Pre-LTO Technologies Oral History Panel:

Thomas Albrecht, Robert Biskeborn, Timothy Chainer, John Teale

Interviewed by:
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Bajorek: This LTO-related oral history complements another LTO-related oral history entitled "IBM Tape History, Session 4, LTO Virtual Company Panel". John Teale, one of the panelists in this oral history, was also a panelist in a previous oral history. This interview will involve Messieurs Tom Albrecht, Bob Biskeborn, Tim Chainer, and John Teale, regarding their contributions to key technologies that enabled the family of linear tape open, LTO, tape drives.

No one has yet invented data storage technology that could replace magnetic tape recording for archiving of information. Magnetic tape continues to offer by far the lowest cost of data storage. Until recently, this product space used two classes of devices-- digital linear tape, DLT, and LTO. However, LTO proved to be superior, and as of 2019, LTO has achieved 100 percent market share. The success of LTO is based on dramatic increases of data track densities achieved via use of time-based servo, longitudinal position encoding, flexure-based actuators, flat head-to-tape interfaces, and adaptation of three generations of film-based magnetoresistive disk heads. Impetus for these developments originated in the early 1990s in an IBM research effort led by Dr. Jim Eaton, which was funded by IBM Tucson. This oral history records the contributions of the individuals responsible for the invention through prototyping of these technologies. So John, I would like to ask you to lead with a brief summary-- and all of you then follow-- with a brief summary of your personal backgrounds.

Teale: Okay, good day. As Chris mentioned, I was part of a couple of other oral histories and I talked about my background extensively in some of those, so I would refer you to those if you're interested. For the purposes of this meeting, where we're focusing on IBM Research contributions to the tape industry, suffice it to say I was a long-time leader of the IBM tape development team in Tucson, Arizona. I retired in 2009. I still live in Tucson, and I will be providing background and context for these gentlemen here.

Bajorek: Tom?

Albrecht: All right. I'm Tom Albrecht. My background is I grew up in a small town in rural western Wisconsin. As a kid I liked to do a lot of hands-on-- you could call it technology if you like, but mechanical and electrical things, repairing things, building go-karts, but most of all I liked making electronic circuits and doing things with that. That ended up being useful training for my career-- also ham radio. I did a lot of that in those days. Went to college at a liberal arts college in Minnesota called Carleton, and that was also useful in my career development in terms of really learning to speak and write clearly and think critically, and also I was a physics major, so that helped establish some of the technical knowledge needed for the career. I went to Stanford for graduate school, was originally interested in free electron lasers-- that's what I thought I was going to go to Stanford to do-- but I got there and I wasn't as comfortable with the group doing that work, so I was looking around for a group that I thought was really doing something very interesting and a place where it looked like the students were having fun, and I ended up then in Dr. Cal Quate's group, working on scanning tunneling microscopy and atomic force microscopy, which at that time were really hot fields, and that turned out to be one of these deals where you're at the right place at the right time, and you maybe end up getting a little more exposure than you really deserve just because the field is so hot. Anyway, that was a lot of fun, got to work with a person who later won the Nobel Prize for inventing the scanning tunneling microscope, and so forth. After

Stanford, then this sort of notoriety that had come from working in such a well-known field sort of got me in the door at IBM, and there were groups interested in hiring me, and it came down to Almaden-- actually went to Rochester too, I think, and a few other places, but came down to Almaden, visited several groups, found some that I liked, but I did not talk to anybody in tape at that time. However, for whatever reason, Jim Eaton got wind of the fact that I had interviewed there, and he said, "Oh, I would have liked to interview that guy." I'm not sure why he-- what connection he saw or what he was looking for. So he came up to Stanford and interviewed me there, and it was sort of an embarrassing thing where-- getting a job to me was very important at that time and I actually forgot that Jim was going to come and visit that day, so he had to kind of hunt me down <laughs> and find me. Very embarrassing for me, but then we hit it off well. He has his little satchel. I bet you saw that same little satchel with a few motors in it, and he talked about the scaling of inertias, and he had this grand vision of how he was going to make-- I think he was mostly interested in fast access--

Teale: Yes.

Albrecht: --among other things, which turned out not to ever really be the main deal for tape. But in any case, he was very interested in that. And so when I got to IBM, I did join the team at Almaden. I didn't decide on just one thing; I actually worked on three different projects simultaneously. I stayed with scanning probe microscopy, working a bit with Dan Rugar, and then John Foster sort of had me pulled into some hard disk drive work that he was doing, and Jim Eaton had me working on tape, and tape was very interesting because it was this mix of mechanical and electronic and software and physics-- everything is in tape-- and it suited me well. Having a bit of an interest space in mechanical engineering as well as electrical engineering and physics, I really enjoyed all those aspects of tape technology, and although I actually never reported into the tape organization-- Jim was never my manager-- I kept this thing going on the side for like ten years, stayed involved, sort of culminating at the end in the LTO Standards Committee stuff and so forth. So that's how I got involved in tape. I did end up working on lots of other things in my career as well, many things in hard disk drives that I worked on over the years, sort of culminating in a ten-year leadership of IBM's patterned media project, which turned out to be a bust in the end but that was really a highlight of my career to be able to lead that project for ten years and really do cutting-edge work. In the meantime now I've moved on to a small startup company, Molecular Vista, which takes me all the way back to my grad school roots, so I'm now back in scanning probe microscopy. So in a nutshell, that's where I come from.

Bajorek: Out of curiosity, who was your actual first manager in Almaden, of the people you worked with.

Albrecht: The first one I signed up for full-time I believe was John Foster. But I kind of had a deal with John that I could keep on working on tape, and that worked out okay.

Bajorek: Good, good. And if I'm not mistaken, in your hard drive stint, did you have something to do with the Microdrive?

Albrecht: Yeah, quite a bit. So Tim Reiley and I did a lot of work on the Microdrive, and that was a fun project as well, another one that had some very interesting mechanics in it. You had to make this very,

very small package. In the end that was completely supplanted by Flash memory, but it was a lot of fun while it lasted and, yeah, good project.

Bajorek: It got a lot of attention in the industry. Thank you, Tom. We'll move on--

Teale: Hang on, Chris.

Bajorek: Yeah, go ahead, John.

Teale: Why don't you say a few things about your family?

Albrecht: Oh. So my father was a medical doctor, and-- but he liked hands-on technical work himself also. So he was always into repairing appliances and so forth. I just remember when our dishwasher-- when we got a new dishwasher, he sold the old dishwasher to one of the office ladies at the clinic where he worked, and then along with that, we repaired it for the next ten years. We'd go over to her house and then fix that old dishwasher. So he sort of also played a role in getting me interested in things electronic and mechanical, even though that wasn't his career at all. So, yeah, but small-town Western Wisconsin; Dad a doctor; Mom was a stay-at-home mom; and I had three brothers.

Teale: And you're married?

Albrecht: Yes. And three kids now-- 17, 18, and 19 years old.

Bajorek: You have your hands full-- right?-- at this stage in their ages.

Albrecht: Oh yeah. Yeah, for sure.

Bajorek: Tim, how about you?

Chainer: Okay, so starting at the beginning, family background?

Bajorek: Yep.

Chainer: I grew up in New Jersey and went through the New Jersey school system. I'm from a small town called Emerson, and attended an engineering college, the New Jersey Institute of Technology. While there I became interested in Physics. I changed my major from Mechanical Engineering to Engineering Science, and then I went to Rutgers University in New Jersey where I received my PhD in experimental low-temperature physics. It was quite a change.

Continuing on in terms of growing up, I was raised by the Greatest Generation who were amazing. They could fix or build almost anything, so I had some incredible role models. My Father was a Textile Chemist after serving in the Army and my Mother was a Nurse. I had an Uncle who worked in the Oscilloscope Division of Dumont Labs and my Grandfather was a machinist and model-maker. I was surrounded by all these innovative people who could tackle almost any problem. The first exposure I had to technical innovation was in the early 1950s, when above-ground pools were just starting to become available. For the first time middle-class families could actually have a pool in their backyards, but at that time there wasn't any infrastructure to support these pools. My Father and Uncle teamed together and built their own water filtration system for our above-ground pool from a 50-gallon drum and a washing machine motor and pump. They created layers of gravel, sand and other media to do the filtration. My Father being a chemist at a time when there weren't pool chemicals available, would go to an industrial supply to obtain chlorine to maintain the pool water based on his measurements. That was a pretty innovative experience.

My Uncle, who worked in the Oscilloscope Division also had an electronics shop, and that's where I first became exposed to electronics with my cousin. I think that was the first time I ever turned on a soldering iron and saw transistors and resistors and started building things. I eventually went on to build Heathkits, which you may remember sold electronic kits to build your own tools. I built a Heathkit Voltmeter and a few other tools. I knew from a pretty early age that I liked to take things apart and was interested in engineering. I think my parents recognized that after I took apart several appliances in the house. They gave me a Gilbert Erector set and a home chemistry kit, which we probably all had as kids. Luckily, we didn't blow ourselves up. I think they wanted me to stop taking apart more appliances <laughs>. When I was around 12, my first system engineering project was to build a minibike. That was the first time that I looked at an entire system to be built using a bicycle frame and an old lawnmower engine. I also had to find all the components. We found a local welding shop to relocate the bicycle center bar, and did my first engineering drawing, which I gave to my brother, who built the axles in our metal shop in High School. After taking a few spins around the block, I knew I was hooked, and I was definitely going to engineering school. Do you want me to continue past High School?

Bajorek: Yeah, yeah, yeah, yeah. Fill in the details.

Chainer: I started college majoring in Mechanical Engineering, but what happened is I quickly became enthralled with physics and learning about the mysteries of the universe, in particular quantum physics and special relativity. The idea of superconductors and superfluids I found quite amazing, and that supplanted my interest in engineering. That motivated me to attend graduate school and receive a Ph.D. in Physics. My thesis work turned out to be on Superfluid Helium-3 which a Cornell group won the Nobel Prize in 1996 for that discovery. It was known that Helium-4, which are bosons, was a superfluid and would have amazing properties such as flowing without resistance, but Helium-3 is a fermion. It was hypothesized that Helium-3 should become a superfluid based on the BCS theory of superconductivity by forming pairs. My advisor worked with John Wheatley, at UCSD in La Jolla, and they were part of the race to show superfluidity in liquid Helium-3 below 3 mK. Cornell had observed the phase transition however, John Wheatley, who was a luminary in low-temperature physics, and my thesis advisor, Harry Kojima, did one of the first definitive experiments to prove that Helium-3 had superfluid properties by measuring the speed of fourth sound, which is a sound wave that only exists in a superfluid. It was interesting to learn about this amazing race for a Nobel Prize and my advisor being very close to that. This was why I went into Helium-3 low-temperature physics research at around 2 millikelvin. It's interesting to see the technology in low-temperature physics, including Dilution refrigerators which can produce continuous temperatures down to 10 millikelvin, for which John Wheatley advanced the state of the art, are now used everywhere in quantum computing and have become a standard tool. You see photos of what people refer to as chandeliers, which in low-temperature physics we call cryostats. Dilution refrigerators are becoming ubiquitous, used by every group looking at quantum devices. It's an interesting application of really what was a race for absolute zero. So that's how I got into low temperature superfluid physics. Should I continue on how I got to IBM?

Bajorek: Yes, yes. We want to know how you got here.

Chainer: All right. So, while I was at Rutgers doing superfluid Helium-3 research, I met a postdoc, Tom Worthington. Tom was also a low-temperature physicist, and he had joined this new, exciting group at IBM Research. When I was looking for a job, Tom told me, "You know, you ought to come to IBM. This place is amazing. There's a bunch of innovative researchers, and in the afternoon, there are rock-climbers who climb the walls of the Research Center". I came to IBM to interview with two groups. One was-- the Josephson Computer project—who were looking at a low-temperature device to replace the transistor, and I could have applied all my low-temperature skills. The second group was Magnetic Recording with Dave Thompson and yourself. I was more excited about joining the group that was climbing the walls and the exciting work that was going on in magnetic storage. That's how I ended up coming to IBM, and Chris you probably remember my first project was the Hall probe magnetometer.

Bajorek: Yes.

Chainer: The goal of the Hall probe magnetometer was to measure the nickel thickness on a ceramic substrate. IBM was making advanced multichip modules and I was tasked to measure the thickness of the nickel film, which was on the order of the surface roughness. IBM had invented the idea of measuring the magnetic moment of the nickel film to determine the thickness. I built an air bearing to fly a Hall probe magnetometer over the top surface which also helped me realize my dream of computer automation. In low-temperature physics the experiments were arduous. Data-taking would go on for 36 hours once you demagnetized your experimental down to 2 millikelvin. I quickly realized that 36 hours of taking data manually could easily be done by a computer, so I became interested in computer technology. When I came to IBM the Hall probe magnetometer was automated by a Series 1 minicomputer. I was able to not only do that application but also realize my dream of computer automation. That got me hooked and I've been at IBM ever since.

Bajorek: Now that exposure to the nickel challenge was an early exposure to semiconductor packaging. Have you worked in that some more?

Chainer: Yes, it's ironic that my first project in magnetic storage was an electronics packaging project. In fact, I recall many times when you cleared the way for us to get the Hall probe magnetometer tool installed on the manufacturing line and measured ceramic substrates. Many years later, after IBM divested itself from the hard disk drive business, I went back into electronics packaging and cooling, and I have been a Principal Investigator of three different government programs on Chip Embedded Cooling and Data Center energy efficiency. So, I've kind of come--

Bajorek: Full circle.

Chainer: Yes--full circle, all the way back into electronics packaging. So that's where I am now.

Bajorek: Very good. Thanks for that summary. Bob?

Biskeborn: Sure. I was hoping to be much more terse. <laughs> I'm going to speed it along here.

Bajorek: No, don't take any shortcuts.

Biskeborn: Well, okay. So, I was going to start with when I joined IBM, which was 1978, but I can look back, but let me begin there. I joined IBM in 1978. I have a PhD in physics from Columbia University, low-temperature physics.

Biskeborn: My advisor was Bob Guernsey, whom you may have known.

Chainer: I interviewed with Bob Guernsey. He was managing a group in the Josephson project.

Biskeborn: And so when I was in grad school, I was not really too sure about what I wanted to do. Did I want to continue on in academia? Did I want to go in industry? What happened was there was a person at IBM, Larry Spector, whom you know, Chris, was at the time a second-line manager and was looking for people to join his group, which was looking at packaging considerations for multichip, multilayer ceramic modules, and he contacted me, I interviewed, and thought it was kind of an interesting change from low-temperature physics that I had been doing, where my area was exploring superfluid effects in liquid Helium-4, which is kind of mundane <laughs> compared to liquid Helium-3. But in any case, I accepted the position. It was kind of interesting that--

Bajorek: Was that in Yorktown or in San Jose?

Biskeborn: That was in San Jose. I'm sorry, in San Jose-- I'm sorry, Chris, that was in Fishkill. I'm moving 13 years--

Bajorek: Yeah, yeah, no, no, because Larry Spector moved around too, and I wasn't sure where did you connect with him.

Biskeborn: He did. So Larry had been in Poughkeepsie and then he came to Fishkill and then he went to Mainz in Germany, and then when he came back to the U.S. he came here to California, to San Jose, where he hooked up with Jim, which is how I wound up coming here. When I was in-- when I hired into Fishkill, it's kind of interesting that Jim would have been-- Jim was running the laboratory at that time, which was the combined semiconductor and packaging labs, and so Larry was very excited-- well, your résumé would have gone up to Jim, so in a sense Jim was in part of my hiring process. I don't really know. I don't think Jim ever said that, but anyway. So I had a connection with Jim and Larry, of course, early on in my career in IBM.

Bajorek: Which date was that? When did you join Fishkill?

Biskeborn: I joined Fishkill in May of 1978, and I think at that point Jim had moved on or was just in the process of moving to Yorktown, I believe it was, or to headquarters.

Bajorek: I think he moved down to headquarters, yeah.

Biskeborn: So in IBM in those days, I worked in packaging and then I moved into the semiconductor lab, and then -- I worked on some interesting projects there. I got pulled back into packaging by a guy that I had met in my first couple years in IBM, whose interest was how do we improve the thermal packaging for the multilayer ceramic modules, something I had worked on only a little bit in my first couple years. And anyway, he and I hooked up and came up with a scheme for doing just that, and eventually the scheme was adopted. I think it's kind of interesting because later when I got better acquainted with Jim, it turns out he was also very interested in the same identical problem and had come up with some schemes that were somewhat like what I had wound up doing and we had great fun talking about that and debating what is the best approach there. In any case, what happened to my career in Fishkill is that it transitioned to San Jose in about 1990. This was the result of the outcome of the taskforce that Jim had set up in the late '80s, and I think-- I'm not really sure, John, of how it actually came to be, but it was decided to set up kind of a tape head development group in San Jose, and Larry Spector was going to manage that, and I believe the Tucson management funded--

Teale: Yes, very early on we were exploring-- I think Fontana was involved, Bob Fontana.

Biskeborn: Not in my--

Albrecht: Oh yeah, he was. Yep, in the very-- early days he was.

Biskeborn: Was he? Okay.

Albrecht: He was part of it, yeah.

Teale: If anything, that group was advocating a tape head concept that was way before its time, because it did end up being a lot like what we actually did. But it didn't come to fruition at that point in time and I don't really know why. But yes, there was an effort here. Never really got too much traction, but we were aware of it.

Biskeborn: Right. So, Larry called me up one day-- I was in Fishkill in my office, said, "Hey, what do you know about tape and tape recording?" and I said, "Not a lot." I had a tape recorder. And he said, well, he and Jim Eaton were brewing some ideas and they wanted me to come out and interview, which I did, and got a job offer and took it, moved to California in the early '90s--

Bajorek: Before you go further, who was your colleague in Fishkill who worked on the improvements to the cooling of the multichip modules?

Biskeborn: You might have known him. Joe Horvath-- Hungarian. Very brilliant guy.

Bajorek: Yeah, yeah. I just thought since you mentioned, it would be nice to know who that was by name.

Biskeborn: Yeah, he and I had just-- it was just such a-- it was a project that went on for several years. It was very consuming. I know you may have--

Chainer: Yes, the thermal conduction module.

Biskeborn: Right.

Chainer: Yes.

