# IBM Tape History – Session 3:
# 3480 Tape Drive
# Andy Gaudet, John Teale, and Dan Winarski

Moderated by:
Tom Gardner

Recorded: October 14, 2015
Tucson, AZ

CHM Reference number: X7619.2016

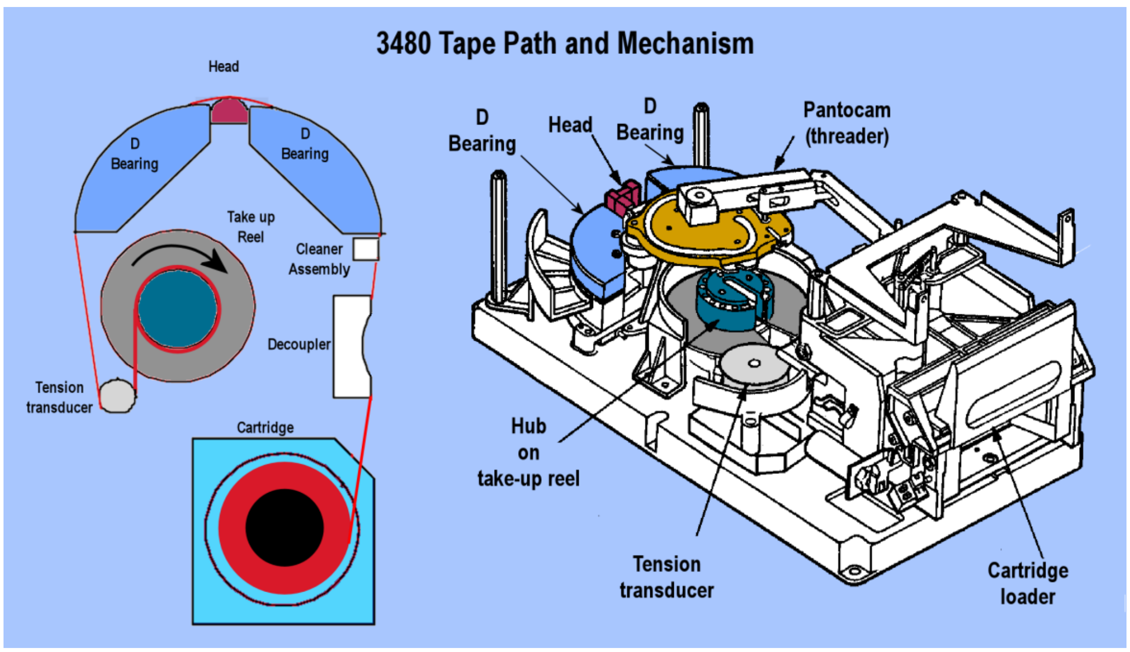
**Introduction**

This is session one of five sessions held in Tucson, AZ, regarding IBM's tape storage history. The five sessions are:

1. Tape Media (CHM catalog number: 102737992)
2. Overview of tape products and product management (CHM catalog number: 102737994)
3. 3480 tape drive (CHM catalog number: 102738021)
4. Linear Tape Open (LTO) Consortium (CHM catalog number: 102738023)
5. Recovery of tapes damaged in Challenger disaster (CHM catalog number: 102738025).

See IBM Tape History Session 1: Tape Media for an overview of IBM Tucson,

The primary focus of this session is on the mechanics of the 3480 tape drive. The mechanism evolved significantly from its first embodiment, code name Intrepid, through an intermediate version, Ocotillo, into the final shipped version, code name Saguaro and illustrated below:




Two articles worth reading on this subject are:

1. Mechanical design of the cartridge and transport for the IBM 3480 Magnetic Tape Subsystem, Winarski et. al., IBM JRD, November 1986 p. 635-644
2. Use of Ceramics for Tape Guiding in the IBM 3480 Tape Path, D. Winarski, ASME Adv. Info. Storage Syst., Vol. 1, 1991, p. 37-47

Appendix 1 is a list of 3480 technical Innovations provided by John Teale.

**Interviews**

**Tom Gardner:** This is Tom Gardner on our third day in Tucson on a tape oral history project. With me right now is Dan Winarski, who will tell us his history, including his involvement in tape products.

**Dan Winarski:** Well, thank you very much. I'm Daniel Winarski. I was born and raised in Toledo, Ohio where not only was I born, but my wife, Donna, was born, and our parents were born. Went to elementary school, Kleis Elementary, in Point Place of Toledo, Ohio. About halfway through that they shifted me to a new elementary school called Ottawa River. It was at that time the Soviets were launching their Sputnik and the teachers all looked at us and said, "Go into engineering." It's like, "Yes, I will go into engineering." So, my roots go way back, and I always enjoyed science back then. It was on to-- from Point Place Junior High to Woodward High School where my senior year they wouldn't let me take three study halls. So, they placed me in debate, and that's where I started dating Donna Robinson, and we dated through college. She went to Adrian College in Adrian, Michigan, and I went to the University of Michigan in Ann Arbor. It seemed incredibly far away, but it was like an hour's drive. I studied-- first, I was in nuclear engineering and I thought, "Yes, I want to do something with nuclear physics." But then after a while, I saw some of these job ads and it's like, gee, aerospace, could use mechanical/electrical. Nobody wanted nuclear engineering. So, I jumped ship to aerospace for about a semester. Then I thought, gee, if there's ever a layoff in the aerospace industry, I'm really up the creek. So, I went to something more general, and it was mechanical engineering. Then upon graduation, I went into the 82nd Airborne Division for just shy of two years. Donna was my war bride, and we were stationed at [Fort Belvoir, Virginia for the Engineer Officer Basic Course (EOBC); Fort Benning, Georgia for Airborne School; and then Fort Bragg, North Carolina for the 82nd]. it was an interesting story. Tom, you and I were both at Fort Belvoir for the Engineer Officer Basic Course at one time.

**Gardner:** What time were you there? [I went through EOBC in spring of 1962]

**Winarski:** Like August to October of 1970 [for EOBC]. But, it was at that time I went crazy and decided to go into the 82nd Airborne Division. My orders were to go to Vietnam, but I didn't know what I was doing. I just had this impulse one day and as it was, the 82nd Airborne had just gotten back from Vietnam. And so, it was like, wow, this is great. I'm stationed in the States. On my third jump in Airborne training at Fort Benning, Georgia, I broke a bone in my foot. And so, there I am one day driving around Fort Benning with my left foot-- my right foot slung over the passenger side and the MPs stopped me. I'm going, "Oh, this is going to look very good," but they said, "Sir, you're wearing your seatbelt. So, we're going to give you $5." It was great. From there then was the 82nd Airborne, made 13 jumps, even one jump in Turkey, [as part of NATO exercise "Deep Furrow"] which is very interesting, very nice soft landing. After the Army, went back for four months to Libbey Owens Ford, a glass company, the company sadly that no longer exists in Toledo, Ohio where I did mechanical engineering, and it was from there off to the University of Colorado where I got my master's degree in mechanics, and saw the IBM plant site for the first time. I thought, "Wow, what a great place to work." And then, by then, Donna was expecting. We went back to the University of Michigan for me to get my doctorate where I studied below-the-knee amputees. So, I did a lot of work in dynamics and force measurement. Some of that actually worked out for IBM. But, it was after that there were no jobs, and sadly, IBM wasn't hiring. So, I actually spent a year with Exxon Production Research in Houston. It was like miserable near the end. It would take almost an hour to drive just seven miles to get into Exxon. And so, one day, I saw this IBM customer engineer and I'm going, "Hey, it's not too late to try IBM again." And so, a Dr. John Harris decided to interview me, and I remember talking to Harley Oppeboen and Jack Wells, and Dave Norton. So, there I was, hired onto IBM. And it was a glorious time when we drove into Boulder. We were told a move might be coming, but not for three to five years, and we could stay in Boulder forever. Then two months later it's like, "Well, we're going to Tucson."

**Gardner:** This is '78 or '79?

**Winarski:** I'm sorry, 1977. It probably worked out for the best to be one of the first, if not the first group to move down to Tucson. So, we were able to get an affordable home. We were at the Grant Building at first. This Grant Building I think was like an abandoned like department store or something and near the airport [Drexel Road and South Sixth Street]. And so, it was like, "Oh, what am I doing here?" But, there was a funny story from that. I'm sort of diverging from my biography. But, Scott Graham and I were testing what was then the Pegasus [tape] media for interlayer slip, and we were trying to decide what sort of hub might be best for the tape reel. So, there we are in an environment chamber at 95 degrees Fahrenheit and like 90-percent humidity or something. It was just miserable. So, as you might imagine, we were in our gym shorts. So, Mr. Wells brings in a customer and we were behind a table like this. So, all you can see were naked legs and naked torsos and arms. He goes, "Huh," quickly excuses himself because of naked people in the chamber. So, it felt like heaven on earth when we got to move to the airport site. That was a huge step up, and that was about in '79 maybe. It took a while for us to get to the main site, even though the main site was inaugurated or whatever in 1980. But, yeah, then we find some things. That was really great. In parallel with IBM, I kept my Army Reserve career going. And so, I did my first tour of duty at the Engineer Research Lab in Champaign, Illinois. It was at that point I met Bill Chow, Dr. Bill Chow, who had gotten his PhD at the University of Michigan in the same area I had. He had studied gel and how to use sculptured gels to lessen bedsores. I was thinking, man, I'd really like to come to the Champaign-Urbana University. So, I was so pumped to talk to him about academic life, and he was all pumped to talk to me about IBM. So before you know, he's had his interview trip, and I remember taking him and his wife, Catherine, through the Saguaro National Park, the eight mile loop in the evening, and we got to see mule deer. Of course, they fell in love with Tucson. And so, they were hired by IBM. Did other tours of duty, but finally it was in 1980 -- so, I actually missed the inauguration of the main site for IBM. My wife and son got to attend, but I had been at Fort Belvoir -- I made a summer tour to Fort Belvoir looking for a home in the Army because I was like, "Mmm, if this is going to work, I've got to find something better than just doing little assignments here and there." Somebody said, "Well, you probably ought to get a new ID card because yours is like expired." So, I show up to the ID place and there's this other second lieutenant with his badge and underneath his name was United States Military Academy Instructor. And I'm going, "Wow, how did you get that?" "Well, you just send them your resume." So, duh. I send them my resume and that's how I spent almost all of my military career, teaching at the Department of Mechanics, Civil Mechanics Engineering at the West Point Military Academy. So, it was interesting. That was a fun career. My three courses that I taught would be Strength of Materials, which I liked, Vibrations, which I just loved, and it must have been a mental block, but Statics and Dynamics [was very hard]. There's something about that course. It's like, "No, not more dynamics." So, here it is 1999, after great times at West Point, being able to see fall foliage, going up in the springtime into Vermont, seeing the sugaring off of the maple syrup. Hurricane Floyd comes. We remember watching-- my wife came with me for my very last tour. Hurricane Floyd was going to like really smack into Florida. Somehow like this opposing wall of weather came to the Florida coast and just stalled the hurricane for a couple of days, and it's like, well, that's interesting. Then finally, Floyd starts heading with a beeline to New York. And so, there we are. We're quick grabbing candles and matches. We're eating really quick because the power's gone out and we know if we don't eat like right now, there's not going to be any food for a long time. There was a just a torrential downpour that Friday evening of my tour -- Army Reserve tours are like normally two weeks long. So, it's like Friday and then over the weekend the hurricane struck. So, dutifully Saturday morning, at the Hotel Thayer the workers painted the hallways, I mean the stairways, and the elevators were off. So, everywhere you went, you had paint on your hands, paint on your shoes, paint on the carpeting. But, it's really nice. I really miss Army Reserves. That was fun. Our son was born in Ann Arbor during my doctorate, and so, he was thrilled with Boulder and he enjoyed coming to Tucson, and I got a lot of inventions through IBM through the Invention Disclosure Program. So, I wanted to sincerely thank IBM for that, and Bob Freisen, who is the site general manager, and he-- I'm not sure how this happened, but he got the idea of having me come in for a number of times with my family and he would hand the check to Donna, the plaque to me, and give me a few good words, and then send us on. Well, our son loved the office. Bob Freisen is going, "Oh, inventions. Money. Plaques. So, intellectual property must be a good thing to do." So, he ended up getting his bachelor's degree at the University of Colorado. So, he got to go back to Boulder for a while. That was like '91 to '95, and then he went onto law school and became a patent attorney. At the same time he was becoming a patent attorney, I said, "Gee, maybe we ought to take the patent agent exam," because that's a formal bar exam, patent bar exam, you have to take. Engineers can take it. You just become a patent agent rather than a patent attorney. So, one night it's—he is about halfway through law school. And so, we'd been waiting and waiting for our exams. We took the exam-- it ended up being the last exam which was hand-graded and hand filled-out. You had to write everything down in long hand. And so, it took a long time to grade. So finally, our car had died. So, we're looking around Tucson for a new car. We couldn't find anything. So, it's Valentine's Day. We got home hungry. It's late. We're tried and grumpy because we couldn't find the car, and then we go to the mailbox and there's this real thin envelope for our son, and real thick one for me. So, I had mistakenly thought I'd passed. Well, it turns out he got the thin letter saying, "Yay, you passed; you're done" and I flunked. So, here we are on the phone. He's going, "Wow. I can't believe I passed," and I'm crying going, "Oh, my gosh. I got to do this again." So, I did pass on the second time, but that's certainly a memorable thing, but we owe it all very much to IBM and Mr. Freisen for giving our son kind of a look ahead to what his career could be. And he works now in Mountain View, California for Intellectual Ventures, not far from the Computer Museum. Donna, here in Tucson, was a substitute teacher for many years, and she taught at some 28 different schools on a part time basis as a librarian. And so, she enjoyed that very much. Now, she's retired from that, and I retired from IBM so to speak in 2013, two years ago, and then a few days later came back as a contractor. So now, I work, doing the same thing I did when I left IBM, scanning and licensing open source software. So, all those computer licenses nobody wants to read, that's what I help build. In between the open source software and working on tape, I did work with Andy Gaudet in the optical area, and that was a lot of fun. There were certain similarities between an optical library and a tape library. So, there was some transference of skills from one project to another. Then that was like roughly '88 to '94. Then in 1994 there were strong rumors of layoffs, that IBM wasn't doing very well, and something had to go. And so I recall the optical sales weren't that great. So, I had suggested to my son that he get his mother a University of Colorado nightshirt. I thought that might be fun for her to get. So, he ended up getting a XXX large, like football jersey [and she is only five feet tall]. Said, "Okay. Well, with layoffs coming, I'm going to wear that." Usually, IBM was the white shirt and tie and wing tips and everything. So, I'm showing up to work in shorts in this XXX, large football jersey, which you couldn't even tell I was wearing shorts. It went down to my knees. And this Doctor Vic Jipson, who was our functional manager in optics says, "Dan, there's somebody's who's going to interview you today for a job. Take it." It's like, "Oh, okay. I wish I would have known about this sooner." And that's when I was interviewed by a Joanne Mumola Williams to do patent licensing. That also tied then in with our son being a patent attorney. So, me doing all these trips around the world licensing IBM patents, so that helped him make his career decisions. I did that until about 2007, in this patent licensing. So, roughly about 12-13 years. As you can imagine, things changed within IBM. They took all of the patent licensing groups in the various divisions and coalesced them into corporate. And so, then I was briefly for a while, but not doing patent licensing. I was doing like technology transfer. And I, frankly, wasn't very good at that. You can imagine that like in Tucson, the tape area wasn't anxious to sell off its technology to like Oracle because we'd lose our marketing edge. So, I thought, well, maybe I can invent my way into some sort of palatable technology that IBM would let me license. So, when the end came to my being in this technology licensing area, I was working on trying to use IBM's giant magnetoresistive heads and nanoparticle tagged antibodies to detect cancer. A number of patents came out of that [such as US9,081,004]. Well, frankly, my management at the time was ready to fire me because, "Don't do that, Dan. We want you to concentrate on core things." I'm going, "Well, yeah, but nobody wants to sell the core things because they're core." We have to think outside of the box, but yet use technologies that IBM's familiar with like GMR heads and nanoparticles, like as used in Ric Bradshaw's tape. But now, they're frantically-- those patent applications that I filed in 2009, which was, by the time, the time I joined open source. I was sort of like given the opportunity to either leave IBM, or do open source. I'm going, "Open source sounds like a great plan." But, IBM went ahead and filed for patent applications back in 2009, and they're still dividing up those patents, that IBM is now getting more into the medical area, and maybe it's more medical records than medical technology. But, yeah, they're excited about it. And so, I just signed off on I think it was three divisionals just like a month ago. So, the medical area within IBM still lives.

