



Oral History of Arthur “Art” Astrin

Interviewed by:
Rich Redelfs and Marc Weber

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Marc Weber: I'm Marc Weber of the Computer History Museum, and I'm here on October 2nd, 2015, with Art Astrin, major Wi-Fi pioneer, as well as other things. And Rich Redelfs will be the main interviewer, another Wi-Fi pioneer. So thank you both for doing this.

Art Astrin: Thank you.

Rich Redelfs: My pleasure. Thanks, Marc. So Art, I'm looking forward to this, because you just have a fascinating history. And I'd like to, you know, start with the beginning. I mean, one of the things I love about you, you're the only guy I know who can honestly claim that Elvis changed his life.

Astrin: Yes.

Redelfs: <laughs>

Astrin: I wouldn't be here.

Redelfs: And so I know that's way back, but why don't you start even earlier than that. Tell us about your early days in Poland and what your parents did and your family situation and how you got interested in technology.

Astrin: Yeah. I was born '45 or after the end of World War II, and my father got me interested in engineering. He was an engineer. And I also had a sister who has a great deal, I have, a great deal of love for her, and she does hopefully for me. She was two years younger, and as I started experiments I used her as my experimentee.

Redelfs: A guinea pig?

Astrin: A guinea pig. <laughs>

Redelfs: Younger sisters are good for that.

<laughter>

Astrin: I shoved her once in the stove and we had to call my dad to pull her out of it.

<laughter>

Astrin: But I did that because I couldn't fit. And she told me what she saw inside, and when my dad gave me a little electronic kit, wasn't much, was a iron nail, some roll of copper wire and a battery. And I started winding up transformers on the nail with the wire. Became magnetic. It kept pulling in the levers. And the first thing we did is I hooked up the, I left, the relay transformer, in my sister's bedroom and told her to pull a piece of paper slowly by it. And I hooked up a, I taped a pencil, to the relay, so when the relay was energized, the pencil would be down to the paper making a mark. And then I ran the two wires to my room with a battery and I was starting to do a Morse code. And so we were able to send messages to each other without our parents knowing about it. So--

Redelfs: So as she pulled the paper by, the pen went up and down on the paper.

Astrin: She kept pulling the paper while the thing was working. So it was kind of like--

Redelfs: Very good.

Astrin: --first time I realized the magic of electricity and--

Redelfs: And how old were you when that happened?

Astrin: I think she was five and I was seven.

Redelfs: Wow, that's pretty young for that.

Astrin: Yeah. <laughs>

Redelfs: And this was where? Where did you grow up? It was a small town in Poland or...

Astrin: We grew up in Kraków.

Redelfs: Kraków, okay.

Astrin: And after about, when I was about eight, we moved to Warsaw. My dad had got a high position in Polish government. Became responsible for all the-- he was a forestry engineer, so he became responsible for most of the woods and 40-some factories of wood, paper, furniture, matches. I have a lot of good memories about walking in the woods with him and him crossing little X's on trees that should be cut and so on. And with that, we had moved to Warsaw. By that, government was pretty Stalinist. Was really hardcore Communist. And conditions were getting worse and worse economically. We had barely enough to eat.

Redelfs: Even though your dad was high up in the government there still was a food shortage.

Astrin: Yeah. Because he was Polish, not Russian.

Redelfs: I'm sorry, because there was?

Astrin: Because he was Polish and not Russian. I mean, there was big difference there. They, the Russians, had, like, a little village inside Warsaw with gated community and their own stores, which were fully stocked. And we lived outside, <laughs> and the stores were mostly empty and there was never any food. And I learned quickly. We developed very... <sighs> Not normal relationship <laughs> with the Russians. When I was in high school, we tried all kinds of pranks. I was getting more and more interested in electronics. My mother was working for a recording company, Polish recording company, which was a branch of Deutsche Grammophon in Poland. And there was a technical department in that company where they were getting all the amplifiers and equipment to get the recording going. And every time they threw something out I would be outside by the trash bin, taking it apart, collecting boards, unsoldering resistors, capacitors, sticking them in my little boxes by sort and everything. And then I

started building radios for to pick up "Voice of America" from London, where we got the real news. And by that time Russians had really clamped down. Any radio that could receive Western communications was illegal, and I've seen some people on my street get sent to Siberia.

Redelfs: How did you figure out how to do these though? I mean, a high school kid just doesn't pull stuff out of the trash and build a radio. That takes a lot of knowledge.

Astrin: <laughs>

Redelfs: You couldn't go to the internet and look it up.

Astrin: No. <laughs> There was no internet.

Redelfs: Or there were no Heath kits at the corner store, I'm guessing.

Astrin: No. There was a neighbor of ours who was a physicist and he showed me, or he somehow built a little crystal radio where you kind of had to hunt and peck with a needle and you finally got a signal and there was a big condenser you could tune it. And then later I learned about superheterodyne.

Redelfs: Heterodyne. Yeah.

Astrin: And about middle of my high school, the Polish recording company started getting amplifiers with transistors. And I took them apart. I still remember the RCA CK702 transistor. Was like a little blob of glass with three wires hanging out of it. And that was a good amplifier, except when I leaned over it, the volume went down, and when I leaned back the volume went up. And I started asking my friend what that is.

<laughter>

Astrin: And he said, "Oh, that's the photoelectric effect," which just been discovered in the West <laughs> with the transistors. So I started building radios in the little soapboxes. You take a soapbox, just like here, a little soapbox, bottom, top, and if you take a resistor with wires and you heat up soldering iron, the wire holds it hot. You can push it into the plastic. It would melt the plastic and then you'd let go and it would just stay in place. So we took transistors and resistors and run them through so everything was up vertical. And then the radio would be receiving the "Voice of America." And the soapbox was just the perfect size to fit inside of a brick. Polish bricks have a little two dual air compartments, so people would pull out the brick out of the wall, put the radio in it, push the brick back in it and then Russian's couldn't catch them. So there were all kinds of people on my street and down the street, and I'd become like a major supplier of these radios.

<laughter>

Astrin: And... But we got the news from the West.

Weber: How did you learn English?

Astrin: I didn't. Oh, that's-- <laughs>

Redelfs: Not at this point.

Astrin: Not at this point. My first language is French, because my nanny was French in Kraków. And my parents spoke German. And then I went outside when I was five and I said, "What is this language people talk, speak, here?" And it turned out to be Polish. <laughs>

Redelfs: Okay. So you were saying about you didn't learn Polish until actually five years old.

Weber: Engli-- oh.

Astrin: So I--

Redelfs: Started with German, then French.

Astrin: First French and German, and then Polish. And then in high school it was Russian, so I had seven years of Russian. And then when it eventually became clear I had to leave to U.S., I said, <laughs> "What did they use for language over there?" Said, "English." I went, "Okay." <laughs>

Redelfs: Got to learn another one.

Astrin: So on the plane I was learning a language.

Redelfs: But the "Voice of America" broadcasts were in Polish then, because they were--

Astrin: They were in Polish.

Redelfs: --designed for the local market.

Astrin: Yeah. They were produced by a Polish government exile in London.

Redelfs: Okay. And so what did you listen to on "Voice of America"?

Astrin: Mostly <laughs> Western music.

Redelfs: Uh-huh.

Astrin: We got-- rock 'n' roll has just started. Oh. Elvis Presley became very popular in Poland, underground. And later I also, well, other singers from Poland brought a lot of their music. And something else happened in my high school, last year, was the missile, Cuban Missile Crisis, in 1962. And my high school Army unit, that was my last year of high school, they were kind of mobilized. We actually packed up our backpacks, got our rifles, and were told to report at the Warsaw airport. And we sat by the runway, all my friends, all my high school buddies, with my little radio <laughs> listening to the news between the Khrushchev and Kennedy. Khrushchev and Kennedy. And sweating the bullets that we might have to go. We were going to be airlifted to Cuba to fight on the Russian side. <laughs>

Redelfs: Wow. And it was everybody in high school, all male high school students were effectively in the Army whether you liked it or not?

Astrin: Yeah.

Redelfs: Wow.

Astrin: And then the resolution came and we <laughs> actually saw the Russian plane, transport plane, flying in from Moscow going over the airport in Warsaw, getting ready to land, right at the time when Khrushchev relented. And the plane literally just flew over a runway, turned around, went back to Russia, and we just went home and mother said, "This was really close. This is too close for comfort." And she went over to American Embassy in Warsaw, which was about a mile from our house, and applied for a visa to U.S. Me and 10,000 other people. So we get put on a big--

Redelfs: So this was just for you, not for the whole family?

Astrin: Just for me, as a student. And so there wasn't any hope, really. There was like, I think, the quota was 50 people a year could come to U.S. And so a year later, in '63, I started first unit, first year, at University of Warsaw, physics major, in September. And by that time, the clamping of the Russian government got even worse, and they finally, in December, banned the Western music completely and specifically the paper, front line paper, said, "You are not-- you're forbidden to listen to Elvis Presley, Brenda Lee, and Ricky Nelson."

Redelfs: <laughs>

Astrin: Which were, like, pretty much my three most favorite musicians.

<laughter>

Astrin: So we said, "This shall not stand." You know, I was just 18, almost 18. So we made up big placards and started marching down the main street in Warsaw. <laughs>

Redelfs: So how big of a march was this? Was this a small group or a lot of people?

Astrin: We had about hundred people.

Redelfs: A hundred people. Okay.

Astrin: Plus the students from University of Warsaw. So I'm carrying this Elvis Presley sign. Friend of mine had a Brenda Lee sign. Another friend of mine had a Ricky Nelson sign. That was a girl. Was a student. But she was really tiny. And so we keep marching, and all of a sudden the Russian police round us up and start tearing the signs up and the policeman in front of me grabbed the little girl, because she was real tiny. Put her against the wall of a building and started beating her with a rubber stick on the face. And about two, three blows and she was unconscious. <laughs> So I pulled out a camera. I had

gotten a video Super 8 camera for high school graduation and I started filming it. And guess what's the worst crime in a Communist country? Worse than music? <laughs> Is filming--

Redelfs: Filming.

Astrin: --a policeman. Back then. So they dropped her, grabbed me, and took me off to jail. And I sat in jail for about six hours. Apparently my mother run, friends of mine told my mother that I was arrested, and she went over to American Embassy. I don't know what she did, but somehow the ambassador pulled out another 10,000 files, my pile, snap visa, and she grabbed it, run to the police station, while--

Redelfs: So the guy in the Embassy was an Elvis fan?

Astrin: Yes.

<laughter>

Astrin: I don't even know who the ambassador was.

Redelfs: <laughs> But you got moved to the top of the pile. And go ahead. I interrupted you. <laughs>

Astrin: Yeah. So she run to the police station and I was just being interviewed by these three policemen, and she comes in the room and this... <laughs> This main cop looks at her and says, "Madam, your son is a first order antisocial element, total hooligan, and he wants to listen to Western music. You have 24 hours to get him out of the country or he goes to Siberia." So I went home, we packed all night. Somehow she went, sold all kinds of stuff, and I got this little \$5.00 bill that was all we were allowed to take out of the country. So I have \$5.00 on me. I was rich. <laughs> Rich. <laughs> And next morning, went to the airport and flew the only plane that was to the West, which was Copenhagen. And then I stayed with some friends in Frankfurt and then some friends in Paris. And then flew to-- my visa started January 1, but that was holiday, so January 2nd in Glasgow. I think I went from Glasgow to Los Angeles, direct flight TWA. And this is when I started learning English.

Redelfs: On the plane. <laughs>

Astrin: On the plane. And I'm learning, I'm up to two words, "yes," and "no".

<laughter>

Astrin: I still remember stewardess coming my way and she'd say something and I would say, "Yes."

<laughter>

Astrin: Then she would say something else and I'd say, "Yes." She brought me a drink. Turned out she had asked me if I was 18 so I could drink. <laughs> And I wasn't. <laughs>

Redelfs: But you said "yes"?

Astrin: Yes.

Redelfs: Because you didn't know the question?

Astrin: I was almost-- oh, wait, no. I was 18, yes.

Redelfs: So then where did you settle when you got to the U.S.?

