids to be closer to their grandparents, a lot more family back east. And the opportunity came up. And I-- it was really hard. Boy, it was hard because I had so much fun at HP Labs and just learned so much working with such great people. But I just thought well, if I think I want to teach, if I don't leave now, I'm never going to leave. I was just having too much fun. As it turned out, though, of course, things changed a lot at HP starting the next year I guess. So, I guess it was just lucky timing. I'd like to say I predicted the dot com bust and all that. But that was just dumb luck. I wish I'd held onto that little townhouse I had in Santa Clara.

Steinbach: Yes, that-- by now, it would be a very good investment.

Blalock: It's very close to the spaceship.

Steinbach: Oh, yeah. Okay.

Blalock: Yeah.

Steinbach: I visited there recently. It's quite impressive.

Blalock: Yeah, yeah.

Steinbach: The Apple spaceship. Okay, so and you're still at University of Virginia. What are your areas of interest for research and teaching?

Blalock: Well, it's interesting. I came out to UVA. and I was full-time at UVA until 2013. And myself and a couple of colleagues, John Hossack and Bill Walker, we started a project to build a handheld ultrasound scanner. And we kind of developed that as a research project initially. And we had a number of-- filed a number of patents, which took forever to issue. And we thought "well, somebody will license this and it'll get out there and have some impact." And we realized that we had created a way to form ultrasound images that was just completely different than how it was done before. And we had to do that to get it into a handheld form factor because if you tried to do things the traditional way, you just-- we wanted it to be able to work all day on a cellphone battery. And so, we dramatically changed how we both acquired image data and how we processed it and how we formed images. And we realized "wow, this is such a departure from the way anyone else does it that they probably don't even believe this could work. And so, if we really want this to happen, maybe we should just build a company and do it ourselves." And so, we did that, created a company called PocketSonics, ultrasound in your pocket, and worked on that for a while, research grants, developed the company, licensed the technology out of the university. And eventually, the company was acquired by Analogic, a company in Boston, a medical device company north of Boston. And then when they acquired us they asked me to come on full-time and run an R&D group here in Charlottesville. I had already taken a couple of years of leave from the university, I was sort of out of time that I could take leave. And so I ended up leaving the full-time position and doing full-time running that R&D group. I still have an appointment at the university and I still teach some. But I haven't been full-time at the university since about 2013 or so. But my research, to answer your initial questions, was mixed signal CMOS. We worked on a lot of different kinds of things, worked on some inertial sensors, worked on an infrared-- a very high sensitivity infrared detector, developed some circuits to avoid power supply crypto attacks. Have you ever seen power supply crypto attacks? I don't know if you know now that works, but if you watch the power supply current, and you know something about the algorithm being implemented, with enough patience, you can find the keys by looking at the power supply current. And so we just developed this little circuit that tended to normalize that current. It wasn't very efficient. But it tried to keep that information from leaking out through the power supply port.

Steinbach: Which means you have to waste some power, right?

Blalock: What's that? Yeah, you waste some power, for sure.

Steinbach: In low power times, right?

Blalock: Yeah, yeah, yeah. It was definitely inefficient. But it-- if you cared about-- if you were that concerned about crypto security, then you did that. And of course, ultrasound, I did a lot of work with ultrasound and inventing some new ways to integrate low voltage CMOS with high voltage ultrasound and how to acquire the data differently, how to process the data differently, a lot of fun things there.

Steinbach: Because ultrasound, I guess, requires piezo-electric drive, right? And so, you need high voltages. What kind of voltages do you use for--

Blalock: Well, in a cart-based system, it's maybe a hundred volts. In our handheld device, it was twenty volts. But even twenty volts is a big deal if you're using very short channel CMOS. At that time, when we first started doing this, there weren't very good high voltage processes available. If you were going to start it today, there are fifty-volt processes available-- well, processes that have fifty-volt devices added to them. And so, you could do it that way today. But we actually sort of changed the way that we interacted with the transducer and were able to do it with low voltage CMOS and still could protect itself from these high voltage signals.

Steinbach: Okay, and I did see online that you wrote a book, too, or co-wrote a book on circuit design.