**Gardner:** "Open source" in the sense of open source software?

**Winarski:** Yes. Open source software, yes. So, it's funny. Like harkening back to the old days where IBM wrote its own MVS system and that, now everybody grabs, or most everybody grabs stuff off the Internet. It's like you go to-- it's a giant like discount store and you just grab things here there. The programmers maybe in certain ways are more system integrators. They'll take these various diverse packages and then link them together into working modules. Now, it depends on the program. Some programs at IBM like the DS8000 used some open source, but it's mostly homegrown software. And other programs are almost entirely open source software.

**Gardner:** So, are you writing open source, or requiring open source to take a license?

**Winarski:** Well, not requiring it, no, but it's like market-driven within IBM. I'm sure other companies too. Rather than having to develop your own program, you say, "Well, OpenSSL does that for me. I'll grab it and just stuff it into my project, what I'm trying to do."

**Gardner:** So, you're doing software projects using open source.

**Winarski:** Right. Right.

**Gardner:** Okay. And the projects are in the area of?

**Winarski:** Well, one of them is like XIV in Israel. That was an IBM acquisition [January 2008]. So, they've got their Linux kernel, and then Linux user space and then there's other open source programs on top of that. Then finally, there's some of their own icing on the cake so to speak, and that's just one example. There's been SONAS [Scale Out Network Attached Storage]. SAN Volume Controller is a big user of open source;
**[00:20:00]**
tape projects, the tape libraries. Yeah, even the tape drives themselves, the LTOs are using open source.

**Gardner:** So, you've made the transition from a mechanical designer, a mechanical manager to a programmer?

**Winarski:** Well, a partial programmer. What I do is I'm more like an umpire in the ballpark. I look at what the programs are using and then I scan it with a scan tool and go through-- the scan tool is not perfect. Sometimes, it's better just to do it manually and you dig out all the licenses and sometimes they sneak something in there which they shouldn't. It's like, okay, you've got a GPL license package here which is interfacing with the IBM proprietary code, and there's something called a viral effect, that anything that your-- the IBM proprietary code, or anybody else's code that touches this, or links to this GPL license code now becomes available to anyone who asks for it. So, what we try to do is say, all right, find alternatives. So, I'm not so much a programmer per se as much as a, well, I can find this alternative patch for you. Why don't you try that, and this BSD license instead of GPL? So, we work with the various programs to try to put a firewall up between the GPL code. But then if it's like the GPL code is going inside the Linux kernel, well that's fine. It basically has to be GPL. So, a lot of that. So, then we go through the attorney justifications to use this code, and then we have to create the license, which is like a labor of love. It's like reading the phone book. What can I say? It's like uh. No. Fortunately, IBM's gotten more into the soft copy licenses and CDs. When I first started this job in 2009 there were a lot of hard copy licenses, and those were enormous. So, technology has moved on.

**Gardner:** Now, amongst your many patents is the patent I believe on the tape handling mechanism of the 3480. Is that correct?

**Winarski:** Well, I had like, if I recall, four patents on the 3480. One of them was on the tape cartridge, and that actually grew out of my work on the take up reel. The take up reel had to have a slot on it so that the leader block from the tape cartridge could seat, and then you move the take up reel to bring, to spool tape off of the tape cartridge.

**Gardner:** We'll go into a lot of detail I hope on how the tape mechanism works later today.

**Winarski:** Oh, sure, but I was just going to say-- but, so, we had to do something to the take up reel to make it work, and it's like we can do the same thing to the leader block of the tape cartridge. So, sort of like a backwards evolution so to speak that it was a serendipity, an unintended consequence of working on the take up reel. Then all of a sudden, we got something to work on the tape cartridge.

**Gardner:** So, that's one of your four. The other three?

**Winarski:** Oh, no. That's actually two for it because one for the take up reel US 4,350,309], and then the other for the tape cartridge US 4,426,047]. Then one was on [detecting Interlayer-Slip in the tape cartridge with] the Pegasus tape US 4,389,600]. Now, you were talking about Stallion tape earlier, and I'm not sure where Stallion and Pegasus all came together. But Pegasus tape was a thicker tape as I recall, 1.6 thousands of an inch, and it had a back-coat. I'm thinking, well, carbon back-coat; I wonder if that doesn't absorb water? And it did. So, what we would do is we would stress test the tape by we'd wind the tape at high temperature humidity, and then we'd plunge the temperature in the environmental chamber and sure enough, you could get interlayer slip, which would mean that the reel wouldn't rotate as a disk. The outer part would just sort of stay there. And so, we came up with a test, and true, as the tape then improved, the test probably, and I forget exactly when they probably took it out of the micro code bucket first-- but what you would do is you would actually cinch the tape against the leader block before you'd actually thread the tape path, and if there was slippage, you'd know, "Ah-ha." You just have to rewind the tape and then when the tape was rewound, then everything was fine.

**Gardner:** That's your third patent?

**Winarski:** Uh-huh, and then the fourth one actually grew out of West Point US 4,541,027]. So, there I am at West Point and I'm learning force/acceleration, and okay, because even though I had my doctorate by then, it was a requirement to teach at West Point, as you might imagine. But, just to see the stuff all over again, it's like, wow. It's like I'm back in school for the first time. And so, okay. So, force, acceleration, and impulse momentum. That's what I worked on my first tour of duty at West Point in 1980, and I get back to IBM and they said, "Dan, we want to have a way of detecting a tape cartridge, which only had like," and I forget exactly the amount, but like "half the amount of tape." They wanted a mini-tape cartridge so to speak. And I say, "Oh, I know how to do that" because I just learned that at West Point. But, what we did is we just put in a little impulse to the motor in the unwind direction and unwound the tape, but only like a few degrees of motion, and you could tell by the duration by that whether or not it was a full reel which hardly moved, or a half reel which moved more. And so, I go back to West Point and I tell them, "Wow. Look what I did." They're going, "Ah, we don't think so. We don't believe you." It's like, "Yes. Yes." This stuff, it was imminently practical what we're teaching here.

**Gardner:** Forgive me if I'm asking something that you already said, but going way back now to your wife; her parents were from?

**Winarski:** Oh, Toledo, Ohio as well.

**Gardner:** So, the entire family is a Midwestern family.

**Winarski:** Yeah, we're all very Midwestern. Now, my grandparents, I remember my grandfather, he actually came from Poland. He came a few years just before World War I broke out. So, he was a lucky guy. So, he met my grandmother in what was called now Polish Village in Toledo, Ohio. It was Bronson Street, near-- in fact, they lived near [the intersection of] Bronson and Warsaw [streets]. I mean how much more Polish can you get? I remember my grandmother telling me you want to learn Polish, get a job at a little grocery store at the corner of Warsaw and Bronson. Grocery stores now are nothing like they were back then, and this one was even smaller to begin with. It was like somebody took the tiny living of their home and made it into a little grocery store. There might be a couple of loaves of bread, and a couple of cans. That was all there was. But, it was interesting that Poland didn't exist before World War I so to speak. It was divided up between Austria, Russia and Germany. And so, when the Russians launched their Sputnik I, and I remember them counting down in Russian, going, "Wow, I got to learn Russian." So, I asked my dad's father about this, and he was able to teach me. I remember dva, odin, like for that would be two, one. I don't remember much more than that, but it's back like 60 years ago, or, yeah, about that, 55 years ago. But, if you ever watched the movie-- oh, I'll have to think of its name now. It's this submarine movie ["Ice Station Zebra"] where the satellite is-- we launch a satellite and the Russians take it over and take all these pictures of our bases. The satellite lands in the Arctic. But anyhow, the beginning of the movie showed the same types of computers being used by Russians and Americans, and they're both counting, be the Russian or English, and I could actually understand just maybe two or three of the numbers.

**Gardner:** That's both sets of your grandparents are from Warsaw area?

**Winarski:** No. My mother's parents-- well, I never met her father. He was in the coal mines in West Virginia and died of black lung disease. So, I only knew her stepfather. He was actually in the Spanish-American war and was bayonetted. So, he showed me his scar probably one time. But, my mother spoke of them being part Ukrainian. In fact, one of our relatives, distant relatives, and of course the records are gone now, but was a Cossack. So, there's some Russian in there too I guess.

**Gardner:** How about your wife's side? Did she share any of that with you?

**Winarski:** Uh-huh. We know much more about her parents, I mean her grandparents and great-grandparents. We have an uncle. Now, she's going to murder me for not remembering their names, but it's Herman Hinkleman, that's right and his-- it's like great-grandparents. They hang, their pictures hang in our living room. They were from Germany, and we have their immigration papers, when they swore away the Kaiser of Germany and were agreeing to become US citizens. She's also part Scotch. There's a reading in some books about people in England, some of them have a characteristic like little white flash of hair, or white, and she had that. Now it's mostly white.

**Gardner:** We'll edit that out of the tape.

**Winarski:** Oh, but it's interesting. Okay. Go ahead.

**Gardner:** I apologize if I'm repeating, but did you say how you decided to become a mechanical engineer?

**Winarski:** Well, that's a good question. Going back to the University of Michigan-- I loved high school physics and I remember nuclear physics and neutrons, protons, electrons. I'm going, that's what I really want to study. So, I went off into nuclear engineering, but it was not really a department. It was more of a curriculum. You go in there and it's like a little office with two professors. I'm going, "Uh, I don't have a good feeling about getting a job when I'm through with this." So, I went into aerospace, and that was about like 1967. It's my sophomore year and that was not long after Chuck Yeager's big spiral-- a jet plane went out of control at like 100,000 feet and he spiraled down to 40,000 feet. When the invention was that the-- to make a fighter craft supersonic, they had to go into like a wasp wing to shrink down the center of the body because the area of the wings was like a box. So, if you shrink down the diameter of the plane at that point, the plane could sustainably go beyond the speed of sound. I'm like, well, that's all very interesting, but just looking at the job, it's like if you were going to be in aerospace, they also hired mechanical engineers and electrical engineers, and all sorts of engineers. So, I'm thinking, gee, mechanical sounds more versatile. We'll, you're essentially studying the same things, not exactly per se. I mean we, as mechanical engineer, didn't study wing shapes and angle of attacks, but I still took fluids, and I still took structures and dynamics. I figured if I were to go into aerospace, maybe mechanical engineer were a safer bet because I could go into other areas as well, not just aerospace. So, that's how it all began with Professor Leland Quackenbush at the University of Michigan. So, I still remember him, and I had finished up at the University of Michigan and was off in the Army. We visited one time briefly and I somehow, well, not somehow, but there was this -- Pi Tau Sigma, an honorary for mechanical engineers, and Professor Quackenbush, whose desk was heaped up with paper, he sort of said, "Well, Dan, I think I know where your certificate is," and he sort of dug over on the left corner of his desk, and he sort of felt around, and he was able to pull it out. It just seemed like an impossible, unorganized mess of just papers he dumped there, but he knew exactly where it was.

**Gardner:** So, any more background information you'd like to share with us, or anything I didn't ask about?

**Winarski:** Well, sure. Sure. Just from a military standpoint, in addition to my wife's brother having been in the Marines, my dad was in the Normandy Invasion. He was [the helmsman] on the LST 60 [Landing Ship, Tank]. So, he landed Patton's tanks at Utah Beach.

**Gardner:** Utah Beach.

**Winarski:** Uh-huh.

**Gardner:** Have you been to Normandy?

**Winarski:** No, never have, but I think that would be good. We'd been to France, but no, we haven't been to Normandy yet.

**Gardner:** Yeah. I personally highly recommend it--

**Winarski:** Sure, a must do. Near the, or after finishing my Army career, because the Army let you stay in only so long. It's up, or out, and I made it to lieutenant colonel, which was better than I ever thought. But, in 1999, I politely retired. I had a great retirement ceremony. It was on the heels of that Hurricane Floyd that I mentioned earlier. I really missed teaching, didn't really see it as a career. But then, a few years later, the Native American Diversity Network at IBM said, "Dan, we need teachers. We're going out to the Tohono O'Odham Community College, and we need people." So, Donna and I showed up for that and we became very much involved with the Native American community, teaching a lot at the Pascua Yaqui Intel Clubhouse; Tohono O'Odham's [Baboquivari] High School in Sells [Arizona]. And the last four years, I was able to mentor students to go all the way to the Intel International Science and Engineering Fair mostly with solar projects. So, that was a lot of fun.