Astrin: Came to Los Angeles. Lived with friends of my father's from Vienna. Lived in their garage for about a year. Went to state department. Had a kind of a liaison person for people like me, and they placed me in the San Fernando Valley College, which is now called Northridge California State University. And I went there, started in physics and math. Fortunately, we had, in science, I was like about two years ahead of my peers, so I was going to lectures and I knew exactly what they were saying. And most of the words were English-like. Polish word for "mathematics" is "matematyka." "Physics" is "fizyka." Most of them are Latin-derived words. So the only thing I was, I couldn't understand, is these things in between like "is," "has," "let," "go." So I was learning those as fast as I could. And I was also taking an English as a second language at night at a local high school. And I started studying physics. And then I realized I really couldn't do physics unless I knew mathematics. Lot of stuff I was getting to was requiring higher and higher math, and I just wasn't up to it. So I switched my major to math and I actually graduated there, from there, in '67 in math. And then I went to UCSD, UC-San Diego.

Redelfs: Now, how were you paying for all of this, if I may ask?

Astrin: Oh, oh. I had three jobs.

Redelfs: Okay.

<laughter>

Redelfs: I'm guessing there was something going on there.

Astrin: Yeah. I was working in cafeteria, busing dishes. Got a job at a library sorting books, putting them back on shelves. Also my, well, I called her aunt, worked in a little ladies' <laughs> factory in Los Angeles that was making dresses for Neiman Marcus. And I learned how to cut cloth and I eventually learned how to sew and...

Redelfs: Well, you've always had a good work ethic, Art, so you learned it young. I understand now.

Astrin: Yeah. Yeah. One of the funny things to happen at that time was there was-- this is '60s, late '60s, and L.A. was in real riot race problem area. And I was working with these five black guys in the shipping department at the factory, packing all these dresses. And they were all from, just moved back here, from Mississippi or Missouri, and I could barely understand them. They couldn't understand me. They took me under their wing and they taught me good English. <laughs> And one day one of them comes over, says, "We're getting ready to do a riot." He says, "You're from Poland." I said, "Yeah." He

says, "Have you heard of Molotov cocktails?" I said, "Yeah. We used them on the Germans and Russians." <laughs> He says, "Well, could you teach me how to build one?"

<laughter>

Astrin: I said, "No."

<laughter>

Astrin: So I went to UCSD, again, in math. But at that time I was working in L.A. in another company besides these three other jobs in the college and that packing job in L.A. I also worked for a little electronic company called Northridge Engineering. Started the first-- they had a contract to solder the 50-pin telephone PBX connectors. Took a cable, strip the 50 wires, you solder them all to the connectors. And then I noticed their engineering department and I visited their location and they were starting to build government-- they got a government contract to build logic cards. I guess I skipped part where I was very interested in logic in Poland. I built a little computer or so out of relays. I love the binary system. So when this company started designing these little boards, there was no TTL. It was DTL. Signetics just came up with the first digital logic family.

Redelfs: Digital Transistor Logic? Is that what DTL stood for?

Astrin: DTL. I think that's what it was.

Redelfs: Okay.

Astrin: Yes. Was going to say diode transistor, but no. I think it was digital. And the chips were very simple, like four flip-flops or two end gates or whatever. And the board would have 8 of them or 16. They were small boards. But government was using them to build custom logic things with them, so pretty soon I got the job. I learned also how to wire-wrap. And they were putting little subsystems with these little cards by wire-wrapping backplanes. And one of the first applications they got was something called stable platform for the Navy. Where you put it on top of the deck of a ship, one surface, and the second surface was moved by servos to counter the movement of the ship underneath it to keep the gun platform stable. So there was a lot of sines and cosine math in there. <laughs> They always ask me for help in that with the engineers. But I was, whatever always helped me, was mathematics. I was in there. And as I built circuits that did the analog conversion and calculated all the angles and did the roll, pitch, and yaw correction, and then the next thing this company got was a contract for the anti-submarine warfare. And it was a big sonar array. It was about 100 x 100 microphones and the signals were going into banks of thousands of filters. And out of that they would calculate the directions of the signals coming into the microphones to detect where the submarine is, which direction it is. The Doppler frequency would show the velocity of the, relative velocity, of the submarine towards the-- you. And so we were doing a lot of calculations, and then they hired another engineer from Control Data and he said, "Let's try to do something called central processing unit," out of these little cards. And I went, "Oh, that's like my 4-bit computer in Poland. Except instead of relays, which took like "click, click" to add four numbers, this one was, to me, instant." You know, it's like--

Redelfs: Sure.

Astrin: I mean, we had clock rates of kilohertz.

<laughter>

Astrin: Then we moved--

Redelfs: Blazing fast speeds.

Astrin: Blazing fast. So I learned wire wrapping and so there were these drawers of these cards. On the bottom was a bunch of wires, wire pins. And by wire wrapping bunch of these logic cards, designed a 16-bit and then later 18-bit CPU. The core memory was in another box. <laughs> Four K. One of the boards on the CPU had, I designed this little board that had bunch of diodes in the rows. I think it was 16 rows of 16 diodes. And if I cut them with dikes that was a 0. If I left them alone, that was a 1. So this is how you put up boot bios into the programming. You--

Redelfs: You clip.

Astrin: You program it on a piece of paper very carefully, write 1s and 0, and you take a card and you go "click," you know, and you cut and click. And if you made a mistake you have to go solder that diode back in. <laughs> But eventually I got it to run a loader, a boot loader, and the bios, in about 32 words. So two of these little boards were doing the whole job. And then the rest came from the core memory. And then... Now, I couldn't talk about it for a while, but now I know the agency was NSA. And so they asked us to design a computer that would process all this solder-array data and perform free transform on them. And then take the result and send it off to another UNIVAC fire control system computer. And that worked. I could get about, oh, thousand samples of spectrum at resolution of .001 hertz. So I think I went from 0 to 3 hertz. In these fine increments.

Redelfs: And this was all while you were doing your master's degree?

Astrin: Yeah.

Redelfs: So... And you were working the dress shop and other things as well.

Astrin: And I was working.

<laughter>

Redelfs: Wow.

Astrin: Yeah. And I started dating her too at UCLA.

<laughter>

Astrin: We met at a ski trip in Utah. Of all places.

Redelfs: Very good.

Astrin: People keep asking, "How did you meet?" <laughs> She was a student from Massachusetts. Got a scholarship to UCLA in mathematics, and I was a student at UCSD, and I had a scholarship. I wouldn't call it really a scholarship or any kind. Maybe it was scholarship, but that paid half the rent and little bit of food. <laughs>

Redelfs: Yeah.

Astrin: And yeah. So this worked. And this computer system got shipped to the Naval research labs and then they tested it and they increased the frequency to 10 hertz. And whenever I coded up the 16-bit computer, no matter how I squeezed the code, no matter how I squeezed it down to last instruction out of the loop of all these computations, it was taking, it was still like hundred times too slow than it should've been. So I decided to take some of that algorithm and put it in hardware. And we called it Fast Fourier Transform processor. Was basically a box that would do a DMA transfer out of the mainframe, perform the sine, cosine, the algorithm I discovered before for the stable platform in digital domain, and then do thousand rounds of that, and then put it back in the main UNIVAC computer. And when I finally got it working, that took also several trips to Fort Meade NSA, and I'm still a...

Redelfs: You're just part-time.

Astrin: I'm still a Polish citizen and communist refugee, not U.S. citizen, and I had to go visit headquarters of NSA. So, every time I went there red lights would start flashing in the hallway, and they assigned a marine guard to me, which was a young kid, maybe-- it seemed to me like he was 18.

Redelfs: Even younger than you.

Astrin: Even younger than me by maybe two, three years, shaved head, machine gun, no sense of humor, and he says "I have orders to shoot you if you get away by more than 20 feet." I would work, work on my bench. I would do-- get up and say "I have to go to the bathroom." He says "I go with you," and he went with me to the bathroom <laughs> Followed me. So, that was one of the trips. Then finally we get ready for sea trials and we went to Scotland to Holy Loch where he was-- a navy base was with Polaris submarine missiles, and in the middle of the bay was an aircraft carrier, Ticonderoga. And so, we lived in Gourock, Scotland for like three months, and every day I had to take a boat in, boat out, and I still remember somebody told me as soon as you get your machine on board the aircraft carrier somebody will drop it and it will just go down the plank, and I said "Come on. This is too valuable. You can't possibly do that." Well sure enough on the first trip we get on the aircraft carrier, two navy guys pick it up, the case. I'm walking right behind them and they drop it, and the thing just went "blonk nonk konk konk kah". Well by the time we got in the fire control room, it was completely unfunctional. The boards were knocked out. The cards were broken. So, it took me a little while to get it all repaired. I had to glue things together. I had to reroute things, solder things, and that's just when I met one of my main highlight of my career. I met Grace Hopper, Captain Grace Hopper.

Redelfs: She was a captain at the time?

Astrin: She was a captain at the time.

Redelfs: Later rear admiral?

Astrin: Yes, I think. I think she was an admiral.

Weber: Admiral, yeah.

Astrin: Yeah. She's a fellow here, right? So, and this rack-- I have to describe the situation to it, really. My machine was in the rack drawer about a foot and a half from the ground. Y-A-K computer UNIVACs was right above it. There was something below it, but anyways I pulled it all the way out and I can't find the signals that are missing on the motherboard. So, I lay it out the oscilloscope on the-- next to the side of the computer. The rack is basically-- I'm lying. Maybe I have six inches between the bottom of the mainframe and I'm troubleshooting with a scope to see what's wrong. I even drew a picture of it. So, there--

Redelfs: There's a diagram, huh?

Astrin: There is a diagram. You see the rack?

Redelfs: Yeah. So, you're working on a rack. It's almost like working underneath a car.

Astrin: Right.

Redelfs: And somebody comes up and is standing next to the car, right?

Astrin: Right.

Redelfs: It's an analogy to that.

Astrin: Yeah. So, I'm sitting there. It's a fire control room. Roof is real low, less than six feet tall roof. Lot of noise. I'm right next to a nuclear reactor. <Laughs> The marine guard is standing in a corner watching me remove my make, and all of a sudden I hear this "dink dink dink dink dink", high heels, and I could look through that-- and I could see it's just the legs from knee down, the rim of a skirt, and I was just laying sort of like this, and I hear this "dink dink dink dink", feet walking up closer and closer and closer and closer. Stop right here.

Redelfs: Right in front of you. <Laughs>

Astrin: And I just froze. <Laughs> And she says "How's it going, Art?" I said "Well, I still can't find the problem." <Laughs> She says "It's Monday. If you don't get it working by Wednesday, I will kick your nuts in," and then she "dink dink dink" walked away. <Laughs>

Redelfs: Did you know who it was?

Astrin: No.

Redelfs: No idea? <Laughs>

Astrin: No idea.

Redelfs: But it sounded like she had authority. <Laughs>

Astrin: Yes! <Laughs> So, I crawled out from under the rack and I asked the guy with the machine gun, the marine guy, I said "Who's this?" He says "That was Captain Grace Hopper." I went "Okay." So I--

Redelfs: Did you know who she was?

Astrin: No.

Redelfs: By name?

Astrin: No. I sort of heard about her reputation because she forced most of the computer industry to standardize on COBOL.

Redelfs: Right.

Astrin: And she was also famous for walking around with a pile of wire.

Redelfs: And invented the compiler.

Astrin: She also had this little bundle of wires, maybe 12 inches long and she would say "That's a nanosecond." So, it made everybody understand what a nanosecond was. It's about 12 inches of electrical wire.

Redelfs: How fast an electron goes through 12 inches, yeah.

Astrin: Yeah. So, I crawled under back the rack and I said "I better get this done," and I worked and worked, I think around the clock, and on Wednesday it worked and it runned, and it was a hundred times faster than the previous machine because most of the hardware-- most of the software was now done in hardware, and that's when-- and I was doing what today we know as OFDM on the signal, sonar signal.

Redelfs: Or Orthogonal Frequency Division Multiplexing.

Astrin: Multiplexing, yes. <Laughs>

Redelfs: Did you ever--

Astrin: You're picking it up. <Laughs>

Redelfs: Did you ever see Grace Hopper again?