Blalock: Yes, it's a junior level undergraduate electronics textbook. It covers everything from sort of semiconductor basics to some digital circuits, op amps, and then we go all the way into transistor level amplifier design, feedback. It's an overall electronics textbook for undergraduates. And yeah, I wrote that with Richard Jaeger. I really was lucky to get involved with that because Richard did the first edition by himself, which really-- I mean my gosh, that's where most of the work was done. And then I came in and helped on the second, third, fourth, and fifth editions of that and added some things. And I convinced him to rework the feedback treatment and different things here and there. But yeah, that was a lot of fun.

Steinbach: All right, so but it has had five editions then?

Blalock: Yeah, and they're-- I'm supposed to talk with them Monday about a sixth edition. But I'm not sure what we're going to do differently for the sixth edition. We'll have to figure that out. But yeah, it's pretty widely used. It's actually, it's used quite a bit here in the U.S. But it's used overseas a lot. It has a-- there's a Korean version and an Italian version and, I don't know, one or two others. It's been translated into three or four languages. It's very bizarre to look at your own textbook in a different language. It's like "what? I recognize the figures."

<laughter>

Steinbach: Okay, so I guess we have come to the present, and we have kind of covered your professional career. What do you do outside of work?

Blalock: Hiking, cycling, road cycling and mountain biking, do a lot of that. Lately, we just moved onto a farm here in Virginia. And so, now I have cows to take care of.

Steinbach: Really?

Blalock: Yeah, yeah, yeah. It's a lot of fun.

Steinbach: I heard you say a farm, but I thought okay, so it's a farmhouse. But it's a real farm with--

Blalock: Yeah, it's about thirty-five acres. And we have some angus grass-fed beef.

Steinbach: Okay.

Blalock: And so, I don't know. I guess I'll be sharing beef with friends. Send me a note. And I'll freeze dry it and send it to you.

Steinbach: Oh, but so it's for meat, not for milk?

Blalock: Oh gosh, dairy is much too hard.

Steinbach: Really?

Blalock: Dairy's really hard work. Oh, my gosh. It's like-- you've got to be there at the same time every day. It's a--

Steinbach: Oh, yeah.

Blalock: I have a lot of respect for dairy farmers. They-- it's a really, really rigorous and-- it's just-- you can't miss a day. Somebody's got to be there.

Steinbach: Yes. Okay, so your angus beef, they kind of take care of themselves?

Blalock: Well, you've got to make sure they have enough water and grass and minerals, supplement their minerals and things like that. But it's not as-- it's not nearly as rigorous as dairy farming.

Steinbach: Okay. Do you get to ride around with a lasso and so on?

Blalock: Ha, ha. I might learn that. I don't know. And then we're going to add some chickens here soon. So, we'll have fresh eggs every morning. That'll be nice. But yeah, it's fun. So, that keeps me out of trouble. And then cycling and hiking and my kids are in school, and so we go see them occasionally, things like that.

Steinbach: Wow. Okay, that-- I grew up in the country, but we never had a real farm. So, my hat's off to you.

Blalock: Well, it's funny. I have two tractors, Gunter. And one is a 1953 Ford. And it-- so, now it's, what, sixty-five years old, runs beautifully. It just starts instantly and is just really, really an old tractor. I kind of got that for nostalgia because I used to help my grandfather on his farm. And he had a tractor just like that. So, when I saw it come up for sale, well okay, I'm going to have to get one of those. It's more of a toy.

Steinbach: Cool.

Blalock: But it's fun.

Steinbach: Okay, so to conclude, do you have something you want to say to young engineers or electrical engineering students?

Blalock: Well, I would say first, you never know where opportunity is going to come from so don't close the door on potential opportunities even though it looks like something that might not be related. The other thing that's super important is, when you're in school, don't be too quick to judge what courses and content might be valuable later and might not. I made the mistake in high school that, "oh biology. I'm not interested in biology. I'm going to be an electrical engineer." I knew in high school I was going to be an electrical engineer. So, I didn't take high school biology. And then I ended up working on lab on a chip projects I didn't mention at the university. And sort of bio interface-- circuits that ended up interfacing with biological systems. And boy, I had to learn some biology fast. So, I was like, "Oh, I wish I'd paid more attention, been more interested in biology in high school." So, I would just say just learn as much as you possibly can. And you have no idea where your career is going to take you. And something that seems unrelated now might become super important ten years from now. So, just try to soak up as much as you possibly can. Just learn every day no matter if you're young and old, just learn, learn, learn. You never know what's going to happen.

Steinbach: Yeah. Okay, thank you very much once again for this interview. And I wish you success with your farm.

Blalock: Thanks so much.

END OF THE INTERVIEW