**Gardner:** It is, again, today, Wednesday. We're here in Tucson [Arizona] at West Press conducting a series of oral histories on the history of tape with a focus on the 3480 tape drive. Today's session is intended to be mainly about the mechanism, the drive itself, and we now have Dan back with us, but we have added John, who graciously gave the Computer History Museum a plug yesterday and to show his enthusiasm, joined us today wearing its t-shirt. In addition to John and Dan, we have Andy as our panel. So, we did yesterday spend a little bit of time on vacuum columns in general as buffers, either electrical or mechanical depending upon your background. Of course, there's much discussion over the last two days over how the mechanism itself beyond the technology of the tape, the mechanism itself had a number of innovations to improve reliability, accuracy, performance. That's really the subject today. Dan, can you sort of walk us through in your view the difference between a conventional reel-to-reel vacuum tube mechanism and a mechanism that wound up guiding the tape to the head and to the take up reel in the 3480?

**Winarski:** Okay. The IBM 3420 used a pair of vacuum columns, which decoupled the 10.5 inch reels. And so, the 10.5 inch reels would have to move eventually. But in order to make a rapid motion of the tape, you only had to change the vacuum a little bit, or no, I'm sorry. Not change the vacuum. There is a little like spindle motor, which would move the tape across the head. So, you actually had very little moving mass as opposed to the revolutionary 3480 where now we're going to move the reels in unison. So, the 3480 had a lot more mass to move. And so, in the 3480 the tension control was very critical, as well as the motion control of the tape. You had to control big masses as opposed to just the little bit tape going across the head. So, there was a big jump there, and as I recall, the first person who worked out the block diagram algebra for reel-to-reel servo was John Eige in IBM San Jose, and that was back around 1977 US 4,125,881]. Then he transferred that knowledge to me when I was sent out-- I joined IBM on Monday morning and by Monday afternoon, this one manager was looking at me like, "Hmm." And so, they actually wanted me to fly to IBM San Jose from Boulder at 5:00 that day. And so, "I don't have any tickets. I don't have any luggage. I don't have any reservations. I'm just going to like show up at the airport." So, I begged them off, and so finally, I think it was the following Monday I went up. But then, we had a very long tour. That's where I met John Eige and then, the person who did the very first pneumatic tension transducer, which became part of the 3480 tape drive. Although at this point, he did, and I'm sorry. I don't remember his name, but he did-- it was a three-pronged tension transducer where the tape would come in, wrap around, and it was a little solid state pressure sensor in the center of this and there was pressure-- the [pneumatic] pressure exerted on by the tape was this function of this tape tension divided by radius of the wrap and the width of the tape. So, at that point, it was only instrumentation. But then, Tom Osterday and others made that into an actual physical part of the tape drive US 4,842,177]. So, in addition, you have to have tension control, making sure that the reels were opposed to each other so that the tape would lay against the head. At the same time, the tapes had to rotate in unison to keep the tape moving across the head. Then you had this tension transducer to measure the tape tension to ensure that the tension was within a reasonable spec. One motor had a fine tachometer. So, I recall like 500 lines, and then the take up reel was a single line tachometer to count revolutions. So, the entire servo system is totally different from that of a vacuum column tape drive. It was certainly a big leap for IBM. Does anybody have anything to add?

**Teale:** No. We talked about it a little bit yesterday. That's pretty much the same thing we said. Maybe a slight variation. The tension and velocity control derived from the tachs, which give you the radius estimates of two reels, you could pretty much open loop control velocity and tension. Like Dan said, you always have a torque, opposing torque differential between the two motors to maintain the tension, and when you are accelerating, you would increase torque here and decrease torque here, but you always maintain this differential. My recollection was only slightly different. I recall that the tension transducer was kind of put in really not from time zero to control transient events more than steady state, but I could be wrong.

**Winarski:** Oh, no. Forgive me. When did you hire onto IBM?

**Teale:** 1978.

**Winarski:** Wow. -- didn't I interview you?

**Teale:** You might have.

**Gaudet:** You can never forget, Dan.

**Teale:** So, we can back up. I was very impressed by Dan's biography. Dan was one of the first people I met in IBM. I remember him even if he doesn't remember me. I remember, I think you were working for a guy named Dave McMurtry.

**Winarski:** Yes.

**Teale:** And he worked for a guy named Dave Norton.

**Winarski:** Yep.

**Teale:** And I was kind of on the technology tower. Dan was on the product tower with Joel and others. We had some interaction because as we talked at some length yesterday about what the impact of getting rid of the vacuum columns caused, and there were just a number of ripple down things. You put it in your own words where we had so much more mass to deal with instead of that rubberized capstan with a vacuum in, which is all you were spinning in 3420. But, my recollection is that the Saguaro deck, or whatever it was called at the time [called Intrepid] -- we started with an assumption of no pneumatics.

**Winarski:** Correct.

**Teale:** So, that was one of the things we talked about yesterday, what was assumed and then later what happened.

**Winarski:** Oh, that's a good point.

**Teale:** And I remember one of the things is I designed the air bearings [on the D-bearings]. I remember handing you a little piece of paper that said--

**Winarski:** Yes, I remember that.

**Teale:** --10 mil holes on 100 mil centers, 150 mils from the edge.

**Winarski:** Yes. That's right. <Inaudible.>

**Teale:** That was all there was to it.

**Winarski:** No. No, it was important because originally, the 3480 was called Intrepid.

**Teale:** Oh, that's right.

**Winarski:** Yeah, and Intrepid had-- in fact, as I recall, John Eige did the basic design, and he was an electrical engineer. So, he did all of this servo work, which was invaluable. Maybe other people helped him, but from a tape standpoint, he said, "Well, we're going to use fixed tape guide separated roughly about six inches.' And so, they need to be separated that much to control the skew of the tape. They would be open channel guides, but there would be enough tolerance there so that this rigid beam of tape wouldn't go off track. Well, as we all know, a tape is elastic. Remember, it's not rigid. So, it took us a long time to figure out that that [open channel] design wasn't going to work. We tried moving these open channel guides closer in. Of course, then the skew went crazy, but we were able to control lateral motion better. And then, we moved them further apart. So, skew is better, but the tape would go crazy from the lateral standpoint. So, that's when we threw up our hands and we went with Ocotillo. Ocotillo had hydrostatic air bearings, -- so, we're evolving. We knew we needed pneumatics back. Now, it's true LTO then got away from pneumatics, but this point, we were like desperate. We knew that the open channel guides weren't going to work. And so, it was like, well, the MSS 3850 used air bearing guides. So, it's like, well, gee, maybe they knew what they were doing. So, we're going to try that. So, we actually tried bigger D-Bearings and these smaller D-Bearings, and the smaller D-Bearings with the head positioned opposite the D-Bearings so the tape kind of wove in and around the D-Bearings; it [initially] performed better than what eventually became part of the 3480 where you had these bigger D-Bearings in the head. But, it turns out it was impractical to thread the thing. The threader was designed and particles would just shower down. So, we had to eventually change the design from Ocotillo to what became Saguaro and Saguaro is with the big D-Bearings. We were getting close now to the final design.

**Teale:** Yeah. We talked yesterday about how we flipped the head back and forth a couple of times, and we had the Laugh Track threader in Ocotillo.

**Winarski:** Yep.

**Teale:** I would like to amplify the word "skew" because it is something that's somewhat unique to tape. When you've got 18 tracks or whatever across the width of this tape, and it's interchanging between heads, some heads might be tilted a little this way and other heads might be tilted a little that way. In 3420, skew buffer as we know it today didn't exist. So, they actually had something called skew tapes. So, that was a master gold tape, and you'd stick that tape in there and you'd look at the timing of the top track and the bottom track and adjust the heads so that all the tolerances were contained for skew. 3480 we had some skew buffer; not a lot. As Dan said, there were still some constraints over how you had to control really all six degrees of freedom as it turns out, and they all have their own kind of story. But of course, this concept of skew, because it's multitrack doesn't exist in disk. So, that's a term that's purely tape.

**Winarski:** Yes. [Also, the read signal amplitude was proportional to the sinc function "sin(x)/x" of the skew angle, so an inappropriate skew angle, exacerbated by interchange, could render the tape totally unreadable, regardless of the size of the skew buffer.]

**Gardner:** You mentioned, Dan, the term D-Bearing.

**Winarski:** Oh, that's what we called the air bearings because they were D-shaped [from the top view]. They had the curved outer track, and then because there was limited space on the tape head, we had to cut off-- but, we could have had big circles, but we had to cut it off somewhere to make room for other things. So, it was D-shaped.

Tape head

**Teale:** Yeah. I don't see something here to simulate it, but this is a head. You're looking at the end view. The tape is going like this, and these D-Bearings were two large bearings that sat on either side of the head, but of course it's a truncated cylinder. So, imagine that this is gone. Something like that on either side, and that was mounted on a casting known as the head guide FRU [Field Replaceable Unit]. So, these are the D-Bearings, the head, and all of the critical alignments of the head were relative to that casting as a base and those two D-Bearings, including the penetration, the wrap, the azimuth, the skew all had to be fairly well controlled. But, we did have the luxury of having a-- one of the things we talked about, Dan, was that we didn't have a data buffer in 3420. So, the tape drive had to be ready to rock and roll at all times. When that data came, the only place to put it was on there. The advent of electronics and the evolution of electronics allowed us to have a modest data buffer on 3480. So, it was okay to have that reduced acceleration and tape repositioning time. We also had the skew buffer, and it's relieved some of the tolerances, and skew tapes kind of went the way of wherever they go – to the History Museum. So, I'm kind of just bridging some of the things that already have been said.

**Winarski:** Oh. Sure.

**Teale:** So, the D-Bearings were initially not pressurized. There was no air in that [Intrepid] path.

**Gardner:** That was one of the assumptions that did not pan out.

**Teale:** It was one of the assumptions and it didn't work. You know what? We tried it. We tried hard. It didn't work. Put air back in the system, and then we found out, oh, now that we have air in the system, we've got three other reasons why we need it.

**Winarski:** That's right.

**Teale:** Let's put a vacuum on a cleaner blade. Let's stick a tape lifter in the middle of the head. So, it turns out we really did need it. We didn't learn a darn thing from that experience because the next follow-on after we shipped 3480 was a project called Barrel where we made every single mistake we made in Intrepid all over again with a new group of people. Barrel failed without pneumatics.

**Gardner:** So actually, maybe for Dan's benefit, I think yesterday we sort of came up with the assumptions that came from Boulder to Tucson about the product. It included a fundamentally major improvement in unscheduled instances and scheduled instances -- that the product not require cleaning, the head would last forever. In IBM's terms as I understand it, UI and SI are the--

**Gaudet:** DUI, duration.

**Gardner:** UI is the incident rate. DUI is the duration. Since IBM typically maintains the product, these are very important financial numbers, and the objective then was push that football way down the field to paraphrase my friend John. And then taking out pneumatics would be one way of doing that, right?

**Winarski:** Oh, yes.

**Gardner:** Pneumatics are not as reliable as other things. So, a major objective was major improvement in the reliability/maintainability of the product. There was a fundamental decision for chrome dioxide as the particle type. I guess underlying that, we went through a lot with Ric on Monday -- the formulation was going to be the same as then being used in the MSS, and that turned out to lead to a bunch of changes, but it remained fundamentally chrome dioxide throughout. Magnetoresistive heads, inductive writers, 160 megabyte cartridge capacity so, the old reels could be written to a cartridge.

**Gaudet:** Wasn't it 200 megabytes?

**Winarski:** Yeah, I remember 200.

**Teale:** The initial requirement was 160, and if you recall, during the course of the six-year war, we upped linear density a little bit. We made the tape a little bit thinner at some point.

**Winarski:** Yeah, that thinner tape helped, yep.

**Teale:** We ended up shipping 200 megabytes. What we did inherit in 1978 when we all landed to do this was, okay, you're not going to have any vacuum columns. It's going to be a significant improvement in its reliability and maintainability; hopefully reduced cleaning requirements because 3420 was kind of a pig that had to be cleaned every day. We assumed thin film write head. We assumed magnetoresistive read sensor so that we could operate at lower velocity so that now the signal amplitude was velocity independent. Tom had a list and kind of the gap we were bridging yesterday was the impact all of those assumptions had on the universe of we didn't know what we didn't know.

**Winarski:** That's right.

**Teale:** And then subsequently, we spent six years attempting to engineer our way around the impact of those assumptions. For example, I don't even think the guys that invented the vacuum columns realized what a terrific invention that was.

**Winarski:** It was absolutely.

**Teale:** Because it wasn't until we got rid of them that we discovered a whole universe of stuff - ISVs [Instantaneous Speed Variations] and interlayer slips and Z-folds [where the tape doubles back on itself forming a Z] and just a ton of stuff that just was a non-issue with vacuum columns.

**Winarski:** That's right.

**Gaudet:** But the end result-- it was a six-year war. But, the end result was that the technology, the tape deck working together; the teams working together, bought the tape deck together with the technology. They had the deck, the recording channel, and all that. It was a very, very successful design, implementation, and very good field experience in terms of UIs and DUIs.

**Gardner:** Actually, the other two things that we sort of agreed on yesterday; I think actually the caching was fundamental. That replaced the vacuum tube. That allowed the isolation electrically as opposed to isolation electrically as opposed to isolation mechanically. The other one was the cartridge itself. The decision was abandoning 3420 open reels, go to a cartridge.

**Teale:** We talked a little bit about, okay, what is media life, and those are mostly marketing apples. Those are not generally eating apples. It's a bunch of voodoo numbers because the magnetism on a piece of tape will be there until the sun explodes. It doesn't go anywhere. Most errors in tape are caused by some type of tape mishandling, overexposure say to high temperatures that would erase the tape. So, for example, back when there were mom and pops first sprouting up to rent you a VHS tape and a player if you needed one to go home and watch a movie, they had a thermal label on them, a little dot because if you exposed that VHS cassette on a Tucson car dash then the magnetism would be erased. But, the mom and pop doesn't know that when you return the tape. So, they check to see the temperature that thing has been exposed to. They also attempted, believe it or not, to design the plastics to melt at approximately that same critical temperature, and its obvious I'm guilty of bringing a VHS tape back overheated

**Winarski:** Oh, you know all about it.

**Teale:** So, that cartridge was just in and of itself, and Dan, I see you have some exhibits, was more than meets the eye.

**Winarski:** Yes, absolutely.

**Teale:** Yesterday, we talked about squealing. Remember squealing when we plugged these things in and there was this squealing all over the laboratory?

**Winarski:** Oh, yeah.

**Teale:** This cartridge was supposed to be one inch think, and now somehow it became 24.5 millimeters.

**Winarski:** Oh.

**Teale:** So, there wasn't enough clearance on it to lift the brake button.

**Winarski:** Yep, that's right.

**Teale:** We had all the squealing in all the labs and eventually, we changed the brake button slightly to fix it. But, it was just kind of an anecdotal--

**Winarski:** Uh-huh.

**Gardner:** So, again, part of the reliability/maintainability plan was static guides which then went to air bearing guides?