Astrin: No.

Redelfs: Just the one time. So, you never really saw her. You just saw her ankles. <Laughs>

Astrin: <Laughs> Yes, I just saw her ankles and I.. <laughs>

Redelfs: Very good.

Astrin: But it was amazing how clear the picture was. You could see all the submarines around, their movements, and since we got so much data all of a sudden, a hundred times more data than before, it would show up on the display like a spectrum pulses for different submarines, different frequencies, and then about a tenth of a second later it would be another trace, another trace. And so, then we kind of slowly moved down the screen and my program manager from NSA said "Let's call it water display, waterfall display," which is this called today, and I was still translating from English to Polish and I could never understand his last name. His name was Noyes, N-O-Y-E-S and I'm thinking "Why would somebody have a name called no, yes put together in one word? Why didn't you just go with a maybe?"

Redelfs: <Laughs> That's good.

Astrin: But, and so then we came back and by that time that product was actually put in production at RA [Republic Advanced Technology Systems Group]. Fast Fourier transform processor was put into production and the company sold I don't know how many units but it was going to high end units. It wasn't a cheap product. It was a quarter of a million apiece, but it went in many applications. Besides sonar it went into seismic oil detection. They did the same thing where they would put microphones over an area and fire these explosives and tell where the oil is.

Redelfs: Still do it today.

Astrin: Yeah.

Redelfs: Same way. Now, had you finished your Masters at this point or-- because you spent a few months in Scotland?

Astrin: No.

Redelfs: That must have been hard to do with school.

Astrin: Yeah. No, I finished my Masters in '68. I could have. If I wasn't messing around with this other stuff like work, I could have probably gotten an Ph.D. because UCSD back then, you could get in one shot a Ph.D. but-- and then you had to take an extra exam and there was all kinds of classes I never took. So, I just got my Masters and then I transferred to UCLA because she was at UCLA and I was tired of flying out there every weekend for visits. <Laughs> And I would drive. I learned to fly. I became a pilot and-- but it was mostly driving every weekend. So, I transferred to UCLA in '68.

Redelfs: And so, you had to leave that job because it was down in San Diego. Is that right?

Astrin: Yeah.

Redelfs: Okay.

Astrin: And then I came back to LA and I went back to this job, and that product was-- well, like I said it sold for seismic exploration. It was sold for medical, vibration control, even <laughs> one point it was almost hard to believe. One of the-- well to me seemed like a really strange person in Los Angeles was a Hollywood producer with bushy hair, crazy eyes, and everything and he wanted it to process the sound effects for movies and hook it up to computer brain, transfer it into sounds, and we actually built it and I went over to Hollywood Studio, watched a filming of a Marathon Man with Dustin Hoffman and then processing the signal from that movie into the sounds that they had for the movie.

Redelfs: Interesting.

Astrin: This time-- so, but I was working really for defense industry, and my long term goal was to become a capitalist because I escaped communist system and I hated it with a passion. And so, occasionally I could see in Los Angeles little things. Like my first hero, engineering hero was Howard Hughes. The guy had enough money that he could do a crazy project like the Long Goose, the Bruce--

Redelfs: The Spruce Goose?

Astrin: Spruce Goose, and then ask anybody for-- just get resources and do it. Of course he tried to sell it to the navy.

Redelfs: Right.

Astrin: But then..

Redelfs: So, you got a business degree at some point, too. Is that.. ?

Astrin: That was later.

Redelfs: That was much later.

Astrin: When I was at Memorex.

Redelfs: Okay. So, were you working-- you worked for Gould. Was that where you were doing this military?

Astrin: The last Northridge Engineering became Unicom. This is like <unintelligible>. It was bought and final--

Redelfs: Acquired and acquired again.

Astrin: Then it was Hoffman Electronics and then it was bought by Gould.

Redelfs: Okay.

Astrin: And I think now it's Signal Processing Division of Gould.

Redelfs: Got it.

Astrin: But by then LA was getting kind of rough to live in. It was smoggy. We had kids. We were worried about their safety. There were all kinds of racial problems. Like I almost-- instead of going to UCSD I was going to go to Cal Tech, but the day I walked in there, the second day my professor's wife got raped in the parking lot. And so, he quit and went to UCSD. So, that's why I went to UCSD. I basically followed him.

Redelfs: Wow.

Astrin: But when I came back the smog was getting worse and worse, and we really wanted to get out of the LA area. So, we wound up and got an offer from Memorex in Cupertino and joined that company, and first I worked in the Disk Division. This is where I met Tom Gardner, and it was a fascinating place. There was just talent all over. I got an office between Al Shugart¹ and Syed Iftikar and Keith Plant was in the corner. He later went [to], Iomega and so on, and I was like really solid, hardcore electronic guy by then and they needed some work on the electronic frontend of a head recording channel, but mostly there were big problems in their control units that they didn't have any digital people or electronic people. So, they handed me all kinds of projects. I was working like crazy, fixing things and..

Redelfs: So, it was purely digital or mixed signal?

Astrin: Purely digital, except for the frontend. The head read/write circuitry. And then about a year later.. do you know Dick Allen?

Redelfs: I don't personally.

Astrin: Oh. He was their-- and we went through basically a garbage bin, just like back in the recording thing. I went through the whole warehouse full of.. I mean when I went there Memorex was bankrupt. They were working in bankruptcy. They were owned by B of A. They brought in Bob Wilson who was the CEO from GE and Rockwell Collins, and they had tried to go in mainframe business competing with IBM and that's what really crashed the company. So, we're going through this bin. There's like a few hundred prototypes of IBM mainframes, 360, and the disc drive division was still operating because they had good disc drive controllers and everything. Then we found this other pile and we said "What is this? Oh, it's a frontend processor." I went "Oh, I know a little bit about communications," and we pulled out that product line out of the trash bin literally.

Redelfs: Was it a Memorex FEP or an IBM?

Astrin: Memorex.

¹ [Editor's note] Al Shugart left Memorex in 1972 while Art Astrin arrived in 1977 so one of the offices was not occupied by Al Shugart. One hypothesis is that the office was instead occupied by John Kevill who became head of Memorex storage engineering in 1975.

Redelfs: Memorex had had their own.

Astrin: It was a copy of an IBM. It was called Memorex 1270 which was copy of an IBM 270X frontend. So, it was just a rack full of line cards and card cages and modem cards. Everything was 28K modems or _____ a bunch of serial lines cards and also cards to 3270 terminals which were running over a 1 megabit coax from computer room to terminals and people's desks and that. And so, we pulled that off, moved it from Santa Clara to Cupertino, formed a Memorex communication division, and then about a year-- oh, and at that time IBM actually made a strategic mistake. They announced a replacement, because they were worried about this Memorex 270X replacement with 1270. So, they said "We're going to announce something completely different, better called SNA," and the new frontend processor which was 370X and couldn't get it to work, and couldn't get it to work. It was too much. It was an incredible software job. I mean moving from TCAM to SNA was the BIOS to a Windows operating system. So, they had thousands of people working in Raleigh fixing it. And so, we said "Let's take that 270X to 1270 and beef it up," but this time I had microprocessors and I could put microprocessor on each line and we start replacing modem cards with-- eventually we actually got an Ethernet card and it took off like crazy. I couldn't believe it.

Redelfs: So, you were sort of doing a next generation of their old architecture because they had abandoned that architecture at IBM.

Astrin: Right. Right. Without changing any software in the mainframe. So, it run with TCAM and..

Redelfs: What year?

Astrin: This is '78.

Redelfs: '78? Okay.

Astrin: So <laughs> this is a division that started, and first year revenues were \$400 million.

Redelfs: Wow.

Astrin: Profit was \$150 million.

Redelfs: So, you saved Memorex from their bankruptcy it sounds like.

Astrin: Well, not quite but we.. Bob Wilson called us in, said "You guys are 10% of the sales and 35% of the profit."

Redelfs: Sure.

Astrin: So, we got all kinds of awards and things, and since I put microprocessor on these line cards and I can program it and do SDLC and HDLC and Async and Sync and all these other things, we started to program X25, which is now TCP/IP, and try to hook it up to the military ARPA Network, which I'd worked on at UCLA, and that worked through timeshare. You could timeshare these mainframes. So, it just was

amazing, but we were over a billion in three years and made great profit. I was able to take some of the engineers I had and we, besides working on this line processor, we started redesigning a new 3270 terminal and a 3270 printer, which was color. It was ranked like number one 3270 terminal, better than IBM in 1980.

Redelfs: So, this had to satisfy your desire to be a capitalist.

Astrin: Yes!

Redelfs: Building a \$400 million to business in a year.

Astrin: Right, right.

Redelfs: Which even in today's standards, that's pretty darn good.

Astrin: Right.

Redelfs: Back then that was a lot more money.

Astrin: And it was more fun than defense electronics where every engineering change required 350 signatures, including generals and admirals and..

Redelfs: And this you just made it happen. So all that--

Weber: Sorry. Tell me if this is.. let's take a break after Memorex.

Redelfs: Sure.

Weber: <Inaudible>

Redelfs: Followed by a good time. I was just about to ask you about after all that success why did you leave. So, maybe that's a good question to pick up after break. Do you want to take a break?

Astrin: Yeah. By 1979, let me just finish this. By 1979 Memorex was back in Fortune 500. Stock was back from \$2 to \$75, and..

Redelfs: And you had to be a hero of helping that happen.

Astrin: Yeah. Bob Wilson considers me his golden boy to this day. <Laughs> But what we did is woke up the giant, IBM.

Redelfs: Sure.

Astrin: Their competitiveness and they started dropping prices and doing all kinds of predatory stuff.

Redelfs: This is when they started leasing the machines, too, right?

Astrin: Leasing machines, yes.

Redelfs: I did a case study on this in business school of how they really changed the business model.

Astrin: Yeah, they leased. Yes. Yeah. That was amazing, too. It's all a completely separate story. But anyway, we wound up in a lawsuit, Memorex versus IBM, and that's where Tom and I again spent a year in court being deposed by IBM lawyers, and I just got really fed up with that. I just kept seeing 8086, 80186, 286, and I'm thinking I'm going to miss this whole technology thing when I'm sitting here in a courtroom getting deposed for some silly thing. So--

Redelfs: But that's hard to get out of because even if you change your job you could still be deposed for something that happened in the past.

Astrin: Yeah. Yeah.

Redelfs: How did you manage to--

Astrin: But it was mostly the disc drives that they were fighting over, and there was another technology battle on.. at the time industry was converting from read/write heads made in magnetic cores to thin film heads made on wafers, silicon wafers, and I worked on that program for a while because they needed a lot of electronic and semiconductor help, was the first time. It was a real culture shock because those people were grinding granite, ferrites into little tiny cubes, wiring tiny wires, they operated with little microscopes, and on the other side was wafers, lithography with none of the electronic parts but also magnetic parts, and the wafers were made out of a very hard material because after they were sliced up and cut up, then you had to shape the head in the shape of a wing so it would fly at the right height and everything. So, it was an-- somebody once told me back then that it was like the most complicated process known to man because it was everything, lithography, magnetics, electronics.

Redelfs: Aerodynamics.

Astrin: Aerodynamics. Yeah. The flying height, all those things, and the lawsuit was going on and Memorex was bought by Burroughs in 1981 I think, and I left there. It's just didn't have anything to do within that-- with the lawsuits. I went to a couple of startups. One was actually a read/write head.

Redelfs: So Art, then after Memorex you bounced around at a few startups?

Astrin: Yeah. Yeah. Well, startup. One of them was Intersil which--

Redelfs: That was the first Intersil when it was--

Astrin: It was bought-- it was the Jack--

Redelfs: GE.

Astrin: And it was acquired by GE.

Redelfs: Right.

Astrin: And then there was Read Rite which was a thin film head startup, and that one got sued again by IBM because it did produce thin film heads in volume. At that time people were going around the country showing one saying "See, we just made it," and this company actually put it in production.

Redelfs: No. It was a great company for a while.

Astrin: It was unreal. It was the first time I saw a suitcase with a \$100 million.

Redelfs: So, tell me about that? <Laughs> I don't think I've ever seen a suitcase of \$100 million.

