



Oral History of Paul D. Frank

Interviewed by:
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Recorded October 25, 2017
Mountain View, CA

CHM Reference number: X8372.2018

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Dennison: Well, both hard disk and tape drives have survived as the information storage density devices of choice because of sustained and steep advances in storage density. Density advances required downward scaling of key components. The reduction of the size of stored bits caused signal amplitude reduction, which necessitated the invention of ever more capable writers and readers. This interview centers on the development history of the heads used in floppy disk, hard disk and tape drives although the primary focus will be on hard disk heads. Dr. Paul Frank was a leading pioneer in the development of head technologies at the largest independent head supplier, Applied Magnetics Corporation or AMC. His career began with ferrite and encompassed metal-in-gap, thin-film and magnetoresistive technologies. He was also one of the founders of the Information Storage Industry Consortium, the leading technology research organization for both disk and tape heads and with that, Paul, we'll begin. First of all, tell us a little bit about your family background, where you were born, grew up and went to school.

Frank: Thank you, Ron. I was born in 1949 and grew up in a-- on a small farm just south of the city of Walla Walla, Washington, in southeastern Washington, a town most known for its farming, wheat, peas and the famous sweet onions and whose largest employer was the Washington State Penitentiary, and needless to say, there were few high-tech opportunities there. Today, it's actually become a mecca for the Washington State wine industry; it's actually kind of the Napa Valley of the Washington State wines and is very popular in that regard, but still not much high tech. My parents were both born there in Walla Walla; they were the first generation of their family-- families-- both families, born in Walla Walla or born in this country, for that matter. My grandparents were all emigrants from the same region, the German colonies on the Volga River in Russia, which had been there for-- well, since about the 1760s, and they came over and my father was actually born a few months after they arrived here so he made the journey but doesn't remember it, and my mother's family came over, as well, from a different village on the Volga in Russia. My father was a-- by trade, a grocer and a meat cutter and he ran his own business from the time he was 14 years old.

Dennison: Okay, and you went to school in Walla Walla then.

Frank: Yes. I went to public-- through public schools entirely in Walla Walla, went to a small rural grade school called Prospect Point, went to junior high and then graduated from Walla Walla High School in 1967.

Dennison: Who were the people that most influenced you as you were growing up?

Frank: Well, first and foremost my parents, my mother, Katherine Frank, and my father, Carl Frank. My dad I would say is one of the hardest working people I ever met and he-- also because of the fact that he had to take over the family business when he was 14 years old-- his father became ill and my parents were each one of nine children so my father had to-- as the oldest son, had to step in and run the family

business. So he started out in the grocery business at 14 years old, went to high school one day, but growing up put a very heavy emphasis on education. He himself was self-educated, read voraciously but wanted to make sure his children got their education and went from there so-- Others that influenced me a great deal were my grandfather, my paternal grandfather, John David Frank. He was a very gentle, compassionate man, went through a lot to get his family, a pregnant wife and two young daughters, over from the Volga area of Russia to Walla Walla. You can imagine back in 1913 when they came, that was quite a journey involving wagons and trains and boats and more trains and finally got to Walla Walla where he had two older brothers who had already immigrated -- so he was a major influence. I'd say, other than that, I had some excellent teachers even in the public schools in Walla Walla. I remember one in particular, my high-school chemistry and physics teacher¹ who certainly influenced my interest in technology, his name was Johnnie Thessarius Dennis, and a few years after I graduated, he was named the National Teacher of the Year by whatever organization does that in the U-- in the entire country, so—

Dennison: Well, it helps to have those kinds of influences--

Frank: Indeed.

Dennison: --growing up. When you were growing up what did you want to be?

Frank: Well, when I was—

Dennison: I mean after fireman and policeman.

Frank: Yeah, I know. <laughs> Yeah. I worked enough in a grocery store, even when I was little, that I didn't particularly want to do that, but when I was eight years old the Russians launched Sputnik and started the space race and boy, that captured my attention. I remember going out in the front yard in those early days and looking up, and in Walla Walla there was no light pollution and you could see the light glancing off of Sputnik as it went over the backyard -- and all the early satellites. And so I got very interested in space and space exploration, wanted to be an astronaut, and I-- it turned me on to science fiction. Before I got to high school, I think I read every sci-fi and space-related book in the Walla Walla Public Library, which was not a bad library, and I read them all and read the classic authors like Jules Verne and H.G. Wells and then current authors like Isaac Asimov and Robert Heinlein. Now the goal of being an astronaut kind of faded when I discovered a little bit later in life that I was susceptible to motion sickness and I needed glasses, and in that day you had to qualify as a test pilot, and so that wasn't in the cards for me. <laughs>

¹ [Interviewee's note] It was calculus and physics.

Dennison: Understood. You had a number of uncles. Apparently, one of them started Applied Magnetics?

Frank: That's correct, yeah. It's maybe a common misconception that my father did, but as I mentioned, he was a grocer and a meat cutter. Applied Magnetics was started by his youngest brother who was ten years younger; his name was Harold Roy Frank. And he grew up in Walla Walla, as well, went through high school there, went to one year of college and at that point it was 1943 or 1944 and he joined the army to fight in World War II. They spoke German at home so his knowledge of German stood him in good stead and I think he was put in army intelligence and he served in Italy and Germany maybe behind the lines at some points deciphering code and-- Morse Code and enemy messages and did that until he returned home in 1946, got out of the army. Then at that point he went back to college on the G.I. Bill and graduated in 1948 from Washington State University with a EE degree, which would be a bachelor's in electrical engineering.

Dennison: So how did he end up in Goleta?

Frank: That's a good question. From Washington State U., after he graduated he got a job in what he liked to call the geophysical exploration industry at Continental Oil in Oklahoma and Texas and they were obviously searching for oil in that area and from there he-- well, he-- part of what he did there was basically figure out how to record on magnetic tape the seismic waves coming back when they did the oil exploration. They'd go out to sites where they thought there might be oil. As I understand it, most of the time they would drill holes, throw dynamite down the holes after putting out an array of seismic sensors and then gather all the data back from the seismic sensors and he fairly quickly-- well, and just to make a long story short to-- then they would look at the seismic waves coming back and look for domes where the signal came back faster from rock and they would assume that under those domes were either oil or natural gas and that's where they'd drill. Now he discovered fairly quickly that they didn't have very good components for doing that and, in particular, they did not have very good multi-track instrumentation tape heads for doing that. So at some point in about 1956 his job brought him out to California, he brought his wife and two young sons, at the time very young, and they fell in love with the Santa Barbara area, and he looked around and there wasn't much in the way of employment in his area there. His option was to go back to Oklahoma and Texas, so he took the other option -- which was to start his own company.

Dennison: Was U.C. there in those days?

Frank: Yes, I think so. Yeah, it was and it was not far away from where he originally located the company but—

Dennison: So basically you were in Walla Walla. Tell us how you ended up in Santa Barbara and going to school--

Frank: Okay.

Dennison: --where you went to school.

Frank: Yeah, sure. When I was not quite ready to graduate from high school the sort of neighborhood grocery business that my father was in became untenable due to the influx of supermarkets, large supermarkets with definitely a cost advantage and a pricing advantage and so, even though at one point in his career he had four neighborhood supermarkets around eastern Washington and Idaho and he even served as-- a year, the same year that my uncle founded the company, Applied Magnetics, my father was the President of the Washington State Grocers Association. By 1967, the business had gone away and he tried his hand at a few other things around Walla Walla, but that didn't look very promising, and his brother, Harold, offered him a position as facilities supervisor-- facilities manager at Applied Magnetics in Goleta -- and they had several facilities in Goleta. And my dad took the offer and moved down and as soon as I graduated from high school, he came back and the whole family moved to Goleta in July of 1967; I remember, in fact, we arrived on the Fourth of July in '67.

Dennison: So then did you go to school there at U.C.?

Frank: No. Actually, at that time I was still legally a resident of Washington state. I hadn't been in California long enough, and of course applications and acceptances for universities were all done by then, so I applied to the best school I could afford, which was the University of Washington in Seattle. And, fortunately, I had a National Merit Scholarship and another scholarship and was able to-- thanks to my father, I worked that summer as the gardener over at Applied Magnetics, and so I planted a lot of ivy <laughs> and other things and actually made two dollars and fifty cents an hour, which is a little ironic because two summers later, when I first worked inside in engineering at Applied Magnetics, I made two dollars an hour <laughs>, so not exactly a step up in that sense but—

Dennison: Okay. So tell us about those summers and then did you graduate from U. of W. or--

Frank: Yeah. Let me talk about the-- my university experience first. I went to the University of Washington starting in the fall of '67. My interest in being an astronaut had morphed into an interest in being an aeronautical and astronautical engineer, which was a discipline they had at the University of Washington thanks in large part, I think, to the presence of Boeing just down the road, and that's a fancy word for being a rocket scientist, and that was then my goal. So I started in engineering, gave up on the whole astronaut thing, and was in-- there you started in general engineering for the first two years and then you went into a specific discipline for the final two years, but during my first year in general engineering I discovered that for the full four years I would only be able to take technical courses, most of them in engineering, and a few others in chemistry, physics and the like. And my interests, academic interests, were a lot broader than that. I was interested in history and music and foreign languages and so

that kind of disappointed me and-- but at the same time in those first few semesters-- first few quarters-- I took several classes in programming languages and that did fascinate me and spark my interest in computers and in programming, specifically. At the time, Washington did not have an undergraduate program in computer science; they had a fledgling graduate group which was interdisciplinary and had not-- didn't really have their own faculty members, but borrowed on faculty members from the various engineering disciplines, the various sciences, mathematics and even one from library science. And so after looking at that and looking at what classes I could take in some of the other disciplines after my first year, I transferred into mathematics and I finished-- had some excellent teachers there, finished with a degree in math, a bachelor's in math in 1971; graduated first in my class, I'm proud to say, and-- but a lot of the classes I took, particularly the last two years, my junior year and senior year, were taught by the computer science faculty, because that's where my interest was. So, I got a lot of computer science theory, a lot of programming and a lot of other computer-utilizing classes, that in those days you were-- it was largely sitting down at a keypunch machine and punching out your cards and then taking them to the big computer center and having them run it and so on, but I learned a lot doing that. Then at the end of that, my appetite increased for computer science. I just stayed at the University of Washington. I got an NSF Fellowship and went into graduate school in the computer science group there and finished eight years later in 1979, and I'll describe a little bit of the why of that if you like, but that was a really good experience for me and I appreciated very much the education I got there.