**Winarski:** With compliant metal foil.

**Teale:** That's right.

**Winarski:** But, the tape was abrasive, and nothing against the tape, we just underestimated it. And so, then Joe Garcia and others worked on what was a 3480 two-meter/second model, the B22 with a compliant guide with little ceramic buttons on the end. And so, that became the compliant guide with eight fingers on each D-Bearing to ease the tape down.

**Teale:** So, we had started with open channel guides. But, there was too much play. There was a lot of wear. Dan mentioned; so, on one side, we put kind of a flexible, thin metal member.

**Winarski:** Like a leaf spring.

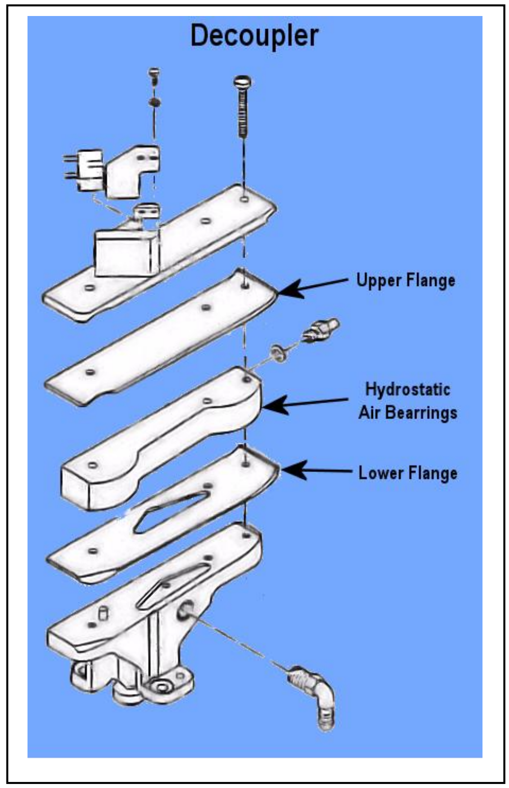
**Teale:** Like a leaf spring, and the chrome tape was just wearing that thing out. So, the ceramic buttons, I had forgotten about those, but that was quite clever and it worked very well.

**Gardner:** That was another one those unexpected consequences of using chrome dioxide.

**Teale:** We didn't know what we didn't know.

**Winarski:** Because once we finally got the basic tape head with the larger D-Bearings of the 3480, we thought we were home free. But, it was more like the eye of the hurricane. There were all these other complexities -- Joe Garcia's ceramic buttons on the compliant guide. But, a lot of invention was needed even after we had the basic tape head understood because now you were getting-- you were talking about reliability issues. Now, we were starting to use the drive for a longer period of time and seeing, "Oh, this issue is coming up. The wear is a problem." Another problem was caused by the guides not being up to the abrasiveness of the tape was a 50 kilohertz shear-wave. Imagine JELLO between your hands and you're moving them back and forth. Well, the tape would oscillate at 50 kilohertz. And so, we knew at that point we not only needed to implement Joe Garcia's little buttons, but we had to cermatize the entire tape path, both up-- any flanges like on the decoupler [see diagram], or the tension transducer -- or the D-Bearings themselves, everything. The tape would only touch something that was ceramic.




**Gardner:** Verbally walk me through the tape path as it comes out of the cartridge.

**Winarski:** Okay. So, Bill Rueger invented what's called a Pantocam threader [US 4,399,936]. As the tape cartridge was loaded into the drive, the leader block would nestle against a pin, which was hanging upside down, and it had a little bulbous part so that as the leader block hit it, then it would come down and it would stay in place. Then Pantocam threader had a miniature version of the tape path on its inside, and then a linkage would follow that cam so to speak and thread the leader block first around the decoupler. There was a long distance. In order for these D-Bearings to work, we felt they had to have a high angle of attack. And so, that meant a long distance-- let's see. The head might be here, and the cartridge back here. There was a long distance for the tape to have one might call like a can lever or a leverage arm. So, Bill Rueger invented this decoupler, US 4,406,425, which would put a gentle omega-shaped loop in the tape, a bow in the tape. So, in a way, we were going home to mama.

**Teale:** It had a vacuum in it.

**Winarski:** Yeah. It had a little mini vacuum in it.

**Teale:** So, this would take the tape path up this way. So, this thing is like this. It's coming up here. It goes past this thing called a decoupler. It had a vacuum in it and a couple of

pneumatic bearings on it just to kind of, I guess, stabilize that long unsupported beam of tape. It would go all the way around this, cleaner, D-Bearing, Head, D-Bearing. It would come all the way back here and around the tension transducer as I recall. Then I think it went back to the take up reel, which Dan has brought some examples of, and I think it went back in like that is what I recall.

**Winarski:** Correct. Yep.

**Teale:** This leader block-- yesterday, I poked a little bit of fun at it because we did discover some design flaws long after the fact. But, setting that aside, at the time, this had several functions, and it was quite ingenuous. Dan has brought some examples of what the take up reel looked like because the leader block would go into those slots.

**Winarski:** Do you want me to talk about this?

**Teale:** Yeah, go ahead.

**Winarski:** When the design came from San Jose to Boulder, and of course from Boulder to Tucson, we knew that the leader block, which is here, would have to go into a mating take up reel. We were very concerned about the print-through where print-through would be a plastic deformation of the tape due to maybe an imperfection or a mismatch between the leader block and the well [in the take-up reel] that is holding it.

**Winarski:** So, I thought as a mechanical engineer maybe the first thing to do was to control the tolerances so that the leader block, any step function between the leader block and the hub of the take up reel would be minimized. And so, the goal was that this had to sit for 24 hours because they thought that [to be the longest time for a customer engineer to arrive and finish fixing the tape drive].


**Teale:** So, this leader block in the hub is what Dan was talking about [Editor's note: Unfortunately the tape is mangled in this photo]

**Teale:** Notice the back end of that leader block has to have the exact same radius as the take up reel itself. So, there's a lot of mechanical business on the front-end to engage with the threader and to get it back seated, but there's equally critical function on the back end. The print through Dan's talking about -- we talked about winding stress yesterday and I think Dan even wrote a model of that once. If any deformation in here could permanently deform the tape after it's been sitting there for some period of time then that could cause errors. So, let me give you some more, give you more leeway here.

**Winarski:** Okay. So, this thing had to sit for 24 hours with tape tension on it. The goal was that might take 24 hours for a customer engineer to fix the drive -- let me see if I can get this leader block back in there.

**Teale:** It's probably the metric conversion, Dan.

**Winarski:** There you go [leader block fits into hub]. It might take a customer engineer that long to fix the tape drive. But, the print through was terrible [with an all aluminum take-up reel hub]. So, I'm thinking, okay. We knew from this model of tape stresses on the hub that if the hub is more compliant, that the tape stresses will be reduced. So, we tried a pure polycarbonate hub and it was pretty bad, but a little improvement. So, maybe we're getting close. So, try some circumferential holes, and the holes got bigger and bigger and finally, the holes broke through. And so, ah, little mini doors. And so, these mini doors were contrivance where if there is a mismatch between the leader block and the hub of the tape that these mini doors were compliant, and they would actually conform to that mismatch and the print through problem was at least mitigated enough that it became part of the tape drive. It was sort of an accidental thing, that we said, "Well, something is not working. Let's just keep messing with it," and finally it did work. In terms of these mini doors, the idea of having a compliance in the hub, it's like, okay, well, where else could you use some compliance, and that was also in the leader block. And it's possible by dumb luck that they were going to core out the leader block anyhow. But at the time when this was all being invented, the leader block was a solid mass, and they said, along with Moe Richard, my co-inventor, "Let's core out the leader block to have this mini door effect on the leader block as you do in the take up reel." So, that's where my first two patents on the 3480 came from. It was sort of interesting that when Jim Pershon, the patent attorney, saw all the leader blocks cored out, and you guys wrote an invention disclosure on it, it only took them two and a half weeks to finalize the patent application on that. So, it's an all-time IBM record for me in terms of getting out of the starting gate.

**Teale:** So, this is non-trivial. I mean you can see that there's a lot of devil in the details, but this is a direct consequence of the cartridge assumption because in the open reel, all threading was a tape hanger going like this over a round, a perfectly round cylindrical take up reel hub and away you go. It was basically a non-issue in 3420. So, this was all brand new challenges to us.

**Gardner:** And John, you're not a fan of leader blocks.

**Teale:** No, I didn't say that. So, we had some issues with leader blocks down the road, okay? I think this is elegant. It solved the problem, but that doesn't necessarily mean that it was the exact optimum design. It turned out we did some force analysis later. We had issues with leader blocks not getting back into the cartridge at times, and of course the-- it's certainly in an automated environment. You don't know that the leader block is hanging loose when you load it, and that caused problems. I remember we had to put you some care manuals out telling tape hangers to check and make sure the leader block was seated before they loaded the tape.

**Winarski:** And there was a tool for reattachment.

**Teale:** There was a tool. First of all, you got to detach that bridge. You notice how I was pushing pretty hard with that pin over there, and give Dan some rope to-- so, you had to be able to decouple that. So, there was a tool; it went on the collection, and I think it was magnetic.

**Winarski:** Uh-huh.

**Teale:** And then you could pull this out and there was a little kit for replacing the leader block.

**Winarski:** Right, because sometimes it would tear. So, John's concerns about the leader block were valid and that's where they first--

**Teale:** They just didn't show up until like automated environments and things that we hadn't anticipated.

**Winarski:** But, then he worked on that for the LTO.

**Teale:** Yeah, LTO I had mentioned the other day and we're having a whole separate session on it tomorrow, and you're welcome to sit in and observe if you'd like. I mentioned that this LTO cartridge was very much designed by a committee, and we even admitted in a press release that there wasn't much to brag about here. It was what could big companies agree to. Of course, HP had a hard requirement to enable a half high form factor, which is why we did not use the 3480 cartridge. We couldn't agree on the leader block because it was going to get in the way of their plan to make a half high cartridge. So, what we all did by committee is we decided it was going to be a pin. That's it.

**Winarski:** No. No, but that was great.

**Teale:** That pin, when we did Jaguar [IBM 3592, the convergence of Enterprise and LTO], I mentioned that we wanted to basically put this into this cartridge for automation/compatibility, and we just translated the pen right into this cartridge, but preserving that form factor for automation. But no, the leader block was-- I'm simply saying there's some science in there. It's not just--

**Gardner:** A piece of plastic as the end of the tape.

**Teale:** Right.

**Rizzi:** Can I ask a question?

**Gardner:** Sure. Al Rizzi would like to ask a question.

**Rizzi:** You mentioned the design, I forget the name of the person,

**Winarski:** Bill Rueger.

**Rizzi:** Was that the original design the pantograph that was actually implemented, was it the first design, or was it a fix to some other approach?

**Winarski:** It's a fix to another approach, and that's a good point because Ocotillo used like a racetrack and the racetrack was above the tape path and it's a channel where there as plastic and the plastic would move through this channel and carry a threading pin with it. Because you have plastic-on-plastic now there's a lot of debris. The debris would shower down on the tape path. So, even though it would function maybe most of the time, sometimes we'd get-- because we were trying-- it was very complicated. Here's the two smaller D-Bearings and the head was across from the D-Bearings. So, it had to come around and form an omega loop to thread through what John called the head guide FRU [Field Replaceable Unit]. Most of the time, it would do that. It would get hung up a little bit, but the debris issue was terrible. And so, this is where when Bill Rueger invented the Pantocam threader and he didn't have debris at all.

**Teale:** But, we also had to bring the head back on the other side.

**Winarski:** They said we also had to bring the head back on the other side. But, we needed to do that because then we also enlarged the D-Bearings to make them just as big as we possibly could to maximize the guidance surface along the edges of the tape.

**Gardner:** And what is a Pantocam threader?

**Winarski:** The Pantocam threader comes from a pantograph where you'd have a stylus tracing over a known object and then there was a linkage which would extend. And so, you could make a copy of the different size of that original drawing. And so, what Bill Rueger did was to say, all right, at the end of this longer linkage I'm going to put the threading pin, and then move that around the tape path as the Pantocam itself followed this internal map of a miniature of the tape drive.

**Gardner:** And any debris if there was any was at the miniature, and not out at the head.

**Teale:** Right, and not even in the tape.

**Winarski:** Right, and it used a roller bearing to go through the cam surface. So, there really wasn't debris there.

**Teale:** It was a very elegant design. The predecessor, what did you call it? I called it the Laugh Track. [Editor's note: In Ocotillo the head was flipped to other side of the D-Bearings which required a very complicated threader to perform an omega shaped curve over one bearing, under the head, and over the other bearing. To accomplish this threading, the threading-pin / leader-block followed a grooved channel above the tape path which freely rained debris on the tape below. A motor drove the mechanism with the cartridge leader block attached to thread the tape. The apparatus was slow and noisy, sounding a bit like a toy electric train. The engineers didn't like the inelegance of it, and could not tolerate the debris it generated, and dubbed it the Laugh Track. Source: emails with J Teale.]

**Winarski:** Or a racetrack. But, yeah, Laugh Track.

**Teale:** It was painful to watch it thread. It was noisy. It was clunky.

**Winarski:** Yeah, it was clunky.

**Teale:** It was like, is it going to make it? Is it going to make it?

**Rizzi:** What kind of time frame are we talking between the two?

**Winarski:** About a year and a half as I recall. This is going back into the early '80s. So, it's difficult to--

**Teale:** What I recall Dan is we had the head on the same side of the D-Bearings when I arrived at IBM. Somebody had the brilliant idea of moving it to the other side. I confess to that by the way.

**Winarski:** Oh, you do? Okay, because I was going to take the blame.

**Teale:** That was probably about ’79 or ’80 that we did that.

**Winarski:** It was about that time.

**Teale:** And then we realized very quickly what a thorough disastrous idea that was.

**Winarski:** Yes, it was.

**Teale:** And we brought the head back. So, I don’t know if the Pantocam was on that original version with the head on the D-Bearing side, or if it was later.

**Winarski:** Oh, for Intrepid, we didn’t have a threader at all.

**Teale:** Okay. Okay.

**Winarski:** We weren’t that far along.

**Teale:** So, it was probably around ’80 where we went from the Laugh Track [Ocotillo] to the Pantocam [Saguaro]. As Dan indicated, the Pantocam, the cam guide was just a plastic plate. It wasn’t very large. It had a groove. It basically was a miniature geometry of the tape path. And like Dan said, it’s kind of like a-- that concept is used in lots of places. It’s used in printing, for example.