Astrin: A Japanese disc drive company came and wanted to buy up all the thin film heads before anybody else and they just showed up with this big giant thing and--

Redelfs: With cash, literally.

Astrin: With cash. <Laughs> But then right after that a bunch of IBM orders walked in and closed the door. Sheriff came in and sealed the door and I wound up as a deposition again for like two or three months, and then I said "I've seen this movie before."

Redelfs: Was it patent infringement?

Astrin: Yeah. Yeah. The other founders were from IBM and they weren't sure. I mean I wasn't sure if they weren't not infringing. So, I kind of parted ways.

Redelfs: Was this when you finally went to IBM after--

Astrin: No, no.

Redelfs: Getting tired fighting them? <Laughs>

Astrin: No. That was when ROLM bought IBM.

Redelfs: Oh. Got it. Got it. So, you ended up at IBM with ROLM first.

Astrin: I went to ROLM first.

Redelfs: Got it.

Astrin: And it was PBX and telephone instruments, digital instruments.

Redelfs: So, that was different than what you'd been doing.

Astrin: Well, it was-- yeah. It was sort of the same thing that I did.. well, we also skipped, but yeah. It was a real-time computer system that was responding to real responses, which is hook switch and closures and dialing.

Redelfs: Got it.

Astrin: And allowed me to push twisted pair, which I believe that could go much further than that. When I first worked with twisted pair and the system in the '70s most people believed that you couldn't do more than 64K.

Redelfs: This was the Bell 103 modem era?

Astrin: Yeah. Yeah. That you could only do 4K channel, 3 kilohertz bandwidth and maybe get 64,000 bits per thing, and we pushed that Memorex all the way up to I believe it was a megabyte. It was actually useable half a megabyte, twisted pair, but after that once the line currents were there talking to the phones, there was all this spare bandwidth on the twisted pairs. So, my job was to add data interfaces to all the phones, which we did, and then our VP was a pretty great guy. He was friend of mine. Bob Maxfield became a believer in data and he was the M in ROLM, and we came up with a product line of PC phone combinations, which unfortunately didn't really take off that well because IBM was changing PC too fast. And so, we needed a PC motherboard and a telephone instrument and you set it up for DOS 3.1, right, production. IBM was already on DOS 4 and DOS 5, and then you had to-- and these were just built enough to support a telephone plus a little Rolodex.

Redelfs: Yeah. They were called IVDTs, if remember. Integrated Voice Data--

Astrin: That's right. Yeah.

Redelfs: Telephony was the term, right?

Astrin: That's right.

Redelfs: And it was the-- I mean one could argue it was the first smartphone.

Astrin: Yeah.

Redelfs: You had a computer and a phone integrated but it was a desktop, not a mobile device.

Astrin: Right. Right.

Redelfs: And ROLM did those and it was a company, a French company that did them, the little Minitel terminals?

Astrin: Yes, Minitel. It was <unintelligible>.

Redelfs: And Compaq did one I remember.

Astrin: Compaq did. There was a company here in Cupertino, TimeShares.

Redelfs: TimeShare was the affiliate of the Minitel over in France.

Astrin: Oh, okay. Okay.

Redelfs: Yeah, and I work for TeleVideo Systems, and we actually made one as well here.

Astrin: A phone terminal?

Redelfs: Integrated. Yeah.

Astrin: Yeah.

Redelfs: Small world.

Astrin: Yeah. So, it became very popular with legal. Yeah, most of the legal clients that ROLM had. ROLM kind of tied up all the <laughs> the legal company, PBX market. The main reason was when the lawyer picked up the phone, the computer and the PC started counting minutes, so you got an immediate billing and it was hooked up through PBX to billing. So, you got a billing in six minute increments based on client in a case, and law companies loved it.

Redelfs: This was when most people didn't really have PBXs. They were still using Centrex, right?

Astrin: Centrex, right.

Redelfs: Where the PBX effectively the switch was still at the phone company rather than on your premise.

Astrin: Yes. Right. So, that was a great company, one of the first companies in the Valley that-- you know, it coined the term great place to work, and I just loved it.

Redelfs: You were there a long time.

Astrin: Yeah. Yeah. I did a little bit of phone mail, voicemail.

Redelfs: So, you were a hardware guy. Were you doing software there? What were you doing with voicemail?

Astrin: Mostly hardware.

Redelfs: Okay. So, what was the hardware that was required for voicemail specifically?

Astrin: Well, it was the controller of the disc drives that would interface the voice, again, speech sample as real time.

Redelfs: Got it.

Astrin: Two hundred, a few hundred-- no, few hundred, a few hundred times faster than telephony signaling, because now from the phone you were getting PCM samples of voice which were going directly

to disc drives and you're filling up disc with voice from hundreds of users. So, I was pushing a disc drive controller a little bit. They almost didn't do it. I remember going to a TMT meeting, which they called Top Management Meeting, with the four-- three, our OLM and a friend of mine who was a business guy, Deidre, a German guy who was very pessimistic, and we presented the plan for voicemail and Bob Maxfield really liked it and pushed for it and Ken Oshman pushed for it, too, and then Deidre gets up and he said <laughs> "If you ever sell a thousand of them I'll eat my hat." <Laughs> But we did it anyway, and then by a year later when that TMT meeting again and Deidre, to his credit, brought a hat and started chewing on the rim. <Laughs>

Redelfs: Hopefully made of something edible. <Laughs>

Astrin: By the time we sold like 5,000 units.

Redelfs: Right, because that was really what made the company take off, wasn't it?

Astrin: Yeah, and that's-- that and interfaces through the network and the networking side of it, and it made the company very attractive to IBM. So, the company was bought by IBM in.. I think was it '86?

Redelfs: And so, you stayed quite a while after the acquisition.

Astrin: Yeah, and then IB-- yes, and I worked in engineering for about a year or two and then IBMers started taking over and they said "Well, we don't really develop products, we sell them. We just don't-- we're just going to be buying products from now on," except for voicemail.

Redelfs: So, they wanted to outsource the hardware?

Astrin: Yeah. That was just general philosophy at IBM. They no longer would do development. They would just market it and sell it. And so, I said "Okay, well where's the exit door here?" <Laughs> And one of the VPs came and said "Well, how about you do some marketing training," and back at Memorex they sent me to MBA class at Stanford and I was kind of interested in sales and marketing and the finance part of-- side of the business. So, I said fine and best reputation in the country, so I'll get some marketing training. So, I went to Armonk and spent about a year there in marketing training.

Redelfs: That's a long time.

Astrin: Yeah. The give you a voice coach, a presentation coach. I went to the airport, had to read Wall Street Journal while the coach is backing away, and pretty soon he's a quarter of a mile away and he's just going "And this morning news," reading it. He's says "I can't hear you." So, it was kind of--

Redelfs: Learn how to project your voice.

Astrin: Project the voice. Use color in presentations and use all kinds of tricks. I actually kind of liked it and then they formed at ROLM they formed a group called the Executive Marketing, and brought in a construction company that built the Apple and ROLM briefing center at the same time. So, we had all same equipment and same training, and I started doing executive presentations and running executive

briefings and I wound up being an executive customer/client contact for over 40 companies, and actually wound up getting 100 percent quota, which at IBM was a real badge of honor. If you look at all IBM business cards they're basically playing all-- no matter who you are, president or vice president, except there's this little tiny gold thing which says 100 percent. That's when you reach 100 percent quota for that year, which I did. It was like \$45 million with several insurance companies, General Motors, AT&T.

Redelfs: That's a big quota.

Astrin: Yeah. Well, a lot of people did basic work. The branch managers always came out, the sales people and asked and we took customers and then give them a three day tour and try to convince them why their way is wrong, why their way of using AT&T is wrong. <Laughs> So, that was a good training and it really taught me more about marketing and sales than anything else I've done prior to that. And then IBM got tired of ROLM and sold first part and then later all of it to Siemens. So again, my desk hasn't moved now in 12 years.

Redelfs: Okay.

Astrin: ROLM, IBM, now it's Siemens, and Siemens went "Mmm, Dr. Astrin. Oh, Dr. Astrin." Says "Which development part do you want to run?"

Redelfs: Your German played out here, didn't it? <Laughs>

Astrin: And I'm like "Whoa, back to engineering." So, did a couple of things. I actually wrote a business plan for head of Siemens for why they should care about wireless and why they should care about cellular phones. <Laughs> I mean they were making PBXs also, like ROLM did, and it was all wired. The only people that were building anything wireless in that area was Ericsson back then. So, I wrote a business plan and I got very interested in wireless. Used all of my technology, the OFDM, the fast Fourier transform. And so, for the first time after that I went and did a little startup, Telergy [ph?]. Didn't make it. We raised half a million or so and I got a team of engineers and we built a prototype and the product was going to be a PBX for a construction site. So headset, like the little noise cuff _____ for the construction people, the little _____ they wore. There was a speaker and a microphone and they carried it a little tiny box, and this is when I needed some wireless length of a central switch.

Redelfs: Sounds like a good idea actually. Why did it fail?

Astrin: Oh. We had a strange management structure, is all I can say. <Laughs> We hired a CEO and first thing he said "I need all the money we have in the bank to hire a CEO," <laughs> and the board says "yeah." I went "What? What?" <Laughs> And so, he's spent all the money on executive searches and we ran out of money before.. and were almost ready to close the door when Apple called, and the length that I used for the speech between the headsets and switch in this construction thing was 80211. So, I started go--

Redelfs: So, this was the original 802.11, the one megabit.

Astrin: The one megabit.

Redelfs: Okay.

Astrin: So, I rejoined IEEE. I actually, my first stint at IEEE was 802.3 when I was at Memorex still.

Redelfs: Sure.

Astrin: Because we were this frontend. Everybody needed a counter to token ring. IBM was pushing token ring and was telling people you need SNA and token ring, and Memorex was kind of leading the other five-- the bunch, the Burroughs, Control Data, NCR, the other five computer companies, and we said "We need a counter thing to token ring." And so, I heard about this little standard called-- I met Bob Metcalf at Joint fall [ph?] Computer Conference in '76 and went to visit him at the PARC and I saw that the prototypes of Ethernet MAU, Media Access Unit, was running on thick coax cable with this big vampire cables, but it was doing a megabit and it was a thousand times cheaper than token ring. Token ring was these big connectors but--

Redelfs: Hermaphroditic connectors as they were called, right?

Astrin: Yes, hermaphroditic. <Laughs> And they were like a thousand dollars apiece. And so, we said "Could we do this on a twisted pair," because customers I knew from PBX, customers have twisted pair all installed in walls. Could you do an Ethernet on twisted pair? And he was going to go try it, and it eventually succeeded. The guy that did MAU built another one. But anyway, the one from ROLM which was co-developed with UC Berkeley. There was a professor at Berkeley, Martin Graham, who just actually a couple of weeks ago died. He was great magnetics transformer professor, and he wound up a little thing that I used at ROLM to convert twisted pair to run a megabit. I knew this could be done physically. So, I needed-- well, as soon as the IEEE 802 started their deliberations on Ethernet, you know how IEEE is basically one man, one vote, open door policy, and opens the door and in walks in 40 IBMers in suits and ties and they started voting no, no for everything. So, this guy called me up from Tektronix and says "We need more people to vote for Ethernet." So, I rounded up my Memorex troops and we all showed up there and we started counter voting it because everything was being blocked, and I started hearing this strange word in engineering. Diplomacy. I went, that can't be right, and there was a great chairman at IEEE and he finally diplomatically, very diplomatically covered and convinced IBM that they need their own standard called 802.5 and they should leave this crummy thing called Ethernet, 802.3 and we should just split our ways and, I still remember this, let the market decide. I sat there with Bob and we said "Let the market decide." Of course we wanted Ethernet because it was twisted pair. I could do it on my frontend. And so, that took off and I <unintelligible>. Now it's 802.11. So, I started going again to this 802.11 working on the 1, 2 megabit standard, and that's when Apple called me because I was.. and people were just proposing 11 megabits. They hadn't quite gotten there but it was kind of clear that in order to really be competitive in the marketplace was that by then 10 megabit Ethernet, wired Ethernet you had to be at least 10 megabit on the wireless side. So, we started going to IEEE standards again, supporting it, and that led to.. well, the standard was going by itself. Somebody convinced Steve Jobs that wireless was a good thing. It may have been Cees. I don't know. Somebody at Lucent. No, it was his boss at Lucent. I forget his name <unintelligible>.