Biskeborn: It was just great fun, and it was great fun to-- that's when I actually learned how to cause a revolution to occur, and once you have that taste, then that's what you want to do from there on out. But in any case-- if that makes any sense. In any case, I hired out into San Jose and we-- I worked on some tape problems. One of them was studying some new films that were envisioned for possible use in tape heads. An example is a multilayer nitrogenated iron, nickel-iron film that was being looked at by some people in the hard disk drive business for improving the writing capabilities of our disk heads. As the hard disk media coercivity goes up, then you need heads that have more oomph to write to them. But we were interested in looking at those for the opportunity they may provide for tape heads because they may be more durable, the idea being that nitrogenated iron is a tougher material than some of the other magnetic materials that were being used in magnetic heads at the time, such as Permalloy and stuff. So anyway, we were in that sandbox for about three years, and then the funding dropped, and John knows a lot more about that than I do, but the folks in that department were me, Dave Siegel, Morris Dovek, who is now CTO in Headway, and some other folks-- Tom Beaulieu -- you may have remembered him-- scattered. Most of us found jobs in the hard disk drive areas, which I did. That led to-- this may be-- you're right, John, I talk and talk, and I really--

Bajorek: No, no, no, you're doing fine. You're doing fine.

Biskeborn: Okay. <laughs>

Teale: No worries, Bob.

Biskeborn: It's an embarrassment, but--

Bajorek: No, no, no, you're doing fine.

Teale: Bob's plane never lands.

Biskeborn: Right. <laughs> Well, I [presumably] know where I want to land when I take off, so that part's good, but <laughs>. Maybe I don't call the airport ahead of time, but-- anyway, this is really a great part of this story. Dave Siegel, who Larry had hired into this group in California, was a trained magnetician, PhD, and EE from CMU. He and I worked together in Larry's group. We scattered. He went into HDD. He then approached me one day with a story that, "Hey, somebody from the IBM tape head wafer line was in Fry's in Sunnyvale one day," and he encountered this little end display with a couple guys on QIC drives, and he struck up a conversation with the two people there, and it turns out that at the time-- and this was '93, I guess, '94 maybe-- were looking for a way to build MR tape heads for QIC drives, which at that time were not MR-- were just brass heads, basically. They were the dominant provider of QIC tape heads. I think they had 90 percent of the market. And this person from the tape head wafer line, which had moved from Tucson to San Jose in the late '80s, came to Dave-- he knew Dave-- and Dave said, "Well, let's see. Maybe there's something we can do there." And it turns out that we were kind of lucky because at the time the disk line in San Jose was under capacity due to lots of things taking place at that time. It was not a great period for IBM in general, I would say, from a business standpoint. There were a lot of changes taking place. And so a small group of people got together and went back to this company, which was Herald Datanetics, and said, "Hey, tell us more." That led to us actually, for the first time ever-- I'm skipping about a year of effort here-- building the first single-track quarter-inch cartridge QIC tape head wafers on the hard disk drive line. So that was really quite fun and quite exciting, and I helped-- I worked on various aspects of that, but was only more obliquely involved until HDL needed some help in figuring out how to fabricate the heads-- how do we lap them, what kind of contour do we put on them, and that's where I became more heavily involved. And that was successful enough that IBM funded it for about a year and a half, but eventually the plug was pulled on that, and I was told by my manager, Erin Keeley at the time-- and I think, Chris, you were involved in some aspects of that.

Bajorek: Yeah. I remember Erin. I remember so far everyone you mentioned. <laughs>

Biskeborn: Yeah, good, good. And so Erin said to me -- it was kind of a sad day-- no more QIC-- and at that point there were about a half a dozen of us working on the project, and she came to me and said, she's got quite a bit of money left over from that, probably a year or two of funding for a person, so, "Stay on." And I said, "Well, what else am I going to do! May I do whatever I want?" and she said, "Yeah, but you've got to help me with some of her manufacturing problems." She was I think a [second or] third-line at that time in charge of wafer and fab for the tape heads that IBM was producing. And so I took--learning and experience that I had acquired from my activities in QIC-- it was really fantastic. I got a chance to work on magnetic design of heads to some extent and fabrication and integration, and there was some interaction with Tucson and HDL. Flew to Hong Kong a number of times as a part of that work. But one of the things that struck me is that I-- so at the end of that, in this point of time where I now had some free time, if you will, I thought, "Well look, I'm now convinced that we can build full-blown multichannel Magstar-type tape heads," not in the ferrite-based wafer line that was running parallel to the hard disk drive line in San Jose, but to build them right on the hard disk line using all their processes, and furthermore, it seemed to me that maybe there's a way we can even use their fab process, that was a little more tenuous, I would say. So, the question was could we use flat-lapped heads and make a good tape head bearing surface doing that? Because we didn't want to do-- HDD heads were flat-lapped, not contoured. So anyway, you know how it turned out, but I think along the way I thought, "I can't possibly do any of this alone. I need a helper," and I didn't have any helpers, so I asked Erin if it would be okay if I called Jim Eaton back from retirement. She knew Jim. I did, and I said, "Hey Jim, are you interested in this endeavor?" and he said, "Absolutely, you bet," and I said, "Fantastic. Come on back and let's have some fun together," which we did, and he told me later it turned out that he was actually on his way to an interview at Hewlett-Packard in their tape division and that I caught him just in the nick of time. <laughs> So he and I started a bunch of work together that maybe I'll talk about more when we get to that part. Prior to physics, my passion-- my first passion in life was butterfly collecting and that stuck with me to about the age of 18. Passions change, but I was absolutely overwhelmed-- consumed-- by that passion, and travelled all over the place, and I joined up with other people, and had some very good experiences. But my interests morphed from-- let's call it natural history and biology, which required a lot of memorization-- to, "In thinking about the world, I'm thinking chemistry is sort of an underlying layer beyond biology." I became very interested in chemistry, especially theoretical chemistry and organic chemistry, and then I began to realize that underlying all of this, how atoms come together and create what we call chemistry, there's another layer behind that which is physics, and I became very interested in that, and math.

Bajorek: This is in high school already, or in college?

Biskeborn: In high school. And I wanted to say something that is off-track, running off the rails here. So one of the things-- and I probably really shouldn't be saying this-- but one of the things that really I have always been very interested in is the relationship-- is really how mathematics is able to explain and describe the things we see in our world, and-- I mean, this is-- I mean, Galileo first was articulating thoughts like that, obviously. But there's a physicist, Max Tegmark-- I don't know if you guys are familiar with him. He's a physicist at MIT, and his thinking, and what he's talking about-- you can see his presentations on YouTube and stuff-- but his idea of the world is that the world isn't explained-- the universe is not explained by math; mathematics is expressing itself in the universe. It's a really, really interesting idea. And so that-- to me, when I heard that, I was telling everybody about this and how it so much resonated with the way I like to look at things, not that I'm a mathematician nor ever will be, obviously, but. And then the last thing I want to say here is that Max Tegmark's view is the following: "I think consciousness is the way information feels when it's being processed in certain complex ways." There we are. That's my introduction.

Bajorek: Just to fill in for completeness, where were you born and grew up?

Teale: I learned nothing about Bob there.

Biskeborn: <laughs> There's nothing much to say. I was born-- my father was a EE at Western Electric in Baltimore, which is where I was born, and he actually managed a-- he was a very, very inventive person, a very brilliant guy, and he managed the communications cable development for Bell for many years, and retired.

Bajorek: And your mother?

Biskeborn: My mother was a stay-at-home mother. She went to Goucher College, I believe, in Baltimore, and loved business and investing, and so when she wasn't trying to deal with all my shenanigans, she was working on investing in the stock market and stuff like that. <laughs> I was a bundle of trouble, I'm afraid, so therefore I like to just skip over that part of my life. <laughs>

Bajorek: I see. And do you have a family currently? Any children?

Biskeborn: Yes, I have a son who works about a mile from here. Actually, he recently moved. He works at Google. And I have a brother who is living in Utah now. My brother was a EE, worked for Bell Labs in Boulder, Colorado.

Bajorek: Has your son paid your back for your troublemaking when you were younger?

Biskeborn: You know, he's such a great, fantastic kid, he didn't. He's a lot more level-headed and much more responsible than I ever was or will be. <laughs> So, my investment in him was worth it.

Bajorek: Great. Well, thank you very much. Anything else on your personal fronts that we missed?

Teale: You didn't say anything about your family, Tim.

Chainer: I have two brothers, three nieces and two nephews. Unfortunately, I'm widowed, my wife passed in 2009.

Bajorek: Sorry to hear that.

Chainer: Thank you.

Bajorek: Okay, so let's turn to the meat of our interview. John, perhaps you could take over and give us the background and context that energized the rest of the team here.[1]

Teale: Okay. Chris called me up and in a moment of weakness I agreed to do this, and then later on I was trying to think of a good way to worm out of it and my wife told me to man up.

Biskeborn: It's funny, I had exactly the same feeling. "I can't do this." Too shy, too--

Bajorek: By the way, the person you can blame for this is Bob, because Bob-- I went up and talked to Bob in Almaden trying to poke around how this happened, right? And Jim by then had passed away, unfortunately-- Jim Eaton-- and first thing he said is, "I've got to talk to you, because you were a key mover behind this. Not only that, you funded the work, a lot of the work." So I said, "I have to draft you. This thing wouldn't be complete"--

[1] For more details about the background and context see the Appendix to this transcript.

Teale: Thanks, Bob.

Bajorek: --"without you being here." So that's how you got into this.

Teale: That's fine. Glad to be here. I'm here partly because I joined IBM also in 1978 and had a very unique career, in that I was in tape development for 31 years. So I've only had one career, but it allows me to kind of provide gaps in the history of the business that I experienced. I joined IBM because it stood for "I've Been Moved" and I wanted to get moved, and they hired me in Tucson and I'm still in Tucson, so. I was reflecting on our relationship as a developer with the Research organization, which is, in IBM, it's an autonomous organization, and when I joined IBM in '78, I was doing mathematical modeling of the head tape interface, and I was asked to come and give a presentation to the Research community. I think I'd only been in the company for two months. I came out and there was this really intimidating hall in the old research building off Cottle Road, which you probably never heard of, but.

Albrecht: Oh sure. Building 28.

Biskeborn: Yeah, 28. Yeah, the triangle.

Albrecht: It's gone now.

Biskeborn: Yeah, right.

Teale: It was a horribly boring presentation. Even I thought it was boring, and it took an hour, and I was just scared to death because it was such an intimidating environment for me as a relatively new employee. But I ended up visiting Research pretty much annually every year for one event or another, and experienced a number of changes in the various processes and voodoo models to establish Research priorities, and the answer always seemed to be that most researchers worked on what they want to work on. <laughs> True fact. And in some cases, Research even competed with development. I think GPFS, for example, there were some research-hatched things that development didn't adopt and then research would champion them and got some success with many of them. But in general, I was not aware of any actual tape activity in research from when I joined in '78 up until events around 1989 or 1990 that I'll discuss in a minute. So we'll just jump to that. I think it was sometime in 1989 I came to work one day and there was a taskforce report on my desk that my boss had put there, written by a guy named Dr. James Eaton. I had never heard of him. The subject was tape, and this was fascinating and exciting because I didn't know anybody else in IBM cared about tape, and so I read it eagerly, and I think I kind of summarized it as a scaling exercise to look at the potential upside-- technical potential-- in tape devices, and in particular I recall that it centered on track density as a primary, highly leverageable concept, and I don't know when HDDs adopted track-following servo. I didn't think it was till the '90s,

Albrecht: No, it was already in in '89, but it was quite new at that time.

Teale: Okay, gotcha. And so that was my takeaway. That would be a tremendous artifact if anybody has a copy of that report. I looked in my files and I didn't save one, unfortunately. Dr. James Eaton I found out was a luminary in the Research community, had participated in lots of things, and we became very good friends over time, partly because he understood my world, and that's always comforting. We didn't know who commissioned, sponsored the report; we didn't know why-- just kind of came out of the blue. In hindsight, it became clear that IBM had been positioning the root technology of the tape drive and the hard disk drive, not the subsystems, not the robots, but just the-- we call them the bricks, if you will-- for exiting from IBM in some fashion, and there were weird organizations that got formed temporarily. We were split out from what was SSD into something called the Storage Technology Division. There were just hard disk people and tape drive people. I actually worked for a guy named Mike something-- I forget his last name-- in San Jose. He didn't even know who I was. The Storage Technology Division suffered from an unfortunate acronym.

<laughter>

Albrecht: That was always funny.

Teale: …that a lot of people made fun of. And so I kind of after the fact put together the idea that there-- part of the reason you did that, by the way, is so that you can generate a set of books specific to what you want to divest, and so that it can be valued appropriately, and there are, as you know, a number of ways to value a business. When I joined IBM, it was mostly an annuity stream company, but that's another subject. So it turns out this report apparently generated enough excitement that whoever was trying to exit our business decided to give us a shot at it, and it presumed track-following servo. We had zero experience with that in Tucson. Number of work scopes became obvious. You've got to figure out how to generate a position error signal; you've got to enable the ability to actuate the head laterally, which was not done at the time; create a control system, etcetera. And we didn't have these skills and we didn't even have any real knowledge of it. In 1989, when this report landed, we had just shipped the last of the 3480-compatible tape drives that dominated the '80s. We really didn't have any direction after that, interestingly enough. I racked my brain for-- if this taskforce hadn't come along-- what were we going to do, and I don't remember us having a plan, so this became the plan, and I agreed to fund directly some people. Jim had connections at the-- I believe it was the Stanford School of Applied Physics or something like that-- and picked up-- identified Tom and Rob Barrett, Jackie Spong, among others, and formed a little working group that was really focused on tape, and I chose to fund it myself because I thought the jobs in Research were more important than more jobs in Tucson. Most managers don't think like that, but it was absolutely the right decision, and it helped-- it instills ownership, it instills commitment to the team goal-- and as far as I know, that was kind of a unique structure in IBM. I've never known anybody else who enjoyed that close of a relationship. So it wasn't just them dreaming stuff up and we got to go figure out how to do it; they were figuring out how to do and help us, in some cases-- Tom will talk about something called timing-based servo-- Tom handed that to us on a platter. I remember the day Jim and Tom visited my office in Tucson and showed it to me. We were walking down the spine to lunch and I ask a question of Tom, said, "Is this velocity-independent?" "Yes, of course." Said, "Okay, you're in. We got it." <laughs> It was a really-- I mean, I'll never forget the moment, because that's when things really started to click between the groups. Sent Jim Karp up to meet you and figure out how to put it in a chip, and I wandered there, but let's back up just a little bit. IBM shipped its first tape drive in 1952. I wasn't there. '89 was the last of the tape drives. During that span of time, the first tape drive had seven tracks; the last tape drive had 36. So that is a half an order of magnitude in 37 years. <laughs> I don't even think we could justify staying in business these days with that as our roadmap, and the capacity wasn't much better; I think it was two orders of magnitude in that same period of time. So I'm talking about tracks and track density. We didn't pay too much attention to it. It was more of a solved variable than it was a variable to be designed, and I say that because the first tape drives were a replacement for the punch card or key card or Hollerith card-- there's a lot of names. They were based upon something called a character, which is derived from a typewriter keyboard. Characters were six bits plus parity, hence seven-track tape. Later on, when the first hard disk drives shipped from IBM, I believe in 1957, they defined something called a byte, which was eight bits plus parity. So tapes became nine-track tapes. The first seven-track tapes, had a one-to-one correspondence between the magnetic image on the tape and the character. You could actually put the iron particle solution on it and you could actually decode the tape, just like you're reading a punch card, and over time, that one-to-one correspondence became completely gone. There were a number of evolutions in tape formatting, including CRCs, ECCs, compression, encryption <laughs>-- whole bunch of them. And so by the time we shipped an 18-track tape, 18 was just totally random and awkward number, and I don't know why, because it didn't have a nine-track compatibility requirement. So I don't know who did that, but it wasn't me. And then 36 was compatible with the 18, and it featured eliminating rewind, even though at the end of the day nobody cared because nobody wrote a whole tape anyway. And so this renewed focus on track density now was a variable to be solved. We also felt at the time, in '89, that we were kind of out of room on track density opportunity because of how we recorded the tape. The recording head spanned the entire width of the tape. There are environmental factors that caused that tape to become narrower or become wider, creating what we call track mis-registration, and we were-- we felt kind of at the limit of what we could do with tracks, and it was the taskforce report that led us to the idea of what we call a banded servo, where you're not writing the whole width of the tape, you're writing perhaps a quarter of the width, which linearly scales that mis-registration error down. So long story short, we got the relationship going with Research; some great things came from that. Initially we didn't have a strong target. We decided to target what was called open systems. At the time all IBM tape drives only hooked to IBM mainframes and that was it. It was ESCON and FICON type of thing. However, there's a growth opportunity in tape in what they called the open systems market. There was a plethora of formats, and although IBM was a tape supplier, we were also a huge customer of all these open formats for our other servers besides our mainframe servers. So we purchased QIC drives that Bob mentioned from Tandberg, QIC media, from 3M, and that was for the AS400 platform. We purchased 4mm DAT/DDS drives from Seagate, the media from Sony. So this was an adaptation of the Sony Phillips digital audiotape, and that was for our WinTel platforms. We purchased 8mm helical scan tape from Exabyte, media from Sony, and that was for our RISC platform. And the mainframe market was just growing with the industry and there wasn't much growth opportunity. IBM was more interested in a growth business than an income model. I miss the dividends; they were pretty big. And Exabyte was king of the hill at the time, so we specifically targeted Exabyte for the first deployment of this new thing that we were developing. We came up with kind of a novel, cool little cartridge, and eventually shipped a drive that hunted down and killed Exabyte wherever it lived, because a lot of where Exabyte lived, the night watchman punched a button when he went home, and in the morning the job was aborted.