**Winarski:** That’s right. Mm-hmm.

**Teale:** It’s used in all kinds of applications. I thought it was a very clever application of borrowing an idea from a completely unrelated field and solving a problem.

**Gardner:** Would somebody just for us, a naive person, compare and contrast the threading in a reel-to-reel.

**Teale:** Well, in a reel-to-reel as I mentioned, you’ve got an open 10.5 inch reel. The end of the tape is just hanging off just like this, and there’s another reel over here. And for them, all they had to do was pull this thing across and get it started a wind or two on the take up reel. Once they had that, they would just hit the switch and all of a sudden tape would suck down into those vacuum columns and you were ready to rock and roll. But, it was a tape hanger that had to do this, and I don’t think it was too unusual for them to lick their finger to get it started so that it stuck a little bit to get it started, and maybe five or six wraps and kind of tighten it up, cinch it a little bit and you’re ready to rock and roll.

**Gardner:** So again, there was some sort of mechanism that pulled or blew or pushed.

[**Editor's note**: An early if not first implementation of automatic threading in 10½-inch reel-to-reel drives was IBM's January 1968 announcement of the 2420 tape drive. Juan Rodriquez of IBM and StorageTek described it as a sight to see, "On loading the cartridge the machine opened a gate in the cartridge. The reel actuated to push the tape through the gate, pressure air jets passed over the surface of the tape maintaining it through to the other side to the take up reel whose hub had vacuum slots to grab the tape and pull it. Needed a cleanly cut tape leader, for which there was a tool to properly trim it. Amazing to see it work so reliably!"[1]

**Teale:** Now later on, as Al reminded me because I completely forgot, and I appreciate that, we did have open reel compatible devices that did not use vacuum columns. There was one called Sunfish.[2]

**Winarski:** That's right. Sunfish, yes.

**Teale:** They tended to be kind of the size of a stove and it was kind of flat here, or maybe slightly angled as I recall. I think we did that in conjunction with Fujitsu-Siemens was one of the products. I don't recall whether there was an automated way of threading those or not.

**Winarski:** I don't remember it.

**Teale:** I don't know.

**Winarski:** But, yeah, Sunfish was another reel-to-reel tape path. As I recall, it shipped before the 3480. It was just a simpler thing. It only had nine tracks. So, it's not like it's struggling with 18 tracks and not much higher density.

**Teale:** We kind of did Sunfish as a little bit of an insurance policy, but 3480 was really the ultimate goal and the path we were committed to.

**Gardner:** So, we've talked about the header and getting the tape through to the take up reel and the first thing the tape encounters is a decoupler, which, again, is perhaps a consequence of the elimination of vacuum columns. How did the decoupler get in there?

**Winarski:** I have my own theory. John and Andy may have other things, but you could envision a solution space which was almost nonexistent in terms of all these variables coming together. And so, the decoupler took a lot of the noise out of the tape head in terms of the standard wrap stream that the tape-- and so the tape would track properly across the head. Uhm, and we could have been seeing some of this 50 kilohertz issues and other issue in the tape path, which we weren't aware of yet. But the decoupler was able to enlarge the solution space so that we actually had something to take into product test and do testing with.

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[1] eMail correspondence with J. Rodriquez July 9, 2016

[2] Announced October 1978 as 8809 magnetic tape unit for IBM's 4331 processor and the IBM 8100 information system. It was the first new product announced by the GPD Tucson Laboratory (though development originated in San Jose). See https://www-03.ibm.com/ibm/history/exhibits/tucson/tucson_products.html

**Teale:** Yeah. This is a wild exaggeration, but imagine putting a tiny vacuum column right where the tape comes out. Before it enters the tape path, imagine a vacuum column. That is helping decouple some of the noise, chatter coming out of the cartridge because there's a lot of variables in the clutch alignment, and just a lot of variables. So in the limit, this could be like a vacuum column the size of the 3420 if you wanted to picture that, that it's going through the decoupler, noise from the cartridge is quiesced up here at the business end of the tape drive. Well, this was a very miniature version of a vacuum column. It had kind of a bearing here and a bearing here, and then there was a vacuum in the middle. So, the tape kind of went like that, and it was getting sucked a little bit.

**Winarski:** Yeah, just a tiny amount.

**Teale:** So, imagine a very mini vacuum column right out of the shoot just to try to decouple some stuff. Was that a critical component? I have no idea. We'll take one and see if it still works.

**Winarski:** No, no. No. It's true. At the beginning, it was absolutely critical, but then as we solved more of the other problems in the tape head, put in all the ceramics, the little gravity buttons [1 m/s 3480 B11] , or the ceramic fingers, Joe Garcia's and other things, eventually then we were turning off the vacuum to the decoupler and found it wasn't needed.

**Teale:** Oh, we did.

**Winarski:** Yeah, and this goes back to Saguaro 1, the B11 and that we were saying, hey-- we were even pressed by our management to reduce costs. It's like, okay. Well, we turned off the vacuum to the decoupler and there's no degradation of reliability. You can think of in terms of a solutions space. We expanded the solution space enough by fixing other things in the tape head, the decoupler, which was critical when it was first conceived. Well, it's not so critical anymore.

**Teale:** It became the appendix of the tape drive.

**Winarski:** Yeah, that's right. And so, in fact when we were trying to market, it was the 3490 I believe. That was reaching its end of life, and this is back when I was now doing patent licensing and technology transfers. We were trying to market the 3490 tape path, and one of the customers said, "Why are you still having a decoupler in there because we've run our own experiments, and we don't think you need it either. But, it was one of those things that it was hard to remove once it became part of it. But, you're right. Eventually, it went from being absolutely critical to something which was simply there.

**Teale:** Along the same lines, one of the things that I did was all the cleaner blade experiments that ended up going into Saguaro.

**Gardner:** Which is the next thing encountered in the tape path?

**Teale:** It's the next thing you encounter as a matter of fact. We kind of forgot about it. It's before you get to the D-Bearing and it's under-- and I had described yesterday in my evolving what the cleaner blade became, which was not an invention of mine. I just grabbed a bunch of existing cleaner blades off of a whole bunch of other products and tried them all. We ended up using one, I think, that may have been from the 3420. I don't remember.

**Winarski:** That's what I remember.

**Teale:** That's what I think it was. I described, again, yesterday about how I spent several weeks at the Grant Building on third shift, on the single track reliability tester only to find out that I was basically measuring how much gypsum dust was in the air.

**Winarski:** Oh, yeah.

**Teale:** Because that's all I captured in the screen. When we got it analyzed, it was-- so, you could argue that it became an appendix, but it turns out that it wasn't clear to us that the cleaner blade was solving a problem, but it did seem to help stabilize, if you will, or certainly remove some debris that might be in the atmosphere. But later upon, it turned out that the cleaner blade might have been causing as many problems as it was solving, if not causing more problems than it was solving. I was the guy who put the cleaner blade in the tape path. So later on, when I was in management, I attempted to take the cleaner blade out of the tape path for I think it was 3490E, and they said, "No, you can't do that." Well, why not? I put it in. They said, "Because we're writing backwards now, we think we need another cleaner blade on the other side of the tape head."

**Winarski:** Oh, remember seeing that.

**Teale:** So, we had two cleaner blades. Then I think at some point, we threw them both out. I don't remember when.

**Gardner:** Again, for the layperson, what's a cleaner blade supposed to do? What problem is it solving?

**Teale:** Well, in theory, because of static electricity, environmental contamination, smokers in the day-- there's something that needs to be appreciated here that doesn't happen in disk. I'm not saying that there isn't a similar phenomenon, but if you take a one micron particle, so that's 40 millionths of an inch in diameter, which is the average size of a smoke particle, very close to the average size perhaps of a piece tape debris, or a piece of atmospheric contamination; when that particle goes through the head tape interface, because the tape has stiffness, it isn't just a 40 millionths of an inch little defective perturbation to a very tiny fraction of a track. It forms a tent 30 thousandths of--

**Winarski:** Right. Yes.

**Teale:** 'Cause I did a lot of analysis, 30 thousandths of an inch in diameter, 30 mils in diameter from this 40 micro-inch particle forms this gigantic tent as it goes through there and it'll wipe out several tracks. So, you would call that soft error rate. If you had a phenomenon like that in a hard disk, you'd do two things. You'd burnish the disk, or eventually you'd beat the dang thing off with the head. You'd demark that sector and never write there. But in tape, we don't do that as I told you. We just write through everything and count on our AXP to save us when we mess it up. So, the cleaner blade was just what we call it. It kind of looks like a little Gillette razor. It's two blades that are kind of angled like this, and there's a vacuum here. So, the tape goes over, kind of goes in, and when it's going this way, in theory, this guy is scraping stuff off. When it's going the other way, this other blade is scraping stuff off. The justification for it was first of all, tradition - 50 years of cleaner blades in tape paths, a little bit of empirical data based on gypsum dust anyway.

**Winarski:** Oh, yeah. Right.

**Teale:** We just thought it was probably good engineering practice. It wasn't in the design when I arrived at IBM and like I said, I was doing the experiment at the Grant Building to see if it was worth doing. I have some patents on cleaner blades. I'm not real proud of them.

**Winarski:** Oh, no. That's good.

**Teale:** I got them.

**Winarski:** That's good.

**Teale:** So, yeah, that was the next element of the tape path. We forgot all about it.

**Winarski:** Then you get to that D-Bearing that was non-pneumatic [Intrepid] and is now pneumatic [Saguaro] and it's got the air coming out and it's got these compliant guides and ceramic buttons and pressing gently against the bottom piece of ceramic on the edge. Then you finally get to the business end, what's in the head and this is--

**Gardner:** The leaf spring [compliant guide] is just a constant compliance? It's not controlled.

**Teale:** Yeah. It's not an active component. It's a passive component. It was like fingers with little ceramic buttons on the end of them that just gently pressed on the edge.

**Gardner:** And again, the ceramic buttons being something that was added because the original, --

**Teale:** Because of the abrasivity of chrome.

**Gardner:** --the old metal design was--

**Teale:** The chrome tape would just slice through.

**Gardner:** Slice through it.

**Winarski:** Once it sliced through it, then it would be setting up a shear-wave in the tape.

**Teale:** Right. All kinds of bad stuff. Then it got to the business end right here.

**Gardner:** Next comes the D-Bearings, right?

**Teale:** We just talked about the-- that was the D-Bearing. So, the D-Bearing was a large cylindrical surface.

**Gaudet:** That's the guide.

**Teale:** Pressurized air, had these fingers that would keep the tape hopefully pressed against that datum and then it would come off that D-Bearing and go over the head.

**Gardner:** Air bearing on the sides too, or just air bearing on the business side of the bearing?

**Teale:** Just in the service side of the bearing.

**Winarski:** Sort of where the tape was.

**Gardner:** So, it was here. The lateral alignment is controlled by mechanics.

**Teale:** By those guides. So, we're not describing this correctly.

**Winarski:** Oh, yeah. The D-Bearings are actually thinner than the width of the tape. So, the tape actually stuck up a teeny tiny amount and that's where then these ceramic buttons and fingers would actually gently ride on the [upper] tape [edge] itself and that would seat the [lower] tape [edge] against the lower ceramic flange.

**Teale:** Yeah. I had a head guide FRU (field replaceable unit) once upon a time and I wish I had one now because it's so difficult to describe without just holding up. But, yeah, this tape was going around this large D-Bearing, and the fingers were like this, pressing it down against something, another piece of ceramic on the bottom.

**Winarski:** Right.

**Gardner:** So, the reference surface was the flange, and the fingers were pushing it down.

**Teale:** Right.

**Gardner:** See, I, in my ignorance, thought of the fingers pressing against the width of the tape, not the [thickness] side of the tape. Now I understand.

**Teale:** Oh, yeah. No, the side of the tape.

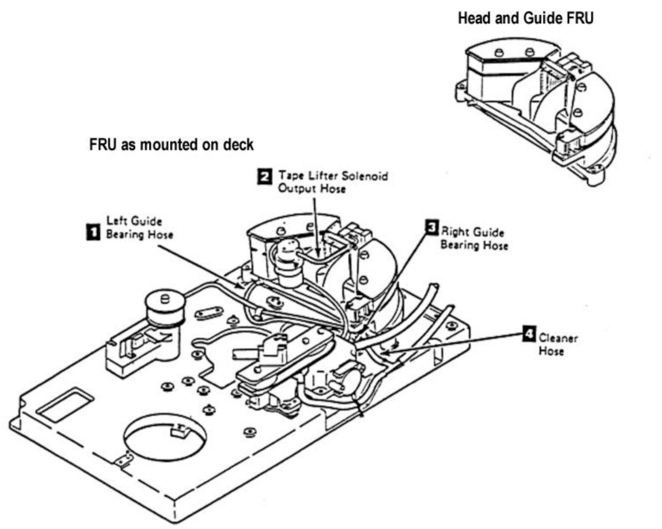
**Gardner:** My ignorance.

**Teale:** I mentioned yesterday for Dan's benefit that the alignment of the head to the tape path in 3480 was so critical that unlike 3420 the head was not a field replaceable part because those alignments to those two D-Bearings had to be established with great precision in the factory. And so, we actually included the D-Bearings as what we called the field replaceable unit, or head guide FRU.

**Gardner:** Was it the casting, bearings and the head?

**Teale:** It was a casting, ceramic plates, the bearings, the ceramic fingers, the head on a skew plate that you could adjust the skew. You could adjust its penetration. You could adjust its pitch. There's awful cables hanging down because I changed many of them and it was no fun.




**Winarski:** We didn't have arm electronics like in the hard drives. So, there was no pre-conditioning of the signal. The unconditioned signal had to go a long distance.

**Teale:** This is actually a 3490E. So, it's got two cables to each module. The 3480 only had a pair of cables let's say.

**Winarski:** Yeah, and just because we called them the crowbar cables, there's no reflection on the design.

**Teale:** But they were stiff.

**Winarski:** And in fact, John mentioned the skew plate because we had to adjust the skew alignment of the head perpendicular to the lower flanges of the head guide FRU using a differential skew standard like in the 3420. But then, pillars had to be designed. I think Paul Bareman came up with that concept. I forget. So, these two pillars were part of the casting and once the skew plate was aligned and the pillars were clamped in place, because there was such torque by these crowbar cables--

**Teale:** Just the CE trying to wrestle these cables back into the cards after he set it down could mess up the head alignment relative to those bearings. So, once you had it aligned, you virtually cemented it in place and therefore, it was never replaceable anyway.