Redelfs: I don't remember Cees's boss.

Astrin: He was-- met someplace and he said "We're working on this thing called Wavelan," or whatever it was called back then. And so, Steve-- when I started Steve comes and says "I want everything wireless," and I said "Are you sure?" <Laughs>

Redelfs: So, he had hired you at this point?

Astrin: Yeah.

Redelfs: Can you just back up for a second? I'm just curious how-- who approached you from Apple and what were they looking for?

Astrin: Oh. It was Dick Allen.

Redelfs: Okay.

Astrin: Had got into Apple. He was running their previous-- their advanced technology group.

Redelfs: Okay.

Astrin: Which was disbanded because it was Sculley's baby.

Redelfs: Okay. So, this was in the Sculley era.

Astrin: So, as soon as Steve got there they were all laid off, about 150 of them, and by the way the whole company was in really terrible shape. When I moved into my office on Infinite Loop Six, the whole hallway was dead. There was nobody else and I went around the whole building of four floors, and I finally found a person in one of the things. It was an old software guy that had been there forever, and I noticed him because I was going down the hallway and I heard sobbing, somebody just crying in their office. So, I went in there and I said "What's the matter?" and he says "All my friends are gone. Everything's gone. We're going down." I said "Well, the worst is over." <Laughs> The stock is down to 50 cents, or whatever it was back then and I said "There's an old Polish proverb. When you're lying down you can't fall down." I said "We're down."

Redelfs: At the bottom.

Astrin: At the bottom. <Laughs> And Steve's like.. so I said "Well first of all I need an anechoic chamber," because I still wasn't trusting this Lucent Intersil prototypes that were sort of shipping in.

Redelfs: So, they were already working with Cees and the team at Lucent when you joined?

Astrin: Not yet.

Redelfs: At least evaluating it.

Astrin: Yes. Yes. I remember flying there the first month to Holland and meeting with the whole team, and they also were depressed, demoralized because they had already been at it for like 10 years, and

they had a product line called Wavelan which was a PC board and an access point which was basically a PC, like a rack mounted PC with hard drives and two slots for a PCMCIA card, and he was offered to sell it for us for \$1,500. <Laughs>

Redelfs: Not exactly an Apple price point.

Astrin: And Steve just went "Okay. We'll talk to you later," and the Wavelan card, which was the same card except it had a little antenna sticking out--

Redelfs: So, pick that up. So, that's a typical PCMCIA card, right?

Astrin: Yes.

Redelfs: So, that was one of your first?

Astrin: Right.

Redelfs: And the PCMCIA card slid in the side of laptop--

Astrin: Right.

Redelfs: Computers of that era.

Astrin: Yeah, except the Wavelan card, Lucent Wavelan card had a little bolt-on the antenna system here so it was actually sticking out of the laptop by about an inch and a half. These were sold for \$495 and Lucent sold I don't know, a few hundred of them maybe, a few thousand. And so, I went-- after a few meetings later I went to inform him of our price points <laughs> which we still don't know where they came from. I think Steve just woke up one morning and said "Card will be \$99 and access point, the upward base station will be \$295." He just went "It can't be done. Number one, it will never work. It won't be profitable. We're going to be all out of business and fired," and--

Redelfs: So, this was Cees you're having these conversations with, who was the VP and General Manager of--

Astrin: He was the general manager of this unit. There were some more optimistic engineers that, under him, who actually liked the idea. I basically scoped out everything that was there kind of, little pieces of everything and then I listed all the things that were still missing. The board, the board had things missing in it. The standard was just converting to 11 from 10. I should never asked that but Steve--

Redelfs: To 11 meaning 11 megabits?

Astrin: Eleven megabits.

Redelfs: Yeah, so this was the 802.11b--

Astrin: B.

Redelfs: IEEE standard.

Astrin: Yeah.

Redelfs: Which was actually draft at that point.

Astrin: Yes. I said "Steve, do you want to go with 2, which is working or do we make them go 11?" He says "11." Okay. So then I had to take apart the card and go through it and block diagramed the radio receiver, transmitter, what's missing, what needs to be added to make it 11 megabits. There were a lot of shortfalls. There was an IF chip that actually Lucent--

Redelfs: Intermediate frequency?

Astrin: Intermediate frequency.

Redelfs: Yeah.

Astrin: Amplifier which Lucent was actually buying from Phillips in Holland, and their-- that chip couldn't do the bandwidth of 10. Could deal with two or eight, which was.. going to get technical here. It has a BPSK and QPSK modulations, which were fairly simple, or switched to OFDM, and-- no, and there was an intermediate step which was doing the 11 megabits with super coding called Barker code, the Eck, which I actually studied at UCLA. So, I was-- I actually went over there and I spent a couple of days with their engineers and said "Okay, we can do it," and France Hoekstra was the guy that actually grabbed it and go "Well, I think I noticed that Lucent was in Holland in general is that people didn't work very hard." I mean I felt like I had a guillotine over my head because Steve told me this is going to be announced in July '99. It's already March of '99. So, I started counting days. I had a little calendar in my office, knocking off days. I had like 27 days. I remember that day for some reason, and I'm thinking.. and it's all R and D prototypes. This-- I'm at tooling up a production line in Taiwan, building the tools, building the test equipment, building the verification equipment, and getting off end production. I finally got marketing at Apple to give me a forecast of 14,000 units for the rest of the year in '99 <laughs> and went are you sure because we're going to buy parts and staff up and put the lines and train people, and that's not that many, relatively speaking for something like this. I mean Apple was already making millions of laptops and things. So, it was kind of hard to convince the vendors to work with you.

Redelfs: When the forecast was so small.

Astrin: Yeah, and the vendor was-- that finally agreed was a modem company that supplied Apple modem 33 K bits modem that fit in laptops, and they had a volume on that. And so, I went over there and they said "Okay, we're ready to start building Wavelan cards or the Airport cards."

Redelfs: So, they were going to manufacturer it?

Astrin: Manufacturer it.

Redelfs: To the Lucent designs.

Astrin: Yes.

Redelfs: To the manufacturer.

Astrin: Right. And we build a few prototypes. We had to change some design on the boards, to change the connector. The RF connector was violating somebody's patents, had to redesign it. I've never done a connector in my life. I had to redesign it with a mechanical guy at Apple. We put it in an anechoic chamber, start testing it in the lab, and I went to Taiwan to the vendor and he says "Well, see this room over here? That's where we're going to build it. So, we set up some tables and everything. It's all ready for you." I'm looking at this room. It's dirty, cobwebs, and I had some semiconductor fab line experience with this Read Rite and I went this just isn't going to hack it. The guy couldn't understand why we had these little tiny capacitors on the board that are like two picofarads. He was using to 50,000 picofarads which you put in modems. So, he just-- just throw them out. They can't be worth anything. <Laughs> You're taking modem capacitors that were between the power amplifier and antenna. One day I found-- I went in there and I found a whole bunch of cards was not working, and I'm looking at the trace on the board and there's a trace going to a little black box. It looked like an S04 type resistor, which was supposed to be five picofarads <laughs> going to an antenna. The signal goes up to it and nothing comes out. So, I pulled it off the boards. First I noticed it wasn't soldered. It was glued. <Laughs> Then I looked at it under a microscope. There's nothing inside. It's just a piece of plastic. So, I said "What's going on, Chu?" He says "Well, I found this neat vendor here in local Taiwan where we just took a sheet of plastic, cut it up in little tiny squares, and we glue them on the board. It can't be good for anything. I mean it's only five picofarads." <Laughs> So, I had like a thousand boards running through production. None of them worked, so they had to be reworked, and so I got tired of it and I'm counting the days, right? It's now like--

Redelfs: To July's watch.

Astrin: To July. I'm like.. and the guy just wasn't responding. So, that's when I adopted my title, Supreme Commander of Wireless. I don't know if that card has it, but on the back of this card it's in Chinese, Supreme Commander Wireless Engineering. I had trouble with the translator. Apple had a business card translator in San Francisco and she says "I don't recognize this title."

Redelfs: It hasn't been approved by Human Resources. <Laughs>

Astrin: No. She was independent contractor. She says "I've never seen a business card called Supreme Commander." So I said Chiang Kai-shek of Wireless Engineering," and she goes "I'm from Mainland, Mainland China. I will not put that down." <Laughs> So, we had to go fire her, hire another translator. Then I went to Taiwan again next week and I called Chu and his 40 program managers on the line and I said "Let me introduce myself," and I went Supreme Commander, you know, Wireless.. they all went..

Redelfs: Yeah. Salute. <Laughs>

Astrin: Salute, and I said "Okay, I don't have time to be politically correct or be nice. Okay? So, I will just order you hour by hour until we get this done." I said "First thing to do, we're going to vacuum this room."

They go "Vacuum this room," and I adopted completely tyrannical management style. Clean up the desk. Wipe out things. Put the filtration pumps. Put the right microscopes. Get a spectrum analyzer -- they'd never seen a spectrum analyzer, and finally we got the production line lined up. So, it--

Redelfs: And Apple was a big enough customer even at 14,000 units that they were willing to jump through hoops?

Astrin: Well, he was grumbling but the modern business was making up for it, so he grumbled but he followed. Little did he know what was to come. <Laughs> I knew but I couldn't convince him. The other thing was test equipment. I needed something to test, see if these things are working. It's very hard. This is in the computer world testing two points for gigahertz signal. This is just unheard of back then. On top of it, you have to check the modulation, see if the antenna balance impedances work and all that, and I really wanted it in Macworld and MacBook, or Mac, iBook, and PowerBook to be tested as a whole system because this was inside the unit and then there was this coax and there were these two antennas in each machine, which is a separate story, but anyway so I called up HP and I said "I need a spectrum analyzer. It needs to be nowhere-- at least three gigahertz," and they had that, and it would be nice if it was programmable. So, they whipped up something and next day the salesman shows up with this.. they call it HP Basic Language Computer. It was really a PC bearing inside of there and it did Basic, and it had one data output, one bit. <Laughs> So, I took the-- interfaced to the antennas and ran it through the system and then programmed that internal Basic through that one bit to turn on that red or green light when the signal wasn't accurate enough. We have conditions on antenna VSWR, SWR and all that, and it worked.

Redelfs: So, now you had your production-- was this the production tester then?

Astrin: Yeah. So--

Redelfs: One at a time.

Astrin: So we built 1, 2, then we ordered 10 then 50. All of a sudden HP started coming. The salesman became my best friend. <Laughs> In fact, I think I was the largest order that year for the spectrum analyzer at HP, and the... we started the production line. Firmware guys are working on the drivers for it. That part was fairly simple. It was modifying Wavelan driver to this. And then at the same time I was also designing on the side the Airport Base Station with this strange shape, which Jony came up with. He had walked in my office--

Redelfs: This is Jony..?

Astrin: Ive.

Redelfs: Jony Ive. Okay.

Astrin: And I'm like looking at this thing. <Laughs> And up to that point in my career I had never cared what my products looked like. They were either defending free world, or saving lives. That was important, and not what they looked like. And actually that marking guy over there, Jaws, really convinced me that

that's what really matters and I'm a now firm believer that it's that first look on the shelf that tells a customer they want to buy it. And so the shape is fun but then putting electronics inside was really hard.

Redelfs: So did Jony think about manufacturability when he came up with his design?

Astrin: No.

Redelfs: So you had to figure out how to manufacture it..

Astrin: How do design it.

Redelfs: You had to make the radio work and..

Astrin: And fit it into this little shape with its power supply. And have the antennas inside and have it all not interfere with each other.

Weber: You told me years ago, I thought, something about it being inspired by a mushroom lamp.