Dennison: So how did that interlace with AMC and your summer jobs?

Frank: A good description of it, interlacing. Starting in 1969 when I was-- just after my sophomore year I got a job at AMC, inside, as an engineering aide and did that, I think, every summer and every winter holiday between then and 1975 -- did a wide variety of things, pretty quickly got into air-bearing design and coding and maintenance of the programs and updating of the programs for air-bearing design, but I also did a lot of other things that fit in with the computer area, like statistical processing for quality control, optimization of assembly line flow, things of that nature. In 1973, the engineer I was working for at the time, Tom Roscamp, who I'm sure you know, started a fledgling research and advanced technology group there and I joined that group in the summer of '73 and pretty much did that for most of the rest of my career there, as we'll see, but that's when we started taking a serious look at thin-film heads.

Dennison: Okay. So basically you were sort of ping-ponging back and forth--

Frank: Ping-ponging back and forth, yeah, for the rest of the narrative, so by the summer of '75 I was getting a little burned out and I had finished-- essentially finished all of my dissertation research but I was faced with writing this humongous dissertation, most of which is-- if you look at it today, is indecipherable; it's all theories, mathematical theorems and things with strange symbols and jargon, and so I took a leave of absence and went back to AMC in December of 1975 and joined, full time, the R&D group.

Dennison: Okay. So that takes us on further to-- so tell us about AMC. What was the culture like and how did it evolve over time?

Frank: I would say the culture, when I started back in the late '60s and early '70s, I would describe it as community. I mean Goleta is a fairly small place. <laughs> A lot of the people working there were working alongside of their neighbors or their cousins, very much was small enough that we knew virtually everybody, and I think those were good years. Of course, as the company grew and developed other businesses, it sort of segmented along the lines of business groups, various business groups moved to other facilities, and so it got a little more detached then and-- but I think it was still a pretty good and collegial atmosphere. I think later on, back in the mid-- early to mid '90s, it started getting a little more adversarial as more management was brought in from outside the company and I think they viewed each other as rivals for advancement and things got a little more adversarial then so--

Dennison: Okay. So we've talked about some of your initial roles at AMC and the founding of the R&D group under Tom Roscamp. Tell us how that evolved and how you became ultimately CTO and VP R&D.

Frank: Yeah. Tom and I basically worked together. The first big project we did was under license to CII Honeywell Bull in France. We tried to develop the thin-film technology that was proposed by Jean-Pierre Lazzari, coming out of LETI and then he went to CII, which then merged with Honeywell, and it was very interesting technology and we spent a number of years-- well, at least four, working on that <laughs> and I think we made a lot of interesting progress, but in 1979 IBM came out with thin-film heads, and one look at those and that's what everybody wanted whether that's what we had or not, and did an analysis of our technology and in one key way it was not competitive and that, kind of surprisingly, was in throat-height control for lapping-- during lapping. IBM was able in their technology to put them on a bar, the heads, with throat-height control well enough so they could lap the entire bar at one time. We were using a through-a-mask deposition technology where we rotated masks in and out and sputtered or evaporated through them, and we were not able to make the masks sufficiently controlled to set the throat height on a strip; we had to do them individually. And so I finally concluded that wasn't going to work, and so we switched to developing more an IBM-style technology.

Dennison: Using photolithography.

Frank: Using strictly photolithography, etching and those sorts of approaches, yeah, exactly, and using the same kinds of materials.

Dennison: So--

Frank: So you had asked about my progression—

Dennison: Yes. Yes.

Frank: So it was-- I sort of progressed in-- slowly, but surely, and I think in 1975 I was made a manager of R&D responsible for the sensor design and some of the wafer-processing approaches, and then in, I think it was-- yeah, I was engineering manager in '75. I became a director of research and advanced technology in '79 as we launched into the-- trying to duplicate the IBM technology-- I was still working for Tom-- and then became VP of R&D in 1982 when we took the thin-film inductive heads into production. Tom went with that to run the thin-film inductive head business and I stayed behind essentially to continue R&D. At the time, I was working-- we were working primarily on thin-film MR tape heads but later obviously added MR disk heads and pressed on from there.

Dennison: Okay. Actually though I think you started with ferrite. Right?

Frank: I did. I did a lot of work in those early years on a variety of ferrite heads and mini-monolithic heads, composite heads; those were both big products for us, metal-in-gap heads, both composite and mini-monolithic heads. I participated in the design of those, not in the production end, but those turned out to be very successful products for us for a long time, which was good because <laughs> it took the industry, I would say, a good ten years to fully adopt thin-film inductive heads. And we had our problems scaling that up, it took about that long, I'd say, and during those years those other products saw us through and in fact made us the-- probably in those years the leading supplier of-- leading independent supplier of disk heads.

Dennison: Yeah, which leads us right into the next topic. What do you think were the most interesting products and technologies that you helped develop at AMC?

Frank: Well, I-- interesting products and technologies—

Dennison: Either from a technology standpoint or difficulty or great potential for something or what?

Frank: Well, I-- I'm going to just start from the beginning. I mean I started working on 2311 heads, and you mentioned that I started with ferrite heads. No. In fact, I started with laminated mumetal heads, the old 2311 heads which had steel air bearings, and graduated from there to the 2314 heads, which we referred to as monkey-face heads; they were round white ceramic with two holes in them for-- to-- bleed holes for the air bearing, and went from there to 3330 heads, which were, I think, the first ferrite heads although I'm not sure which of those two generations was -- which had a rounded rectangular air bearing and then graduated there-- from there to thin film. All of those were interesting. The ones that I mentioned I think were a little bit unique, like the mini-monolithic, certainly was a copy of what IBM was doing. The composite heads were different. They were ceramic air bearing with a glass bonded core and the metal-in-gap heads -- I think were fairly unique to us. I think other people did them but I think we kind of

pioneered that, which was putting a higher magnetic-moment material on both sides of the ferrite-- both sides of the gap on the ferrite core to concentrate the flux there. Well, following that, I think thin-film inductive heads were a real challenge; I think we were ultimately successful at it. I think the R&D segment was fairly successful, I think the difficulty was scaling that up, and, like I say, fortunately that took the industry about ten years to fully adopt, which gave us time. I think the development of MR heads was interesting and I think we were reasonably successful at that. Our prototype heads, our R&D heads, were well received by customers. We had three simultaneous development agreements with drive manufacturers to do those heads. The heads were well received and then we went to scale that up in production. Part of the problem we had all along was we had a limited budget for wafer-fab equipment in R&D and scaling that up we had to go to much bigger and different equipment and that didn't translate well. And the heads coming off of that initially were not nearly as good; they were much noisier, took us a long time to sort that out and put us behind the curve -- and that whole MR transition in the industry was much faster. And then, not that far after, came the GMR transition. I did a lot of the early R&D work on GMR spin-valve heads, delivered a few of those. That transition went really fast and AMC just was not able to-- given the other issues with trying to scale up MR and further scale up thin-film inductive -- just wasn't able to keep up with that very well. I think those were real issues. Other things: I was responsible along the way for creating and managing AMC's optical products division, a little-known group in Colorado born out of some engineers that left Philips, and we developed magneto-optical drive mechanisms, essentially the whole drive except the electronics, and our development partner was Hewlett-Packard. And, as you well know, MO never really made it in the marketplace, but at some point we sold that division to Nakamichi and did okay with that. The other thing that I think went pretty well was MR tape heads. AMC was founded to do tape heads and until we sold that division to Seagate in 1995, at which point it was doing well in production of MR tape heads, hence Seagate's interest, that was still a major product line for AMC. So that's kind of a compendium of products that I worked on that were interesting.

Dennison: Yeah. You mentioned a number of product numbers that were IBM product numbers. Who were your customers for these?

Frank: Oh, a variety of-- well, initially-- I think-- as one of the questions you provided earlier, I think our initial customers for tape heads were the people in the oil-exploration business for instrumentation tape heads, analog heads -- but fairly quickly there developed an interest in computer digital tape heads and the company saw that as an opportunity, went into that, I think [AMC] was the leading supplier in-- independent supplier in computer tape heads for many years. I think for a lot of those years StorageTek [Storage Technology Corporation] was our biggest customer, Seagate later on for the MR heads, but we sold to everybody, Honeywell, Burroughs; anybody that was making tape drives, we sold those heads to. Somewhere in-- and I wasn't there yet then -- but in the late '60s the company was approached by IBM to do disk heads. I read somewhere that the first thing we were asked to do was 1311 heads, but I never saw one of those. A 2311 head, I think, is not that different and those were the first heads I worked on, and from there on we did heads for IBM for a while -- and just an interesting anecdote, I think: My first day on the job in '69, I was supposed to report to an engineering manager by the name of Dave Sutton and I got there and there was no Dave Sutton, so some other engineer took and put me in a desk, and I looked

around and it was Dave Sutton's desk and I had no idea what was going on. A few days later he came in, accompanied by the VP of engineering, and it turned out, much to my surprise, that he and a number of other engineers and managers from the company were walked out the previous Friday because they were busy forming a competitor, Information Magnetics, which was INFOMAG, became our key competitor, and at some point the IBM business, I think, went with them, so we developed other customers. In the early days, one of the big ones was Century Data Systems down in the L.A. area, they were a big customer, and then over the years I think we supplied to virtually every drive manufacturer. You had asked in one of your questions about IBM, and I've described the early days of IBM [as a customer], but that's not the only time we supplied IBM. In the late '80s and early '90s, one of our biggest customers was IBM Rochester. We supplied heads for their eight-inch drives and their early five-and-a-quarter-inch drives, mostly monolithic-- mini-monolithic ferrite heads, and that's, I think, not well known, but they were a huge customer then, but we supplied to, as you probably know, Maxtor and Conner and Seagate, and Micropolis was a big customer; in fact, they [Micropolis] were eventually, I think, our biggest customer for MR heads.