**Winarski:** That's right.

**Gardner:** Al Rizzi would like to add a question.

**Rizzi:** Yes, excuse me. A lot of the I'll call it experimentation or testing you did sounds like it was part of the engineering testing to establish how you were going to do the product. Were some of these problems though-- did we go into test, product test and then have to come in with ceramic fingers and ceramic ties in the guides? Did we basically interest with some level that required some of the type of fixes that you're talking about? I'm talking about the timing--

**Winarski:** Well, my involvement with this goes way back, back even to the Intrepid days where we would -- I hate to say this, but we would wheel a drive into product testing knowing it would be rejected. This would be late Friday. We'd wheel the drive into product test knowing that they'd reject it on Monday. It was very iterative.

**Teale:** That's right.

**Winarski:** It was constant iteration and even going back when I said there were like four basic things for the 3480, Saguaro being the third one, and it wasn't until we entered the fourth phase, which is like we realized we were merely in the eye of the hurricane that we had to really harden the tape path, including the ceramic guides, the ceramic fingers, all of these other things, solving 50 kilohertz. We had to get these to actually finish product test. So, there was a very long involved process with product test.

**Teale:** Yeah. I'll tell you my perspective as a kid. There was no schedule integrity, at least not in the modern program management sense.

**Winarski:** No.

**Teale:** I mean there may have once upon a time had been a schedule that said we're going to have a formal EVT here and we're going to have a DVT here, or whatever we called it in the day. As far as I'm concerned, product test just became part of the development team. They just became a huge resource to help us vet stuff. They didn't like it because they wanted to be that kind of autonomous gatekeeper, but there was really nothing else for them to do if they weren't helping us expose problems. They're just sitting there with a big catcher's mitt waiting for nothing.

**Winarski:** But, no, that's a nice way to say it, that they would uncover these problems and then we'd say, "Okay, this is how we're going to just solve them." So, there was a real partnership there.

**Teale:** Like a lot of software projects, unfortunately, a lot of quality was tested into 3480, and it's painful to admit that, but it was a reality.

**Gardner:** I'm not sure it's clear in the several tapes, but you've talked, I think, about four code name versions of the drive itself. We nailed down the media code names itself. Would you just step through them from the first by name and about the time frame?

**Teale:** Yeah. I had mentioned this yesterday. So, I'll take it and you can finish it. We inherited it as Intrepid from Boulder.

**Gardner:** You inherited it as Intrepid from Boulder.

**Teale:** And then clearly, that thing we inherited as Dan is describing went through a lot of evolution and rethinking as we started finding out stuff that we didn't know we didn't know, and we adopted a cactus theme because we were in the middle of the Saguaro desert, and I believe our first kind of Tucson version of Intrepid or evolution if you will was called I think Saguaro or Ocotillo.

**Winarski:** No, Ocotillo.

**Teale:** O-C-O-T-I-L-L-O. It's a very beautiful kind of leafy branchy thing. It's kind of hard to describe. I've got a couple in my yard. They're gorgeous. Dan was much closer to this, but eventually, maybe it was because we flipped the head again or whatever, but it became Saguaro, and there was a Saguaro 1 and a Saguaro 2. And later on, there was Barrel but that was after the 3480

**Winarski:** Right.

**Gaudet:** That's a cactus also.

**Teale:** That's also a cactus.

**Winarski:** And Saguaro 2 came out first. That was a two meter per second drive. Then there was a thought, hey, there might be some more midrange customers who might want a one meter per second drive. So, that became Saguaro 1, and Saguaro 1 had its own problems, if you will, all these other problems, totally unexpected. But, the recording channel was such that, and Jud McDonald who did the recording channel explained this to me, that the permissible acceleration of the tape, or jitter, whatever within the tape head was a function of the square of the tape's velocity. So, when we reduced the velocity by a factor of two from two meters to one meter per second, we actually shrunk our tolerance window by a factor of four. So, the Joe Garcia fingers didn't work anymore. And so, I was thinking one day because we were getting eaten alive to solve this problem; Joe's fingers-- the original compliant guides were like a leaf spring, a metal leaf spring. He put ceramic tips on the end to reduce the wear. Well, what if we took his design one step further and reduced the spring, got rid of the spring-rate because maybe that's causing the jitter. And so, we just had a dead-weight gravity button. It was still Joe Garcia's ceramic tip, but now on the dead weight. So, we tried with eight. He had eight fingers on each D-Bearing. We tried that, and it didn't work at all. I go, "Oh, we're going to get choked if we don't solve this." So, I said, okay, let's do something really radical. Let's put two gravity buttons by each side of the head, and one in each entrance, or exit way of the D-Bearing and that worked. And so, we were done. That's how-- so, we had to scramble to solve Saguaro 1.

**Gardner:** So, the next sort of time question really followed along Al's theme is which one came out of DVT?

**Winarski:** Oh, Saguaro 2.

**Teale:** We shipped the two meter per second version. I think there was a four meter per second one or something. Saguaro 1 was a reduced performance follow-on option that is typical IBM. We kind of sell them the same thing, and then we've got these code things that we can switch.

**Gardner:** So, Intrepid was the EVT machine?

**Winarski:** Oh, no, no. Intrepid never went that far. It was always rejected going into product testing. Oh, no. It's true. What they wanted in general, as I recall, and again, John and Andy may remember things slightly different. They wanted roughly ten to the sixth [one million] bits per soft error. Out of

Intrepid, we only got ten to the second [one hundred bits per soft error]. So, we were off by four orders of magnitude. It was like a disaster.

**Teale:** Remember I talked about we'd do a pass – we would measure the bit error rate from on pass of the tape, rewind the tape, and measure another pass. We might get a BER (bit error rate) of 1E-5 on a pass, then 1E-4 on the next, maybe 5E-6 on another – the BER fluctuated wildly all over the place. It was gypsum dust by the way.

**Winarski:** Yeah, and maybe I remember it being at its worst case. So, we went to Ocotillo with the D-Bearings, but the head on the opposite side. As I recall, we were getting our reliability into the ten to fifth [100,000], not quite ten to sixth [one million], maybe five times ten to the fifth, but we're very close, and we had actually tried the larger D-Bearings, which became Saguaro, but we couldn't get that high [initially]. So, we went down this blind path of Ocotillo. But, once we realized that wasn't the way to go, we went to bigger to D-Bearings [Saguaro], and finally went with ceramics and everything. We got to the ten to the sixth and even as I recall, we were starting to get to ten to the seven [10,000,000 bits per soft error] with all of these improvements of raw, uncorrected bits per soft error. Then it was at that point they said, "Yes, we have a product."

**Gardner:** So, that's Saguaro 2 that went into EVT, problems were fixed, went into DVT and actually then shipped. And then Saguaro 1 became the one meter per second version.

**Winarski:** Right, because they wanted a family. And so, that seemed like the easiest way was to-- and again, when you're thinking midrange customers, they don't need a tape drive that's going to suck up all of this data when they can't deliver it at that speed. So for the people with the smaller computers, less data rate requirements, that a slower tape path would be more in concert with the speed of delivery that they had.

**Teale:** So, we hadn't finished the tape path yet.

**Gardner:** No, no, we're not. I was going to say perhaps when we go back through some of these problems, it might be interesting to say, well, that occurred during the Saguaro 2, or this occurred when -- sort of space it out.

**Teale:** I'm not even sure Saguaro 1 ever got to market.

**Winarski:** I don't think it did.

**Teale:** I'm not even sure we ever really shipped very many.

**Winarski:** Was it ever shipped?

**Gaudet:** I don't remember.

**Rizzi:** I know we shipped some prototype machines and beta test machines. I don't know that we ever shipped any to paying customers.

**Winarski:** It took so long to develop, a certain length of period to develop this B11 Saguaro 1 that it's possible by then the customers were upping their data rates so they needed the original version of Saguaro 2. So, it's like the customer requirements were continuing to climb, and we were designing in certain ways a retro drive for more midrange, but maybe the market just disappeared by the time it was ready

**Gaudet:** Did we have the same form factor though?

**Teale:** It was the same machine.

**Gaudet:** Okay, same machine.

**Winarski:** With the exception of the tape guides.

**Rizzi:** From the outside you couldn't tell them apart.

**Gaudet:** Okay. All right.

**Teale:** In fact, there was compatibility wasn't there?

**Winarski:** Uh-huh.

**Teale:** Read/write compatibility.

**Winarski:** Yeah.

**Teale:** Or maybe not write, but certainly they did read each other's media.

**Winarski:** I think it was.

**Teale:** But, I think the main point, Dan, was making this as simple thing as changing the velocity by a factor of two. Not everything scales directly. Some things don't scale at all. Other things scale more radically than we thought. And so, it's kind of like every time we did something that we thought was going to be a no brainer-- we were back in the soup. What happened?

**Winarski:** That's right. It's true. It's very true.

**Gardner:** So, I think we're at the head now.

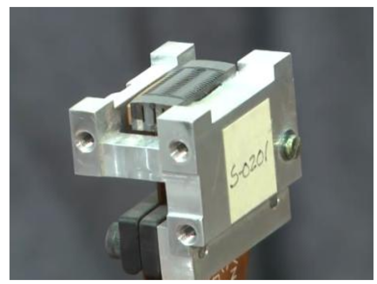
**Teale:** Yeah, we made it to the head I think. So, this is where I come in because I was actually hired to design the micro geometry of the surface of this recording end. I borrowed heavily from a concept that a guy in San Jose had. Bill McConnell I think was his name. What you'll see in this micro geometry, and I might have a picture over there I can dig out, is you'll see what we call the bleed slots.

**Teale:** Okay. Let me briefly tell you what problems that I was hired to solve and took my time doing it like we all did because for some reason, this was not quite as critical of a deal on 3420. The alignment specifications were a lot more relaxed. The head tape spacing didn't have to be as close as this was. That was a big deal. If they had a little bit of head tape interface problem, they just cranked up the vacuum up a little bit.

**Winarski:** Oh, yeah. That's true.

**Teale:** Bob Riley did it more than once. So, this was going to be much more critical because we wanted to establish a uniform fly height of approximately five millionths of an inch at the business areas on the head where the write gap is and the read gap is and control it. So, this was a radical new concept. You can't see it, but I'll dig out a picture at the break, but there are slots called blind slots that are machined into the leading edge of that head, and those slots don't go all the way to the gap. They go a certain ways into the head, and the tape, when it lands on the head, lands somewhere in the region of those slots, between the edge of the head and the recording gap. Now, the reason those slots exist is because it was observed a long time ago that air has a viscosity and that air approximates a Newtonian fluid law. As a result of the fact that air has a viscosity, although we never really thought it was important before and because air is compressible, if we just sent this thing over a cylinder like what we did in 3420, the thing would fly at about 40 millionths of an inch and it was inoperable. We couldn't write it or read it. So, those slots were designed to spoil air pressure buildup, and we had these elaborate two-dimensional coupled non-linear partial differential equation programs that we had written to play with that micro geometry and try to optimize it. In addition, we were able to reproduce this geometry in the form of a glass see-through head. We were able then to take a glass head, put it up against a real piece of tape with a little vacuum column and a cap stand, a camera with a magnification of about 10x, and observe Newtonian rings from reflected light that would tell us what that fly height was all over the surface of that head. If I took one white light picture, I took a hundred thousand. So, I wasn't always sitting at the computer. And so, it was super critical. We had literally-- the wrap angle tolerance was very tiny because if you over-- if you under engaged the slots, there was something called a dynamic shift. In other words, when the tape is at rest, you might think, okay, it's right there. Well, it's not. Imagine pushing a 2x4 over an oil drum, okay? That's not a straight line because the thing has stiffness and there's a bowing effect. Well, you get the same thing at the micro level when you're putting tape over this geometry. And so, if it's slightly under wrapped, the tape is actually under wrapped more than you think it is because of the bending stiffness. And also, when you start the tape, there's something called a dynamic shift. The incidence point actually moves downstream about ten mils [0.010-inch]. Now, what is that all about? Well, I scratched my head. I observed it for years. What is it? It turns out tape by and large is a viscoelastic material. When you think about going from a zero moment to a forced conformance to a radius that defines a moment. I'm talking about a moment mechanically. And you do a strain rate analysis of the strain. The tape is basically going from zero strain to some amount of strain defined by the other boundary condition called the radius of the head, and it's doing it at two meters per second, which is hauling ass when you're down here at this micro



Tape head

level. Those strain rates were very large I calculated. Because tape is viscoelastic, it has what they call a complex modulus; in laymen's term, the stiffness of the Mylar® increases when strain rate increases, which alters where the tape actually lands on the head. And so, that explains the dynamic shift. So, that's just a long way of telling you that the alignment of this head relative to those guides was super critical for a whole bunch of reasons, and then subsequent were issues that we're not going to talk about now because we're finishing the tape path. Then it exits the head, and then my job is done and now it's Dan's turn.

**Winarski:** Maybe you'd like to talk about the puffer head and the leaf spring.

**Gaudet:** Yeah, the puffer head to keep the tape up

**Teale:** Oh, yeah. Hey, Armando Argumedo did most of this stuff. He's a brilliant guy, and he originally was going to be invited, but the problem is that his participation in 3480 was kind of limited to the head fabrication, mechanical fabrication. At some point in time, we had this stiction problem. We were concerned that if the tape was loaded, but otherwise in idle mode, we would continue to apply some tension because we had to, or the tape would fall out of the guides. If it sat there like that for a long period of time, environmental conditions weren't favorable, even though we had largely solved some of this stiction problem that we could still get tapes sticking to the head.

**Winarski:** It's sort of like a Saran™ Wrap effect.

**Teale:** Right. If nothing else, all the air pressure bleeds out and you've got a Jo block effect.

**Winarski:** Oh, yeah.

**Teale:** Which, by the way, the Jo block effect became the future HTI [Head-Tape Interface], -- I'll talk about that tomorrow on LTO. We didn't even have any wrap. We had flat head [US 7,193,813 for LTO], and we just simply set up the angle of incidence so that we just squeezed all the air out, shaved it off, and the atmospheric pressure would hold it together, not even tension. So, we had no vertical tension component pulling the tape onto the head. So, in between these modules, Armando invented this super cool thing. I don't even know how he fabricated it. You might know more about this than I do.

**Winarski:** No, I don't.

**Teale:** It was kind of like two layers of something with an orifice in and an orifice out, and it could be pressurized. Now that we have air pressure we might as well use it everywhere. When the tape was stuck, it would push air, and we're talking about a fairly large air pressure, you've got to offset that tension to some degree, to push the tape away from the head so that it wouldn't stick while it was waiting for either an unload, or another job, or a reposition or something. There's a spring in here to keep that head-- this is a precision ground housing, very precise. This was actually a brilliant concept that Armando owns the patents on, Armando and Bob Freeman [US 4,420,782].