Albrecht: Oh, I see. <laughs>

Teale: And Coyote was only sold in an enclosed black box automated-- internally automated system, and it was just reliable as all get out. I got letters from customers just ranting about replacing Exabyte with Coyote and how much it improved their life. So that was a good thing. It wasn't long-lived. A couple of years later there was a change of the guard. A lady named Barbara Grant became the big boss, and her first announcement was that, "Tape is dead, and we're phasing out of the tape business." We had a small portion of the Coyote team that was working to leverage that technology back into the mainframe drives-- that was known as Magstar, or 3590. The Magstar tape people were told, "Stay, finish the product, and we'll get rid of you later." Very motivating, I'm sure, and the Coyote team was told, "You're done. You're leaving. We just don't know how, and we don't know when, but we'll let you know." There wasn't much else to do; we kept working, because we're still on the payroll, there's nothing else to do, and the significance of this event, about 1992, was that Tucson lost its ability entirely to do any tape head technology. We had a pilot line where we could model and tool up to give it to Nancy Jubb and her team to manufacture. All of that thin film equipment I watched as it was loaded on trucks and sent to the used equipment market. Kind of a sad day. That whole team ended up disintegrating. Some of them retired. One of them died. Many of them went to STK. And we all had to do something different. So I mentioned all these other open systems tape drives. They took us bleeding-edge developers and we became qualifiers of these devices, which seems insulting at first, okay? I'm high-end, world leader, and I'm testing a QIC toy tape drive? <laughs> Well, that was-- it turns out that attitude didn't last long. We learned a lot from these people-- a lot about cost, a lot about integration. It was one of the most fun jobs I ever had. Plus, when I was told I was on managed departure, frankly I was scared to death. I didn't know how I was going to support my family. I wasn't connected external to IBM. So this was an opportunity to meet every CEO and tape leader and company in the entire universe. So that really developed my network and made me feel comfortable that when they do let me go, I'll know what to do. Fast-forward two years, about '93 or '94, another new leader named Jim Vanderslice. Dr. Vanderslice had come from the IBM printing business, and the IBM printing business was running a version of what's known as the razorblade model, where like HP, they were selling printers and then making a lot of money on paper and ink and toner, just like 3M and x-ray machines. They'd give a hospital an x-ray machine so that they could sell them--

Bajorek: The film.

Teale: --the film for, yeah, huge profits. We didn't know how to enable this. We were told to get back to work. I kind of flailed around with how do we-- I had told them there's no way we're getting back into the technology business. I mean, we're done in Tucson. They said, "Well, we need a tape head." And the only place to get a tape head was the HDD line. I had no idea how to do it. Tape heads were contoured and slotted and did all kinds of things that were foreign to HDD. I'll let Bob tell more about the story of the heads later, but probably the most significant thing that happened was in about '97 we announced that we were going to do a joint project with HP and Seagate called LTO, linear tape open. The motivation for that was that Exabyte conquered the world, as I indicated; Coyote was hunting it; and then a company called-- what were they called? They bought the DEC storage business.

Albrecht: Quantum.

Teale: Quantum. Thank you. In the DEC storage business, Quantum mainly wanted the disk portion. But they found a tape drive in there that was a proprietary DEC only tape drive. Fairly simple design, certainly not made for the environments that we were putting our drives into, the large automated environments. They were more standalone devices. And they recognized what they had and they put an open interface on it and went to compete with Exabyte and killed them-- they went out of business-- and they became the darlings of the universe, and some of the nontechnical leaders that we get in business are always, "How come we can't do that? How come you're so stupid?" <laughs> It just never changes. So LTO was designed to go hunt DLT, which is digital linear tape, so we did linear tape open, meaning we're not going to be proprietary. The moral of that story is when you're trying to beat an entrenched monopolist, you do it with an open standard and invite a lot of participation to gang up. When you're trying to beat an open standard, you need to develop a better mousetrap. <laughs> They just go back and forth like that, historically. So we got lined up on this LTO thing. Some other innovations came about that Tom will talk about-- longitudinal position encoding turned out to be-- don't know if you know this-- but one of the most significant contributions to all of tape history, and I can tell you why in a few minutes. Tom also worked on this Coyote project that we shipped before we started the LTO project. We had defined, loosely speaking, if a tape cartridge-- if a tape piece of removable media has a single spool of tape in it, we refer to that as a cartridge. If it has two spools of tape in it, we refer to that as a cassette. So think of audio cassettes, VCR cassettes. But those cassettes have hubs that float, and so when you insert them into the drive, they align onto the fixed motors. Coyote did not have floating hubs; they were actually pinned in the cartridge. So the interface between the cartridge and the motors in the drive becomes highly nontrivial, and that led to the second most significant contribution in tape history. So now I'll explain those things. Tom was working on the-- we called it, I think, the flex clutch, to try to solve this problem of mating a fixed reel cassette to two fixed axis motors, and one of the byproducts of doing that was that we-- he designed it in a way that you could only apply torque to the reel in one direction. Remember we had the teeth at an angle?

Albrecht: Yep, sure.

Teale: Which meant that we wouldn't ever-- in a tape drive free body diagram, you're accelerating the tape but you're maintaining a tension in the tape, so as you increase the torque on one reel, you have to decrease the torque on the other reel. It accelerates and keeps the tension, and if you keep accelerating faster, faster, faster, eventually the supply reel has to reverse torque and actually push tape out, and this is how all the tape drives worked. So you take a piece of tape that has gone through that type of process and you archive it for a while, it will stress-relieve. There's a lot of winding stresses, hoop stresses and radial stresses in these things that are a whole study of their own. And they can create gaps in the pack, and then when that thing is subsequently mounted it can create something called a Z-fold, where you have a hunk of tape turning within the reel, causes a Z-fold, you don't know it's there, it creates permanent errors, all because of torque reversal. So we got rid of torque reversal. We solved that problem, and I remember I was really proud of it. I didn't do it, but I got to talk about it to the analysts once and I said, "Well, I'm going to draw some free body diagrams. It's only going to hurt a little bit." <laughs> But they got it. Now, the other one I mentioned was the longitudinal position encoding. So Z-folds were a fundamental permanent error scenario in tapes until Coyote. Never happened again. The other fundamental error in tapes was something called a chopped block. So when we're writing a tape, typically the buffer runs out of data; the tape has to stop, wait for more data, and reposition. That repositioning is a blind process. It's based on timings and assumptions about the radius ratios between the two reels, and it's not rocket science but it's a blind operation, and if for some reason there's any slippage or the tolerancing was incorrect or environmental factors, you might start writing to soon and cut off the last block that you wrote on the tape. You've created a permanent error condition that will be discovered in the future. You don't know you did it, so you can't tell the customer you did it, and that's what we call the worst sin in storage. It's the bartender overserved you and you can be liable for that. So with longitudinal position encoding, think of as a mile marker along a highway-- you see them every mile-- and it basically allowed us to know where we were in the tape so that we don't have to reposition blindly anymore. We had a whole new lexicon in tape called "if LPOS valid," you may write. If it's not, you can't write. And this all just occurred to me one day at an analyst meeting. I thought, "Coyote has addressed"-- did we put LPOS in Coyote first or LTO? I don't remember.

Albrecht: LTO actually. Coyote didn't have it.

Teale: Between those two things, so I must have been talking to LTO at the time. That was just so profound to me. These are the only two bugaboos in tape since 1952, bang, resolved, and we can confidently say today and people know it, tape is one heck of a reliable place to put your data. It's not going away till the sun explodes. You might have trouble finding a device to read the tape. But that kind of brings us up to that precipice of LTO, which is the topic of our research contributions. Another major work scope was this lateral actuation of the head that I talked about. We didn't even know if track following would work in a tape drive. We're talking about micron-level motions. There is a vertical tension component based upon the way we used to do the heads, where they're wrapped. For all we knew we're just going to push the tape up and down with the head micron <laughs> and you're chasing your tail. That's how much we didn't know what we didn't know, and these are kind of the "gotchas" that blow up schedules and <laughs> things like that. Tim was involved in the actuator. I had mentioned to you, Chris, one day that I had writer's block and I was going to go have a drink. It wasn't writer's block, it was memory block. I got to the bar and realized, "I don't remember anything about the actuator. Nothing. I don't know who did it. I don't know where they came from." You would think I would know, but--

Albrecht: It's because it just worked.

Chainer: It worked so perfectly it never was an issue. He never worried about it.

Teale: I had met Tim Chainer-- I visited him in Yorktown. You were working on sympathetic vibrations in disk arrays or something like that, as I recall. I didn't really know, wasn't really conscious of your involvement in the actuator. I knew Dave Harper, of course, was involved, and Jim Eaton. But I just-- you'll have to fill in all the blanks here, because I don't remember anything about it.

Chainer: Well, the Flexural Actuator went to Jim Eaton and his group at Almaden, and then from Jim Eaton over to Tucson. So, it was not until later I had a more direct link with Jim Overacker in Tucson when you--

Teale: Oh, I remember him, yeah.

Chainer: And we started working directly with Tucson. But it started by working with Jim.

Teale: Another honorable mention that didn't make it into any product was the flipper bearing. I was fascinated with it.

Albrecht: <laughs> Oh, yeah. I forgot about that.

Teale: It was a cool concept. I remember I wrote a model of it and it was really, really fun. It was a Jackie Spong thing.

Albrecht: Jackie, yeah, exactly.

Teale: I mentioned that I may have been a little bit hasty telling Jim and Tom that timing-based servo was in, because I was looking for an alternative to that other thing we were doing that I won't talk about. May have been hasty because I had no idea what a gigantic headache the format had become, because it turns out the way Rob Barrett prototyped it was not considered to be a manufacturable process by our manufacturing team, and we ended up going outside the company. I think we got a little bit lucky there. Another story for another day. I think that pretty much sets the table. Well, last thing of course is where did we get a head? They told me to go to San Jose and don't come back until I form a group. So I came to San Jose and posted a job for the manager-- start with the manager. Several people would come and talk to me but I didn't realize that in San Jose, unlike Tucson, nobody makes a career move without their four godmothers and godfathers telling them to do it. <laughs> In other words, there was a lot more career management in the San Jose environment than the Tucson environment, and I wasn't getting anywhere, and Kevin Reardon came out, my boss, and said, "All right, who do you got for me to interview?" I go, "Nobody." So we went to Bob Scranton, said, "Bob, we got this problem. We can't seem to staff this position in San Jose," and it didn't make any sense to staff it in Tucson, of course. Bob and Kevin dreamed up this idea of making it a notch-on-your-belt opportunity-- guaranteed one year in, one year out. "We only want the superstars, and we're going to feature this as something you'll be able to have in your résumé that not many people have." Sure enough, it worked. Sholeh Hassami signed on as the first manager that I hired. I came back a year to the day later and hired Neil Robertson, came back a year to the day later and hired Gary Decad. These were all people with Research backgrounds, so this very much ties into the theme of this discussion. Came back a year later and Gary Decad said, "I like this job." <laughs> Still there.

Biskeborn: Still there.

Teale: But Sholeh did some of the early recruiting, and really notable people. Of course Bob was involved in the group, got roped in. Calvin Lo and Sassan Shahidi were brought in. Peter Koeppe. Jim Eaton eventually was in that group. Really a special group. They had their own camaraderie and their own kind of renegade attitude-- and I visited them a lot and enjoyed all the visits, and then after I left, my replacement-- I forgot-- Calline Sanchez?

Teale: I don't even think she knows you guys exist.

Biskeborn: Well, she's moved on too, so.

Teale: That's true. That's all right. So that's the background and backstory, and hopefully the context. So Tom will talk about his contribution to LTO and then Tim and then Bob will talk about the head.

Biskeborn: I should say this thing about Calline knowing do I exist. While I did report to her, she was a VP, your replacement, and we were at a meeting one time-- it was an executive summit with our major media supplier, room full of-- I don't know if you ever went to those. They were-- yeah, anyway--

Teale: Oh, I know what you're talking about.

Biskeborn: Yeah.

Teale: The ones Diane Hellman used to run. They were called tape summits.

Biskeborn: Well, no, this was an external thing. This was run by actually Fuji Film.

Teale: Oh, gotcha. Yeah.

Biskeborn: Yeah. And in a room-- and I was there. I was the only-- I was maybe the only IBM-er there. Room full of 300 people at least, and Calline was giving a talk, and she said, "Now"-- and I only mention this because you brought it up-- says, "Now"-- and she did know I exist-- "Now I want to bring attention to-- we have a rock star among our midst. Would you please stand up, Bob?" And I went, "Oh god, rock star." And I couldn't live it down for the rest of the conference. <laughs>

Teale: Cool.

Biskeborn: So if nothing else, I was a rock star for a day. <laughs>

Teale: That's cool. Okay, I think I said most of it.

Bajorek: That's very good. Let's fill in the big blanks now, Tom. Take it from here.

Albrecht: Sure. So mainly I'll talk about the topic of how the timing-based servo and the LPOS, the linear position encoding, came about, and right off the bat, I mean, one thing really striking in your comments was how easily this was accepted and adopted by the Tucson team. I was fairly new at IBM at that time. I had only been there a year or two when that happened, and so I had no reason to be prejudiced in any particular way, but somehow I had already picked up from all the people around me that getting a technology from Research into a project, or into a product, is a battle to be fought. You really had to-- they don't want your stuff and you have to force it on them. <laughs> And that wasn't at all the way in this case. This was just the complete opposite, and really changed my perspective about IBM, and in fact I think back of it with some of the warmest fuzzies; of all my warm fuzzies I can remember, it was the adoption of timing-based servo, both for 3570 and then later for LTO, where it was not just IBM but it was three companies that just said, "We want it," and off we went.

Teale: Yeah, and the focus was on best practice or best design. Technical merit was the focus, it wasn't on the organization--

Albrecht: It wasn't some kind of turf battle, which is what these things can often become. So anyway, that was neat. So where did this thing come from? One thing I want to clarify-- the basic idea was not mine. It was Jim's, and when I joined the company in '89 one of the topics that came up for discussion occasionally was the fact that the type of servo that they were trying to use on tape, which in certain respects had copied some technology from disk-- and I'll get a little more clear about that in a moment-- wasn't translating so well to tape because there were some unique challenges in tape, and basically the thing that Jim would highlight a lot-- and I don't know whether this was the main thing for you guys as well-- but he talked all about micro-track profile changes and the fact that the head could wear or the head could accumulate some debris and it would change the spatial response of the head, and that would create a servo tracking error, among other things, and that could obviously limit what your track pitch could be, and so forth. So here was the basic problem that was being solved. If you look at the servo systems that were used in disk, and still are today, they all rely on writing two tracks next to one another that have different properties. It can be different frequency, it can be whatever, could be different phase-- Rochester was promoting their special servo for disk drives. In any case, you make an A track and you make a B track. These days we do it in little bursts, but it's still the same concept. You've got something on the left and something on the right, and you want to put the head right down the middle, so you're looking for an equal response from the left and an equal response from the right, roughly. And if something changes the spatial response of the head-- like, for example, if the head yesterday had equal response on the left and right side, but today is favoring the right side a little bit, you'll servo to the wrong position and that'll get into your track misregistration budget, and at the end of the day you can't write your tracks as close together as you had hoped. So Jim was-- he talked about that a fair amount, that this was a big deal and thought to be the main problem to solve. I also understand the whole field formatting thing, which was also compatible with that idea of two tracks next to each other. They actually tried to do it in the drive, or in one pass you'd write Track A and you'd come back and write Track B, and I think you even did a C to try to make these things. So you can do all that, but, as we're saying, if the head changes-- and it doesn't have this problem in a disk drive because in a disk drive it floats on a cushion of air and contact between the head and the disk is rare. So there's nothing really there to be loading up the head with contaminants, although with disk drive we do have that problem but at a lower level, and there's nothing wearing off the head and changing its properties. But tape is just the opposite. You run in contact. You throw particles into the tape to give it the ability to clean off the head. And so significant wear of the head occurs over the life of the head, and not only are you just slowly wearing this thing away, but you're also occasionally depositing gunk on it that stays for a while then eventually gets worn off by these wear particles. So there's a lot going on in the tape head interface that caused this interaction of this head you're trying to use to servo to not be constant, and that was felt to be a killer issue. So Jim had this basic idea of instead of writing two tracks next to one another, if you could write a single track that was wide that had transitions with different slopes, and then identify you're at the top of the track, these two transitions are close together, and if you're at the bottom of the track, they're far apart, and by timing when these pulses occurred, you could tell am I at the top or at the bottom of the track. And so the concept is very nice. It turns out it has all kinds of other interesting advantages that we did not anticipate right at the beginning, and we'll come back to that in just a moment. But bottom line is this is a fundamental change in how you generate the servo signal, or what they call the position error signal. Instead of using two tracks and trying to servo on the seam with a wide head, you go to make a wide track which is continuously variable in its own right and you sample it with a very narrow head. Now no matter what happens to that head, if you goof it all up, you put gunk on it, you make the left of the head different than the right side of the head, the worst that happens is you might be off by say a micron in those days, because the heads were only going to be a few microns wide when servoed in this particular way. So it really put an upper bound on how much error could be generated by screwing up the head, and so-- but there's a great big problem with this, in that that track I just described, with some transitions, say, perpendicular and some sloped, or, more generally, just at two different slopes, you can't write that with a normal write head. Write heads don't do that. They make perpendicular transitions, or at least all parallel. And so this was a major problem. But both Rob Barrett and I were intrigued with this enough, we thought, "Hey, this is really interesting. It's completely different. It looks like a wonderful challenge. Can we write this track?" And you were talking about the fact that the head we eventually came up with couldn't be commercialized. I think you momentarily have forgotten what we started out with, which is far scarier. <laughs> We had a rotating drum with a magnetic film on it in which we actually did lithography on this round drum, made some little slots in it that made patterns, sort of like what we're going to need to do on the tape, and then this roller would roll right down the tape with a big magnetic field right next to it and you would write these patterns.

Teale: I do recall it was something kind of different. <laughs>

Albrecht: And I was smart enough not to work on the roller. Rob was hired after I was-- and he started-- actually really smart guy-- really like Rob, just a brilliant guy. And so he goes, "Okay, I'll do lithography on a cylindrical surface." So he bought a blue laser and we did all these things, and he would sort of dunk the thing in photo-resist and he would expose it under computer control to make these little chevrons or diamonds or whatever we had on it, and we actually made a few of those, and they kind of sort of worked, but it was really not a good plan. It also would have prevented all the things like LPOS later because if you make the tape with the roller, there's nothing going to change.

Teale: That's true.

Albrecht: The pattern will get written again and again and again. At first we thought that was no problem.

Teale: Well, we wouldn't even imagine the need, right?

Albrecht: Yeah, exactly. But that's where we started, and probably at home I actually still have one of those rollers somewhere. But Rob and Jim then figured out, "Well now, it would be much better to do this with a head." And at that time the concept of a flat head was not yet there. So we made contoured cylindrical heads, where it's a section of a cylinder, and it even had the cross-slots and all the things that tape heads had in those days to try to make sure you had good contact between the head and tape, and then we would do lithography on that curved surface. Now here we didn't need to resort to that blue laser and trying to write on a full cylinder. We were able to use a flat mask and we did it on a Casper aligner-- really old piece of junk that we had picked up for 300 bucks from a surplus place here in San Jose, and we had it in our own little room, because this was so primitive and such messy stuff, we knew that the HDD head research line wouldn't let us anywhere near their stuff. <laughs> So we actually had our own little lithography lab upstairs where we did this, and had our masks made, and did make a number of these heads. I definitely have some of those at home still. I was thinking as I was driving up here today I should have dug some of that stuff out and brought it along just for fun. But so the very first heads for writing this pattern were done basically by Rob Barrett making them in Research, and those heads even made it to 3M for a while and were being used. It was clear that there was no way we could support the needs of the business, and indeed a lot of effort went into bringing up external suppliers to do that, which was successful. I think they're still doing it today.