Dennison: You touched on the Dave Sutton story. Tell us about some of the more interesting people at AMC that--

Frank: Oh—

Dennison: --you then worked with.

Frank: Yeah. I've got a list here, but Dave was an interesting one. He was the most-- one of the more interesting people that I didn't work for, <laughs> he was gone, but maybe also a little bit ironically, Dave went on from INFOMAG to form a disk drive company in Goleta, the name of which I can't remember, if either of you can <laughs> let me know, but he and Dan Gillum and Don Minami and those guys formed a disk drive company after INFOMAG. And then when that didn't work Dave came back to AMC, Applied Magnetics Corporation, and he headed up what we called our central engineering group; toward the tail end of his tenure there, that group reported to me <laughs>, so for a day or two, and I don't think it was much more than a few months, not a year, he reported to me in sort of an ironic full circle -- and then he went to Maxtor, and unfortunately not too far after that, suffered a heart attack and passed away. Some of the other folks at AMC that I think were pretty interesting: I had during my tenure there what I think of as two partnerships, really close working relationships, with other technical folks. One was Tom Roscamp; he and I had a very close working relationship up until the point where they split off the thin-film inductive group and even for a while after that, but we were off doing different things and eventually he left the company -- but a very interesting guy, a very, very sharp guy, and yeah, we had a really good relationship for a long time. The other one was a guy that I hired away from Burroughs; they were trying to develop thin-film disk heads down in, I think, the north L.A. area somewhere—

Dennison: Westlake Village.

Frank: Westlake Village, exactly, and that was Dr. Gary Roberts -- and Gary was a wafer-processing expert, but knew a lot about the rest of the things involved in the technology. He had his Ph.D. from Rice University, was a Texan, came from the Houston area originally, and I hired him and he worked for me right up until oh, I guess 1995, and we had a very good working relationship; he was somebody I could really rely on to bounce ideas off of and get things done. Well, in about 1995 I became the-- I guess vice president and CTO when all of the businesses other than thin film were pretty much drying up, and so the R&D group was only doing thin film and so that was moved over to that business and Gary went with it; not terribly long after that I guess he left the company and went to DAS Devices, a head startup and run by Shyam Das up here in the Bay Area. And again, in another twist of fate for our industry, after I left Applied Magnetics, in fact virtually the day after I left, they bought DAS Devices and brought Gary and some of his group who had gone with him back to Goleta <laughs> -- so very interesting. A few other people I might mention, a couple of CEOs that were interesting to work with, both of them probably because they were nontechnical: My uncle was the original CEO, but by the time I graduated high enough in the management hierarchy to be even interfacing with a CEO, he was gone; he was chairman of the board and had moved up to his ranch and had his office there, and the [new] CEO was his original accountant, [then] his CFO, a fellow by the name of Ben Newitt -- who, unfortunately, passed away just last month. This is starting to be a theme, <laughs> which probably has something to say about our age and the age of the industry, but Ben was interesting in that he admitted he didn't know technology and he wasn't afraid to ask for advice and that I appreciated in him. The downside of that was that when he got conflicting advice, he had difficulty sorting it out and occasionally he took the wrong advice; I think what was unique about him is he would come back later and admit that, too. Another one was Craig Crisman, and I think we'll talk more about him coming up, a turnaround specialist brought in in 1994 or '5 to turn the company around, and I think we've got some questions about the demise of the company, so we'll come to that. Another guy that was interesting to work with was Rich Balanson. He came out of IBM, 3390 fame, and after IBM came to work at AMC to head up the inductive thin-film head business, certainly grew that into something more, and eventually I was reporting to him. He was interesting in a lot of ways personality-wise, but he had an interesting philosophy which he described as "rocket ship up, rocket ship down," meaning that-- take your-- take a shot that's higher than you think and go for it and if it doesn't succeed, that rocket ship will come crashing back down, but at least you gave it a shot, and unfortunately that's exactly what happened <laughs> during that period -- but an interesting guy to work for. I had met him before in the university programs but-- let's see. I've got a couple of marketing guys that you've probably heard of that I very much enjoyed working with. One was Ray Freeman -- didn't get to work with him that long, but he was at Applied Magnetics for quite a few years. And the one I particularly appreciated working with was Don Collier. I don't know if you remember Don, but he went off to form his own consulting business, but Don was a great guy and he was my-- one of my partners in starting the optical products division -- and he was a guy that I could definitely bounce ideas off of and get a-- get an honest opinion. Now I've got to mention the most influential person in my life that I met at AMC, and that's my wife. My wife, MaryAnn, worked there in the late '70s; she was in quality control for tape heads. She left and went to work at StorageTek in quality control for tape drives, maybe didn't quite agree, as a Santa Barbara native, with the weather in Boulder, so came back and had a number of jobs at AMC and we've been-- where we met, and we've been married going on 35 years now.

Dennison: Congratulations. Apparently, AMC was amongst the first to move manufacturing to South Korea. Can you tell us how that came about?

Frank: Yeah. That was actually done very early and, in fact, a little before my time but I've-- I experienced a lot of it and am familiar with a lot of the reasons, but first let me say in-- by the early '70s when I really became cognizant -- not only did we have large manufacturing operations in South Korea, well, we had manufacturing operations in Belgium, in Portugal, in Barbados and in Puerto Rico for various reasons and for various products. In Belgium it would be-- it was tape heads, to be close to the market there, which was big in Europe. In Portugal, it was to do some of those early-generation disk heads. Barbados -- I don't actually remember what they did. Puerto Rico, I think, was also working on disk heads. And subsequent to that, they started up operations in-- let me see if I can remember them all-- Singapore, Malaysia, China in Shenzhen, in the Philippines, in Mexico, I'm forgetting some I'm sure, in-- for a variety of reasons -- but getting back to Korea and the main reason to go there was first of all, as I mentioned, Goleta was fairly small and the supply of skilled labor willing to do assembly and those sort of more manual operations was very limited and very mobile <laughs>, so they might be there long enough to be trained and move to another job. In Korea, there was a large supply in those days of what I would call very skilled (in the sense that they were very conscientious about their work, very conscious of quality) labor, and at the risk of being politically incorrect it was, I think, the custom at that time for young women, after they left high school, to go work for several years and then go back to their native village, get married and raise a family. And during those several years one of the places they went was Applied Magnetics Korea and—

Dennison: Now you say “in those days” so--

Frank: This was back in the-- I would say the late '60s all the way up to the end of the company, and what AMC would do is build dormitories for those young ladies and cafeterias and buses to the factory and fields where they could bury the kimchi <laughs> and all of that, and that was an excellent work force, and in Korea in those days they were able to get some very skilled and trained engineers, Koreans, who mostly ran the operations. I mean we occasionally had an American over there as an expat overseeing things but I think most of the management was local.

Dennison: You mentioned also Singapore and Malaysia. I assume that was to be close to the hard drive manufacturers.

Frank: Indeed. Malaysia was more production oriented; Singapore started out that way but then moved into higher-level assemblies and testing, but yes, that was to be-- as some of those earlier plants -- to be close to the customer base. Let me just tell you one little anecdote about one of those plants I mentioned, if you don't mind -- Portugal. The Portugal factory was interesting. We were doing, I think, 2314 heads there, maybe even-- probably not yet 3330 heads. There was a political coup in Korea-- not Korea-- in Portugal, a Communist coup, and one day we woke up and found that our factory had disappeared lock,

stock and equipment; it was not there anymore. A year or two later we found out where it was again; it was in Bulgaria and it was making heads for the Soviet Union's efforts to make disk drives and computers. So the whole thing got boxed up and shipped off to Bulgaria and never became a serious competitor because their only supply-- their only customers were the Soviet hierarchy or whatever disk drive companies they set up, but I think that was an interesting-- You had asked about some of the challenges of overseas; that's one that I don't think we ever foresaw of overseas manufacturing.

Dennison: Oh, my. So we sort of talked about up to around 1995. That takes us I think to "rocket ship up, rocket ship down" and maybe also the Read-Rite story so--

Frank: Yeah. Actually, rocket ship up and down was in the early '90s. I think Rich was on sabbatical at CMRR-- the Center for Magnetic Recording Research at UC San Diego, in 1990 probably, when I first met him, and I invited him to give a talk at AMC at some point and the management liked what they saw and offered him a job and I think he probably came in '91 or '92. By '95 things were not going so well, I think we were into the "rocket ship down" phase, and so the management-- top management-- the board actually brought in a turnaround specialist who had been at a variety of companies before; his name was Craig Crisman. My reading was that he didn't really have a background in high-tech industry much. I one time looked up what he had done and he came to us, I think, from an automotive parts company that he had tried to turn around and may had been successful. He had done a winery, some software, some capital equipment, a few other things, some things in the food industry, I think-- I don't remember-- is it-- soft drinks, I think, something like that. Anyway he came in sort of with a charter to turn the company around and that was an interesting experience. By then, as I mentioned I think, the R&D group had moved over to join the production group to try to expand our thin-film head production and to get MR particularly into production and-- Okay, so back to the not so golden years <laughs> at Applied Magnetics. I looked at my notes and actually Craig Crisman was brought in in 1994 as a turnaround specialist and, as I mentioned, he was coming off a number of, I assume, successful turnarounds, but other than the capital equipment business not much of it was high tech and-- but the company was stagnating financially, having difficulty scaling up, just wasn't growing, and as a consequence, was losing money and--

Dennison: What was your yield on MR heads--

Frank: Oh, boy, I couldn't tell you-- I couldn't honestly tell you that I remember. It was not great.