Astrin: Yeah. I still have that mushroom. One of my friends from Poland escaped early on to Sweden. That was one of the ways to get out of Poland is you wait 'til Baltic froze up and then you ice skate to Sweden. And he came to visit me about that time and gave me this Swedish folk art. It was made out of glass and it looked like a mushroom with little crystal different color of glass. So this was sitting on my desk and we talked about it and I come back and he comes back with this thing. I said was this inspiring for this-- inspiration for this, and he said no. But I knew better. So we run that-- so that was really hard. And then we had to put in an operating system in this thing, and of course software guys want to put Mac OS, the old Mac OS. At the same time..

Redelfs: Into the access point?

Astrin: Into the access point. And at the same time we're also working on new Mac OS because Steve wanted this UNIX-based thing and I spent a lot of time with Avie figuring if this could ever do..

Redelfs: And who's Avie now?

Astrin: Avie is the VP of software. He actually was the architect of Mac OS based on UNIX. They knew Mac OS 10. I have a t-shirt that said that. And which I was a big supporter of. I think that's the right thing to do, it will be reliable, it will work. I'm sick and tired of Windows crashing every week at home with my little PC. But that operating system just wouldn't hack networking operation of access point because you have to pump data in and out at 11 megabits per second, and that was just way beyond what real time the OS could do. So I went shopping and ran into this little company in East Bay called Wind River, and the reason I ran them is-- read about them was their operating system was a real time operating system. It was all used in defense industry and in space industry, and they're very proud of the fact that its operating system was running the Sojourner on the Mars. So okay, if it's good enough for NASA it's good enough for me. And it was very light, incredibly light. The whole code was like 90 K of code, and it could push data-- the processor we inherited-- the processor from Lucent, which was a 286 chip, I built a kind of

a customized flash interface so it would run faster with the flash, the VxWorks. And we got a software guy who reluctantly-- he was a strange guy, but that was a good thing because he didn't like Mac OS so he could work on this VxWorks that was fun for him. So sometime around May, this is the beginning all to shape, you know, running around to Taiwan every week..

Redelfs: And is the same manufacturer going to manufacture the access point as the PCMCIA card separate manufacturer?

Astrin: Yeah.

Redelfs: So you had two manufacturers to be dealing with as well?

Astrin: Yeah. The guy that did the access point was also building the iBooks and it was top-secret project. The iBook back then was the color iBook that had orange and green colors and some people called that, it looked like-- had the little handle. I won't say what it looked like. And one of the top secrets that we had never to mention was the fact that there were-- and we're building also the iMac, the one iMac. There were five colors-- no, scratch that. Flavors. So we had-- and we had to put antenna and the card into it and the iBook, and the iBook vendor was the one that was doing access points and the card. Sometime around May this started to-- it started to look feasible to me. Not that it was practical, reasonable, but at least not crazy. It could be done. And I get my calendar and down from day chunks to hourly chunks.

Redelfs: And how big is your staff at this point?

Astrin: Well, it was just me.

Redelfs: It was just you?

Astrin: When I started in..

Redelfs: Because you were working with..

Astrin: In an empty hallway.

Redelfs: Engineering team and then you were working with the manufacturers on the other side.

Astrin: Yeah. But by then I got-- I was teaching outside of the states, I hired a couple students as interns. One as technician, one was testing, we had a consultant on antennas, and yeah. Most of it was Lucent and Taiwan. And so I wound up traveling back and forth every week. It was just murder on me. Couple years later I knew it was getting too much is when I was coming in from Taiwan on United at San Francisco airport. The guy at customs would say, "Hi Art. Any samples for me this week?" I always had few old iBooks in a secret box or hundred of these cards or a couple airport base stations. And we started testing the whole system and kind of nothing worked. I started fixing software bugs in the OS, in the drivers and iBooks, having increasing resistance from Lucent Cees Links. When he heard about these price points, and he gave me a long lecture. I said, you know, we have to put a big effort in this and it's

very ambitious, probably one of the most important project in the history of computing in this decade. And it would be revolutionary in the industry. And he says, you know, in Holland we don't work like that. We don't work to be-- how did he put it? We live to-- we work to live and not live to work. Well, that's opposite of me. And that's why I found Frans and a couple other guys, a software guy, really neat Dutch guy with a big beard and sat in his office. He wrote the driver for Wavelan and the PC.

Redelfs: This was Frans Hoekstra.

Astrin: Frans was doing the-- oh, Frans was doing the IF chip and the part of base band. In around March I jumped him and I said okay, you know that one and two megabits that we got going now? We're not going to this. It's 11. And he almost cried because we had to add CCK coding to the base band and increase the bit rate and everything went just nuts, and bit rate interference, all kinds of problems.

Redelfs: Lucent was doing the design for you, but yet you were contracting directly with the manufacturers?

Astrin: Manufacturer in Taiwan?

Redelfs: In Taiwan.

Astrin: Yeah. Because we were definitely going to take over production of the Airport card and access point base station, so there's a point at which we started with our design and the pieces and then we kind of finished it. So we started testing it, in Infinite Loop One, Steve's building, which was right next to mine, which was Six. And he always looked out the window and was-- I was on the second floor, he was on the fourth floor, and I could kind of see him looking wondering if it's going to happen or not. Because he had to also muster the marketing resources because by May there certainly cut offs on vendors and booth and presentations and..

Redelfs: You've got to decide whether to launch this thing or not, right?

Astrin: Yes.

Redelfs: You've got to print the collateral material.

Astrin: And it was a huge launch. This was like the first launch since demise.

Redelfs: So we have a picture here of you and Frans Hookster-- Hoekstra from Lucent in front of the Airport booth at Mac World in July of 1999. So the launch.

Astrin: So Frans and me became very friendly, a couple of the software guy, the technical guys there, Bruce Tuch, who actually—figured out the exact logic equations for this eleven-bit coding. And so we took over the Infinite Loop One lobby one Saturday and we taped all the windows with paper and-- to make it not visible. And we had hired-- we had brought in like 20 most trusted employees and had a couple base stations set up and maybe 15 or 20..

Redelfs: This is testing before you had launched?

Astrin: Yeah. Putting the iBooks through the paces; people were doing internet browsing and things. And I actually found a little quick speed up on it so when you went to CNN and you had a QuickTime plug-in, you could actually get a real-time video on the laptop-- the iBook. And then we went in production. I spent about two weeks in Taiwan and this was-- we're down now to minutes, you know. I knew when the plane had to leave to New York to make it to the show and we backed out from that. And it was, again, we're fighting this incredible Taiwan ingenuity entrepreneurship and how to go around the things. And there were times, like these capacitors. One of the other things is I had to ship 100 prototypes to Cupertino, get software people working on it. And I said well put them on the FedEx so it will be there tomorrow morning. So I called up Cupertino the next morning, software guy, and said did you get them. He says no. Okay, we checked FedEx, they didn't get it. Waited another day and I said did you get anything? No, no. Turns out this Taiwanese manager of this factory had a cousin who was in the compete with FedEx business.

Redelfs: And it would be cheaper.

Astrin: It would be cheaper. And the way he found it was that if you wait 'til Wednesday, he found some kind of transport plane that went once a week and he could take all the boxes, put them into Cupertino for half the price, and we saved \$300 or something. Wasn't a big box. It was two big boxes of hundred power books. I said do you know how much money we wasted. We have 100 software guys in Cupertino waiting for a day and a half to get their hands on it? It's like-- I didn't want to scare him. I said millions, you know, millions. You can't do that anymore. Anyway, doing things like this, there were all kinds of accidents, things. We finally ran the production line with full borne production released manufacturing documentation; manufacturing released testing, manufacturing release verification. Some place into late July and-- there were all kinds of comical things happening. I remember the last thing was we were putting them-- we said now we have 20 base stations and we're going to put them in a box, ship them to New York tomorrow, and they were just putting Airport base stations like they were off the line, still a little hot, and he said we can't send them like that. Steve won't like it. I said we've got to shrink wrap them. And he says we don't have a shrink-wrap machine. So he literally, and me, sent out 20 engineers all over Taipei looking for shrink-wrap machine and we finally found a pizza place that had a machine and we bought it off this pizza production line. They had these little round plastic things and we brought them in, put the Airport base station in them, heat up with a heat gun, and it shrink wrapped just right. So we got the 20 boxes in the mail and iBooks, maybe 40 or 50, I can't remember now. And I took the three main guys from Taiwan, the manager and a couple of his engineers, and we also sent them with our spouses to New York, and Jean came and joined me and Frans, and a couple other guys from Lucent came out from Holland and it's day before, so we had rehearsal and we rehearsed the presentation. Steve was running around really nervous because this was it. I mean, and it's like five brand new iMacs in five flavors, the two iBooks in orange and green, the Airport station, and so I think we sat all night there. He had the script written up and we kept crossing out words, adding words and everything. He actually had the same training that I had at IBM, so he was great presenters. I mean, he was one of the best presenters I've ever seen. And it all looked so casual, but it wasn't. It was..

Redelfs: He went to the Nth degree of detail?

Astrin: Nth degree, yeah, repeated maybe 50 times before the actual stage time.

Redelfs: And so how long did it take for you to go through the 14,000 units? They sold pretty quickly, I'm guessing.

Astrin: First day order on the web: 100,000, 50,000-- 150,000 units. Second day order: 150,000 units. Third day order: 150,000 units. Fourth day -- lawyers shut down the web page. He said there's no way we can keep selling it. They turn off the webpage so we can't take orders because it looked like it was going to be two years before we could ship it. I had a little-- I had like a Dieter moment with the marketing guy, you know. If you ever saw [ph?]-

Redelfs: So I'm guessing you spent a lot of time finding additional manufacturing capacity very quickly?

Astrin: Yes. And adding lines, adding people, training, making HP very rich with their spectrum analyzers, I guess. Must have had 100s by then.

Redelfs: That's a great story. Now help me with remembering. IBM responded with the Centrino-- not IBM. Intel-- with the Centrino, with the other laptop computers, right? The PC compatible lines that competed with Apple, and that was after you guys announced the Airport, correct?

Astrin: I don't remember that. You mean Intel?

Redelfs: Yeah, Intel Centrino was their big push into Wi-Fi and I think it came after you..

Astrin: Our big competitor was Dell at the time. Dell got on TV and said Apple was dead, it should be taken out of its misery and killed. And Steve just went ballistic and we didn't like certain stations afterwards 'cause use them. But yeah, that first year production scale-up was amazing. Oh, we still had problems. We found some more subtle problems after the announcement. I still had to go to Holland. Actually did the ones that were subtle were harder. They were harder to find. Mostly customers didn't see them, but we knew them and we knew that some corner cases there would be problems. And we didn't want them so we kept modifying design. I was personally getting sick and tired of flying to Holland and just my health, you know. Two years of flying every week, so I started looking for a vendor in U.S. and we looked at Intersil and they were sort of-- they had a five-chip solution and we didn't think it would even fit into this thing.

Redelfs: But they were really a chip provider, not a big system provider like Lucent, right?

Astrin: Right. But Lucent had only one chip or two chips. Intersil was like five chips. Amazing enough, back then chips were different than now. They were a little bigger, half an inch by half an inch. And there's a lot of other stuff here besides that. Antenna's, circuits, power amplifiers, everything. So we finally, I think, convinced Broadcom, Atheros was not existing yet. We were trying to see-- I heard they might do it but I didn't-- we met with them there.

Redelfs: Rick Bahr at Atheros?

Astrin: Yeah. Rick Bahr.

Redelfs: Was V.P. of engineering.

Astrin: Yes. And I spent an hour trying to convince him that he should do a 2.4-gigahertz and he says we're just not going to do that. We're 5-gigahertz only.

Redelfs: And that was the first product.

Astrin: Yeah. And Broadcom came in at first very reluctantly. They've got a few million-unit order they became very engaged and gave us a lot of support. So very quickly we redesigned the board with the Broadcom chips that-- and went in production.

Redelfs: So that was still 802.11b before you went to g?

Astrin: Yes. And also we were going to 802.11 meetings when they were once a quarter or so and we were in a famous meeting where Frank Howley got up and said let's take 802.11b and a and turn it into a g. So it was..

Redelfs: Which is taking the speed of 802.11 a the 54 megabits but doing it at 2.4 gigahertz?

Astrin: Right.

Redelfs: Which was illegal by the FCC rules at the time. They didn't allow you do OFDM at 2.4.

Astrin: Really? I didn't know that. So how did they do it?