Teale: And they were individually wired, so we could take them apart and play with them.

Albrecht: Yes, yeah. That's another-- I'm glad you reminded me about that. <laughs> The first heads that-- not the roller but the big cylindrical head-- that was a ferrite head with a big slot through it through which we wrapped a few turns of wire-wrap wire. So that was it, one common coil to write actually several different servo tracks for several servo bands, as John had explained. So we were also, in that configuration, forced to write exactly the same thing on all tracks simultaneously, and since we actually put two gaps on the head, it also still was not-- well, I'll expand on that a little bit later. But it was still fairly limiting what we did. Eventually when it went into the commercial production, they learned how to put separate coils on the heads and that was very, very nice in terms of being able to code slightly different information on the three, or however many--

Teale: They wanted to be able to identify which band you were in.

Albrecht: Yep, and in LTO for a while at least, that was-- one was a little ahead and one was a little behind, and there were various tricks for doing that. So anyway, this whole business of how do you create this special servo track was a big deal, and Rob Barrett was really the hero who made that happen the first time. It was the kind of crazy project I would say most mature researchers would run the other way from, <laughs> but he was young and he was very capable and he got it done.

Teale: Yeah, it was terrific.

Albrecht: I took on the much safer job of building the decoder.

Bajorek: Before you do that, where did the final pattern end up? What was the final solution for the--? Maybe I'm jumping in too soon, but I just thought it would be appropriate to close.

Albrecht: No, that's fine. In the case of 3570, we had-- we had the diamond pattern already, right?

Teale: Yeah.

Albrecht: Yep. We called it the “Diamond” servo for a while.

Teale: I was clued by Dr. Kluge when he left the business. He gave me a name and a number and said, "Someday you're going to need this." And the company was called ARC in St. Paul, Minnesota. ARC was Advanced Research Corporation-- generic. And he had been working on how to do this, and he had the five different servo tracks, the wide ones, individually wired, and we outsourced the business to him, and he had a great business model. He wouldn't sell the heads to the media companies. He wanted them back. So he had a lease model, and then he would recall them when he wanted to, either because they were returned or he just wanted to study how they held up over time. He was really a smart guy. His name was Matt Dugas.

Albrecht: Matt Dugas, yes.

Teale: Little bit talkative, almost more so than Bob, I think. But yes, he-- so we sourced them from him.

Bajorek: And the transitions were at an angle to the--

Albrecht: Correct, yeah. So we ended up having a diamond pattern that looked like this, actually had several transitions on one side of the diamond and several transitions on the other.

Bajorek: And covered a fraction of the tape and you step and repeated that pattern in bands?

Teale: These servo tracks, there was maybe five of them across the width of the tape, that's all written simultaneously in the factory at the pancake level with these heads from ARC. The data's in between those bands. So the head will shift from writing these two to writing these two to writing these two to writing these two, and then you put the data in between them. And the data tracks are--

Bajorek: And that's how it's stayed ever since?

Teale: Yes.

Bajorek: To this day?

Albrecht: Yeah, a little bit enhanced for LTO with this linear position encoding, which we'll come back to, but yeah, the basic concept stuck.

Bajorek: Interesting.

Teale: And I would say ARC deserves a lot of credit for the enablement. That was huge.

Albrecht: We enjoyed that project. That was great to try to dream up all the things to optimize this and understand it.

Teale: And that relationship didn't end well, not with us. But the media companies hated being dependent upon a single source to do their whole business, and eventually they found alternatives to ARC, and then that led to a bad divorce at some point, between Matt and the media companies.

Albrecht: There were lawsuits and things going on as I recall.

Teale: Yes, yes.

Albrecht: Yeah.

Teale: I was depositioned? I was deposed, or whatever they call it.

Albrecht: Anyway, long after I left IBM too I was helping patent attorneys fight about that. <laughs>

Teale: And I thought, "Well this will be easy," and I went in there and the lawyer said, "Well, I'm going to train you on how to do this." "I don't need training. I'm an experienced executive. I can handle myself." By the time he was done training me, I felt like the biggest idiot in the universe. These lawyers can just nail you to the wall, and to the extent that engineers like to talk--

Albrecht: <laughs> Use it against you.

Teale: Use it against you.

Albrecht: <laughs> Yeah, yeah.

Teale: He said, "Did you ever apologize to Matt Dugas for--?" "I've never apologized to anyone." Shows me an email, John Teale to Matt Dugas, "I'm sorry about..." Turns out it was a damn fake email that he had made up.

Biskeborn: Wow, really?

Teale: But his point was, "Do I have your attention yet?" <laughs> Anyway.

Bajorek: Sorry for the distraction. I just wanted to capture that.

Teale: So we got closure there.

Albrecht: No, that's great. That's a fun aside, and by all means, jump in if at some point you've got an interesting tangent. I like to hear it too. <laughs> So anyway, as I was mentioning, I kind of took on the job of making the servo decoder. So let's say Rob Barrett is successful, we have this tape formatter, these patterns are on the tape; now we need some narrow head and we have to read these transitions and turn that into a position error signal. That's not so hard. It's fairly straightforward logic, and you probably picked up a little bit in my background story-- I'm not really a trained electrical engineer. I went through physics and so forth and all of my electronics was self-taught stuff I did as a hobbyist. But I felt it was really important for us to really demonstrate this and make it into a nice package that we could show to the Tucson folks, where it really did spit out the PES. So I built the first decoder using wire-wrap and TTL chips, which was very much out of date by 1990 or '91, whenever this was. This was already a 15-year-old way of doing things, but I knew it and I was familiar with it, so I put in a million wire-wrap wires and made this big rack thing with a bunch of stuff, and it mostly worked-- it wasn't perfect. We did implement a few things along that come up. As soon as you start working with a pattern like this, you realize there's a bunch of stuff you can do. One of them is error checking. So you're basically timing various transitions, and we had several of them running in parallel, sort of nested intervals, and you could check out how these three or four or five intervals that you were timing, whether they agreed or not with each other, and if they didn't, you could flag this as a low-confidence PES sample. So we had that built into this circuit as well, and of course velocity sensitivity-- we took that out as well. We had a special thing that would compare the time of this variable burst to one which was fixed, which was actually the distance to the next pair, and that one we could use for normalizing. If you were going slow, of course all the bursts took longer and you could check the timing of that fixed one to tell you how to adjust the shorter one. So bottom line is we put a few features in there for error checking and also for velocity cancelation and made it all work, and I'm sure guys like Jim Karp were just smiling when they saw the way we did this.

Teale: Yeah, he was. But Jim is like a world expert at what he did.

Albrecht: Oh, fabulous guy. I respected him very greatly because he saw what we did and he goes, "Oh, that looks like a good idea. We should do that." <laughs> But he did it right, of course. Programmable logic and things like field-programmable gate arrays were just becoming commonly used at that time. So he turned around and took my giant box and compacted it down into four little chips that actually worked a lot better.

Teale: Yeah, he did the timing base. Jim also did the first Reed-Solomon ECC in tape. The first SCSI interface in tape.

Albrecht: I'm not surprised.

Teale: Tremendous stuff that he did.

Albrecht: Yeah, just a really fabulous guy, and-- yeah, so.

Teale: He was smart and he'd tell you.

Albrecht: Well, for whatever reason, I never picked that up from him too much, that there was an ego behind that.

Teale: It's because you didn't live in the same town.

Albrecht: Exactly. We saw him only occasionally. He was-- for us, he was just really nice and very helpful and, obviously, had skills that greatly enhanced what we were trying to deliver.

Teale: I want to do just a quick interjection here. Tom mentioned there were beneficial byproducts of this concept that certainly weren't by design at time zero. They were kind of "Oh, we can do this, we can do this." One of the things that we were able to do was use this servo pattern to provide the velocity position error signal for the motors, so that we could get the tachs [tachometer marks] off the motors, which are unreliable--

Albrecht: That's right.

Teale: --and completely eliminated hardware costs, reliability issues, and in conjunction with LPOS my interest in LPOS when I first asked you to consider it-- and I think I had to ask you twice and then the second time you did it-- I wanted to get rid of the tachs altogether. But then I needed a way to know what are the radius comparisons? And, so, LPOS for me, was a way to--

Albrecht: Exactly. Now I remember that.

Teale: --in conjunction with the velocity feedback. Wow!

Albrecht: Yeah.

Teale: That's a robust power--

<overlapping conversation>

Albrecht: And this was cool. You know, we had put in the ability to measure the velocity simply because we wanted to make the position error signal velocity independent. I wasn't thinking about his problem at all.

Teale: Right. No, you weren't.

Albrecht: But we were spitting that velocity out.

<overlapping conversation>

Teale: "What's a tachometer?" <laughs>

Albrecht: You know, that data was there for free--

Teale: It was.

Albrecht: --and just the way we built it, it’s sitting there spitting out the velocity on a continuous basis.

Teale: Serendipity is real.

Albrecht: Took him about, I think, probably a micro-second to figure out, “Oh, we can use that.” <laughs>

Teale: Yep, yep. I had a lot of things going on in my head.

Albrecht: Yeah, yeah. And since you're mentioning other positive side effects, another one which we totally didn’t understand when we started this project off is the fact that if you made this servo pattern in generation one, you could leave it alone for generation two and generation three and generation four. You did at least four generations, maybe more, because once you had this continuously variable pattern, unlike the case where you're trying to servo on a seam between two different tracks, you can choose anywhere you want to servo in that pattern. So, if you want to double the track density-- you know, just have 16 defined rather than 8 or 32. And that became another sort of unanticipated benefit, is we ended up making something that was just wonderful for intergenerational--

Teale: Scale.

Albrecht: Yeah, scalability and also intergenerational compatibility to the extent you wanted forward and backward compatibility. The servo wasn't going to be your problem. What you did on the data tracks probably mattered quite a bit, but the servo would just plain work, whatever you wanted it to do for many generations going forward.

Teale: I like the word “robust”. It was a-- that’s a powerful word.

Albrecht: Yeah, yeah.

Teale: And it was very robust.

Albrecht: And that error checking there and the fact that it wasn’t susceptible to head wear and all these things and it all kind of worked out. So, yeah. And, indeed, I was quite surprised how quickly that was adopted and used for Coyote.

Teale: It took them 30 minutes. Sold.

<laughter>

Albrecht: Yeah. And I know that they had wanted it for 3590, but it was too late. They already had someone else--

Teale: They had their own set of issues.

Albrecht: Yeah, exactly. But then, fast forward a few years, LTO comes along and this was just another wonderful example where something was adopted with no resistance. And the three companies, Seagate and HP and IBM, getting together to create this DLT killer. And we all understood what we were trying to do. And, to a large extent, we tried to copy many things about DLT: same general cartridge size, same-- well, you know. In any case-- but all three companies coming together. You know, probably there were many things where technologies competed between the three companies. Somebody wanted maybe a certain tape formulation or a certain head technology. I don't really-- you'll know far more of those things than I do. But at least my understanding was that everybody just said, "No, we want IBM's timing-based tape servo." And in it went and became a very vital part of that and ended up generating really nice royalties for--

<overlapping conversation>

Teale: Big royalties and, you know--

Bajorek: Were you able to patent some of these ideas?

Albrecht: We did. We patented it pretty well. Not perfectly, but pretty well. And, so, yeah, and that enabled these pretty bullet-proof coverages that generated the royalties for many years.

Teale: Still are today.

Albrecht: Still today. And it's how much in aggregate?

Teale: Well, it was running-- when I left the business it was running about 180 million from LTO alone a year, divided by three. And that's revenue that doesn't cost us anything to generate.

Albrecht: Yeah, yeah.

Teale: That basically was my development budget. It's a free development.

Albrecht: Yeah, yeah.

Teale: It's paid for. And-- but that didn't count the ones that we got from our individual suppliers, which were outside of the scope of LTO, where we were getting an additional two to three percent depending on the product. Like, for example, the Jaguar version, the enterprise version of LTO that replaced 34-- 3590, that was a whole separate annuity stream of royalties.

Albrecht: Yeah. So, this ended up being a rare case where IBM sort of properly took advantage of the IP it owned and actually got money out of the rest of the world for it. You know, IBM always had more patents than anybody else in the world and basically got very little for that over the years that I worked for IBM. But this was a wonderful exception.

Teale: Well, we got it done. We got billions.

Albrecht: <laughs> Yeah, yeah. So, this was really cool to see these patents. And since you brought up the patent, I'll just-- 30 seconds on this. Rob Barrett and I were busy writing these patents. I think Jim was in there, too, obviously. Jim and Rob and I and maybe-- certainly in later ones, Tucson collaborators as well, like, Jim Karp and later Glen Jaquette when we got to LPOS. But at the beginning it was just Jim and I and Rob writing these things and they wouldn't give us the good patent attorney. If you remember, we had a really good patent attorney at Almaden. Wow! What's his name? Well, anyway, it just escapes me right now. I thought for sure I would remember this guy. Tom Berthold. That's the guy. You may remember that name.

Bajorek: Yeah, I remember Tom. Yeah.

Albrecht: He was just wonderful to work with. But they only gave him HDD stuff, <laughs> because that was way more important. And, so, we got some hired hand, an external guy who really didn't know anything about magnetic recording at all. <laughs> Just a horrible patent attorney. And, in the end, somehow we felt this was an important patent, and Rob and I wrote that patent application ourselves. We had each done enough patents by that time--

Teale: The whole thing.

Albrecht: --we kind of knew the--

Teale: Leave in all the boiler plate.

Albrecht: Yeah, all the boiler plate and all the funny language they use and the structure of the claims and all that. So, actually, that was, in a way, that-- I ended up having actually more than a hundred patents with IBM, but those were the ones where I really had to step up and write the patent application myself, because the person we were assigned to was so bad, because they were considered-- it was-- this was tape junk. <laughs> And, yet, probably no other Almaden patent made more money than that one--

Teale: I bet it did.

Albrecht: --I suspect. So, anyway, funny story on the side there.

<overlapping conversation>

Bajorek: Were you able to-- sorry, I wanted to-- don't forget to bootstrap us to longitudinal--

Albrecht: Yeah. Oh, this, the very next topic I'll--

<overlapping conversation>

Bajorek: Sorry. <laughs> You wanted to say something, John.

Teale: Oh, I was just going to say, in tape we had a saying that if you talk to a Japanese person about their culture, they'll say, "China's the mother culture. We're the children of that." We used to say, "Tape is the mother culture to disk." We did everything in tape first. I mean, a multi-track system is a RAID by definition. People in San Jose still don't admit this, but we did ship the first magnetoresistive read-head in 1984.

Albrecht: That's true. Yep, yep. We did. Go ahead. Yeah.

Teale: It was a center-tapped, shunt-biased head. So, a lot of people think, "Well, that's not a real--"

<overlapping conversation>

Albrecht: "Doesn't count."

<laughter>

Teale: Well, it does.

Albrecht: It does, absolutely. Yeah.

<laughter>

Teale: So, I don't know why I said that. Just tape junk.

Albrecht: Well, there were good reasons to, because tape was at a low velocity. So, MR paid off sooner--

<overlapping conversation>

Teale: Well, there's-- the back story on that is that the ring heads-- we just had to keep moving the tape faster and faster and faster and faster to increase linear density. And it was ridiculous. I think we were doing four meters per second or something in 3420. And the magnetoresistive tape head-- was another one of those serendipitous-- it solved that problem and we didn't realize how many other problems it was going to solve down the road.

Albrecht: Sure, sure.

Teale: Every bit as good a story as timing-based servo, but anyway.

Albrecht: So, in the case of servo, of course, disk did go first.

Teale: True.

Albrecht: But the cool thing is we didn't copy them. We actually did our own--

Teale: Right, here we go.

<laughter>

Albrecht: So, that was that. So, then, yeah, the one other sort of big topic on the servo thing-- but it won't take nearly that long to explain is linear position encoding and it became clear-- and this was really a pull from the product people; we in Research didn't really appreciate that it was very important. We thought, "Well, there's other ways to know where you are on the tape. Why can't you just write it into the data tracks or something." I don't know. But, in any case, you guys were quite clear after a while that, "No, we really would like to know where we are on the tape and you should be able to put it into the servo." And, of course, that's true. Just by sort of putting in special little perturbations on the servo pattern, moving one transition a little ahead and the other one a little bit behind, we could, in fact, do that in a way that did not affect the position error signal, because we were timing several intervals per sample. So, if we made a few of them longer and a few of them shorter, we could hide some additional information in there without screwing up the servo at all.

Teale: Unbelievably--

Albrecht: Yeah, yeah.

Bajorek: And that signal was also picked up by the same head that--

Albrecht: Correct. The servo head.

Bajorek: The servo read head. Not a separate head.

<overlapping conversation>

Teale: It's processing it differently.

Albrecht: And was able to be written with the servo write heads that were already in use at that time just by changing the timing of various pulses slightly on the--

Teale: So, the integral was the same--

Albrecht: Yep, yep.

Teale: --but inside you'd get the differentiating--

Albrecht: So, we had a sum of A intervals that didn't change and we had a sum of B intervals that didn't change, but the individual ones did. And that allowed us to stick a one or a zero in each of these bursts going down the tape. And you don’t need a lot of data. You know, the data rate here is abysmal. I don’t know what it would be-- maybe a hundred bytes per minute or something. It’s not quite that bad-- <laughs>

Teale: It was pretty small. It was pretty small.

Albrecht: Yes, but it’s a small number like that. But that’s enough to tell you where you are.

Teale: But you're not wasting a lot of tape to wait for LPOS to be--

<overlapping conversation>

Albrecht: Yeah, exactly.

Teale: It was well worth it.

Albrecht: Yeah, and it allowed you to know much more precisely because under that procedure that John described earlier where he was worried about truncating a block, you had to leave plenty of extra space to make sure that didn’t happen very often. But if you know much more precisely where you are, you can bring these blocks closer together and--

<overlapping conversation>

Teale: Their registrations were very crude.

Albrecht: And I do want to give a lot of credit to Glen Jaquette, Tucson, another guy who sort of--another smart guy just like Jim Karp, but a little different background. He was good at coding and channels and these kind of things and probably lots of other stuff, too. But I knew nothing about coding and channels, just because I was more thinking about other things. And, so, I knew how to put these ones and zeros into the patterns, but I didn’t know how to create a system out of that that would really efficiently use this and also do error checking and all the things that you want to do. And Glen just took it upon himself to work with me, to teach me how the kind of coding that would be necessary for that type of serial bit stream would be done. And then, once I kind of understood it, he and I sort of competed with each other in a very friendly way. I’d send him an email one day, he’d send one back the next day saying, “Mine’s better.” So, I’d send one back the next day saying, “Oh, this is a little better yet.” And, finally, after a while--

Albrecht: --he stopped answering me. He said, “This is good enough.”