Dennison: That's what I'm--

Frank: My recollection is that we shipped about a million MR heads before I left. Most all of them went to Micropolis, I believe; that's my recollection, but I don't know subsequent to that what exactly happened. The issue there was if I could amplify--

Dennison: Please.

Frank: I think I mentioned we had some pretty small-scale deposition equipment, a lot of it left over from <laughs> the thin-film inductive head development, and we were able to make some really good, stable, noise-free MR heads, which was the challenge in those days, but when we bought the bigger equipment to scale up for production, boy, that went out the window and we had a hell of a time figuring out why. And the best heads we ever made, one of the engineers later pointed out to me, was when they accidentally sputtered some of the tooling into the stripes <laughs> and so there was a problem here with the composition and the magnetostriction and it took us forever to figure that out. I kept advocating they do design of experiments, but they resisted that for a long time and I think probably ultimately took care of that and figured out what the issue was but by then-- like I said, the MR transition was very quick and the GMR transition even quicker in the industry as a whole. And if I might say I think the GMR transition was as quick as it was because of the INSIC program on heads, but <laughs> we'll get back to that--

Dennison: We'll get to that.

Frank: --later. Anyway back to the Crisman years. I spent most of my time working with him on a variety of things, but he was trying to figure out with his management team, some of which he brought in with him, some of which were folks already there, what to do with-- how to turn the company around. And they were developing this idea of making Applied Magnetics a "boutique" magnetic head supplier-- disk head supplier, and by that they meant making very customized heads for drive companies that wanted them in relatively small quantities for relatively high prices. And in one of the management retreats I heard this idea and immediately came back with the argument that it was clear to me that the head business was strictly headed for economies of scale, and the only way to survive would be to get big enough, because a shrinking number of customers were all going to basically want the same technology in large quantities, as cheap as they could get it, and I didn't think there was going to be a market for boutique drives. My argument was that the drive suppliers would differentiate their products on some other basis, probably post-head/media <laughs> assembly, and I think that leads into your next topic, which was the Read-Rite fiasco, but I don't know if you want to ask that question <laughs>, if you'll segue into that but--

Dennison: Basically, the situation's sort of churning right now and then how does it evolve and how does that lead to Read-Rite and so forth?

Frank: Well, the honest answer is I don't exactly know but I suspect that, unbeknownst to me, my argument resonated with Craig and his team because my impression is they then went out and tried to talk to Read-Rite and maybe other head suppliers about mergers to grow the size of the company, and Read-Rite at that point was significantly larger than AMC already in thin-film heads, and I think the Read-Rite reaction was they could go it on their own and do it just as well and didn't need-- didn't see the need to merge with AMC. At the same time, AMC was, I think, looking for some developed technology particularly in the GMR area because they were struggling at that point. So, basically, I gather what

happened is that they were rejected by Read-Rite in terms of a merger and by other potential head partners, and given the nature of this management group they sought a solution which I think had never been tried in our industry before and maybe never <laughs> since; they tried to do a hostile takeover of Read-Rite, of a larger company. And they went directly to the shareholders and offered so many shares of AMC for shares of Read-Rite and-- which at the time was relatively attractive because when they launched this, AMC's price per share was like 60 bucks a share and Read-Rite's wasn't, and what happened was that, essentially overnight, after Read-Rite said no, basically two things happened. One, overnight the AMC stock price plummeted to single digits and Read-Rite's board basically said officially no and they adopted poison pill provisions to prevent AMC from going to the shareholders, or at least make it unattractive and that sort of put the end to the whole deal. I was not involved in all of that other than <laughs> maybe making what became the impetus for it originally. I got a call one-- I think it was a Sunday morning, from Craig Crisman telling me that they were going to make a hostile takeover bid the following day for Read-Rite and that I shouldn't sell any shares of stock, and in those days most of us were compensated not in cash but in stock options. I looked at those sixty-dollar stock options (that I couldn't exercise yet) go down <laughs> to seven-dollar stock options in a couple of days and I calculated once that I lost seven million dollars overnight <laughs>, which I never got back but-- and the rest of the management the same, I guess, so that, afterwards, I-- he and I, went on a world tour at one point trying to sell new stock to various people, or bonds or whatever. We visited the Fidelity Magellan folks and pitched it there, went to Paris and London. I actually got to ride on the Concorde with him to Paris, he was not one to skimp on travel or accommodations, but nothing was really working with the stock price in the tank, shipment volumes not doing so well, and-- so by-- during my tenure there between 1982 when we went into thin-film production and 1998 when I left, they changed the top management of that business six times and-- in efforts to find the right formula. They tried home-grown guys, they tried guys from other head companies, they tried Rich from IBM-- Rich Balanson, and nothing seemed to work to sort that out so, as I say, I left in November 1998. The company struggled on for another year and three months, I guess, and went into Chapter 11 in early 2001 was it-- 2000—early.²

Dennison: Two thousand I think, yeah.

Frank: Yeah. Sadly, they sent everybody home on Christmas break and then called them and told them not to come back <laughs> so-- and that was the end of that.

Dennison: Wow. Do you know what the final disposition was?

Frank: Oh, yeah. You had asked about the disposition of the facilities and all of that. I don't know what became of any of the offshore operations and there were still quite a few at that time; I really have no idea. I know the-- mostly my interface with those was with the sales folks or the marketing folks or the top technical folks. I in fact never visited-- in my entire career there never visited the factories in Korea -- went to Singapore a lot, as you said because that was more customer interface, went to Belgium, went to

² [Interviewee's note] It was early 2000.

Ireland, which was another one we started up later that I think I forgot to mention, but basically, I have no idea what happened to any of those. I kept up with some of the sales folks for a number of years, some of the folks from Singapore, but I don't know what happened to those. I know what happened to the two large factories in Goleta. The thin-film business factory, the big fab, that building was sold and later carved up into a business park incubator for smaller technical businesses-- technology businesses -- and it's still doing that today. If you drive by, you'll see four or five fronts on it for different business names and I think there are more companies in the back of the building, and I have no idea what happened to all of that equipment, but I think it [the building] was essentially gutted and refitted as a-- as an incubator sort of thing. The building which was the corporate headquarters and where the R&D fab was, was acquired by some of the management from AMC when it went out of business and they formed a company called Innovative Micro Technologies, IMT. It's a company that does essentially contract wafer design and fabrication for microelectronic-- microelectromagnetic systems, MEMs, so they do MEMs wafers and, as far as I know, they're still in business. I have no idea how the business is doing, but in preparation for this I looked online and their website's still there, and I saw a few faces I remember, and so I assume they're still a going concern, but haven't been there so I'm not sure.

Dennison: Interesting. So '98 you left. Then what happened?

Frank: Well, they gave me an agreement for salary continuation for I think it was nine months, provided I didn't go to work for a competitor, which I had no intention of doing. At the time, I had a history with NSIC, which I think we'll probably segue into.

Dennison: Yeah. Well, let's maybe drop back and talk about that from the beginning.

Frank: It might be a good idea.

Dennison: Yeah.

Frank: Anyway before I—

Dennison: So tell us about NSIC.

Frank: Before I left the building, just to finish that thought, I called Barry Schechtman [then the Executive Director of NSIC], who was looking for his successor at NSIC, and I told him that I might be available and he said, "Okay. I'll wait" and I said, "Well, it might be nine months" and he said, "I'll wait" <laughs> and so nine months later that's where I was, but yeah, cycling back to the whole university research thing that led up to NSIC you—

Dennison: Yeah, because you were one of the--

Frank: Right. You had asked—

Dennison: --the proponents of--

Frank: --in your-- in-- a couple of questions, one about how the university centers started and my role in it and about NSIC and my role in that. So, university center-- so back in-- by the early '80s our business was still expanding, particularly in disk heads -- the whole industry was expanding and growing, and a problem we were all having was there was a lack of really well-trained folks coming out of school-- out of universities, particularly out of graduate schools, knowledgeable in the technology, and we were all having to spend time training them before they could become productive, and there was a lack of university research going on in the field; there was some, but there just wasn't enough there to support this growing industry. So in talking with-- at various conferences and things -- with some of my competitors and some of our customers, that was a real issue and I think that word got back to a few of the folks in universities, a lot of them who had come out of industry and gone to universities, and I got a call, I think in 1982, from Jack Judy at the University of Minnesota saying he was starting up a research center dedicated to magnetic recording called MINT and he was looking for sponsors who would help fund that. Shortly after, while we were still pondering that, our CEO I think got a call from Jim Lemke who was down at-- I don't know if he was-- I think he was still at Eastman Kodak, the research lab in San Diego, but we knew him because previously, at Spin Physics, he was a competitor of ours for conventional heads, a really sharp guy and a-- and great at convincing you of things that he wanted to do-- was spearheading forming a university center at UC San Diego, which became CMRR, the Center for Magnetic Recording Research.³ And we decided to pursue that one first and I went to various meetings down there with various folks and, in the meantime got a call from Mark Kryder <laughs> who had come from IBM research and was going to Carnegie Mellon University and wanted to start a magnetics technology center at Carnegie Mellon, and knowing him and the quality of individual he was, that one resonated, too, so we actually decided initially to pursue those two. I was involved in discussions for both of those from the start, and somewhere in between, Al Hoagland had moved from CMRR to-- back to Santa Clara and was forming IIST, the Institute for Information Storage Technology at Santa Clara University, so we decided to pursue those three and I was on essentially the-- they called them different things -- but essentially the sponsor, industry sponsor board for all of those from the beginning of those three organizations. In fact, I'd say one of my prouder moments in the industry was when I was asked to represent the sponsors at CMRR for the groundbreaking ceremony, when we put the shovels in the ground to build the new center, and that was in, I think, 1984 and I still have a copy of the first page of the very first CMRR newsletter and it has a picture of all of us with our hardhats on and our shovels in the ground <laughs> and I was asked to give a talk there and I did, and my basic message was I hoped in five years to be there with some of my competitors, competing for their students coming out in the industry, and that proved to be true. Later on, we joined the Computer Mechanics Laboratory at UC

³ [Interviewee's note] Now it's the Center for Memory and Recording Research.