**Winarski:** Mention his last name.

**Teale:** Bob Freeman. Oh, Armando Argumedo, and I can get him out here tomorrow if you want to meet him. We can talk about that later. So, I don't know. There's probably more to say about this. I was confined to the micro geometry.

**Winarski:** Oh, sure. But see, the aluminum expands and contracts with temperature. So, the leaf spring needed to put in there under a certain amount of compression so that-- as I recall, before the leaf spring that the head modules could become loose. Armando did the leaf spring?


**Teale:** Yeah.

**Winarski:** So that was genius in terms of, okay, now you've got something-- it's a compliant member, it's stiff enough to hold the modules in place but without cracking them, and as you get temperature variations, the aluminum may expand and that's fine; the leaf spring still holds the modules in place. So that's certainly part of the genius--

**Teale:** This was very elegant. Very elegant. This whole concept of the housing and the whole structure, because it just made the alignments just so much easier because now it was precision ground. Because you notice that-- this clearly came out of a casting but you'll notice that there are machine marks in certain specific places.

**Winarski:** Right. And as I recall, these corners were datums that we used for alignment that had--

**Teale:** They were datums. That's right.

**Winarski:** --into the head guide FRU--

**Teale:** Because we had to control at least four of the six degrees of freedom that were critical.

**Winarski:** Right. And so the alignment of the head involved shimming it in place so that you would get the tracks aligned with the lower flanges so that it was repeatable, so you get repeatable data with interchange, and in one crazy moment I had ordered this great big worm gear set, and this was before I actually knew that-- but I just thought, "I'm going to need this thing." And so one day they said, "Dan, you got to set up"-- in manufacturing-- "you people-- how to stick these into the head guide FRU under a manufacturing standpoint." I said, "Well, I know how to do that." So we took the head guide FRU and mounted it on this giant worm gear so that the people could align this under the microscope, and then they were able then to use the differential screw on the skew plate to align the skew after they had this head shimmed in place, and you'd get the penetration right, and the angulation of the head too. It might be perpendicular to the skew plate and it's perpendicular to the guides, but you didn't want it rotated too far to the left or the right relative to the D-Bearing. So you had to set up those four degrees of freedom.

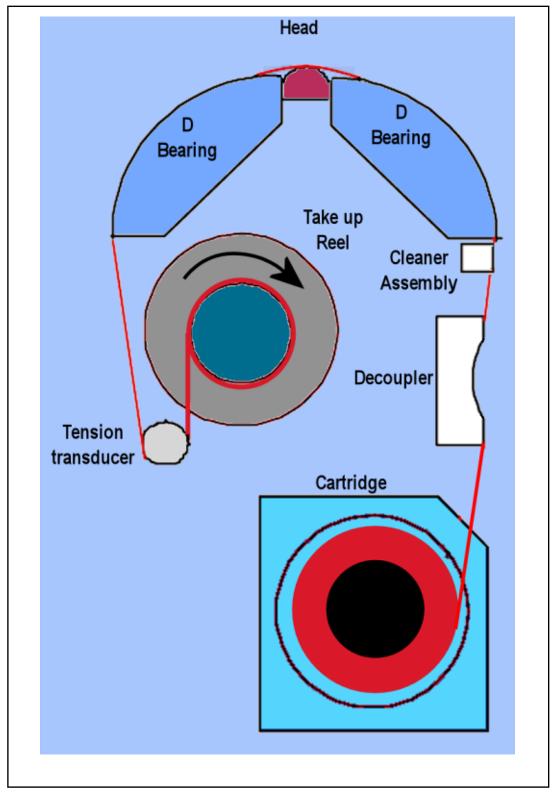
**Teale:** And all Dan's talking about is orienting this entire unit. Inside of this unit there are two independent cylinders, a write bump and a read bump.

**Winarski:** That's right, yeah.

**Teale:** Those cylinders were offset with respect to other. There's a ton of microgeometry and alignment that goes into just putting those modules in here before we even give it to you to stick it in the machine, and I hope I can dig out a really cool picture of that because Saguaro only wrote in one direction, and then it rewound. We only had one set of leading blind slots in each of the modules. Later on when we did the write backward to eliminate rewind, we had to add more rows of blind slots and change the — re-optimize the geometry again. So you can tell a 3480 head from a 3490E head by seeing how many rows of slots are there, and you can see that there are slots on both sides of each gap of each module, and that's clearly-- this is a 3490E, in addition to the extra cable. So now it goes back to Dan because now it's going to go to the other D-Bearing on its way to the take-up reel and the tension transducers.

**Winarski:** You had two D-Bearings which were identical, and as the tape left the second D-Bearing heading towards the tension transducer, there is maybe 160 degrees of wrap or something-- it varied depending on how much tape you had on the take-up reel-- but the idea is to have a lot of wrap on this tension transducer so you'd get an accurate measurement of the tape tension. There's a little-- as I recall a Kulite® pressure sensor that was centered roughly where the tape would be going around the cylinder, roughly maybe an inch in diameter, and the pressure measured by the sensor was tape tension divided by radius and width.




**Teale**: Decoupler, cleaner blade, D-Bearing head

**Winarski:** The original [Intrepid] tension transducer was a cantilevered member on what was called a Bendix® flexural pivot, and the flexural pivot adds spring rate and the motion of this cantilevered was detected by a [electric differential] transformer called an-- it was an E sensor. There was a center tab and two legs, and so that thing would tell-- as the tension transducer was pulled [rotated] more or less by the tape-- well, see, as this-- the tension transducer also had a roller bearing on it, so the roller bearing-- the viscosity of these bearings became an issue. If it was too thin a viscosity, you saw the ball bearings and the tension transducer causing signal problems. Of course if the viscosity was too high, the tape couldn't move <chuckles> the roller on this tension transducer. The tension transducer would pivot like this, and it would then tend to cock, causing the tape to steer inappropriately. So the idea for a mechanical tension transducer was a disaster. And so with the advent of the solid state [pneumatic] tension transducer a lot of problems went away.

**Teale:** I wanted to show a little bit-- a small clarification, if you can zoom up on this, about-- to amplify Dan's point. So one of the things, Dan, that we did, the reason we took the tape back this way [clockwise] instead of this way, which might have been simpler on the surface, was to maintain a good wrap angle around this tension transducer, and Dan talked about how that angle can change. Well, we never know how much tape is on that take-up reel. We don't know whether we're near the end of tape or the beginning of tape or the middle of tape. So we wanted to minimize that change in wrap angle with respect to how it affects what the tension transducer is sensing. So there was some rhyme and reason for doing something that looks somewhat counterintuitive on the surface.

**Winarski:** Now, that high-angle wrap on the tension transducer caused problems with the Pantocam. The Pantocam was whipping--

**Teale:** It's going to whip around there, yeah.

**Winarski:** That's right. And so what we did with that was simply to slow down the Pantocam as it went around there, because it was called cracking the whip. It's like, well, how do you redesign the Pantocam? Well, you really can't, but in microcode they simply slowed it down, added a couple tenths of a second to the load time, but we weren't tearing the leader block off the tape. <chuckles>

**Gardner:** Tell me a little bit more about the solid state tension transducer. You went through the mechanical one, which was--

**Gaudet:** Piezoelectric, yeah.

**Gardner:** Yeah, piezoelectric. It was still a leaf spring but the sensor was--

**Winarski:** Oh, the tension transducer?

**Gardner:** Yeah.

**Winarski:** No, it actually used a pressure sensor that would be used in a pneumatic circuit, but it was a solid state pressure sensor. But there probably was a little tiny diaphragm in there somewhere, and it probably had a Wheatstone bridge with the strain gauge sensing circuits on it, and as the diaphragm changed its-- like a drum head, so to speak-- because of the pressure exerted by the tape across this air bearing, then it would pick up what the tape tension was. So it was a solid state.

**Gardner:** As opposed to this three-finger mechanism.

**Winarski:** Oh, the three-finger-- the three-finger mechanism was used for the mechanical tension transducer [in Intrepid], and this three-finger one was a displacement sensor, and it used-- it was essentially an electrical transformer. A differential transformer is one side got more flux, the other side got less flux. So from an electrical standpoint, the E sensor made sense, but from a mechanical standpoint this cantilever arm of the Intrepid design was a disaster because it was steering the tape, there were viscosity problems in the roller bearing, the Bendix® flexural pivot -- no discredit to Bendix® -- but as it rotated, it also changed its axial position a little bit but, see, that was steering the tape again, and so we had to get away from something mechanical to detect tape tension.

**Teale:** We also needed decent bandwidth for what we were trying to sense--

**Winarski:** Oh, that's right.

**Teale:** --because we were mainly interested in the transients that were-- a lot of those were associated with back hitching--

**Winarski:** That's right. Uh-huh.

**Teale:** --and non-- what I will call non steady-state streaming, for example. I wanted to talk a little bit more about that reel-to-reel system. We mentioned it, but you've got these two reels. They always have a delta torque to maintain a tension, and that's pretty predictable, knowing what the radius of the two things are, -- but when you sped it up, you had to increase torque here and reduce torque here, but you had to maintain a torque differential to maintain tension while you were accelerating. Well, believe it or not, we accelerated so fast in 3480-- much less than 3420 but still very fast, because our data buffering was not infinite--

**Winarski:** No, it was pretty small, yeah.

**Teale:** --that we would reach a point where, okay, we're trying to haul ass that way and maintain this delta torque. So as we're increasing acceleration, we're increasing torque here, increasing torque. At some point, this torque that was going this way all of the sudden has to reverse and start what appears to be pushing tape out of the pack. So we called that the point of torque reversal. It occurs at about 15 meters per second squared, I believe it was. Saguaro was about 40. 3420 was 100.

**Winarski:** We got 100 meters per second squared.

**Teale:** Okay, so 3420 was a lot higher than that. At any rate, when you have that torque reversal-- and yesterday we talked about pack stresses, the hoop stresses, the radial stresses that are in this pack, different things that can cause that stress to relieve, whether it's thermal or mechanical shock, and we talked about ISVs [Instantaneous Speed Variations] and all of all folderol trying to fix that, but one thing we didn't mention yesterday-- said the word "Z fold" this morning, but there were two tape failure mechanisms since 1952 that were the bugaboos of every product that we ever shipped. That torque reversal, if there is what we call a loose wrap in here, or some place where stress has been relieved, a portion of the pack might slip relative to the rest of the pack and you could actually get tape that would get smashed in the middle of the pack into what we called a Z, and it was a result of this torque reversal that occurred in combination with the stress relief of the pack, and occasionally, if you happened to put the tape away with a Z fold in it, you'd have no way of knowing you did that, and it would sit there on a shelf for a long period of time. Eventually the tape would permanently deform in some unpredictable fashion, and you might pull that tape out and have a permanent error, which is the-- which is death. <chuckles> That was-- and that was a failure mechanism that was with us from 1952 until the 3570, when we designed a unidirectional-only torque capability and reduced the acceleration and eliminated Z folds for eternity. So that was a pretty cool--

**Winarski:** That was Magstar, right?

**Teale:** That was Magstar MP. That was the little one, the two-reel [cartridge] one [US 5,284,308]. Because by then data buffering was so cheap. Electronics had become so cheap that we could put a huge data buffer in there and we didn't care how long it'd take to get repositioned and ready to rock and roll, because we just-- it buffered for-- basically think of it as a semiconductor-cached tape drive, is what tape drives evolved to. The other big one was something called chopped blocks. In this servo system, when we repositioned the tape to, let's say, append data, somewhere out there in tape, we kind of knew where we needed to go. The radius counts and ratios would kind of tell us where we were, and it's time to write tape, or maybe that it's been stopped. The repositioning was blind repositioning-- we're just hoping our servo system doesn't fail us-- and we start writing data. Well, every now and then we didn't reposition far enough. We would begin appending data over the end of the last data that was there, and that's called a chopped block. You have now basically overwritten data that is irretrievable, and at some point in the future, you're attempting to read that particular block, and all of the sudden you realize it's gone. That's an even worse sin than a Z fold because that is data loss that you didn't know and didn't report to the customer.

**Winarski:** Oh, yeah.

**Teale:** And the customers got nasty surprises. Later on-- and again 3570, very innovative product-- we had a type of track following format called timing-based servo, and this was actually my idea. I'm going to blow my horn a little bit there. We were able to modulate that pattern to give us a milepost all the way down the tape, just like on a highway-- Mile 110, Mile 111-- and they were about every couple of millimeters, and we had a whole new lexicon in tape. It was called LPOS, Longitudinal POSition indicator, from the format, and the new lexicon was if LPOS is valid, you may write.

**Winarski:** Ah. That's--

**Teale:** So we never had chopped blocks again. So one of my great pleasures and one of the stories I love to tell the analysts is how, at least in my participation in the industry, during my four orders of magnitude of participation, it turns out-- of the six that tape was evolved in-- we eradicated the two biggest permanent error mechanisms in tape, and today's tape drives are unbelievably reliable. Unbelievably reliable. Just all by themselves.

**Gaudet:** Yeah, we thought they were also before we shipped the 3480, but you did a phenomenal job.

**Teale:** Well, that Magstar-- remember I talked about this place where we did all this cool technology and then we almost went out of business, and stuck it on the shelf? A version of that became 3590 Magstar [code name Blythe], but that had the amplitude-based track following servo--

**Winarski:** Right, the different-- different--

**Teale:** --because of the bogus requirement that we probably shouldn't talk about.

**Winarski:** Oh.

**Teale:** In the old days-- okay, we're not quite digressing because the next thing after 3480 was 3590, and the big leap there was track-following servo to get 128 tracks instead of 36. And there was a practice in the enterprise where media was expensive. You walked into a customer like WesternGeco and the first thing you saw was 700 thousand tape cartridges on racks at the front door. So media was expensive, so media reuse, backwards, read and write compatibility, these were important customer considerations because I wanted to buy my new tape drive but they don't want to replace 700 thousand media cartridges as a consequence. So you had to protect their investment both in media and in automation, if they had any, and there was a lot of bugaboos. But one practice enterprise customers had was that rather than buy new media they wanted to reclaim media, and they had old-fashioned degaussers, these large magnetic field-generating, vibrating things. You stuck it in there and, kind of like a microwave, hit the button and you'd hear all this rattling and rolling around in there because there's magnetic stuff getting pushed around, like an MRI and you got a piece of metal in your body-- you're not supposed to do that. And that would give them two things. One, in some cases they did it for security. "We want to make sure nobody ever reads data should this cartridge find its way into the wrong hands." But the other reason they did it was to reuse the media, repurpose it. Put it back in and it's a fresh-- it's like a brand-new tape. Well, guess what? You can't do that if the tape has a factory-written servo format pattern on it. When you degauss the tape the servo goes away. So how do you mitigate the customer's concern? Well, we did all kinds of stuff that was really done historically. We had this thing called data security erase. It's kind of like reformatting a hard disk and putting all 1's on it to try to obliterate what was there, but there's still always going to be a little bit of magnetic print-through and it's not-- anyway, it was good enough. But we had a requirement that said in the event that a customer degausses their media, the drive has to be able to reestablish the servo format pattern.