<laughter>

Bajorek: At the asymptote you stopped, right?

<laughter>

Albrecht: Yeah. In any case, that became the linear position in the coding system that was adopted by LTO. And I don't know whether that's been greatly enhanced over the years or what. I didn't pay attention to that after that time--

Teale: Not to my knowledge.

Albrecht: --or if it's still being used.

Teale: Glen was a person that you had to be-- have super clarity in what you wanted--

Albrecht: Yeah.

Teale: --and a minimum of constraints. Over-constraining engineers, really, that's a bad thing.

Albrecht: This was perfect for him then, because we had a totally blank slate--

<overlapping conversation>

Teale: So, I was good at posing the problem.

Albrecht: Yeah, yeah.

Teale: I'd pose it and Glen was more of an architect.

Albrecht: Yeah.

Teale: Where Jim was the hands-on, nuts-and-bolts guy.

Albrecht: Yeah, yeah. But this worked out well. This was a clean slate. So, between Glen and myself, we could just do that to LPOS-- -

Teale: Yeah, that was cool.

Albrecht: --and decide what it was going to be. And that's what it was.

Teale: And you didn't know what it was going to enable. You were involved in solving the two biggest problems in the history of tape.

Albrecht: Yeah. Didn't--

Teale: You eliminated it.

Albrecht: Didn't understand the significance of it or maybe I would have been more intimidated or something. I don't know.

<laughter>

Bajorek: So, now we have-- now we know where we are on the tape. And we want to decide where we're going to go to, right? So, how did we actuate the head? How did we marry the head to that signal? Right?

Albrecht: Well, in a very quick nutshell, but, obviously, this is mainly Tim's bailiwick. You know, take that PES signal, run it into the right compensator, and apply it to this actuator that these guys made. And there's a lot of missing details there that Tim will fill in.

<laughter>

Chainer: Yes, digital servo control.

Bajorek: Please pick up from here.

Chainer: The next step was called the Flexural Actuator.

Teale: Yeah, I thought Santa's elves dropped it off.

<laughter>

Chainer: I came to work on tape from the disk drive program at IBM. We were not actually working on tape drives when we conceived of a Flexural Actuator. To explain I have to go back into that time history. When I joined IBM in the 1980s, IBM was still making very large, 14-inch disk drives, But the PC was just coming out and the PC XT was the first to ship with a 5 ¼ inch form factor disk drive. I believe the first 5 ¼ inch disk drive was introduced around 1980 and later, IBM built its own 5 ¼ inch disk drive, the Pixie drive, which you might remember went in the IBM PC AT. So, there was a move to take technology from large enterprise system disk drives and start producing small form factor disk drives, in part driven by the PC. At that time, Dave Thompson and others in Almaden, started the Compact Storage Lab. Chris, perhaps you remember how that was started. The goal was to start looking at ways for IBM to build small form factor disk drives around the time the 3 ½ inch disk drive was just being introduced. As IBM started looking at smaller form factors, I was working for Dave Thompson and we started working on two small factor disk drives. The first was a very low profile form factor drive, ½ inch high, in a 3 ½ inch form factor which we called the Flatfile. The second prototype we worked on, which might have been the first ever 2 ½ inch form factor disk drive used a roughly 65 mm disk. Going back to the Flatfile prototype, we decided that we would introduce a new Flexural Actuator. One of the nice things about using flexures, which we invented in the early 80s was that a Flexural Actuator did not have bearings and therefore would not have stictional forces. It could also be made from stamped sheet metal at very low cost. This aligned with the goals of the Compact Storage Lab, which was to build small form factor disk drives at low cost to compete in this new world we saw coming. Ultimately, 3 ½ and 2 ½ inch from factor disk drives took over the market as RAID (Redundant Array of Inexpensive Disks) technology emerged. The large disk drives that IBM made were replaced with small factor drives. So, there were a lot of challenges.

Also, at that time, the Compact Storage Lab in Research wanted to ramp up its prototyping capability. We didn't just want to build a component, we wanted to demonstrate full functionality. So, we built what was known as the Flatfile prototype, which was going to be a fully functional 3 ½ inch disk drive. We planned to servo write the Flatfile and demonstrate digital servo control and seek performance. Which is what you alluded to: How do you move from one track to another? You need an actuator, a position signal and servo control to close the loop on the actuator. The Flexural Actuator uses the parallel motion of two springs and a voice coil motor to produce a parallel motion of the head.

We got quite a few people involved. Dana Brown from Rochester came to Research for an assignment and did the servo writing. Sri-Jayantha, a servo control expert in IBM Research, developed the digital servo control. We hired Wayne Sohn, a mechanical engineer, to further refine the Flexural Actuator concept that we previously invented. Nicholas Apuzzo did mechanical design. The inventors of the Flexural Actuator included Dave Thompson, Suri Hegde, Bob Hammer, Sri-Jayantha and me. So, it's interesting to see how the personnel changed. We had the original invention, followed by the development of the Flatfile Prototype with another team and then, finally, the third part of the project was to take that Flexural Actuator that we developed for a disk drive and redesign it for a tape drive. So, it was a three-step process and the personnel changed as we went from one mode to the next.

It turned out though, the Flatfile Prototype was going to be an amazing learning experience for everybody in the group, because that was the first time we ever servo wrote a disk drive in Research and demonstrated voice coil motor digital servo control. In my own case, and the case of several others, that was going to lead us to developing new ways of writing servo patterns on disks. We ultimately, came up with the idea that a disk drive should write its own servo pattern. We learned in servo writing the Flatfile that servo writer systems were very expensive and required a laser system to position the head to write the sequential servo tracks. And the interesting thing was that every time you doubled track density you would have to double the number of servo writers you have in manufacturing. So, we had an unsustainable manufacturing model, where ultimately servo writing was going to become the major capital cost of building a disk drive. We knew track density was going to scale thousands of times, requiring many orders of magnitude increase in servo writers. The ability for a disk drive to servo write itself (which we called Self-Servowrite) became a really compelling technology which we developed in Research and transferred to IBM's storage product division. In fact, the Microdrive that you referred to earlier was Self-Servowritten in Fujisawa.

Teale: So, does that almost eliminate repeatable runout, because it's--

Chainer: Yes, it does. It's fascinating technology because it's a step and repeat process. You write a track, servo to the edge of that track, and write another track. And you do that about a million times or so across the surface of the disk. If you have an error on each step that error is going to grow as the square root of the number of steps. So, we invented writing a track and measuring the error and applying a correction on the next step. This also led to, which was serendipitous, that when you wrote servo tracks your ruler really was the head width. Now, it turned out as track density was increasing. head width tolerances were not scaling with track density. When I finally left the disk drive business the head tolerance was roughly plus or minus 30 to 40 percent of the track width. So, we came to the conclusion that Self-Servowrite wasn't only a good way to write servo tracks, it was the way you wanted to write servo tracks. If you had a narrow head, you really wanted to have a constant gap between the tracks rather than writing tracks on a fixed pitch. Ideally you wanted to write a track, have a constant gap, and then write another track. You did not want to write tracks at the same pitch and have this plus or minus 30 to 40 percent error in the track width. Self-Servowrite gave you that naturally and that became known as Adaptive Track Pitch. Each disk could be written to the head dimension on that individual disk surface. In sector servo every surface had its own servo pattern, so you were able to do that. So, it's amazing how things spun from the effort of going through the process of building an actual disk drive with a servo pattern and doing the servo control which led us to the next project, Self-Servowrite, which actually went on for a decade and was very successful.

Bajorek: If I could just take a side for a moment, that may have been a first in the industry, the self servo write approach--

Chainer: Yes.

Bajorek: --and then IBM adopted it.

Chainer: Right.

Bajorek: And then has the industry-- I think the industry then adopted it, right?

Chainer: Yes. When IBM divested its disk drive business, all our technology went to Hitachi (HGST) and Self-Servowrite went with it. HGST later merged with Western Digital but maintained their name for some time. The last time I checked there were hundreds of thousands of these Self-Servowriters, which are basically just electronic boards to enable each disk drive to servo write itself. The cost could be made arbitrarily low because it was just purely electronics.

<overlapping conversation>

Bajorek: And I was curious, because I didn't follow it. I assumed it would have flowed through those sales, right? HGST--

Chainer: That's right.

Bajorek: --then Western Digital, but did it flow to Toshiba? Did it flow to Seagate? Do you know? Or perhaps you didn't follow it after that.

Chainer: I know that it moved to Hitachi. I do not know that it flowed into other companies.

<overlapping conversation>

Bajorek: Because it would have been an issue for them, too, right?

Chainer: Right.

Bajorek: I mean, this wasn't just an IBM issue, what you do with servo writers.

Chainer: Right. everyone had to basically solve the scaling problem of servo writers. And I don't know what technology other disk drive manufacturers utilize. They may or may not have adopted these concepts. There was another approach called Servo Copy, where you would servo write a master disk by putting 10 or 12 disks in a pack and write the initial pattern. Then you would populate the drives with these disks and generate a second servo pattern from the first one. But, in Self-Servowrite, you didn't need to do that.

The Self-Servowrite project I led at IBM Research included Ed Yarmchuk, Mark Schultz, K.F. Etzold and Buck Webb. We worked on this project for over a decade.

But, now, circling back to the Flexural Actuator: So, we had this fully functional actuator and one day we were contacted by Jim Eaton, who was leading a new tape program which was looking for a candidate actuator to provide track following on tape. And I suspect that Dave Thompson, and perhaps yourself, had something to do with his inquiry. Jim may have been aware of the work of the Flexural Actuator through the regular meetings in Almaden where we presented our work on the activity.

Bajorek: Yeah, to give you a background, before Jim started this tape group in Almaden, Jim also had a stint as-- I think he was the third director of the Magnetic Recording Institute.

Chainer: Okay.

Bajorek: He headed that joint General Products Division -- Research Lab and through that job I think he got visibility to everything that was going on in Research, including the Compact Storage Lab. So, I wouldn't be surprised if Jim took the initiative just on his own volition! <laughs> Right? Was he--

Albrecht: I would sure think so, that that's how it happened.

Bajorek: Yeah, I suspect nobody had to ask Jim to go <laughs> look you up. He probably knew of your work and--

Chainer: He knew of us.

Albrecht: Quick question though: Was the Flexural Actuator ever used in a disk drive?

Chainer: No.

Albrecht: So, actually tape is what ended up commercializing that.

Chainer: Yes.

Albrecht: Okay. Yeah.

Chainer: And there were technical reasons for that. One disadvantage of the Flexural Actuator would be that if you moved off the neutral position, it would take constant power to keep it there.

Albrecht: Mm-hm.

Chainer: So, it became somewhat power-intensive, right?

Albrecht: Power issue. Yeah.

Chainer: In a tape drive the stroke length was reduced by about an order of magnitude compared to a disk drive. We moved plus or minus 10 millimeters on a disk drive which was reduced to plus or minus 1.75 millimeters on a tape drive. Now, having said that, the actuator was much smaller. In a Flexural Actuator, you need to consider a lot of things including how much stress you are generating in the bending elements. The way we designed it, the ends of the beam were bending elements and the center beam section was rigid. So, it bent as a four-bar, almost literally as if you had four ball bearings to form a four-bar actuator. All the bending was occurring in these small bending sections. It turns out that the stress depends on the ratio of the length of those bending sections to the length of the center beam stiff sections. And then you have to balance that with the desired force constant, which determines the power required to move off the neutral point. In addition, the fundamental resonance frequencies limit the servo bandwidth. These resonances included standing waves in the spring system itself and also torsional out of plane modes.

When we did the development, prior to Jim contacting us, we had already developed a complete analytic model for the Flexural Actuator when we brought on Wayne Sohn. Physicists tend to quickly prototype concepts, but then you need a mechanical engineer to remind you of the beam theory when it really came down to finalizing the design. So, we came up with a nice analytical set of equations. When Jim wanted to re-design everything to fit inside a tape drive, we were able to use that analytical formalism to re-design it. For example, we had the voice coil motor outboard of the flexures. Jim wanted the voice coil motor inboard of the flexures. The length would change by about a factor of four. The stroke almost by a factor of ten. There were going to be a lot of significant changes. So, we were probably the perfect group in Research for Jim to find. It reminds me of Ralph Gomory, the former head of IBM Research, who once said, “The perfect research project is one by the time I hear about it is already complete and needs no funding.”

<laughter>

Chainer: When Jim contacted us we had a completely developed project, which he never had to fund. It was free, and then he asked us to build him several prototypes. So, in 1988, we delivered Jim the first prototype of a Flexural Actuator and then we built three or four more. And that's how the project got going.

Albrecht: One quick question, because I'm just curious about this. You know, as I looked at that design, it had-- and also your description you gave right now, there's a lot of overlap with the same problem space as HDD head suspensions.

Chainer: <nods>

Albrecht: But, from what I'm hearing, there probably was no connection between head suspension people and what you did.

Chainer: Well, the head suspension manufacturers were building stamped pieces of sheet metal to create vertical compliance and stiffness in lateral directions.

Albrecht: Right. They were worried about all the flexural elements.

Chainer: Right. Ultimately, Tucson did get these manufactured somewhere. I don't know if they went to the head suspension folks to manufacture them or not. John, do you know?

Teale: I don't have any idea. That's just a total blank.

Chainer: I think the manufacturing would be very similar to head suspensions.

Teale: I'm sure I was involved.

Bajorek: Hutchinson Technology became the dominant--

Chainer: Right.

Bajorek: --suspension maker.

Teale: Well, Magstar had an actuator and I don't know where that came from and I don't know if it was the same as what you're describing or not.

Chainer: Yes, Magstar was the first product that utilized our Flexural Actuator.   It's possible the suspension manufacturers were involved as it was the same type of technology. In fact, you could almost take two head suspensions and put them in parallel to make a Flexural Actuator.

Teale: That was a fairly much larger mass, as I recall. Yeah.

Chainer: Yes. a voice coil was inside the flexures which had to support that mass. So, that was the timeline. What happened next is after working with Jim on the prototypes, eventually Tucson began to do development on the Flexural Actuator themselves and Jim Overacker was the person that we mostly interacted with. And he started re-designing it again. So, it went from the prototype stage through a variety of different designs, but ultimately Jim was aware of exactly how it had to fit inside the Magstar, It went through multiple design iterations with emails going back and forth asking, "Well, could we do this?"

Teale: And, on the Coyote side, I think it was-- you must have worked with Dave-- I forgot-- I said his name earlier. Dave Harper?

Albrecht: Yeah, Harper.

Teale: Because he was the actuator guy, but he was in San Jose. So, I didn't have a lot of visibility to his work.

Biskeborn: Yeah, he came well after Coyote though.

Teale: Oh, did he?

Biskeborn: Yeah. Mm-hm.

Teale: Okay.

Chainer: The end result was we achieved a first resonance of about 1.8 kilohertz. One innovation that Tucson came up with was adding damping material on the flexures, to reduce the standing waves. Your development folks-- Jim Overacker-- came up with a damper which was able to reduce that mode. That allowed us to get higher servo bandwidth.

Teale: I hope they got a pay raise. <laughs>

Chainer: Right. It was a surprise that the Flexural Actuator continued to be used over eight generations of LTO products. They ended up with a dual actuator, with a stepper motor stage for coarse positioning and the Flexural Actuator for fine control to do track following.

Teale: I remember that.

Chainer: And, so, it's evolved over the time, but still the basic flexural concept continued to be used.

Bajorek: Was this the first application in a product of a flexure-based actuator? Or how did DLT solve that problem?

Teale: They didn't have servo.

Albrecht: Yeah, eventually, they did. I mean, after LTO. But I don't know what they did for an actuator.

Biskeborn: Yeah, you know, I don't know.

Bajorek: I was just curious if that's-- and were you able to also get some decent patents out of this work?

Chainer: Sadly, back then, no. IBM Research had a high bar level for patents at the time. So, it ended up published as a technical disclosure bulletin…..

Albrecht: Yep.

Teale: Oh, yeah.

Chainer: ….which gave us freedom of action, but we weren't able to patent it. There was prior art on flexures in general.

Teale: I have a footnote on that for you. I mentioned that it was a real eye-opener working with all of these companies that were making the open systems devices. Tandberg Data was an amazing company. They were-- historically, they were audio tape. But they released a track-following servo QIC tape drive same year we released Magstar. So, it's not like we beat them to market. And I had gotten to know these guys pretty well, because I was qualifying their product. I visited Norway many times. Just clever guys. I mean, teams one-tenth the size of an IBM team and--

Albrecht: Mm-hm. Yeah, I went there once also on one of those trips.

Teale: Oh, good. Well, an idea they gave me was a-- I said, "Well, what do you use for your microchip, for your controller?" They said, "Well, you embed the Power PC. You embed the whole core." talk about taking cost out. That was unbelievable. And, so, we learned that from them and then we did it. But I had to go there once to negotiate something called a sliver patent.

Chainer: Okay.

Teale: There was some claim in their actuator design that we were-- our lawyers thought we were in it as-- so, I went with some lawyers, because they were just leveraging my relationship. Frankly, it was a bit of a holdup. I mean, "I'm your biggest customer. Give me that damn--"

<laughter>

Chainer: Okay. "Give me that--"

<laughter>

Teale: So, there was something there that Tandberg had contributed as well, but I don't remember specifically what it was.

Bajorek: How was it received by the LTO consortium, the other companies? I mean, the flexure-based actuator? Was there any pushback from them or--?

Teale: No. Let me explain. The-- we go into this ad nauseam in the LTO version of the oral history. That was about creating an interchange standard. Zero about any implementation. The only time we ever talked about implementation is if one of the companies says, "I don't get it. I don't see how to do it." And if you really felt strongly that this needed to be part of the interchange standard, then under very strict guidelines we could share an implementation to show the proof of the concept so that they could participate. But that's a big misnomer. There's a lot of people-- there was nothing about product development that was part of LTO. It was an ad hoc interchange standard, if you will.

Bajorek: Thanks for clarifying that.

Teale: And, in fact, you only talk about how to write the tape. You don't talk about how to read it, interestingly enough.

Albrecht: Yeah. When we did the LTO timing-based servo, it was just all about specifying the pattern--

Teale: Right.