Berkeley, as well. I think, sadly, we never joined MINT [at the University of Minnesota] <laughs>, but I was able to give them significant support later from NSIC. So how did that develop into NSIC, which was the National Storage Industry Consortium? So, being on at least those three university center boards, I found that a group of us, and typically the same guys, were getting together at those universities five or six times a year <laughs> and we were all sitting there seeing identical research being done at those same universities and we were paying for it two or three times, and there was no way of coordinating that other than to say something, but there was no incentive for the universities to get together and work together and no real effective way for us to parcel out the problem or to see that they were working on different aspects or different approaches to the problems, so that we could leverage our funding, which by then was significant. So we started talking about, well, how can we do that, and somebody noticed how well the semiconductor industry did it through SRC, Semiconductor Research Corporation, not only coordinated their university research spending but their own collective research to a large degree for things that were more advanced, enough to be pre-competitive. And so, we hit on the idea of starting a research consortium for the storage industry and that idea kind of took hold. That's when Rich Balanson was on sabbatical at CMRR. He kind of spearheaded the discussions. One of the people that was involved early was Denis Mee, who you well know was actively involved here at the Computer History Museum, and we had a variety of meetings, mostly in 1990, hosted by various companies. I remember one at a hotel in San Jose, hosted by IBM, that was crucial, but the one I remember most, I hosted at Applied Magnetics, and it was in late '90 or early 1991, where we not only made the final decision to go ahead and incorporate this entity as a non-profit research consortium but to offer the first executive directorship position to John Simonds, who had previously been the director of the Kodak Research Center in San Diego, when they were working on mostly tape drives, I believe, but in magnetic recording. He had gone back to Buffalo, New York, where Kodak was headquartered (or wherever it is up there in upstate New York) and I think was not enjoying the winters, wanted to come back. And so, he took the job and we officially incorporated as the National Storage Industry Consortium on April 1, 1991. I was not the first chairman of the board. I think Jim Lemke was actually⁴ but I served two years as chairman when John Simonds was still the executive director, and one year, later on, when Barry Schechtman (also out of IBM) became the second executive director. So I participated heavily. AMC was a participant in, I think, at least three of those programs, the heads programs, one of the optical programs with our magneto-optical business, and what became the EHDR program. That stands for Extremely High Density Recording but was a—actually, the first was the UHDR program, the Ultra High Density Recording program, which covered all aspects of magnetic recording other than heads, which was covered by the companion heads program. That one [UHDR] was sponsored by DARPA, and finally the EHDR, Extremely High Density Recording program, which was the follow-on one sponsored mostly by industry, but with some participation by the NSF. Those programs, I think, really stimulated not only research and the production of students coming out, I think many of whom you can still find in the remaining companies in the industry, but seeded people coming out who went back into academia doing research in our industry in other universities and research labs worldwide -- you can still find those folks, I think.

Dennison: Speaking of worldwide, it was founded as the national..

⁴ [Interviewee's note] Denis Mee of IBM was the chairman of NSIC, followed by myself and then Jim Lemke.

Frank: Right.

Dennison: ...and then how did that evolve?

Frank: Yeah. That evolved, I think originally, or came about originally because I think there was government funding clearly available from the U.S. government sources, and secondly in the early days, in the early '90s the U.S. companies were very competitive, against the Japanese companies particularly, and were very sensitive towards sharing any information. So we did a national-only thing and to participate in any of our programs, you had to be a U.S.-based company.

Dennison: Or university.

Frank: No, actually. <laughs> We funded research at non-U.S. universities. That was not a requirement. The requirement was that the information basically came back to the U.S. sponsors, which were U.S. companies, but yeah, we funded [some non-U.S. universities], mostly in Europe and we had one university in Canada, even in the early days.

Dennison: How many different universities were finally involved?

Frank: Oh yeah. If you don't mind my looking at my notes I can..

Dennison: Yeah, not at all.

Frank: ...give you some statistics on the lifetime of the organization. I've just got to find them here. Unfortunately, these are not the things I've committed to memory. Okay, here we go. During its 23 years of operation, which went from 1991 to 2014, there were 11 major programs and a total of 57 industry members, more than 15% of whom were non-U.S. ultimately, funded research at 55 universities and labs worldwide. More than a quarter of them [the funded universities] were non-U.S., and [NSIC/INSIC] sponsored tens of millions of dollars of research. Really no good way to quantify that, because a lot of the government money went directly to the universities but through our support of getting them those grants. In the last year alone, one program, EHDR, the disk technology program, magnetic recording disk technology program, even with reduced funding because of the consolidation of the industry, funded 55 researchers, not including the graduate students. So I'm guessing there were at least that many graduate students at 17 different institutions, and I think you not only find many of the people coming out of that effort in industry, you'll find a lot of the technology in the products coming out of industry and you'll still find a lot of the technology being talked about for the future of the industry. A couple of things I was interested in, if I can mention them, is just a week or so ago I saw a big piece in what's left of the trade..

<laughter>

Frank: ...magazines which are all online about WD announcing a demonstration of MAMR.

Dennison: Yes.

Frank: Microwave Assisted Magnetic Recording. That was part of the EHDR program back as early as, I think, 1996 or 7⁵, when Professor Jimmy Zhu at Carnegie Mellon presented the idea at one of our EHDR programs, after which we tasked one of the sponsor representatives who was interested to go do an analysis of that technology. It turned out to be Bob Hempstead at Western Digital <laughs>. He came back with a report that basically said it was interesting, promising, and should be pursued, but there were a lot of unknowns in those days, and at that time, as you well know, the industry was already consolidating. The sponsors wanted to concentrate on PMR, Perpendicular Magnetic Recording, with a little bit of side work on things like bit-patterned magnetic recording, shingled magnetic recording, and even-- I think the other thing that got left out was TDMR, Two-Dimensional Magnetic Recording, which of course depends on shingling. And so, we deferred activity on MAMR and TDMR for lack of funding, funded some seed work in those other things, threw most of the effort into PMR with the goals at that point being, I think, 4 terabits per square inch, followed by 10 terabits per square inch. We were already trying to think of those, think that far ahead. The other thing in a similar vein that was published not too many months ago was a demonstration by Sony and IBM of tape head recording at 130-something gigabits per square inch, which will allow you to do 300 plus..

Dennison: Terabits.

Frank: ...terabits on a cartridge, and that was based on technology that we looked at in the TAPE program before it ceased.

Dennison: That's an amazing record. So you mentioned the cessation and consolidation. Can you talk about that?

Frank: Yeah. That's one of the more painful..

<laughter>

Frank: ...things to talk about, but yeah. It sort of came about by-- well, getting back to going international which sort of extended the life of..

⁵ [Interviewee's note] It was actually in 2007.

Dennison: Right.

Frank: ...NSIC, I think significantly -- let's talk a little bit about how that came about. When I got there in 1999 -- in August is when I started as the executive director, it pretty quickly became apparent to me that the industry was starting to consolidate in most of the major areas. We were still doing a lot of work in optical recording but a lot of that was going overseas. The interest here in the U.S. in optical recording, MO or holographic or phase change, for data storage was starting to dwindle. Similarly, the number of disk drive vendors was starting to consolidate, and several other things were going on that sort of suggested this was going to be a problem. I mean, among the things that I took the board within a couple of years of being there, the ideas that I took the board were one, it was getting—well, the U.S. suppliers were doing more and more manufacturing and even development overseas. The overseas suppliers were starting to do more manufacturing and even R&D in the U.S. There were more and more joint ventures going on between U.S. and non-U.S. suppliers, particularly in Japan. A lot of the vendor base was in the Far East and not accessible to support our programs, and with the industry consolidating, that was going to be a problem going forward. And we were already supporting university research overseas and it was getting harder and harder to distinguish what was strictly a U.S. company and what wasn't, and for that and financial reasons, I thought we should seriously consider going international. The other thing that was happening, of course, was that the U.S. government funding was drying up.

Dennison: Yeah.

Frank: DARPA had kind of got it in their heads that this was an old technology, magnetic recording, and optical recording had gone about as far as it would, and they weren't going to support that anymore. They were off chasing more "Star Wars" type things, and the program at the Department of Commerce clearly seemed to be winding down. NSF was supporting less and less. And so, that wasn't going to be available, but it also wasn't going to be a problem if we wanted to involve international companies because we didn't have to worry so much about U.S. government funding, and then in 2002 a couple of triggering events occurred. One is that Sony came to us and our TAPE program, technology program at that time was three years old or just starting into its third year. Sony came to us through their U.S. affiliate of their U.S. operation and said "Hey, we'd like to join NSIC and we would like to participate in the TAPE program, because all of the drive manufacturers, a lot of which we support, are on that program and we think we could help." So I took it to the executive committee at their next meeting and they tentatively allowed me to bring Sony in as an affiliate member pending a full board meeting which would occur that August and see what they had to say. At the same time, and this was probably the key trigger, IBM came to us and said "Oh by the way, we're selling our hard drive business lock, stock, and barrel to Hitachi <laughs> and it's going to be HGST and we and they would like them to take over the NSIC membership and continue to participate in the EHDR program." And so, that did two things. One is the TAPE sponsors liked it because it got them Sony and maybe the other head and component suppliers that they didn't have, and the hard drive guys liked it because it kept IBM [which would become HGST] in the fold, and of course they were at the forefront of a lot of the industry's technology and technology direction. So at that point, those two groups were the majority of the board and it was an easy sell. So, we went ahead

and we reincorporated as INSIC, the Information Storage Industry Consortium. I frequently see it called the International Storage Industry but it's INformation Storage Industry Consortium. You asked a little bit on why that happened. By that time, I'd been at NSIC for two years, three years, and I was tired of getting calls from people wanting to know the best place to get a self-storage unit.