Redelfs: Well, Jim Zyran of Intersil is the guy who really jumped on that idea 'cause they had trouble getting a five-gigahertz radio working. It's a lot harder, as you know, with the higher frequencies. And he started the lobbying effort at the FCC and then the IEEE obviously jumped on it as well.

Astrin: Okay. So they finally legalized it?

Redelfs: They made it legal, right. So it was kind of working in parallel at standard development and changing the rules of the game.

Astrin: So think we announced it about two years later, the g. It was plug-in replacement same card. You could go to existing iMac iBook and switch from 11 to 54, which made-- really made the video possible for the first time in a wireless thing. And we started having these ads where people on campus of-- Cupertino campus would sit on the grass and turn their iBook on and watch CNN or whatever, a movie through internet.

Weber: And why did Apple choose the name Airport?

Astrin: A couple things. I probably shouldn't have opened my mouth. I was in some marketing meetings and they said what should we call it? And I was just thinking well we have a wired board, Ethernet port,

and this is basically interfacing to air. So why don't we call it Airport? And Jaws and Woz, and everybody just went yes. And ever since then it's been called the Airport.

Redelfs: Except, if I remember, in Japan where the trademark was already taken and..

Astrin: That's right.

Redelfs: Apple has a different brand name for it in Japan.

Astrin: There were all kinds of semi-legal questions and there were all kinds of-- all of a sudden I was getting into the product support and there were problems in France, problems in other places, with international frequencies weren't allowed. We had a complaint from the U.S. Army that their servicemen who worked in Germany couldn't take their iBook and use it in U.S. on their vacation because it was illegal 'cause they had three extra-- two extra channels in Europe. I think Japan had also a couple other channels. All kinds of stuff. One other funny thing that happened one day, my phone rings and Steve said it's Steve, and he says it's for you. Click. I went hello. Yeah, this is head of NASA and we're about to launch a space shuttle and international station. We want to put Airport in one thing and they're going to fly by each other within a quarter mile. Can we guarantee the link? I went, "In space? This is office product."

Redelfs: It isn't designed for that. Not part of the marketing requirements document.

Astrin: I said you realize this is room temperature only, plus 35 down to 0, or tolerance to vibration because antennas were mechanical. If you shake it you start changing their frequencies and-- but they tried it; it worked. So I was happy about that. There was all kinds of stuff coming out. There were all kinds of stories of strange uses. All the technology. And it took, I guess, culture has changed at Apple by then 'cause when I got there it was like wireless? No. RF? No. We don't do that. I've got people going around saying we shouldn't be doing it. We're in the Apple community, reputation has to..

Redelfs: It was deemed to be unreliable at the time, right?

Astrin: Yeah. Well, two, three years later it was-- it was okay. It was reliable. And then all of a sudden I started becoming like a central point-- most project in Apple. The new Titanium iBook of course had to be wireless. All the products had to be wireless, but then all of a sudden the mouse guy calls up, says we want a wireless mouse. And we want to have-- I don't even remember, some keyboard, some other things that were borderline. Tony Fidel just joined Apple and he was working on iPod and they wanted iPod to have wireless interface too. I remember my-- I used to number project with P. P1 was the first iBook and P2. The actual Airport bay station was P42 because the software guys liked 42 as a number.

Redelfs: I thought maybe there were 41 failures before it?

Astrin: Oh, no it was the "Hitchhiker Guide to the Galaxy." By the time I finished I had P81 was the last project I think was a-- oh yeah, we had the Bluetooth things that Steve flew someplace back to Europe or whatever and-- the PowerBook had an infrared for mouse interface and I guess he sat next to some guy who was telling him all about Bluetooth. Probably some Erikson guy who had a headset on the phone.

And he comes in on Monday and says I want a Bluetooth in there. And I went first of all Bluetooth and Wi-Fi interfere because, back then it was just hopping all over and frequencies were a problem. And then we had to use the same window for an antenna. And that IR window in the back of the iBook was maybe like half an inch by a quarter inch, which is about a quarter size of a Wi-Fi antenna. So that was challenging to design it to fit it-- we used the fracto design bending it all kinds of different ways and then we finally got it to work. And then Broadcom comes in and says we'll supply Bluetooth chips too. And Broadcom by this time was building Ethernet chips, a lot of main board chips, and the Broadcom founders were coming in every few weeks and asking for more business and asking for more business. So I said we'll do the Bluetooth chip too because they just acquired smaller company in Orange County that was making, product line name was Bluetonium [ph?]. I said who's your marketing guy? The most poisonous substance on the earth. And it didn't work and it didn't work. We tried for a year and finally had to abandon them. I actually went around-- I made some enemies there and other hardware groups that were using Broadcom for motherboard chips. And I found this little company in England called CSR, Cambridge Radio.

Redelfs: Cambridge Silicon Radio.

Astrin: And I became friends with the founder, in James Collier. We really hit it off, spent a few weeks designing things, and he had a chip that worked and a one page Xerox data sheet and they were basically a start up in this little science park in Cambridge that was blessed by the Queen, and second time I went there after we gave them an order, in this lobby is a big picture of Her Majesty, with congratulations CSR for becoming an internationally renown British startup. Back then there was like oxymoron, what's a startup? If you didn't have a bank and you weren't in the real estate or gold or oil you didn't get funding. You're going to make a chip? And they did, and they succeeded, and they're pretty-- the company even now. So but I had to backdoor the chip to make it work and it was because Steve really supported Bluetooth that it finally made through. So there was some hurt feelings from the other guys, but so we went up with a Bluetooth and Wi-Fi in iBooks and all the products, and then we switched mouse from Wi-Fi to Bluetooth which was the right thing to do, much lower power for smaller size. One thing that it sort of didn't do is Bluetooth is much small-- slower data rate, it's only one mega bit.

Redelfs: But for a keyboard or mouse that's plenty, right?

Astrin: That's what I thought. That's what I thought. And I kept saying, "It's good enough, it's good enough." And it was-- I'm sorry, it was Jaws, the marketing guy said, "Come with me." And he flew me to L.A., we flew in the morning, went to some Hollywood studio, not Hollywood studio-- one of the studios-- graphic studios where they make posters for movies, and I'm watching these graphic guys, they have a big station and they have a mouse, special mouse, it was a wire mouse, and the guy's hand is moving faster than I could even see it. It was like--

Redelfs: Like painting, was it?

Astrin: Yeah, he was drawing things on the board and the-- my mouse couldn't keep up. It was going click, click, click, click, click. So I don't know what they did. I think we had to go back to Wi-Fi, but that was a corner case. But the biggest problem was Wi-Fi Bluetooth interference, and it was really killing-- it was

the first probably the first product where both antennas were within an inch of each other, and we tried to separate them as much as we could -- that helped a little--

Redelfs: This was a known problem in the industry because there was an IEEE group that started working on that.

Astrin: Because I caused it. I went over to IEEE and I said, "We got a big problem." And in fact, nobody cared at first, but someone at IEEE adopted Bluetooth as IEEE standard 15.1, and so I said, "Well, this isn't working. It was really visible. I mean user visible. You could look at a screen while you're browsing and while you're moving a mouse like this, this screen would stop, stop, stop. So in between the Bluetooth packets the Wi-Fi packets were getting mashed up, especially in the real time video. Every time you're watching a video but every time you move the mouse the video would stop for a second, and so actually I went back to IEEE and I proposed a standard for that. We first tested in our hallway. By this time, I had maybe four engineers and so we could spare one to solve this major problem, and we came up with a solution which was called adaptive frequency hopping, which is that Bluetooth would look at the frequency that Wi-Fi was using. There were three channels for Wi-Fi. So it was using one of those three, and then Bluetooth would limit the hopping to the other two, and it was eventually adopted by Bluetooth standards and IEEE, and it worked, and it's now being used. So there are some place that are standard, it's called coexistence of Bluetooth and Wi-Fi.

Redelfs: Yes. An important innovation. So you're on the top of the world now, Apple's product that you led is a big success, and you're now doing Bluetooth and mice and keyboards and other things, why did you leave Apple at that point?

Astrin: I got cancer. I got melanoma. In 2003 I had my first surgery on my leg where I got it, and I've been fighting it ever since. They gave me a few months to live. Melanoma was like a death sentence back then, and I had a major surgery in 2010 and first drug showed up on the market that was-- had a little potential. Then I signed up for a trial and I was part of the four hundred people that were experimented on. <laughs> Almost killed me. Spent months in the hospital, blood transfusions, they overdosed me with the drug. It was called Ipilimumab, and then it metastasized to my central part here-- I don't have a kidney here anymore, and then last year or this year it metastasized to my brain.

Redelfs: So they gave you a few months and you've been going now for eleven years and fighting it well?

Astrin: Yeah. Not so well but--

Redelfs: You didn't just fight your cancer though. You've gone off and done some other interesting things. Including, I love it, you started a company named Astrin Radio, and I think back to your first radio in high school and that was the first Astrin Radio.

Astrin: Right.

Redelfs: Listening to Voice of America.

Astrin: Right.

Redelfs: So you've been doing some things professionally since then as well.

Astrin: Yeah, actually one of the things I could do even with that state of health is go to IEEE meeting every couple of months, and started a group called the Body Area Network for medical applications, and sort of adopted term BAN like a LAN, except a LAN for a human body.

Redelfs: This is the idea of having sensors around the body that all talk to each other and communicate.

Astrin: Sensors. Right. And it was-- well, took five years as usual, had probably way too many vendors involved way too early. The first proposal, like 802.11 had really two proposals, Lucent and Intersil. This time, Body Area Network had 77 proposals.

Redelfs: Seventy-seven?

Astrin: Seventy-seven.

Redelfs: It's hard to weed through them.

Astrin: And you have to get them all to agree and merge, and of course, the loudest and the voiciest people were semiconductor guys, Qualcomm, Broadcom, TI. Finally got some medical companies involved and they kind of said we don't really need that. We have a market, we have a monopoly, we don't really need it, and I'm thinking, IBM Token Ring, yes, we don't need any other solution. I've seen that movie before. So we finally got all the things smoothed out and we got down to three and finally to two and finally to one proposal. Took two years, and it got published in 2013, and TI is making noises about building a chip, and in the meantime I was trying to think of-- I've been working with some medical people at Stanford to come up with some applications of that for body oriented medical devices that need communication length between-- or inside the body, and there's a few that are promising.

Redelfs: Very good. Anything else you're doing? And obviously your health is a priority in your life.

Astrin: Yes. Not much this year. Mostly in the hospital.

Redelfs: Yes.

Astrin: Mostly in surgeries and recovering.

Redelfs: But you've contributed a lot in many ways on the side with the Body Area Network, and working for companies like Fastback Networks in the wireless backhaul area.

Astrin: Yes.

Redelfs: A few other little projects. You did a wireless headset I think, somewhere along the line, too, a Bluetooth headset.

Astrin: Yes.

Redelfs: So you're an amazing guy, Art. Always some fun projects going.

Astrin: Right. I really want to keep myself occupied and thinking and stretching. Every time something looks impossible-- the more impossible it looks the more I like it. But I've toned it down lately. It's more whether it's realistically possible within this decade. I was for awhile was really interested in singularity. Have you read that book?

Redelfs: I haven't read it, but I'm familiar with it.

Astrin: Yeah. He has-- that was part of my motivation for Body Area Networks because he had little robots going around your body and communicating and fixing damages, and then I realized that's 2040 and I'm not-- probably not going to be here. So I'm looking at some more near term realistic things.

Redelfs: Something for our children's children to be working on.

Astrin: Yeah. But there's a lot of problems right now. There's all kinds of-- that need millions and millions of people that have certain-- probably the biggest example of that is diabetes. It's almost-- I think it's like forty million in the U.S. alone. They're big. They're building a pump-- insulin pump and for some reason insulin sensor needs to be placed here. So they came and asked me for a link-- wireless link, and it's actually even more difficult because it's inside the body, both ends. Turns out it's a little easier if one end or both ends on the skin are outside.

Redelfs: They're both inside and that's an area where you probably wouldn't want a lot of inference or cross talk from other people in your vicinity either.

Astrin: Right. That's right. Especially if it's critical signals.