Albrecht: --nothing about the write.

Teale: Didn't tell you how to write it.

Albrecht: Yep.

Bajorek: And Tim, how long did you group stay connected with that work with Tucson?

Chainer: It was 1988 when we shipped the first Flexural Actuator prototype to Jim Eaton. By 1991 we were working with Jim Overacker in Tucson. The Magstar product came out in 1995. So, it was over a span of seven years.

Bajorek: Seven years.

Chainer: Right, however, the Flexural Actuator was actually invented around 1983. That was the concept, not knowing it would end up in a tape drive, which turned out to be a fantastic application. And, again, driven by Jim Eaton's knowledge of everything that was going on in Research and deciding-- he was a genius-level guy-- deciding what technology would fit to solve the challenge of a track-following servo on a tape drive. You needed a great servo pattern, actuator, digital servo control and a talented team.

Teale: I'd say Jim was kind of the glue there.

Chainer: Yes.

Albrecht: Yeah.

Chainer: It was an amazing group.

Bajorek: So, I gather, Bob, that the early tape drives that adopted some of these innovations were still based on ferrite heads, right?

Biskeborn: So, this so-called flat profile HDD-compatible process head came-- the first-- with LTO. That was the first product. So, there are two aspects, I think, to the head and I've been involved in both of them. I'm actually still employed at IBM, still working in the head area-- well, for the head area, I guess. And, so, it's been since about 1996, I believe <laughs>-- so, it's been a long-- kind of a long career there. I didn't really expect to be doing that for as long as I have been, but it's been good and there's always-- when I'm working, there's always just one more problem or one more idea I want to get going on and then they never end. I mean, we're-- and that's pretty much the way it is even today. In contrast with the [HDD] heads that were being built in San Jose for-- well, the last set of products was Magstar—the tape heads were built on nickel-zinc magnetic ferrite wafers. Tape heads had adopted laminated nickel-iron-- nitrogenated nickel-iron thin films, first explored in HDD. But the wafers and the fabrication of the wafers was unique and not shared by HDD in any other way [that I am aware of]. And, so, the initiative was, you know, "Is there a way that we could just transfer everything over to using exclusively hard disk drive facilities?" And I think one of the breakthroughs was that for this QIC program that I mentioned, I think, we learned that, indeed, it's going to be possible to-- there's really no reason not to build-- not to dream about building multi-channel tape heads in the HDD line in San Jose. And the thin-- something I didn't mention is that back in the development group in San Jose in the early '90s that was run by-- headed up by Larry Spector, we actually explored different materials for the experimental heads that we were building. And, in fact, we looked at this AlTiC material. AlTiC stands for "aluminum oxide, titanium carbide," which is a mixture of those two materials, which are combined by ball milling and subsequently hip'd to form a very hard substrate that is used for the HDD wafers, for the main purpose that it's a hard and nicely machinable material -- in any case, we had some inkling back in, say, '92 or thereabouts that that wafer material might be a good choice for building tape heads, because of its-- the fact that it's very hard and not going to be worn out by the tape. And, in the course of the work that we did for QIC drives (with Herald Datanetics), there was some work that I did on trying to-- I mean, basically, we were wondering, you know, "How do we contour these single-track [AlTiC] tape heads for the QIC market?" This is a question that HDL had. As I mentioned, we were able to produce wafers that had MR heads, which [HDL] wanted. They were [built] on this AlTiC material. The heads [additionally] had AlTiC closure pieces on them. And, so, a question was, you know, "What dimensions? What radius? And what width?" and stuff like that. And, so, I got into-- I got engrossed in that problem to try to sort things out. And, in the course of that, discovered that you can take a-- let's call it a rail-- and put a cylindrical contour on it and you could, in principle, have the tape wrapping around the edges of the cylinder. And, in that situation, we learned that wrapping the tape around the edges causes an air skiving to occur and [that] causes a vacuum, essentially, to form between the tape, the head-- the cylindrical part of the head. And what that vacuum does is it pushes the tape against the head to create a fairly consistent head-tape interface. So--

Teale: Kind of like a “Jo block” effect.

Biskeborn: Yeah. Pretty much like that. And so, as we thought about it more, I thought, well, for the actual radius of curvature, you know -- I mean, we had [started with] -- those heads were fairly narrow and had pretty tight radii of curvature, but in the modeling that I was doing and in thinking about it, you kind of reached the conclusion that, perhaps a large radius of curvature would [also] work. And what’s a very large radius of curvature, but a flat profile? And why wouldn’t that work?” Now, I had had a discussion with Jim, and I was trying to remember when and I really don’t remember when it was. It was before we hired him back to help me with this stuff. But he had mentioned to me that he had had an idea for taking hard disk drive row bars and to-- you know, you have, say, 60 heads on a row bar-- 60 hard disk heads on a row bar, and you want to-- before you go through the trouble of fabricating them into sliders, you want to know, “Are they all good? Are they magnetically okay?” So, his idea was, [perhaps] you could take a magnetic tape with signals on it and run it over the row bars and get a signal out.” Of course, you’d have to make the connection to them and all that stuff. But, anyway, it was a discussion we had and I thought-- “Do you think that would actually work?” And he said, “Oh, yeah, it’ll work.” And-- but I didn’t pursue it with him. So, there were various thoughts that were on the table. And so, the one piece was “Can you build the wafers?” and then the answer to that was yes. And the other piece is that “Can you fab the wafers?” and we knew from the QIC work that we could do that. “Can you fab them flat? And if you can, then you can use the hard disk drive machinery to do that and [at the same time] cut costs.” We were pretty sure we could do that. And then “Can you make a reliable head-tape interface from that whole entire methodology?” So, that's really the thing that we studied for the better part of a year. And--

Bajorek: If I could just interrupt you for a second.

Biskeborn: Sure.

Bajorek: It’s obvious to all of you, but, to the listener of this history, is it-- I think it’s worth clarifying that, I think, until then all, if not most, tape heads had a cylindrical contour, right, to allow for good compliance, right, between the head and the tape. And, so, the tape world, right, grew up believing that that was essential, right?

Biskeborn: That was the paradigm at--

<overlapping conversation>

Bajorek: And you decided, “Well, maybe we could break it?”

Biskeborn: Right, right. So, the idea of-- so, the motivation was to leverage what was available in the disk business. And--

Teale: So, to be clear, there's an air bearing, a hydrodynamic air bearing. There's a resistance of the tape head spacing and tape heads were historically contoured typically in a cylinder to get a vertical tension component. And you can increase the tension to help control the spacing. The flat head is completely different and very-- because it's basically atmospheric pressure that's holding that, because you're taking all the air molecules out.

<overlapping conversation>

Biskeborn: Yeah, only the pressure--

Teale: So, flat head with a sharp corner. And, like you said, skives the air molecules out in a-- which also helps minimize head wear. A number of benefits.

Biskeborn: Yeah, a number of benefits.

Teale: And it was a critical invention.

Bajorek: But it was anathema to the experienced head-tape designers, right? The flat head? It must have been considered revolutionary, hm?

Teale: We never really considered it seriously. It wasn't until we were making the LTO head that--

Bajorek: Did you realize you were stepping into this?

Biskeborn: We were pretty aware of that, yeah. So, the conventional wisdom, as John was saying, is you wrapped tape around a cylinder for compliance. The tension-- there's a T [tension] over R [radius] times W [tape width] term that pushes the tape against the head and that controls the head-tape interface. When you take away the curvature, how do you get the tape to conform to the flat surface? And the way you do it is you wrap the tape around the edges. If you wrap the tape around the edges, you skive off air and create the vacuum, which then causes the atmospheric pressure to push the tape against the head. The interesting thing is that there's a situation where you can take the flat head and give it some [amount of] curvature, but have it operate the same way. Giving it a little bit of curvature creates that extra T over R x W term. Conversely, if you want think about the earlier or the older Blythe cylindrical heads, they didn't rely only on the curvature to form the interface; there were also some air bleed slots that assisted that. So, the thing that was really unique about the flat heads is that it just took away that T over R x W term and [we] just said, "Okay, we'll just rely on the atmospheric pressure pushing down-- pushing the tape down against the head." And that was the thing that we had to learn about and explore and make sure that it was going to work. Nobody was doing it. There was a paper by Hans Hinteregger that I [became] aware of in '96, where he and another guy-- another physicist [Muftu]-- had done some studies of that particular situation [this idea]. Anyway, we embarked on that by starting with row bars from-- that we got from the HDD folks and one of the-- there were some rather shocking and unnerving things that we discovered kind of early on. One of them was that heads wouldn't survive very long without-- in the form of row bars. In a row bar, you've got a substrate and the elements are in thin films at the other end of the-- at one end of the row bar and then, of course, you have the skiving edge at the other end. You run tape over this structure and you cause the tape to wrap the head, create this vacuum, and then the tape exits the side where the elements are. We found that if you had just even the slightest bit of wrap angle where the tape is exiting over the sensitive elements and turn the tape around and run it the other way, heads stop working in a hurry, in a heartbeat. And it wasn't really clear exactly what that was all about, but part of it was just wear that occurs, but there was some tribology taking place that seemed to be causing heads to [fail], basically, by, let's say, [an] ESD-type of processes that we didn't really understand. So, it wasn't clear that if we put a closure on this thing [the row bar], are we going to be okay? Is there something strange about the flat-head profile that's causing [this phenomenon]? So, that was an uncertainty. Another thing that we discovered was that when the tape is running over a cylindrical surface, the cylinder tends to put stresses in the tape that cause it to become flat in this direction <runs hand in transecting motion across paper>. So, when you don't have a cylinder, you can have <shapes paper concave>-- what prevents the tape from doing that? And what's the problem with that? Well, if the tape isn't lying flat everywhere, and maybe it [is not] at the edges, if there are magnetic recording elements in this poortion that we want to have access to, we're going to have a problem. And it turned out that this was-- Jim had attributed that phenomenon to anticlastic bending at the edges. And it actually turns out that 3D modeling [of the tape on a flat head] which I did showed that, indeed, it is expected and it is in the elastic properties of the tape. The problem that it was a fairly large effect and, so, it had a pretty significant-- some constraint on how we designed those heads. The way to circumvent this or to minimize it was that we had to make the head [lands] quite narrow and we had to increase the wrap angles by more than perhaps we were thinking originally. But all of those studies led to something that appeared to be viable from an implementation point of view. And, so, I think John when you came up and asked, “Do we have a head for LTO that's going to be more amenable to put into practice than the current ferrite heads?” which were much larger and had other-- had their sets of concerns and issues, we said, “Yes.” And we had-- I remember having discussions with you about this technology--

Teale: Mm-hm.

Biskeborn: --which was in its infancy in ’97 when LTO kind of came into being. So, we were taking a gamble there. We had to figure out really how to reduce the whole entire thing to practice: “How do we get-- how do we take the HDD process and, in the most compatible way we can think of, get these closure pieces on there? When we have closure pieces on the wafer, how do we lap them? How do we make connections to the electrical contacts so that we can do the lapping?” and just a whole raft of issues like that that were really interesting and fun to resolve. And we went from kind of, I guess, an idea that “It's going to work,” in ’97 to a head that “went out the door” [in the product, i.e. LTO-1] in the year 2000. So, in three years we did it. Now, there was a lot of work and there were a lot of people involved in that implementation. And I think that it worked out very well from a head-tape interface. You pointed-- and, in fact, some of the serendipitous-- one of the pieces of serendipity is that you-- as John was saying, you know, that having atmospheric pressure being the mechanism whereby the tape contacts the head, it's very consistent as long as you're at, let's say, sea level or not too high in the mountains or something like that.

<laughter>

Biskeborn: Yeah. And that led to studies of tribology where we were concerned about tape wearing heads out. You know, tape is abrasive and it can grind away at the materials in the recording gap. So, I think having a more consistent interface there led us to have a better control over head-tape spacing and all of the other tribology that goes along with it. And, you know, it's kind of funny: I remember a meeting that we had with Tandberg, who came to visit IBM at one point. I don't remember-- oh, I think they were looking for some possibility of an alliance of some sort. I don't remember the details anymore, but anyway, we described what we were doing [actually had done!] and they came out and said that they were very thankful that IBM [had done] that flat head, because they thought it was going to work, but they were too constrained by other concerns to actually try it themselves. But here we had done it and demonstrated that it was indeed viable. You know, there are a lot of other things-- other details I could talk about. They are mostly pertaining to implementation and performance and--

Teale: I'll mention one I'd like you to talk about, Bob. Tom earlier mentioned that the disk head is rarely in physical contact with the disk. And tape-- basically, your HDI spacing is the roughness of the tape, period. And that first LTO had-- we had a lot of problems that came up that we couldn't anticipate. Some of them seemed to defy physics, black holes, weird stuff. And one of your major contributions was the tantalum shunt.

Biskeborn: Yeah.

Teale: If you want to talk about what that problem was.

Biskeborn: Okay, so, along the lines of what John is talking about there-- and you had said what patents do we have-- so, over the years we've had to troubleshoot a lot of various issues with tape heads and those have led to some pretty interesting, I think, conclusions. But I think the-- so, one of the things that we were dealing with is that there was this peculiar phenomenon of tape running over heads that we observed where there-- that-- let's see. How do I put this in non-complicated terms? That if you-- so, if you connect a head-- one of the tracks on a head to an oscilloscope-- which, of course, we did-- and you run tape and you are looking at a recorded signal, you will see a sine wave or whatever the signal happens to look like. And then we noticed that interspersed with that early on, that there could be very large pulses that are being injected somehow, some way. And that was a very troubling thing. And, actually, it affected not just flat heads, but it also seemed to have an effect on the some of the Magstar heads. I think that's what you were referring to.

Teale: Yeah, I just remembered the tantalum shunt was something you put in to, I think, control a-- I think some of the problems were asperities hitting the MR element. There's a heat transfer and you did that to--

Bajorek: Were these thermal asperities?

<overlapping conversation>

Biskeborn: Well, no, no. So, well-- so, there are thermal asperities. They're not particularly an issue, but what we were talking about here, that-- John, that goes back so long ago and I completely-- I think, "Okay, all right. Now, let's see--"

Teale: It was one of the first problems you solved.

Biskeborn: Right, right. Well, one of a slew.

<overlapping conversation>

<laughter>

Biskeborn: Okay, okay. So, let me go into that. So, what that was due to, it turns out, is that when tape is running over the [head elements] – [starting with] Magstar and then subsequently LTO, we had introduced metallic magnetic shields [vs ceramic, e.g. ferrite] into the heads flanking the magnetoresistive sensors: first, AMR; then GMR; and later TMR. What we discovered is that those pieces of metal, pieces of permalloy, that are sitting in a sea of alumina a few tenths of a micron away from the sensor itself -- running tape over the head would cause-- could cause those shields to acquire a charge, a "tribo" charge. That, in and of itself, wasn't really particularly an issue. That-- I don't think there was any-- there would be no ESD breakdown or anything like that. The really interesting thing is that the tape has conductive stuff in it. There's the back coat, which contains carbon particles, and there can be other materials that have some level of conductivity. When those asperities [materials] drag across the head and shunt this charged up shield with the magnetoresistive sensor you could get the noise phenomena.

Bajorek: Charge transfer--

Biskeborn: Yeah.

Bajorek: --which manifests itself in this signal.

Biskeborn: It did. And it was a little bit-- there was a little more complication to it than that, but the solution to that particular problem was to not allow the [metallic] magnetic shields to float. And that was something that didn't [affect] only us; it was sort of an industry problem, I think, as it turns out, that we learned in hindsight. But, anyway, so the shunt that John is talking about is we found a way-- figured out a way to modify the head-build process to include [a] resistive shunt between the shield and basically the substrate ground. And what that did was add a high-resistance path [to ground] that bled charge off from the shield, so they never charged up. And I remember, you know, working on this. Actually, I had tried a bunch of different experiments, not-- you know, before I really understood what was going on there. And the interesting thing, to me, was that we built a wafer where-- in order to test this idea out, we have a 36-track head. So, we shunted every other channel in the head, ran tape on it, and then we looked for noise. And we expect to see noise on the non-shunted channels perhaps, maybe, but no noise ever on the shunted channels. It was not a shades-of-gray. It's one or the other. And I remember walking out [to lunch] with some folks who were actually doing the testing on the heads, that were built this way, and having a discussion with them, “Well, how’s the test look?” They said, “Well, it looks pretty good. The heads that have-- the tracks that have the shunt don’t seem to have as much noise.” I said, “Well, no. That’s not what we’re looking for. If there’s any noise, the theory doesn’t work. There’s something wrong with the theory. Or you didn’t build them right. [Or misinterpreted the data]” They said, “Well, that’s the way it is.” And I asked, “Would you please go back and look at the data,” and “okay,” they’ll go back and look at the data. I went to lunch, and one of the guys just by coincidence happened bump into [me] outside as I was coming back from lunch. He [exclaimed], “You’re right! You're right! All of the tracks that are shunted don’t-- are noise-free and all the tracks--” you know. Anyway, that was not much of a story.

Bajorek: You breathed a sigh of relief, right?

Biskeborn: Right, right. It was-- that was a bad lunch with a good dessert.

<laughter>

Biskeborn: You know, so, Jim and I worked together on aspects of this, including designing the wafer and the closures and the lapping processes. Jim left and went to a group that you had formed per some initiation from you, John, in Research. Yeah. And I think I was actually planning to come up and join you guys and just couldn’t get away from dealing with all of the implementation issues that were lingering on. And then that turned into the next generation product. And here I am; still there today. I don't know. So, I think the story is-- that’s the story and maybe it’s hard to really communicate the breakthrough nature of this flat profile. But, anyway, I think that’s what I can say about that.

Teale: It was the big enabler. There’s no way HDD was going to individually contour and lap at the head level. That was not going to happen. We, also at the time, had a strong desire-- or I did-- to go into the OEM 8-tape head business.

Biskeborn: Correct.

Teale: So, I had actually been selling our capabilities to Tandberg to-- even DLT when they were still at DEC--

Biskeborn: Oh, no kidding.

Teale: --I visited them. And, so, I knew what DLT was. I just didn’t know what it was going to become. And, unfortunately, the flat head, while it solved a lot of problems for us, it caused problems for potential OEMs--

Biskeborn: Yeah.

Teale: --because they were still on that paradigm. And for them, this is a huge redesign of their deck. And, so, we never got any traction with the idea. Of course, now we have lots of traction, because we’re the only ones who make them.

Bajorek: Yeah, Bob, I grew up in the disk drive side of the business, so when I started looking into this and I learned of your flat-head profile, I thought it was fabulous. I mean, that was an amazing breakthrough, because without it, I didn't see how you could have adopted--

Teale: I don't see it either.