<laughter>

Frank: So, "Storage Industry Consortium" didn't really tell the story. So I thought, well, let's qualify it that this is information storage. I thought Computer Information Storage was not quite right because we were [also] doing optical stuff. So, we left it at that and I just added an "I" onto the front and we became INSIC. So that's <laughs>..

Dennison: Yeah.

Frank: Hopefully that answered your last question in a long-winded way.

Dennison: No, I think that's great but let's go on to how things evolved.

Frank: Right.

Dennison: You're up to maybe 2002, 2005.

Frank: Right. So the other key thing that happened in that time period was the idea, which I believe was mine, to make key programs what I call "evergreen." In the history of NSIC and INSIC up to that point, no program had lasted beyond five years and several of them only lasted two years or even less. That had to do with either the length of government funding or how long it took them to meet the original goals of the program, and that didn't seem to me to be a very optimal way to make progress, having to restart a new program each time. That happened to us in the UHDR program, where it stopped and then I had-- there was no program doing heads, no program doing disks, and no program <laughs>. And so, I developed this idea fairly early on to take the programs which had set goals, and as we got closer to those goals, to roll the goals forward and just keep doing that as long as the sponsors wanted to do that, and that became necessary in the EHDR program, the magnetic disk drive recording program where we were looking at all of the components including even the electronics. It originally started out, as I recall, and Barry started it in about 1996 I believe, a couple of years before or three years before I got there. It originally started out with a goal of 100 gigabits per square inch recording, preferably using conventional technology, but also starting to look at PMR, and what we found is, as we got closer and closer to that goal it got counterproductive, because the sponsors started being less willing to talk to each other about it and, even more problematically, less willing to share with the university researchers what directions they

might take, and everything was sort of becoming <laughs> very quiet in the meetings. And so, I posed that [namely, the idea of raising the goals] to the EHDR board. They liked the idea. And so, we fairly quickly convened a workshop for the whole group on terabit per square inch recording. We went through that, identified technologies, had a workshop at IBM Almaden, in fact very well attended, and identified the technologies we wanted to shoot for for terabit per square inch, rolled that forward as the goal, and the program just sort of got a fresh breath of life and renewed interest and renewed participation from the sponsors, very actively. And so, we sort of reset the goals of the program and I'm trying to remember the wording correctly, and this carried over to the tape program, to the goal of the program was "to develop the underlying science and technology to allow the sponsors to demonstrate magnetic recording at 100 gigabits per square inch, a terabit per square inch..." [and] we eventually went to 4 terabits and 10 terabits before the program ended. That allowed the programs to continue and we did something similar in TAPE, and TAPE was the first program that was started after I got there, as a follow-on to the tape part of the UHDR program. TAPE was not an acronym for anything. We couldn't figure out what to call it so we just capitalized tape <laughs> to be more descriptive. Those two programs each lasted more than 14 years and TAPE lasted until the last day that INSIC was active. Now the demise of the EHDR program was a little more complicated. That lasted until December 2010. What happened there was going into 2010, I could sense the weather was-- first of all there was a changeover in the R&D management at most of the drive companies, the key sponsors. Secondly, we were down to three key sponsors, Hitachi GST, Western Digital, and Seagate, about to go down to two <laughs> subsequently, and their top R&D management had changed over, and at least some of those folks were either not fans of INSIC or, more to the point, maybe not fans of me for some historical reasons, but also I think there was some lobbying by another industry organization. And so, at some point, I could tell there was less participation going on and "the CTOs," as we called them, those top guys who were above the [INSIC] board of directors but responsible for the program, called me to a meeting in San Jose where they suggested that they wanted to transfer the program over to IDEMA, the reason being that IDEMA already had a lot of the component suppliers, many of whom were Japanese, and they thought it would be easier to get them into the program and they wanted to do that. Other things that they-- well, and they objected to having to pay the overhead, the membership fee for both IDEMA and INSIC at the time, and the strangest thing they faulted us for was that we were doing too good a job of managing the program and it didn't allow them to get personally actively involved enough <laughs>, and transferring it to San Jose would clearly let them do that because all three of them were based up there, but it kind of puzzled me. So, I basically proposed to them okay, well if we're going to do that, let's do like a year-long transfer. We'll sort of transfer the EHDR program intact over to IDEMA and they said "Okay, we'll think about it," and I think by the time I got back to San Diego and got off the airplane, they'd put out a press release that they were starting a new program under IDEMA, which became I think ASTC, and they were shutting down the EHDR program and leaving INSIC, which they did by the end of the year. This was, I think, in August and by the end of the year we were out of-- when their year of membership expired, they were all gone. That left us with the TAPE group and they soldiered on and we spent the next few years reducing our overhead <laughs> and down to the point where, by the end of 2013, we had one half-time employee.

Dennison: Oh my.

Frank: Yours truly. The CFO was now a contract accountant. The web mistress was now a contract employee. All of the consultants, of whom we had some spectacular ones at NSIC/INSIC over the years, were gone, and the office was gone. We were a "virtual" consortium. I was working from home. The CFO was working from her home and the web mistress likewise, and just got to the point where I mean we were carrying on with the TAPE program. It was active and going, but at some point the tape head industry started consolidating more and more and those guys finally said we can't do it anymore. And so, that program ended in February or March 2014. I left [INSIC] at the end of March. That was essentially the end of any active role at INSIC in supporting research. INSIC continues, at least on paper, to this day. The website's still there if you go [to it]. It's run by a volunteer chairman of the board and a volunteer executive director and volunteer board members from the remaining four tape companies that are involved, and the only activity I'm aware that they've done since then is they did a minor update to the roadmap for tape at the end of 2015.

Dennison: Yeah. So I think we're at a point now where you can tell us perhaps about your work with other industry organizations and their impact on the industry.

Frank: Well as I've mentioned before, I was on the advisory boards or the sponsor advisory boards of four or five university research centers, including CMRR at UC San Diego, IIST at Santa Clara University, MTC which became DSSC, the Data Storage System Center, at Carnegie Mellon, the Computer Mechanics Lab at UC Berkeley, and when I got to NSIC, NSIC wasn't officially a member of those organizations, but since we sponsored a lot of research, I got to sit in on <laughs> those meetings, as well. So, collectively, I think that group of universities and the research centers have done a spectacular job for our industry in producing qualified people that can go into the industry and go right to work. A lot of them wind up in management and/or go to other universities and start quality research in our field. So that, I think, has been major. Other things I've done, IEEE Magnetics Society. I've been mostly active there in organizing technical sessions for InterMag or TMRC, some of the conferences, things like that. I think the only committee I ever served on was the Reynold B. Johnson Award. Is that the name?

Dennison: Mm-hm.

Frank: <laughs> I don't quite remember because back from my air bearing design days there's Reynolds Equation and I always want to call it the Reynolds' Award but it's the Reynold B. Johnson Award. I served on that committee for a year or so. I think one of my reluctances to get that involved in IEEE is that I never considered myself an engineer. I consider myself a scientist. My degree's in computer science and my other degree's in math and I had a <laughs> bad experience with engineering when I first started school.

Dennison: Okay. Well..

Frank: I can say that.

Dennison: ...that sort of leads into maybe you can amplify a little bit about the road to your Ph.D. and if you did any teaching as well.

Frank: Yeah. So, as I mentioned before, in 1975 I took a leave of absence from the University of Washington and I went to work full time at Applied Magnetics. My research adviser at the university was a very understanding gentleman by the name of Professor Richard Ladner, who recently retired, actually, finally became Emeritus at Washington just a couple of months ago, June I think. In any case, he was perfectly willing to do that. In fact, he was going on sabbatical himself for a year. And so, I went to work and slowly got myself back into the mode of well, let's finish this thing up. I mean you've come this far. You've done all the research. And so, I finally took time to write the dissertation. <laughs> The even harder part was to get somebody to type it up, with all the formulas and things going on. I had to purchase special IBM Selectric typewriter balls that had custom symbols on them <laughs> for this work and hire one of the secretaries up at UC Santa Barbara to do the work for me, but got it done, and in '78 I got back to Richard and said "Okay. I think I'm ready." I sent him the dissertation. He basically said "Well, when can you come and defend it," and by then I was heavily back at AMC and I said "Next summer." <laughs> And so, that's when I went back and officially finished. I defended it in July of '79 and got my degree in July of '79, but after my year earlier discussion with Richard, he, and I think wisely so, said "Well why don't you explore whether you would like going into academia instead, or just as an option? Don't close out all your options. I know you're heavily involved there now." So, he called a friend of his who was the chairman of computer science at UC Santa Barbara and talked him into offering me a part time faculty position there in computer science, which I went and talked to him and I accepted. So for a few years I was on the faculty of UC Santa Barbara and first year I think I taught strictly undergraduate courses, mostly in things like machine language programming, compiler construction, algorithm analysis from [Donald] Knuth's book "Study of Algorithms"⁶ and then after that I taught graduate courses strictly in a variety of subjects, recursive theory and I can't even remember all of them. I've still got all the textbooks at home but it boggles my mind to look back on them. I'm sure I can't remember half that stuff, but by, as I think I mentioned, by '79 or '80 when I finally finished up [at UCSB], yeah, it was 1980. I had finished up. I was back at AMC full time and had been promoted to, I think at that point, VP of R&D. Just wasn't enough time to do both. That [AMC] was a full time, and more, job. There was a lot of travel involved. It just wasn't practical to try to teach courses at the university. So I parted ways with UCSB, but it [my time working at UCSB] was enjoyable. I enjoyed my students. Some of my graduate students were really top notch there.