Redelfs: Yes. Truly mission critical.

Astrin: Yeah. It needs extra reliability that we usually don't-- currently don't have, and it needs security which we currently don't have because it's life information. First, it's for privacy, but secondly-- I remember on the second IEEE meeting we had a minister of health from France, and he got up and got a speech, and he said, "This is how I'm going to kill the president of France. I'm going to stop his heart pacemaker on the stage while he's presenting." I'm sitting hiding there, and I said, "Do you realize there's two hundred people in this room? Do you really want to be saying this in public?" But it turns out that that's a real problem. People have been hacked, their pacemakers have been hacked. So you need to add extra reliability, extra security, and before you act on any command you really have to be sure it's a real command. So I'm consulting on different things like that. Fastback is a fascinating company. It's trying to do something that is almost within their reach. Oh, it is.

Redelfs: Spend a minute on it, because as a guy who really made Wi-Fi happen, the downside of it is now there's all this Wi-Fi interference, right? So the idea is Fastback doing a high speed long distance using the same frequencies and avoiding the interference.

Astrin: Yes. Well, first of all Wi-Fi has, because of interference, in the last two years has moved to 5 GHz. There's still a lot of it at 2.4, but and then last thing I guess at Apple was switching to Atheros chip.

Redelfs: Thank you for your business.

Astrin: <laughs> I remember several times trying to convince Rick Bahr and Theresa and they just said let us-- I know who it is, but someone wouldn't let them go below 5 GHz, but eventually they did, came up with a 2.4/5 GHz solution, and I remember designing that little board.

Redelfs: Well, it was the second product that did that. The first product as any startup you're already in development, they couldn't redirect the company. But the second product was 2.4 and 5.

Astrin: Yes. I hope it was good business for Atheros.

Redelfs: It was. It was. Thank you. Anything else?

Astrin: And Fastback yeah, it uses really pretty much full 5 GHz band to its fullest, and uses all the channels. So ultimate bandwidth is almost incredible, at this point incredible, and because it's point to point so it's really not interfering with anyone else, and it doesn't have interference from anyone else either. There's access points when we're testing. Sometimes we'd hit an access point that would really mess up the link, but it wasn't in the way. And it's almost possible to do a gigabit link-- I'm not sure what I can say there.

Redelfs: Impressive.

Astrin: Yeah, and then the next band is 60 GHz, which 802 did a few years ago, didn't do it right so then now they are redoing it. The problem is it draws too much power, which is a problem in laptops and portable things, but it's not a problem for access-- for infrastructure products. So I hope this all works out.

Redelfs: Great. Well, thank you, Art. I appreciate your time and it's great to review your history.

Astrin: You're welcome.

Redelfs: It's been exciting and you've made tremendous contributions to the Wi-Fi world, and we all thank you for that.

Weber: Thank you.

Astrin: Thank you.

Redelfs: Do we want to go back and let us do a couple of those quick things that we. So I had the three written down, the original computer and pull in the ARPANET at UCLA, the fact that you were in San Diego and the opportunity at Linkabit. Anything else that maybe we missed? Oh, the Olympic--

Weber: Oh, yeah, right. Decathlon.

Redelfs: Let's talk about that first. So Art, when you left Poland I understand you were on their Olympic team. That had to make it very difficult, and tell us about that and the event that you were on the team for because it's not one that we talk about a lot, in this country at least.

Astrin: I was recruited. I was fairly good in swimming. In fact, I had Poland's record in breaststroke, and then I was also good at running, and pistol shoot, and they asked me to join Decathlon team, which in addition to these three also includes horseback riding and fencing.

Redelfs: So you had to learn those two after they approached you?

Astrin: Yes. So I had to learn fencing. I was good at fencing, surprisingly enough because I was left handed and, people that fence don't expect parries from the left, they expect them from the right, or the other way around. And then the last thing I had to learn was horseback riding, and it was cross country one of those where you jump over things and fall in ditches, and this is old Polish cavalry is a pride of Polish Army. Unfortunately, that's what destroyed them with Hitler times because they sent the cavalry against tanks.

Redelfs: That doesn't work to well.

Astrin: They just got killed, everybody got killed. So but it has a long tradition of cavalry. So I got an old army guy as a coach and he says, "Well, the first thing you do when you learn horseback riding is you got to learn how to clean a horse. So here's a brush and start brushing." So I spent a month, every day cleaning maybe five horses. <laughs>

Redelfs: How old were you when this was going on?

Astrin: Seventeen. Yeah, that was like a few months before I had to leave. So I actually never got to the horseback riding because he had this very slow training method where you clean and clean and clean.

Redelfs: Clean the horse before you ride it.

Astrin: You need to learn how to get up and get off, get up and get off, then you learn how to trot and then you try to gallop.

Redelfs: So maybe you didn't lose too much then by leaving before you actually had to compete there.

Astrin: Right.

Redelfs: Great. Well let's talk about your computer that you built in Poland that you referred to later on in your life.

Astrin: Yeah. I-- it was my high school. I had a very good math teacher who really motivated me to learn binary system, and I just fell in love with binary system. I started doing all my math in binary. I was doing all the calculations in binary and then I-- the simplicity of it was so beautiful that you could do-- multiply-- you can do add and subtract with basically a single exclusive or gate in the carry circuit, and I was getting

parts of the radio station or my weather work, and I got some relays and I started hooking them up. So I did two relays in series, and you put power in it, you relicked both of them on, the lamp would light up. So that was my and gate, they both had to be on. So only 1 1 allowed output. Then or was putting two relays in parallel next to each other, and either one clicked, light came on. So then I built an exclusive or gate, which is almost an or gate, except one stage is missing so that only one or the other stayed 0 1 or 1 0 lights up. They output the zeroes here or 1 1 do not. And that was very easy to do by taking two relays and running them sort of like one output on the left to an input on the right, and only if they were both on light would go through. If one was on or the other-- I would have to draw this up. But it actually performed exclusive thing. So then I wound up getting more parts or relays, and I built a one bit adder, and then for my project in high school I think I was a senior-- maybe junior year I actually got a big box and I put four switches, and four switches and outputs was the five lights, and behind I had-- I don't know maybe lots of relays, tens of relays and you could flip to bits to any number you wanted from zero to fifteen to zero to fifteen, turn the power on and the sum would show up on the lights, and I was really impressing my friends. See I can add numbers and subtract them. So this went up in my high school. I actually went there a few years ago. We went to visit or so, and my high school has moved to a different place and nobody could find the box.

Redelfs: Oh, that's too bad. Probably was sold in a flea market somewhere.

Astrin: Yeah. Or-- I don't know what they would do with it.

Redelfs: One of the teachers still has it stuck away. Interesting. So let's jump to UCLA and you mentioned you were working on the ARPANET. How did that happen, and what stage was ARPANET at this point?

Astrin: Well, I started at UCLA in I think 1970 and-- no, I'm actually not sure what year. I probably could find it if I-- and by that time we had-- after about year or two after I finished all the classes and all the prerequisites for PhD we had then moved to Cupertino to Memorex, and I started commuting, but one of the reasons I really liked UCLA at that time was I looked at other schools in that area and they had the most impressive computer set up. They were one of the two doanees by IBM of a 36195 and just the front panel on that thing was like six feet long of switches and lights. I just-- ah. And then they had a room full of dishwashers and they called it disk drives, and I was in a department which was-- had no name. Well, it was called-- it was called Communications Systems, but nobody was sure whether it was engineering or mathematics, because it did a lot of systems theory and it was, oh-- so finally I actually got kind of worried after a couple of years and I said to my advisor, I said, "How-- what will I put on my degree? Engineering or mathematics?" He says, "We don't know, there's a big fight up in the political world of deanships--- and in fact engineering was in the School of Sciences, and mathematics was in Liberal Arts for some reason. So it was like really big politics -- university-wide, not just the little department, and I remember when Don Knuth's book came out, first version, first edition of *The Art of Programming*, and I ran over to the library, the bookstore, and I bought the book and I brought it to my dean, my department dean, and I said, "It's been settled. We are an art." <laughs> So we go-- two weeks later we were in engineering, literally, formally moved, totally now your degree will be in engineering, which I thought was kind of funny. I actually thanked Don Knuth a few years ago for settling my degree issue politically. We-- there was a lab in there called an IMP Lab, which contained one of the few nodes of ARPANET, and since I knew a lot

about hardware by then and software I started working on this project with some of my advisors, had interesting advisors who became founders of Linkabit, but they were also consultants at TRW and Hughes Grumman [ph?] Systems, and while working on this IMP, occasionally we would fire it up and get a connection going-- this was all based on leased lines at 56K, and I remember typing on the teletype to a guy at MIT, "What's the temperature there in February?" And he'd say, "Minus 20," and I'd say, "Los Angeles, 76." We were just playing games with each other. And occasionally Len Kleinrock would walk by and he'd say "Someday this will replace the post office." There we'd go-- all of us grad students would go, old man's really lost it. And then they had a meeting with Larry Roberts and a couple other people that were from internet, they had a big meeting at UCLA. All the grad students go sit in the back-- in the back of the room or under the table. I was under the table, and they were trying to decide how many bits to put in TCP address. And Len started--

Redelfs: We're still suffering from that aren't we?

Astrin: We just run out a few year ago. <laughs> But Len goes, "UCLA, Stanford, MIT, New York, Chicago, eight." He says, "32-bits should be enough. Five bits, five bits should hold us." <laughs> And we're sitting under the table banging on the table going no, no, no. So it was us, the students that convinced him to go 32-bit address. We saved the world.

Redelfs: Or at least delayed the pain for a few decades.

Astrin: Now we're switching to version 6, which is going to be 128-bits, which is ridiculous. It's-- somebody told me it's more than atoms in the universe. So every atom in the universe from now on gets an IP address. We still will have enough.

Redelfs: That's great.

Weber: And who were some of the other-- Glen Conrack [ph?] was one of your advisors, and who were some of the students or your other advisors?

Astrin: Well, one that I really liked most and he just passed was Bob Massey. He invented algebraic codes, and he actually used me for my mathematical background because I was always amongst the engineers and I was the only one that had deep mathematics thing so when they got to like algebraic topology in groups and rings, and whatever they would call me in. The other one was Jim O'Mora, [ph?] who-- just met him last week. He was-- Viterbi was also there, Andrew Viterbi and there was a rank of slavery amongst graduate students. So I used to call myself a Viterbi slave, second order because I edited one of his books that actually Jim wrote, Jim O'Mora, but then I dotted all the i's, checked all the formulas, the math and everything, and I almost could have gotten-- they made me an offer to go to Linkabit and I didn't take it because I thought they were weird. They were. Especially Viterbi.

Redelfs: How early on was that at Linkabit when they offered you to come join them?

Astrin: They were just forming it. It didn't even exist.

Redelfs and Weber: Wow. So you could have been an early Qualcomm employee.

Astrin: Yeah. They just got a contract order from AT&T for coder-- for decoder which would sit on both sides of a satellite link and given the same bandwidth, transmit three times as much data as the previous boxes they had because of this Viterbi coding used in there, and that funded the company and made them grow, and then later the same coding became foundation of CDMA, which then built Qualcomm by licensing it to Korea, and that's why--

Redelfs: The rest is history as they say.

Astrin: The rest is history.

Redelfs: Well, it just goes to show, Art, that smart people will be successful no matter which way they go. You obviously would have been successful if you'd taken that path, but you've done well in your alternative paths as well.

Astrin: Yeah.

Redelfs: So congratulations.

Astrin: Yeah. When I was a grad-- professor here I used to ask my students-- try to teach them practical world things, and I said-- I made up one midterm exam like if you were offered a job as an intern at a startup and you were given ten thousand shares at ten cents, and the stock ten years later after going public had split six hundred times, what would you miss by not accepting that offer? And the answer-- the answer for my case was six million dollars. <laughs> All the students would go, oh, my God, I better do it. So a lot of people I taught at San Jose are now millionaires.

Redelfs: Because you convinced them to take the shares.

Astrin: Yeah.

Redelfs: That's great. It's a good story. Alright. Well thank you again. Appreciate your time.

Astrin: Okay.

END OF INTERVIEW