Bajorek: --the disk drive heads--

Biskeborn: They wouldn't have-- yeah. No. No.

Bajorek: --the way you did. Now, so, I ask you not to minimize the importance of that contribution--

<laughter>

Bajorek: --but I'm sure there were war stories to be told about adapting these disk drive heads in terms of the MR elements, then the transition to GMR. Now, you're in tunnel MR heads.

Biskeborn: We are, yeah.

Bajorek: And I suspect that the head dimensions are not the same ones as the ones in disk drives. So, for example, in adopting TMR heads, was there any issue with the size of the-- the width of the head, the track width being so much larger than that of a disk drive and shorting events and--?

Biskeborn: So, it actually turns out that-- so, now, that's moving to more recent times, although still years -- so, in, what was it? 2008. I had on my chart-- every year or so-- well, probably more often, but we had-- in January [2008], I'd say, "Okay, here's what I think we ought to be doing for the future." And, in 2008, I had TMR on my slide. We didn't actually get it out the door until 2-- well, two years ago, basically. So, almost ten-- eight years. And it was really quite amazing what we encountered in trying to implement TMR for tape head. In some respects, tunnel valve-- it's almost a natural fit for a tape head, because what you need is large sensors. Large sensors require a high tunnel barrier resistivity, the so-called "RA". Whereas disk has little tiny sensors, you know, and by "tiny" I mean-- well, nowadays, it might be 30 or 40 nanometers' wide, 30 or 40 nanometers' tall. They [HDD] were forced into having to live with heads that were hundreds of ohms. And I think the industry went-- came up with the idea of shunting hard disk heads with just a plain old resistive shunt to bring the resistance down and to make the population of the resistance distribution more consistent for the product drives, but-- so, we didn't really have those problems. In fact, our tunnel barriers were, and are, okay, maybe five times thicker than an HDD, which is a good thing. So, that part was good. The area where we had trouble with TMR is getting heads-- well, when we embarked on that, our heads had 32 channels and, of course, we need all 32 channels perfect, no bad ones.

Teale: Unlike disks.

Biskeborn: Yeah, unlike disks, which is you have a bad head, so, the slider's a buck.

Teale: Right.

Biskeborn: The slider's bad, you throw it away. And as long as that's less than a-- you know, not much more over a percent, you're okay. That doesn't scale well to tape heads. And we actually had that problem going from AMR to GMR and GMR to TMR. GMR was an interesting structure for tape heads. We learned that it easily adopted from the disk drive business; just re-dimension it and some of the same things that I was talking about apply. But GMRs have an unfortunate aspect that they have a copper layer, a 20-angstrom [roughly] copper layer, that has to [survive at] the tape-bearing surface. We did our best to insulate it. But we think-- but we did observe that tape heads-- you really had to do some heroics to get those tape heads to survive, and the GMR heads to survive, in the tape environment. We worked our way around it, but when we went to TMR, we were afraid of many things. Like, for example, in TMR, one scratch [metallic smear] and you're dead. You've got a short and the head [may not] work and other things. But it actually turns out in the end that the TMR head was much more suited to running tape on it, or at least from a development viewpoint, [than either AMR or GMR]. You have much more [~3x] amplitude than GMR and you're more in sync with what's going in hard disk drives and so on and so forth. An interesting thing that we encountered when we were building the heads was that of the 33 heads we'd have on a module, we had trouble building heads that didn't have one or two tracks that exhibited noise. The noise would show up as what later we learned was jumping between magnetic states. The states were coming mainly from the domains in the free layer in the TMR structure. The problem was that we had to learn how to build the hard-bias magnets to do their thing [properly stabilize]. The junctions that were used in HDD and some of the processes had to be [altered] in order to get [stable] heads having no unstable tracks. I think there was a period of time where I wasn't really sure where this was going to go. I mean, we were working very hard on it, me and a couple of other people. And I remember in the course of trying to understand the mechanism of the noise, which was not understood initially by me or our head supplier, I went to Stuart Parkin, who was still at Almaden. I said, "Hey, Stuart, I've got this tape head." And "What is it?" "Well, it's got 32 channels on it." "Yeah." "And we're trying to make them TMR, tunnel valve." And his first-- it was very funny. His response to me was, "Well, that'll never work."

<laughter>

Bajorek: Very encouraging!

<laughter>

Biskeborn: But that may be a stock response. I don't really know, but then I said to him, "Well, we built-- we have some heads where all the tracks are good." And he said, "Oh, well, then it does work."

<laughter>

Biskeborn: But that wasn't helpful. We had to figure out why. Anyway, we were able to sort that all out.

Bajorek: Yeah, the reason I asked you about this is because the folklore in the industry, for those who don't know about tape heads, is that, "Oh, yeah, it's obvious. They just adapted this disk drive heads"--

Biskeborn: Oh, I see.

Bajorek: --and "it was a cake walk. It's an obvious thing to do." And my intuition is that it wasn't quite that simple,

Biskeborn: Yeah.

Bajorek: --that this adaptation required quite a bit of additional-- first of all, you ran into surprises. I think you--

Biskeborn: At every turn, actually. I only touched on a few of dozens. Yeah.

Bajorek: --and that you really had to modify the designs and processes significantly to be able to adopt these heads, right?

Biskeborn: Right.

Bajorek: I mean, maybe I'm wrong, but that's what I would venture, I would guess, really happened.

Biskeborn: So, we tried to leverage as much as possible what HDD has in terms of process and fabrication and stuff, but, in the end, you're right, that everything just-- it wasn't a direct drop-in by any stretch of the imagination. And then there's other issues, such as hard disk drive technology moves faster and we were always many years behind [HDD] [in terms of] what we needed for tape drives, because our sensors and track widths and so on are so much larger. So, we found, particularly with GMR, that the people who had done GMR in our supplier had moved on when [by the time] we needed that skill to figure out what was going on with our heads. So, it made that job a little bit tougher. There were interesting things like that.

Teale: We never had hard film, magnetic bias in tape heads before this.

Biskeborn: Right.

Teale: It was all soft film.

Biskeborn: Right. And that was starting back in-- many, many-- 20 years ago. Yeah. Gee, I don't know, Chris, there's so many different things I could talk about, but that--

<overlapping conversation>

Bajorek: No, but I just wanted to get-- to properly have you characterize-- accurately have you characterize that it was-- I don't want to put words in your mouth, but I don't think it was a cakewalk.

<laughter>

Biskeborn: Yeah.

Bajorek: That it took some hard work. Like you said, just adopting the TMR took seven- eight years, right?

Biskeborn: Yeah.

Bajorek: And I imagine there were equivalent battles you fought with AMR and then the GMR, right?

Biskeborn: There were. And we learned-- you know, so, unlike the disk drive business that employs many dozens of people, we had a group of-- in San Jose-- I guess it reached a peak of approximately 20 people. But we're doing the entire head integration actuator at that time with Dave Harper. I mean, it was the whole soup to nuts done by one small group of people. So, we had to leverage wherever we could, but we also had to learn fast-- we had to learn-- well, I guess I should speak for myself-- magnetics, magnetic design, head design, how to work with people who lay out-- do the HDD process design, and things like that. And then how to re-orchestrate fab to do what we needed it to do.

Bajorek: And I think you mentioned earlier, were you able to get some significant patents to cover these areas, this area of technology?

Biskeborn: So, we do. We have a lot of patents and we've done, I think, pretty well there. For example, we did patent our implementation of the flat-head profile, Jim and I. And I mean, one of the things I didn't talk about were all the efforts that we initiated to protect the tape heads from the tapes running on them. <laughs> And, so, we found that after AMR, that with the advent of GMR, we really needed to come up with a protective coating, and we were not alone in the industry. There were other folks in the industry attempting to do the same thing [HP and Sun Microsystems in particular]. But there was really nothing available. The coatings that were used for hard disk drive heads, the carbon coatings would wear off very rapidly, in a matter of hours. So, we had to find our own strategies for doing the protection and that-- and we had to make those strategies compatible with the need to maintain head tape spacing and protect against not only wear, but corrosion and other effects that come from the tape, which has its own set of chemistries running on the heads, which have their own set of materials.

Albrecht: Are you free to talk about what some of those overcoat materials ended up being?

Biskeborn: Yeah. So, we certainly, Tom, explored a lot of different things, but what we settled on was [based on] a discovery that we made, that aluminum oxide, which you would-- amorphous aluminum oxide, you wouldn't normally think of as being-- it's kind of a low-grade material that's in-- head processing is really designed for etchability and things like that. So, as a head coating it wouldn't be good, because it would be too soft and wear off. But we actually discovered and patented a way to form that [coating]-- during the formation of that coating on the head, to have it grow in a polycrystalline manner, which was really quite exciting. So, basically, what we wound up doing was putting low-grade sapphire on top of the head. And it turns out that that had enough wear resistance to provide the kind of protection we were--

Bajorek: Get you over the threshold of what you needed.

Biskeborn: Right. So, that was, indeed, I think, quite novel. No one was doing that. And probably isn't today. In fact, we're still doing it today. We haven't ever really found anything better than that. And, believe me, we've looked. <laughs>

Teale: The big challenge in tape since we moved to thin film heads, which is the whole area of pole-tip recession, because those materials in that gap are so much softer than the substrate, it doesn't take but a few micro-inches of recession of those materials and, yeah, the head is no good.

Bajorek: An acceptable head, essentially, had to take spacing.

Teale: Correct. It was defining the head-to-tape spacing almost.

Bajorek: So, this brings us to-- I think there was, what, the latest generation LTO-- what are we on, like--

Teale: LTO-7.

Bajorek: LTO-7?

Teale: It's a barium ferrite particle media and I have no idea what the head is, because I left 10 years ago.

<laughter>

Bajorek: It's TMR, right?

Biskeborn: It's TMR now, yeah.

Bajorek: And then that's what? That's about a 40-terabyte capacity cartridge?

Teale: It's huge. It's something like that.

Biskeborn: Twenty.

Bajorek: Twenty uncompressed.

Teale: Just 20.

<laughter>

Biskeborn: Well, 40- 50 compressed.

Albrecht: What's the track pitch now?

Biskeborn: So, the track pitch in our latest, highest density product is 1,100 nanometers.

Albrecht: Okay, 1.1 micron. Yeah, that's come a long way.

Biskeborn: It has. It has. And we're--

Teale: It's almost where disk drives were 30 years ago.

Albrecht: Oh, sure, yeah.

Bajorek: And the roadmap has, I think, at least three or four more generations, right? There's what LTO--

Teale: They're definitely up to LTO-10. It gets fuzzier and fuzzier.

Bajorek: But I imagine LTO-10 is not a cliff, per se, right? It's just-- that's how far we could see--

<overlapping conversation>

Teale: I think there's a lot of other dynamics in the market right now that are going to shape the future of LTO. Just having a roadmap really doesn't mean a whole lot anymore. It's really about the survival of the technology and that relies on the adaptation of the technology by the gigantic data people. And it is making some traction.

Biskeborn: It is. Clouds.

<overlapping conversation>

Bajorek: As I said at the introduction, I don't know of any invention that is superior to tape in terms of cost per bit and--

Biskeborn: I think that's correct.

Bajorek: archivality, right? So.

Teale: Somehow tape got a bad rep as being either low tech or unreliable, which is totally untrue. And all these companies were just building gigantic HDD farms: build a new building, get a whole bunch more cooling in there. And tape just solves that, because at rest it uses no energy.

Albrecht: I'm curious for your perspective: Over the years, once in a while, I would remark that tape technology is basically investment-limited, not so much technology-limited. In other words, it's not that you can't possibly figure out what to do next, it's that nobody wants to spend the money to do what's obvious to do.

Teale: Very capital intensive, yeah.

Albrecht: And do you feel that's still true today? I mean, it's come such a long way. I wonder if it's starting to become very hard now, too, even if people want to spend the money to move it forward. Or do you think there's still a nice runway there for another ten years of improvements?

Teale: Well, my biggest concern is simply that the supply chain. LTO arguably was to increase competition, increase participation. And we got a little traction initially. But the capital intensity of the business has become so large that there's just no other people that want to enter. And if nobody else enters, how long--

Albrecht: Yeah. Well, this is still a perception problem, because often if you hear somebody with magnetic storage make a comment about it's so capital intensive, it's just "How are we going to manage?" Compare that to semiconductor. You are nowhere near--

Teale: That's true.

Albrecht: They spend 10 or 100 times more for an advance than we would need to do in tape. So, that kind of tells me, yeah, it's a money problem. People still perceive it as not worth the trouble.

Teale: Well, and I think the other thing is that the other companies that traditionally participated, their tape head lines were just that: They were only for tape heads. So, that seems capital-intensive to them--

Albrecht: Right.

Biskeborn: Right.

Teale: --where we've got this amortization over a whole acre of HDD equipment. So, I did want to mention towards the end of Bob's pitch, I got a panicked phone call in the middle of the night once. It said-- from my old boss and good buddy Kevin Reardon-- who said, "I need you in Tokyo yesterday."

<laughter>

Teale: But you can almost do that.

<laughter>

Albrecht: That's right! Yeah. It works better coming this way.

<laughter>

Teale: And what it was, was I didn't really know what the topic was. And I showed up at a bank and it was all kind of like spy movie-type stuff, secure doors, and badges.

<laughter>

Teale: And in it was Kevin and 50 Hitachi guys. And they were negotiating the sale--

Biskeborn: Oh, wow.

Teale: --of the HDD business. And some Hitachi guy doing his due diligence found out that there was something called a tape head in this deal. And "What the hell is that?" and "why do we want it?" <laughs> And my job was to defend our honor and, hopefully, not break tape as a result of that sale. And it turns out that they were very delighted once they got her done, because they could make a lot more profit off the tape heads than the disk heads. So, they're making tape heads on a disk cost basis--

Biskeborn: Right.

Teale: --but the profit margin's enormous on the tape heads.

Biskeborn: Yeah.

Teale: So, it turned out to be kind of a win-win.

Albrecht: Well, HGST probably in aggregate made no money on hard drives. So, whatever you made on tape was very, very good.

<laughter>

Teale: Well, in fact, I met the guy who was running HGS-- HGST?

Albrecht: Yeah.

Teale: In Almaden-- north of this area. Forgot his name. Very-- he was ecstatic about tape heads. He said, "They're keeping the doors open around here."

Albrecht: Maybe that was Bob Holleran?

Teale: It was. It was.

Albrecht: Yeah.

Teale: He was a big fan.

Albrecht: Yeah, good.

Teale: But to just go out and invest to make a tape head only line, that would be--

Biskeborn: Oh, yeah.

Teale: --prohibitive to. You'd have to be a very large company.

Albrecht: Well, yeah, that was what was so significant about this flat head stuff, is you enabled all of that to happen.

Biskeborn: Right. And the TMR, I think was the--

<overlapping conversation>

Biskeborn: TMR was the breaking point in recent times for those who weren't ready to do it, weren't going to get into it, because the machines to build TMR heads-- you know, these Anelva tools are 15- to 20 million each, plus all the infrastructure required to get it working and then the know-how. If you're not doing it, you're not going to do it.

Bajorek: If you didn't have that hard disk drive line, you'd probably face a minimum of a billion, of not more, investment, right--

Biskeborn: Yeah, and who's going to--

Bajorek: --to come up with a new line.

Biskeborn: And who's going to do that?

Teale: I can't imagine anybody entering the business.

Biskeborn: Yeah.

Teale: So, how long can a single supplier-- there's a lot of brands out there that people that know *know*.

Albrecht: Just one bad business decision and it's all over.

Teale: Yeah.

Bajorek: If I were the end user, I would carefully protect the supply source, nurture it. Yeah, it'd be better to have ten suppliers, right, with independent streams, but a carefully protected small number of suppliers are better than none, I think, given the demand for data storage.

Teale: I think the story of tape, it started out as an actual data processing tool, believe it or not. Did a lot of sort-merge database stuff, did some real-time transaction stuff, reconciled the Federal Reserve at night. DLT ended up defining tape for what it really is, lowest cost--

Albrecht: Storage.

Teale: --cheap storage. And it's green, which is a huge deal. And given that that's the only parameter that matters now--

Bajorek: It's not the only area in which it matters. Look at solid state storage, right? Whether it's DRAM or Flash, it's cost per bit, cost per bit.

Teale: Well, and the people that have criticized the lack of supply chain for tape don't realize that even for solid state and HDD there aren't that many suppliers. Two or three biggies.

Albrecht: Basically, two or three at this point. Yeah.

Teale: So, it's like the whole storage industry is kind of arriving at this weird place.

Bajorek: Let me ask you a couple more things. Were there any special recognitions given to you as individuals or your people for some of these contributions?

Teale: Internally, at IBM, there were.

Bajorek: There were.

Teale: The LTO-- the people involved in the consortium received a corporate award. And then we had people involved-- I believe there was another LTO award that was a corporate award involving engineers. Unfortunately, I don't know if we got you guys.

Albrecht: I don't know specifically anymore. I think we probably did.

<overlapping conversation>

Teale: I think it seems like one of the--

Albrecht: There were a few awards along the years.

Teale: Because you start these awards and then every manager that reviews it adds their guy.

Albrecht: True.

<laughter>

Bajorek: Any external recognition? Or not yet?

Teale: Not to my knowledge, because we never really did-- this was never a real standard. LTO-- it's a licensed de facto standard. We didn't take it to ANSI or ECMA or ISO. So, it would be hard for an external professional organization to recognize.

Albrecht: Well, there's a little bit of an omission though on the part of, say, the IEEE Magnetic Society; that's really just dominated by hard disk people.

Teale: Right.

Albrecht: They never really thought to recognize any of the interesting things going on in tape over the years and we expected that and never worried about it. But, yeah, there was, to my knowledge, no recognition from that route, either.

Bajorek: I hope it gets revisited, that possibility, particularly now that LTO is, essentially, the last man standing, right?

Teale: Right.

Bajorek: I mean, it took over--

Teale: Well, there is a proprietary IBM version of LTO for the main frame.

Bajorek: No, I understand, but it's--

Teale: Not well known.

Bajorek: And it's rooted, but-- though in the same innovations, right?

Teale: Right. Exact same innovations.

Bajorek: So, I think it would be-- I hope it does get reconsidered in the near future for--

Teale: You know, I think there's some momentum building. For those of us involved in CHM, we get lots of emails generated from the community, your storage group. Recently CERN released a wonderful video of how they use tape in their environment. Very well received. Even Microsoft came out and did a very nice thing on tape-- featuring tape. And they're even starting to make fun of each other. They are, like, "Google guys say, 'Tape won't work,' but they're idiots. It works."