Dennison: Alright. So what are some of your favorite stories about the industry and people that you haven't mentioned?

⁶ [Interviewee's note] The exact title of the book is *The Art of Computer Programming – Vol. 1: Fundamental Algorithms*.

Frank: Let me see. Let me refer to my notes because I did put a few of those down there.

Dennison: Yeah.

Frank: Yeah, a couple of them, well let's see. I had four or five. They're all pretty quick though, I think. So one of the guys I never had much time to interface with, I just ran into him periodically at technical conferences or, in my latter days, I went to a lot of financial conferences and didn't get to interface with him a lot, but admired him a whole lot, was Al Shugart. We were involved with Al several times, from Shugart Associates to Shugart Technologies to Seagate. In any case, I can remember one specific incident where I was speaking at a Porter-Freeman conference. I forget what they called them, but Porter and Freeman together put on this annual technology conference..

Dennison: DiskTrends [ph?].

Frank: ...for the industry.

Dennison: Was it DiskTrends?

Frank: No. I don't think that's what they called the conference, but anyway, it's pretty well-known in the industry. I was speaking and Al was speaking and that's shortly after MR heads took off and I was sort of quasi-famous up to then for always showing the areal density growth chart and projecting out into the future, and of course I had not projected this kink up <laughs> that represented MR technology. And so, I got up and said "Well, here's the kink up and I think it'll last about that long and then it's going to level off again and we're going to be back to the-- not level off, but come back to a similar growth rate to what we have," and Al was in the front row and I heard him say loudly "Exactly right." <laughs> And it turns out we were both right, but we kind of underestimated the height of that shoot-up which was going a hundred percent per year in terms of demonstrations for awhile and carried on for a long time before it finally came back to reality in the last four or five years at least. So that was one interesting thing. We never had a lot of communications but we certainly had a lot of respect for each other I think, at least I understand that from people that knew him. Another interesting one along similar lines was when we sold the tape head business to Seagate. I was involved in those negotiations and we sold it for, I don't know, \$25 million or something like that. It was a good deal for us, but we got into the negotiations and there were a few people from Seagate there and then there was this financial adviser that they'd brought along, and in the discussions, I mean he clearly didn't know a whole lot about the technology but he was pretty sharp when it came to the business aspects of it and it occurred to me, this guy's pretty sharp. Wonder what kind of future he has in store for him? And his name was Steve Luzco.

<laughter>

Frank: And as we well know he went on to be Chairman of Seagate and CEO at least twice in the future. So, that was an interesting introduction to the financial aspects of it. A couple of things related to-- I used to go and speak annually at Al Hoagland's Arrowhead Conference, IIST Arrowhead Conference, and there were a couple of things that happened there that I thought were memorable. In 1990, I went to the Arrowhead Conference, which is usually in the Fall, I think, and I gave a talk about the fact that we were going to form NSIC. We were going to form a research consortium for our industry, and one of the other speakers, namely Jim Porter, got up and said "That'll never work. The disk drive companies are too competitive and they will never share research information with each other. Flat out it will never work." <laughs> So at least I got one in there over the years, and then another I made, I think, probably a year later or so was I said "You know, I think tape storage technology may well outlive hard drive storage technology," and that caused an uproar and a furor and a lot of "No, it's not <laughs> going to happen." But I based that on the fact that tape technology was following disk and therefore had a longer runway. I mean, anything that we're using in disk we could potentially use in tape years later. So far, I haven't been proven wrong. I mean, tape is still, I think, doing reasonably well and certainly in some applications. Let's see. I think I had one more, one more. This qualifies as the scariest episode I ever had in the industry. When I was at Applied Magnetics we were making the early generations of disk heads, including, I think this was involving a 3330 style head which, as you remember maybe, they were loaded externally to the disk off of ramps and what you ramp down was a spring that was very heavily loaded and it shot the air bearing into the air stream and you hoped you had the attitude and gram load right and entered the layer at the disk correctly and it flew and didn't bounce. Well, we were working with a number of media suppliers who were trying to develop thin film media. One of them was Polydisk, which was located down in the L.A. area. Sorry, I don't recall exactly where. It might have been El Segundo, someplace like that, but anyway we went down there and they were showing us-- we had supplied them with 3330 heads to test their disks and we were interested in the disks. We were testing some of our advanced heads and they were showing it to me and we got to talking about the disk and how robust it was and what would happen if the head contacted it, and their VP of engineering said "Well here, I'll show you." The disk was spinning. He grabbed the front of the head, pulled it back to 90 degrees and let it go. <laughs> And it smacked the disk, cracked the head, the air bearing crossways through the core, and the front half of it or was it the back half of it? I'm trying to remember. It must have been the back half of it flew across the room, whizzed past me, and embedded itself in the wall.

<laughter>

Frank: So I took him at his word that his disk was robust.

<laughter>

Frank: But anyway, that was probably the closest I came to ever dying on the job.

Dennison: <laughs> Okay. Are there some people that you haven't mentioned that had a big influence on you?

Frank: Let me see. I know I have that <laughs> here somewhere if you don't mind my..

Dennison: No, go ahead.

Frank: ...conferring with my notes again. Yeah, I would like to mention a few and some of them I've already mentioned but I'll go on with a few others. Sort of in preparation for this, I separated them into a couple of categories. One I call the sharpest guys I know or worked with or had interfaced with. The first one on my list is Jean-Pierre Lazzari. Not a whole lot of what he ever developed ever panned out in the marketplace but the guy was an inventive genius. I mean he was filing patents faster than we could try out the ideas, and we tried, as I mentioned, I think, between '75 and '79 to perfect that technology and I think we got reasonably close, but it wasn't the technology IBM used and therefore it wasn't marketable, and I went and visited him later on when he was doing – Silmag, was it?

Dennison: Silmag.

Frank: The planar technology head and looked at that. Man, that was inventive stuff. It wasn't going to play in the marketplace because it wasn't what the mainstream was doing, but very inventive. Last I heard he was working with his son, Jean-Marc, in his inkjet printing business and he's filed a bunch of patents in inkjet printing technology. So one of the sharpest guys, and the other one that comes to mind at the top of my list is Mark Kryder. I worked with him closely over a lot of years. He was the first and only technical director of the EHDR program for the whole 14 years of the program -- at Carnegie Mellon, at Seagate doing Seagate Research, and back at Carnegie Mellon, and the sponsors were okay with that, even the other drive companies, because of his level of contribution, I think, to the whole thing. So, those two fell into that category. The other thing I'd say is I had a lot of great folks to work with, a lot of them as consultants at NSIC/INSIC. Denis Mee comes to the top of the list, super guy, very great guy to bounce ideas off of and get critiquing of what you might want to do. Definite asset to the EHDR program for its lifetime. Barry Schechtman is another one. I mean, he was my predecessor at NSIC/INSIC. He's the second director after John Simonds. Similarly, I mean, he took the reins of all the optical programs and the TAPE program and HAMR program, for that matter, as our program manager on a consulting basis. Great to bounce ideas off of. Giora Tarnopolsky, worked with him as a consultant for a while, first met him at HP and then he went other places, and we gathered back at INSIC. We had an idea to try to start a-- well we were looking at ways to broaden INSIC and we had two ideas. One was semiconductor based memory, but with the presence of SRC, who was much bigger and doing that probably better and more comprehensively than we ever could, that wasn't going to go anywhere. The other one we looked at was Storage Systems -- move up a level to the guys that are EMCs and guys that are making storage systems and see if we can generate a program there. We even had a big workshop. Bottom line was they were all interested in doing different things. I mean if we had 5 sponsors of a program like that we'd

have 10 projects and none of them would be on the same idea. I mean it was just totally diverse. And so, we finally gave that up, but Giora did his best and he was a great guy to work with on that. The last one I would mention is Sharon Rotter, who was a program manager for EHDR and several of the other programs. She came to NSIC before my time out of -- I think back maybe to John Simonds' time -- out of the Navy, and she was a great program manager, great friend, kept things together while I was off traveling and, unfortunately, passed away just before the demise of the EHDR program. I was glad she wasn't around to see that but, nevertheless, kudos to Sharon. I think those other folks I've already mentioned.

Dennison: Okay. What are you most proud about in your career?

Frank: I've got a fairly long list, a lot of again that we've mentioned, so I'll just mention them in passing: the original formation of NSIC, the transition of NSIC to INSIC to internationalize it, my involvement in the early founding of the university research programs. I mentioned specifically the CMRR groundbreaking ceremony and I brought along a copy of Issue 1 of the "CMRR Report". That's me on the right <laughs> along with, let's see, well, university officials and local politicians. There's an assemblywoman and a judge and some other folks from the university, but anyway that's one of the things. We talked about a few that I haven't mentioned. Well, I talked about the development of various technologies at AMC, some of which were ultimately more successful than others but I think in R&D they were reasonably successful. The fact that I created and defined the position of Chief Technology Officer at AMC, I think, is a proud moment for me. The co-founding and management of the optical products division, basically out of nothing, in Monument, Colorado, working with a couple of other guys. That, I'm proud of. Guess a couple of others -- the extension, the whole evergreen concept that extended EHDR and TAPE, and I think extended the life of NSIC/INSIC by a good 5 to 10 years over what it might have been. One that I haven't mentioned is the HAMR program, the founding of that. I mentioned that we did a terabit per square inch technology workshop at IBM Almaden and the sponsors decided what technologies they wanted to pursue. One of the ones they decided not to pursue was HAMR. At the time it was called "hybrid recording." We didn't know what else to call it. It was "hybrid" because it had some optical, some magnetic aspects, and I thought that had a lot of promise, but there just wasn't the interest on the part of the sponsors. So when I came back to San Diego, I took it on myself to try to stimulate more discussion on this. So I talked to the drive companies and I talked to the universities. The only positive feedback I got was from Glenn Sincerbox, who was then the director of the Optical Data Storage Center at the University of Arizona, had been at IBM, working in optical storage there. Glenn got back and said "Hey, if you can put this together we're in," the ODSC. So I talked around some more and I got some encouragement from a fellow named Terry McDaniel who was then at Seagate. His company's name, I don't remember, was trying to do a flying optical head and got bought by Seagate. He was now at Seagate Research, but he was working out of his home in northern California.

Dennison: Oh no.

Frank: Yeah. <laughs> Maybe we can look that up later.

Dennison: <laughs> Yeah.

Frank: What is it?

Dennison: Quinta.

Frank: Quinta.

Dennison: Quinta, that's it. Yeah.

Frank: Quinta Technologies. That's it, and Terry was very interested in having that whole idea pursued. In fact, he was the guy that chaired the session on that at the workshop at Almaden and I remembered that Mark Kryder had sat in on that portion of the workshop and not the magnetic heads and all of that. So I got a hold of Mark and he said "Well, let's talk at Intermag. We're both going to be there," and I think it was Intermag either in New Orleans or San Antonio. So we sat down face-to-face there and I went through my ideas with him and he went through his and basically by the end of the conversation he says "Yeah, let's do it," and my concept was there was going to be an ATP program (Department of Commerce ATP program) competition the next year. This was in 1990, I think. There was going to be one in the Spring of '91 and-- 2001. I'm off by a decade here, and this was in 2000 that I talked to him. It was 2001, going to be the competition. And so, he went back and talked it up with his group and I went back and got Barry engaged and the next thing you know we were putting together a proposal for ATP involving Seagate, and of course where Seagate went, Carnegie Mellon went. And so, they were in. Arizona was in. I think there was another university or two. It might have been Minnesota [it was] and there were some other suppliers that Seagate brought along. We put together a proposal and we got it almost done and Barry and I were sitting around saying, "Well, what are we going to call this thing?," and he said "Let's make it a contest." And so, he sent out an email to all the people involved saying "Hey, name the program." <laughs> So we got a bunch of different acronyms back, TAMR, Thermally Assisted Magnetic Recording and a bunch of other things, but Bob Rottmayer sent in the winning proposal which was HAMR, Heat Assisted Magnetic Recording. We could HAMR this thing. <laughs> And so, we ran with that and got the [ATP] award and the program started in the Fall of 2001, ran for a little over five years, and as far as I know, I'm not sure I can confirm this, as far as I know from what's been published, that technology was the first to demonstrate a terabit per square inch recording, and Seagate did that.

Dennison: Okay.

Frank: Others have done it since and, in fact, products are out there now, at a terabit per square inch, but my involvement in all of that, even though it hasn't necessarily evolved in production yet and may not for a variety of reasons, that's a proud thing in my career.

Dennison: Understood. So what are you doing now?

Frank: I'm enjoying retirement.

<laughter>

Frank: By and large, as I mentioned to Tom earlier, that I've had a few, some interest in doing consulting, a few requests, a lot of them, though, involved patent litigation and I'm not keen on that. So, mostly I'm enjoying retirement. I'm actively watching my investments and enjoying life at home with my wife of 34 plus years.

Dennison: Do you have other interests?

Frank: Oh yeah. I guess the thing that occupies the biggest part of my time at this point is music. I've always been interested in music. I started in grade school in the band in the fourth grade, played the trumpet for many years but was interested in singing and it's hard to play the trumpet and sing at the same time. It just doesn't quite work.

<laughter>

Frank: I tried the drums and a bunch of other things, but in graduate school, just to find an outlet from working all the time, I took up the guitar and I've done that ever since. So I've been trying to work on perfecting my technique, finally, after 40 something years; took a few lessons, but mostly I've been learning to play the ukulele <laughs>, which has been a really fun thing. You find a lot of interesting people interested in that. I took lessons for a few years and then worked with some friends out of that to form our own study group and we meet once a week, about a dozen of us, and we all bring new songs and new ideas and new techniques that we learn.

Dennison: So you sing and play, right?

Frank: Sing and play, yeah.

Dennison: Alright.

Frank: Yeah. Every week. Oh, and what takes most of my time is I take the guitar songs and rearrange them for the ukulele, which is not as simple a task as it might sound.

<laughter>

Frank: So I'm the "lone arranger" for the group.

Dennison: Oddball question. Did you ever doubt yourself and what did you do when that happened?

Frank: Yeah. I looked at that question and I guess my conclusion is that really never was in my nature to do that because my approach was always to take my time, get all the inputs I could, consider all the options I could think of, get inputs from all of the experts (and there were always guys that were more expert than I was at something), and then make a decision, and once having made that decision whether it works or doesn't work, my philosophy was I always gave it my best shot, and if it was a mistake, learn from it and move on. If it wasn't, great -- but that was always my philosophy.

Dennison: If you could do your life over, what would you change?

Frank: Yeah, I'm not sure I would-- similar thing. I'm not sure it's in my nature to do that or think too much about that. One of the things I really always hated (and still do) is Monday morning quarterbacking. I think it's totally unproductive. Like I say, learn from your mistakes as quick as you can and move on, and don't second guess and particularly don't second guess somebody else's decision. I mean that is just totally non-productive. There are a few things that I occasionally wonder how they would've turned out if I had done things differently. One is coming out of graduate school with my Ph.D. Had I stayed in academia or gone into it full time, how would that have looked? If I had gone into more advanced industrial or more abstract industrial research, if you will, more along the lines of my dissertation. For example, I did have some interest expressed from IBM Yorktown, but the stuff I did was very theoretical in my dissertation. So, I was pretty much embedded in AMC at that point so I didn't take those routes. Later on, as AMC was winding down and things were getting more adversarial and more difficult, I had several opportunities to go to drive companies. I had a very good offer from Western Digital in '97 or '98, working for Mark Nussbaum, but decided to stick with it [that is, AMC]. I mean, I think again that was part of my nature to stick with it and see it through and, in fact, thinking back through it, I think the only job I ever quit was the one at UC Santa Barbara and that's just because I didn't have the time to do it right.

Dennison: So you've spent your entire career at the forefront of technology. Where do you see the future for computing and storage going?

Frank: Well, I think a future for computing, I think it's going a couple of directions. One is artificial intelligence and autonomous computing, which is going to require more and more embedded memory and I think there's still lots of possibilities on what technology's going to do that. I mean spin transfer memories? I don't know. There's lots of things out there and I think the jury's still out and a lot of work still needs to be done to figure that out. In the other direction, it's going toward massive Cloud storage. I mean, I think I'm interested in having less and less stuff on my computer at home because I'm probably more susceptible to hackers (hopefully) than Dropbox is <laughs>, but you never know. So, I think that's happening, too, and I think that's actually playing very much into the robustness of tape storage. I mean, how do you hack a tape cartridge that's sitting on a shelf somewhere? <laughs> So those are a couple of things. I mean there's certainly technology improvement left. There's runway left for both disk and tape. The recent Western Digital announcement that I mentioned on their MAMR thing, which we did study at INSIC and the EHDR program, and in tape the recent announcement by IBM and Sony. They're using thin film media and tunneling MR heads. Those are all things we looked at in the TAPE program. So I think there's some runway left there, but I think the things I mentioned are probably the overarching directions.

Dennison: So what do you think the trees are at the end of those runways? What are the key challenges?

Frank: <laughs> Well, being one of the many who has been burned by Equifax lately..

Dennison: <laughs> Me too.

Frank: ...I would say cybersecurity is something we need a lot more technology and work on. Boy, I think that's a way to go. I think somehow retaining control over artificial intelligence and autonomous computing, I mean I shiver when I see these reports in the last few months about these folks working on these autonomous automobiles, self-driving automobiles, putting a switch in there that says okay, in the event on an unavoidable accident I want to save myself -- or I want to save the other guy.

Dennison: Yeah.

Frank: <laughs> I think we need something a little better than that, but <laughs> I cringe at that, and I think in general, somehow, we've got to figure out a little more what the end of the road looks like, if we can, the best we can what the ultimate smallest thing we can store storage on and whether it be an electron expander or something and try to start working on approaches to get to that. I mean, I think there's an end of that road, but so far we've been able to not get there. <laughs> We've been able to avoid the end, anyway.

Dennison: Yeah. So final question. What advice would you give to a young person starting out in their career today?

Frank: Okay. That's an excellent question. I mean a lot of it stems from my own experience and I think a lot of it might still work <laughs> and I'm not sure I have anything particularly profound here but first thing is I would, based on what was instilled in me by my parents, get the best education you can afford. Now that "what you can afford" part has changed over the years. I mean, I was able to scrape by, but it was not expensive there with in-state tuition and the dorm. Boy, it's getting harder and harder. My daughter is a graduate of Stanford. So tell me about it -- and I'm very proud of her, by the way! She's a college professor now, got her Ph.D. subsequently at Michigan. Anyway, get the best education you can. Get the broadest education you can, from my experience, you never know what's going to be available out there when you start looking for a job. If you get a technology job, keep up on the technology, keep up-to-date, and I would say in general don't be in a huge hurry. I mean you've got your-- if you're in industry, you've got 40 years to go. <laughs> I mean a slower rise to the top is not necessarily bad. So just take your time and pick your spots. So I think that's it.

Dennison: Alright. That covers everything I had. Is there anything that you would like to add that we haven't..

Frank: Yeah. There is one thing and we talked about things I'm proud of in my career, and I would have to say I'm deeply honored to have been invited by you folks to participate in this Computer History Museum video recording project to put some of this down for posterity. I'm humbled and deeply honored and I thank you for your consideration.

Dennison: Thank you, Paul.

Frank: Alright.

END OF THE INTERVIEW