<laughter>

Teale: And, so, I think, potentially, there's a Renaissance. Okay, I consulted a little bit after I left the business and I would get asked these tape head questions all the time. And there's an argument out there about "Which is more important, the metadata or the data?" Because a lot of people argue, and there's been books written, that the metadata is really what's valuable. And if you believe that, then you don't need the data. Use it, burn it. But then there are people that argue that the data's more important than the metadata. So, if it turns out data wins, that is perfect for tape. Tape is perfect and it'll be everywhere. It will go into every social media. I was a customer advocate for the particle smashers. I visited CERN, I visited Los Alamos. And, actually, sold that tape to CERN.

Biskeborn: Oh, fantastic.

<overlapping conversation>

Teale: They're both high-secure areas, as you can imagine. And at CERN all the streets are named after famous scientists, Einstein Way and whatnot. At Los Alamos, all the streets are named after Islands that don't exist anymore.

<laughter>

Biskeborn: So, you know, the other side to this, too, is-- a thought I had is that tape has a pretty good future in terms of areal density. Our tracks are a micron, but we believe we can go much smaller than that. I mean, disk bits are 30 by 30, or whatever, nanometers. So, we've got this huge runway. We've got demonstrations that have been done in Zurich for very high areal densities that translate to 200- or 300-terabyte cartridges. They're not doable now. We'll need improvements in actuators and just everywhere you look. But it certainly looks like it's not out of the realm of possible. And then when you look at disk-- and, oh, of course, where is this tape going to go? Well, it's going to go into clouds. And when you look at disk, the runway for technological improvements has really become severely limited, I think.

Albrecht: Yes, you're right.

Biskeborn: Yeah, I mean, HAMR-- I mean, I don't know if it's every really going to become commercialized. Maybe. But MAMR--

Albrecht: But, you're right. I mean, in fact--

Biskeborn: MAMR is the same way, you know.

Albrecht: --a factor of 10 at this point is viewed as just a wild dream. Right.

Biskeborn: Right. Right, well, you certainly know more about that than me. I'm thinking about patterned media in that, which I think was extremely interesting, but I guess that's-- I don't know where--

Albrecht: Well, that's not being pursued.

Biskeborn: Yeah, it's not being pursued for-- so, you're really-- have a technology that has a very good future potentially, provided there's a sustainable investment coming in, which--

Chainer: But the good news is the demand is continuing to be there. I read articles that the amount of data in the world will double in two years and they project a faster rate.

Bajorek: Yeah, I think, by the way, there's a seminar by the local Magnetic Society--

Teale: Do you want to keep it though?

Chainer: Right, do you want to keep that data?

Bajorek: There's a seminar upcoming next week on the 15th in the evening. The local Magnetic Society has seminar on the future of demand for data, right? I think.

Teale: Talk about some other applications, you know, briefly to-- shall we talk about the social media, which is really just large amounts of data that you don't need online all the time. CERN uses it when they smash an atom. They have all these gazillion sensors and they are real-time writing that data to tape as it's happening. The European weather modelers-- you can imagine a few square miles of space with one millimeter nodes with state variables each.

Chainer: Yes, high resolution weather modeling.

Teale: These simulations are so massive that they insist on saving interim results on tape. So, that if something happens, they don't have to start over from zero. They can reload a position they were at.

Chainer: And then there's the teenagers.

<laughter>

Chainer: The teenagers send videos around like we would send an email.

Albrecht: Yeah.

Teale: Right.

Chainer: I mean, and we used to joke about that, remember?

Bajorek: Right, right.

Chainer: It's true: Videos are just shipped around.

Teale: And the Geophysical Society, they'll take a ship, they'll have 40 miles of wire below it, 40-1-mile pieces, sensor every yard, either temperature, pressure, whatever, salinity, who knows, and they drag it around the ocean and all of that data goes right on tape. Right on the ship.

Chainer: But then you think of self-driving automobiles and there's just no end to the demand for data. So, to have a scalable technology that will store that much data is just incredible, isn't it?

Teale: I don't know what would replace it really.

Bajorek: Before I let you go, you have a vast amount of experience when I add all of your careers. What advice would you give a young person starting today that might be interested in pursuing a career in applied physics in technology and engineering?

Chainer: Well, two pieces of advice or recommendations. One is, of course, follow your passion, what you find interesting. And the second one I've learned over my career is that when you have an idea, you want to go and talk to a bunch of experts who will know all the reasons why your new idea will not work, and then you have to ignore all that and pursue your idea anyway. You don't want to be talked out of something. Because, basically, the experts know why it won't work, otherwise they would've done it. But it's going to take someone with an idea-- it was like Self Servowrite: We talked to a lot of experts who said it would never work. And they had really good reasons as to why it wouldn't work. But the fact is that you could find a way to make it work.

And I'm sure it's true with all technology. Like the earlier example of Stuart telling you, "It won't work". You changed his mind in seconds, right?

Albrecht: I found that to be very true. There was no greater incentive to make something work than to have somebody say, "We tried that years ago."

Chainer: Right.

Biskeborn: Yeah, yeah, absolutely. "Never going to happen."

<laughter>

Chainer: Like predicting the end of areal density. Remember, there were talks that predicted the end. <laughs>

Biskeborn: Yes.

Chainer: It will never end. Human innovation is infinite, I think.

Albrecht: But I'm curious what your perspective is, because I do feel that the Golden Age of innovation in IT hardware is done. And it's not at zero, but there was a wonderful period from, say, end of World War II to the year 2000 where just everything-- it was just a wonderful area to be active in. It seems today there's much more stuff going in software or in bioinformatics or--

Chainer: Well, it's interesting. The scaling of the transistor might have been the greatest achievement by mankind. Going from 10,000 transistors on a chip to 10 billion. But as Moore's Law is coming to an end, there's now a whole new renaissance in packaging technology that's taking place known as 3D chip stacking. We've just seen announced a 3D microprocessor with two chips stacked together. If you look at the volume of silicon inside of an actual server, it's parts per million. So, I think it will never end. Systems will continue to scale. And the next generation-- they will find a way to do that.

<overlapping conversation>

Bajorek: But in a way, Moore's Law, in a way, made us a little bit complacent, right? Because it was just a matter of very difficult turn of the crank, but all we had to keep doing is turning the crank. But I think now it's getting harder and harder. I think we're going to have to look for some new breakthrough and invest in research that we haven't had to invest in--

Albrecht: Right.

Bajorek: --to create that next breakthrough. But, again, I learned very early that you can never underestimate the ingenuity of humans, right? They'll invent some new things that will surprise us.

Chainer: I always like to remind young students that roughly 250 years ago we were living in log cabins burning wood. We have come a long way in a pretty short amount of time.

Bajorek: Any other advice to young students? John, from your perspective?

Teale: Well, nothing specific. I just know watching my daughter and my son-in-law, who are both in the technology industry, they don't intend to have one career. So, their model that seems to work for them is a year of this and two years of that and year and a half of that. And it would be very difficult for me to advise a young person to go into tape drives. I just don't know how I would have that conversation or storage in any storage. So, I think it's a follow-your-passion thing and follow your ideas. So, we'll see. I don't think this is tabled, but it's hanging on.

Bajorek: Well, I want to thank you all for doing this. And I especially want to thank you for giving me the opportunity to talk to you about it. Thanks again.

Teale: You bet.

Biskeborn: Sure.

Chainer: Thank you.

Albrecht: My pleasure. It was fun.

END OF THE INTERVIEW

Disclaimer

Dr. Chainer wanted to make clear that his descriptions were based on his own memories of events which in some cases happened many years ago, and he was not speaking on behalf of IBM or anyone else in the discussion.

GLOSSARY

AIX open operating system from IBM
ALTiC aluminum oxide, titanium carbide
AMR anisotropic magnetoresistance
ANSI American National Standards Institute
CERN European Organization for Nuclear Research
CRC cyclic redundancy check code
DAT digital audio tape
DLT digital linear tape
ECC error correction code
ECMA European Computer Manufacturers Association
EE electrical engineering
ESD electrostatic discharge
ESCON Enterprise System Connection, IBM
Fab fabrication line
FICON Fiber Connection, IBM
GPFS General Parallel File System, IBM
HAMR heat assisted magnetic recording
IEEE Institute of Electronic and Electrical Engineers
ISO International Standard Organization
MR giant magnetoresistance
HDD hard disk drive
LPOS Linear Position
LTO linear tape open
MAMR microwave assisted magnetic recording
PES position error signal
QIC quarter inch cartridge
RAID redundant array of inexpensive (independent) drives
RISC reduced instruction set computing
T/Rw tape tension to radius of tape wrap ratio
TMR tunneling magnetoresitance
TTL transistor-transistor logic
VCR video recorder

APPENDIX 1

Background/Context (authored by John Teale)

Although Linear Tape Open (LTO) became the end result, it is far from the beginning of the successful collaboration between IBM Research and IBM Tape Development. There were three events that initiated and sustained the collaboration. These events will be taken one at a time to establish the context for the Research oral histories to follow.

Event 1: The "Eaton" task force report circa 1989.

For reasons that were not initially known, the IBM Storage Research group based in Almaden, California conducted a task force led by Dr. James Eaton, a prominent figure mainly involved in hard disk drive (HDD) activities. The purpose of the task force was to identify and assess possible upside technical opportunity for tape storage devices. The result was essentially a scaling exercise which concluded that track density of tape could be increased substantially if tape adopted track following servo.

To put this report in context, it is useful to note that from the first digital tape drive shipped by IBM in 1952 until the last of the 3480/90 devices in 1989, the capability of tape as measured by areal density only increased by two orders of magnitude in 37 years - woeful by modern Moore's Law standards. Areal density is the product of linear bit density and lateral track density. The 1952 drive recorded 7 parallel tracks spanning ½-inch width of magnetic tape. In 1989, the 3490E recorded 36 parallel tracks, barely half an order of magnitude increase in 37 years.

As a footnote the number of tracks seem to be arbitrary. but the trend started for good reasons. The drives of the 1950s were designed primarily to replace the Hollerith (punch) card which enabled management of large databases such as Social Security Administration and Census Bureau compilation. Punch cards encoded data as a six bit character plus a parity bit which represented all of the typewriter keys. Hence, seven track tape - these tapes could actually be "developed" with an iron particle solution to create a visual image of the data that could be decoded just like a punch card. A few years later the first disk drives appeared with an eight bit "byte" replacing the character, thus nine track tapes. Over time the correspondence between the bytes on tape and the magnetic representation diverged due to evolution of capabilities such as cyclic redundancy checking (CRC), error correction coding (ECC), data compression, etc. After nine track tape came eighteen track tapes, a truly arbitrary (and somewhat inconvenient) number since there was no compatibility requirement with nine track tapes. Finally, thirty-six tracks did require compatibility with eighteen. Due to the way data was recoded on tape at the time, 36 tracks was considered to be the end of the road.

It turned out that at the time of the "Eaton report" there were serious high-level discussions of discontinuing tape development and manufacture in IBM. The company was converting from an "income" stock model to a "growth" stock model. Since IBM drives only connected to mainframe "enterprise" server platforms, the grown opportunity was limited to this market segment which was growing at low single digits. This begs the question of how does putting more tracks on existing tape drives change the growth opportunity? It doesn't.

There were small but rapidly emerging opportunities for servers and storage in what was termed the "open" market space. IBM participated in the server portion of this space and WinTel, UNIX/AIX, and even AS400 servers were growing satisfactorily. These platforms had storage requirements, and the tape opportunity in those markets was driven by cost and capacity. More on these devices later.

The significance of the Eaton report was to develop a new, "open", tape device whose capacity could be advantaged using Eaton's suggestions. Cost would be addressed by a new, smaller form factor. The biggest winner in the growth tape market at the time was a company called Exabyte who was delivering tape drives derived from Sony 8mm digital video recorders that used Sony metal evaporated tape cassettes. The requirements established for a new open tape drive from IBM, inspired by the Eaton report, were aimed to hunt down and displace Exabyte everywhere.

Two teams were formed in Tucson, one to develop what became known as the IBM 3570 codenamed "Coyote" to tackle Exabyte. The other team was to draft on the emergence of tracking following servo in Coyote and "port" it back to the enterprise tape space, which became the 3590 "Magstar" tape devices. The idea being that development costs of Magstar would be reduced by leveraging Coyote technology. That's not how it happened, but it was a good plan.

The Eaton report was a major Research contribution to Tape in and of itself. It sustained IBM investment in tape that had been at risk. Tape agreed to directly fund a small team at Almaden led by Dr. Eaton, a unique funding structure to ensure mindshare and ownership by Research. Tom Albrecht, with us today, was a founding member of that team. Tom will talk about the significant contributions Research made that were adopted by the Tucson team to enable Coyote. The IBM model 3570 became very successful, achieving its objectives, and ultimately putting Exabyte out of business. Technically it is worthy of its own oral history, but the product was obscure and not long lasting. The firsts in Coyote included Almaden's timing-based servo, the servo format on tape, the flex clutch which enabled fixed motors to engage with fixed (non-floating) tape hubs, a highly non-trivial and robust idea. Almaden and Yorktown Research also contributed to development of the lateral head actuator and Tim Chainer of Yorktown is here to discuss that activity. Later Almaden was involved in the encoding of longitudinal position markers invisibly in the servo pattern, a remarkable contribution that eliminated the need for fine motor tachometers and resolved a long-time data integrity issue called "chopped blocks". Coyote was the first 5 ¼-inch form factor and the fist IBM tape SCSI interface.

Event 2: IBM decides to phase out of the tape business, circa 1991.

This came as a shock to the tape team, a result of a change of the guard at the top. Coyote and Magstar were not coming fast enough and there was tremendous competition for investment dollars at the top of IBM. The new plan was to immediately halt the Coyote project and those employees working on the effort were placed on "managed departure", meaning they were to leave IBM pending the when and how. The Magstar team was expected to complete the project and it would become a cash cow after which all tape investment would cease. The Almaden tape team was to be redirected. The Coyote team was still on the payroll, so even though the project was dead the team kept working because there was nothing else to do.

The Magstar team was in big trouble. As Tom will describe, the Coyote team was greatly benefited by Almaden's timing-based servo which was very robust. Tragically, the Magstar team was held to an obscure outdated requirement that prohibited timing-based servo and forced many suboptimal engineering decisions. The requirement held that some mainframe tape customers, especially NSA, had data security requirements that actually required degaussing the tape to ensure the data was removed. The tape volume would then be recycled back into the data center. But erasing the data in this fashion would also obliterate the servo format enabling track following. So, it was decreed that the Magstar tape drive had to be able to re-establish (write) the servo format at the customer location. A complicated/convoluted amplitude=based auto correlation servo format was developed that enabled this requirement to be met. The code was in the first product but was not enabled or tested pending a customer actually asking for it. No customer ever did - and this is not the only example of a bogus requirement corrupting a product design, there are many. (As they said in Tucson, the truth was somewhere "East of Eaton", Tom might get that.) Barbara Grant, one of the leaders to cancel tape, remarked that Magstar and Coyote had different servo solutions because IBM had "too many servo engineers". Kicking a team when it's down, ouch.

The biggest casualty of this action was the Tape head (read/write sensor) team lost the ability to design and prototype tape heads. The thin film pilot line in Tucson was dismantled and trucked away to the used equipment market - millions of dollars of investment gone. The head engineers dispersed in various ways and no one who knew how to design a head was left. Fortunately, the wafer head designs for Coyote and

Magstar were mature, and later San Jose did a build ahead of enough wafers to sustain at least the Magstar program.

As was mentioned earlier, IBM had tape storage needs in the "open" server markets. In fact IBM was not only the enterprise tape leader, but possibly the biggest customer of non-IBM tape drives. Wintel preferred the 4mm Digital Data Storage (DDS) derived from the Sony Digital audio tape (DAT). IBM sourced the drives from Seagate and the media from Sony. Risc/AIX preferred the aforementioned 8mm devices from Exabyte and media from Sony. AS/400 liked the Quarter Inch Cassette (QIC) solution and sourced the drives from Tandberg Data in Norway and the media from 3M in St. Paul, MN. Several other vendors were also involved to provide automation solutions.

The relevance of this external procurement of tape products is that the business figured that since it's open tape requirements were met in this fashion, then the enterprise devices could one day also be outsourced.
Perhaps IBM would even enable the external supplier. It is a little known fact that IBM encouraged both STK and Exabyte enterprises, and to a lesser degree Iomega. And as it happened, the mission for qualifying these components moved from Rochester procurement to the idle Coyote team due to skills match. Bit ironic going from development leader to tester.

Event 3: IBM decides to re-enter the tape development business circa 1993.

This had to happen because it was revealed earlier that Coyote was a success. Another change of the guard, another business model revision. Dr. Jim Vanderslice moved from printers to storage and saw opportunity in tape for the "razor blade" model - the blades being tape cartridges. Track following servo had dramatically changed the game in tape - media makers were now critically dependent on drive makers to format the tape. They needed heads, electronics, know-how. And this spells non-recurring engineering (NRE) recovery from media makers to drive makers. And it also meant royalties - BIG royalties paid by media makers to drive companies.

In 1995 the Magstar team finally shipped the 3590 which was 128 tracks on the half-inch tape, pretty impressive and proof of Eaton's vision. Coyote followed the next year and would have "owned" the open market by conquering Exabyte except that the goal post moved. A company called Quantum purchased all the storage assets from the DEC corporation. The focus of the deal was HDDs, but there was an obscure propriety tape drive in the deal called Digital Linear Tape - DLT - a DEC only tape drive. Quantum realized what they had, put an open interface on the drive, and proceeded to absolutely dominate the open tape market with the singular value proposition of tape being the cheapest dollar per byte of data on the market. So, Coyote's success was short lived.

IBM needed a new plan to realize Dr. Vanderslice's vision for tape. As an aside, he killed IBMs struggling optical storage business, which had failed to establish a market niche. The talent in that organization was moved to tape, and one of the leaders, Kevin Reardon, had extensive experience partnering with companies to develop products. Eventually the IBM tape team partnered with HP and Seagate to create "Linear Tape Open" - LTO - to target DLT. That story is already captured in oral history at the Computer History Museum. Many of the Research contributions to Coyote were adopted by the LTO consortia.

The question now was, how was IBM to develop a tape recording head for LTO? The only choice available was to leverage the HDD head lines in San Jose. A small tape head group was formed in San Jose led by IBM Research personnel including Sholeh Hassami, Neil Robertson and Gary Decad. Bob Biskeborn is with us today to tell the remarkable story of the LTO tape head.