**Gaudet:** Wow.

**Teale:** It was an amplitude-based servo pattern, and the way we wrote it on 3590 is we would take three of these mini modules and we'd realign them in a certain way and we would drive them with electronics to get the servo on there. Well, all of that that we did in the factory could be recreated in the drive with multiple passes of writing this and then writing that and moving the head around.

**Winarski:** So that's how the requirement came about

**Teale:** And it was one hell of a difficult requirement to meet. It caused all kinds of compromises to the servo system, to the pattern that we were writing, to what we could and couldn't do, and at the end of the day not one customer ever asked to be able to reformat that tape.

**Gaudet:** <chuckles> Did it really work?

**Teale:** And I knew damn well no customers would ask because this was another one of those anachronistic requirements. Nobody actually was degaussing media anymore. They trusted data security erase, or a lot of them didn't even care. And of course later on came in situ encryption, which solved that problem once and for all. So as part of that same pilot technology that I talked about that sat on the shelf gathering dust while we were deciding if we were going to stay in the business or not, Almaden had come up with a timing-based servo similar to a chevron pattern in a disk drive. Some disk drives had this chevron pattern around the OD and that could act as your feed forward for your repeatable runout, and it was a much more elegant, much more robust, much more powerful concept where we could get this longitudinal position encoding in, but it was not field-formattable and by then we didn't care because we realized that it wasn't a real requirement. So the two-reel version of Magstar, Magstar MP, the little guy, shipped with timing-based servo, and timing-based servo was what was declared best of breed for LTO, and it shipped in LTO as well, and we're going to talk about LTO tomorrow. But that was just a quick fast-forward for you as to--

**Winarski:** Well, you get the whole history.

**Gardner:** Al has a question.

**Rizzi:** I've heard you all describe very well a lot of the problems you had getting it to work normally, and some of the things I've heard made me think about what happened-- did you have any unique problems if you lost power in a customer's office or just period, where you lost power to everything, but with the cartridge loaded? Because some of the sticks and some of the things like that might occur under that, and I was wondering did you have to address that at all?

**Teale:** Absolutely.

**Winarski:** Oh yes, and I forget who did----but somebody came up with little guards that would hold the tape in place if there was ever a loss of tension. Those went around-- it was after of course the original design, but this little-- like catchers, so to speak, around the tension transducer and the D-Bearings so that if you lost tape tension the tape wouldn't fall to the deck, and then that was a major problem. It would just stay in place roughly with these little plastic catchers.

**Teale:** And then there was a very special power-up algorithm that we'd go through if we sensed the cartridge was in place, that would very slowly eventually cinch the tape back up.

**Gaudet:** Yeah, the test lab would catch it.

**Teale:** Yeah, they absolutely tested it. It was absolutely a requirement. **T**hat's usually the first thing they do. I mean, their job is to break stuff and they're very proud of it.

<laughter>

**Gardner:** So we've I think now covered a great deal the tape path.

**Winarski:** Well, sort of. There's one thing we left out. <chuckles> That the original tape path-- let me-- here's the cartridge as you see it today. It was originally like this, so to speak. The leader block was on the other side, and someone said, "It's a left-handed tape path." And so the tape path had to be flipped all the way over, and it didn’t change the design at that time, it was just a matter of dimensional flipping, and it was also about that time-- and forgive me, I don't remember the exact dates-- but the original drawings, like from the Intrepid era, were all in English dimensions, and somebody finally wisely said, "Look, this has got to be in metric or SI." So that happened as well. Well, somewhere along the line somebody messed up on the dimension and it caused a cartridge load failure, where the thing would sit at an angle.  I forget exactly-- or maybe the clutch wouldn't quite engage the reel.  And so Joe Bullock, who sadly isn't with us anymore, but he charged Joe Dalmas and myself to "Go solve this problem.  Do whatever it takes."  Well, in building 40, there's this big test lab, the big floor of-- and I forget exactly what it was called, but all this proof testing was going on and they had a failure.  So Joe and I go out and we take <chuckles> as much epoxy as we could find in the model shop and epoxied the drive in place, took it out and-- off the test floor-- and had the model shop cross-section this thing looking for the failure.  Well, in terms of we never did find it, but did we get killed over that <chuckles>, "You took a drive out of that test area?"  <laughs>

**Teale:**  Boy, I remember that.  Yeah.

**Winarski:**  But eventually somebody dug around and they went through all the drawings and conversions and found where somebody-- it was a transposition of two numbers or something, and it was corrected.

**Teale:**  Well, I mentioned one, and it might have been related because it affected the brake button function.  But this cartridge is supposed to be one inch tall, and if you measure it it's 24.5 millimeters.

**Winarski:**  And that could have been part of it too.

**Teale:**  And that's why the brake button didn't--

**Winarski:**  Oh, maybe that-- yes.

**Teale:**  It was squealing, and it might have been related to the load failure.  I don't know.  But yeah, even today-- I've got some calipers at home, and they're still 24.5 millimeters on the nose.

**Gardner:**  So let's talk about the cartridge itself.  That was decided in Boulder, the dimensions?

**Winarski:**  As I recall, pretty much a certain amount of the cartridge was decided in Boulder, but it wasn't until we got to Tucson that Scot Graham did the idea of the clutch having a pole piece US 4,343,441] and that would interact with the brake button [in the tape cartridge].  So I remember that brake button, the spring in there, and the meeting-- the supply reel clutch with this pole piece to disengage the brake button being done when we were at the airport site.  And forgive me, I don't remember exactly the date, but I'm guessing '79, '80 timeframe.

**Gardner:**  And the dimensions remained pretty much the same?.

**Teale:**  I think we inherited it five by four by one.  This was how we inherited it.

**Winarski:**  I remember that basic design.

**Gardner:**  But it probably turned from one to something slightly less when dimensioning changed to metric

**Teale:** Because of that transposition, yeah.

**Gardner:** Transposition of digits from 25.4 to 24.5.

**Teale:** And rather than go fix a whole bunch of molds and we had a lot of cartridges out there, we just decided to adjust the brake button height and that was it.

**Winarski:** And remember how I mentioned about if you lost power that you had these little plastic guards to catch the tape and the tape head? You can see the same sort of concept here where there was guards around the reel so if you lost tension that the tape was constrained so it wouldn't travel far away from the cartridge hub.

**Teale:** This entire system is very ingenious. I had nothing to do with it but I've always admired it. Up here-- you can't see it-- but there's a piece of plastic that sticks down. There's a slot and this circular member called the brake button. That's the button. There's some gears that engage this thing so that when-- and there's a spring that keeps it all exploded-- so you can't turn this reel without separating that button from the actual hub of the tape.

**Winarski:** Yeah, that was a problem because we didn't want the customer having loose tape within the cartridges. So you had to lock the reel in place.

**Teale:** So you have to exert significant force to push that brake button against the spring off of the reel so that that reel will spin. But it's a super elegant solution. It's just kind of built right into the system, and very clever, in my opinion.

**Gardner:** And that was Intrepid?

**Winarski:** I think more Ocotillo timeframe, that Intrepid was more we had a tape path that we would hand-thread. There wasn't a cartridge in place at the moment, although one was being conceived. The Intrepid was more just trying to get something in the tape path to work.

**Teale:** You could almost think of Intrepid more like a plate model.

**Winarski:** Yeah, there you go.

**Teale:** It was not a full developed in terms of function it had-- we were just trying to figure out, "Does this work?"

**Winarski:** That's right. And it didn't, but. <chuckles>

**Gardner:** The notches were in the side of the cartridge from the very beginning?

**Teale:** You know, a lot of the-- okay, I ungenerously indicated that there wasn't super premeditation looking towards automation in the original thought about this.

**Winarski:** No, I'm afraid there wasn't.

**Gardner:** That was actually my next question.

**Teale:** But not because we didn't know what it was. We had shipped it in MSS. There may have been-- this was designed more for handling. The reason it's five inches by four instead of four by four is so people could grab the end of it to stick it in and out of the loader or in and out of a storage slot. There are stacking features in here, and I've got another cartridge, so that when you stack, they don't slide relative to each other. They make a nice, neat, perfect-- so that you could grab 15 of these things and carry them to the next lab without worrying about dropping them. So there was a lot of human factors consideration that went into the design of this, but I wouldn't say there was a lot of automation forethought that was anticipated. We did do a short session on automation yesterday and basically said, "Go talk to STK if you want to get the history of that."

**Winarski:** Oh. Well, I do remember-- well, just going back to the clutch, there was a wear problem that had to be solved because you had this spinning brake button on the tip of the pull piece that was pushing the brake button away, and that was something that had to be resolved. As I recall, they-- just Delrin® or something, but it was just another piece of engineering that had to be done.

**Teale:** It was Delrin®.

**Winarski:** --And I sort of remember, just thinking about it with Joe Bullock, that the first automation we had was like a magazine loader that they would stack these things in and the magazine loader would raise the cartridge up and would load and unload.

**Gardner:** It would hold five of them at first.

**Teale:** That wasn't at time zero though. The ACL [Automated Cartridge Loader] I thought shipped a couple years later.[3]

**Winarski:** Oh yeah, years later, but I just meant from the first automation. But it was after the product was already being shipped.

**Teale:** We called it an ACL, and it was really just so a tape hanger could queue up a few jobs and maybe you could operate with one less tape hanger as a result, or two less.

**Gardner:** So when the power fails and the tapes are spinning and the button drops, does the brake engage?

**Teale:** We had dynamic braking, as I recall. There was a dynamic braking capability. In the event of power loss, there was something that would brake it gracefully.

**Winarski:** Well, that would make sense that there would be probably enough in the power supply capacitors to brake

[3] 3480 Automatic Cartridge Loader feature announced June 1986

**Teale:** Right. I think Jim Karp actually designed the dynamic braking circuit.

**Gardner:** For an orderly shutdown, so you wouldn't break anything.

**Winarski:** Or at least semi-orderly. Yeah, they use the same thing in disk drives, that if there is a power off that there's enough energy in the system.

**Gardner:** Today. There was a time when the disk drive guys just landed, but that's a different session.

**Teale:** There was a time when you had landing zones for the heads.

**Gardner:** That too.

**Teale:** If they power off, you can't necessarily get that get to the zone.

**Gardner:** That too.

**Gaudet:** Right on top of it.

**Teale:** We [tape] is the mother culture, remember, we know a lot about disk drives but they don't know anything about tape drives.

**Winarski:** <chuckles>

**Gardner:** But I'm learning. I'm a quick student, sometimes. Tape has always been famous for powerful motors, right? -- both for the capstan and for the reels.

**Teale:** The 3420 reel motors were about that big around [8 inches]. They were about that long [12-inches]. They were huge to enable acceleration of large tape reels with mass.

**Winarski:** But it's interesting history you bring up because the high accelerations mandated by no buffer meant bigger motors, and so you see a gradual shrinking of motors and reduction of acceleration as the buffers got bigger.

**Teale:** Direct cause and effect, and a very good outcome. Particularly for LTO.

**Gardner:** Were the motors of a 3480 comparable to that of a 3420?

**Teale:** Oh, considerably smaller. The acceleration requirement for 3480 was-- I seem to recall it was two and a half times less acceleration for 3420.

**Winarski:** Yeah, and I only remember 100 meters per second. But I don't remember the two and a half.

**Teale:** Well, I remembered the ratio between them. The reason I remember that is waiting years for Dan to deliver us something that would work--

**Winarski:** Oh, the ratio. Uh-huh. <chuckles> Yeah. I'm sorry.

**Teale:** The wait did not enable us to do head wear testing. And I was in the tribology department, so the microgeometry, that contour, was only part of my job. The other part of my job was testing the life of these things, because that was a big problem in 3420, head replacement. Head replacement rate was a gigantic concern on this project, particularly when we found out how abrasive chrome dioxide was. And what we would have to do, since we did not have a tape deck to run wear tests on, is we would have to modify 3420s. And the modification required that we mimic the acceleration of, for example, back hitching in case of a start-stop wear test. Because just streaming wear, generally the heads-- it's when you're starting to do all this back hitching all the way down the tape. Some jobs required that they really stress the head wear. And what I remember is we had to take that capstan on the 3420 that was rubberized with holes and a vacuum in it to grip the tape, and we would have to fill the middle of that thing up with mass.

**Winarski:** Ah. To slow it down.

**Teale:** Because we had no way to adjust the acceleration. So what we would do is adjust the rotational inertia of that capstan to get the acceleration we wanted.

ElectroCraft® E543 DC-Brush motor used for both the supply and take-up reels of Intrepid, Ocotillo and Saguaro

**Winarski:** Wow, that's cool.

**Teale:** And do our wear tests. And that's why I remembered the two and a half to one, because that was the amount of rotational inertia we had to add.

**Gardner:** So the motors were pretty much not an issue of problems coming from the 3420.

**Teale:** Well, you know, it's funny. IBM had a history of designing motors, manufacturing motors. Paul Hu has got more motor patents than anybody in the universe, I think. It was before my time, but evidently there was a time when IBM made a tape drive from the casters up. Way before my time. By the time we got to us, we were outsourcing a lot of commodity types of components. I don't recall that there was anything all that special about 3480 motors. They weren't this big around like 3420. They were about that big around. They were still pretty long, as I recall.

**Teale:** One of them had a fine tach on it as Dan has indicated. One of them had a single tach [which was part of the take-up reel's lower flange]. And the way you figured out where you were is you counted how many fine tachs went by in a single rev of the single tach, and that allowed you to estimate the radius of the take-up reel, the radius of the supply reel, and ultimately open loop controlled the entire servo system for tension and velocity. It was really quite elegant, actually.

**Winarski:** And the motors, at least as I recall, were made by ElectroCraft®, and one modification they made was to take the armature and skew it slightly so you wouldn't get into a torque cogging. If you had just a straight armature, every time you went through like a lobe in the magnetic field it would be, "Thunk, thunk, thunk." So by skewing it slightly, that smoothed the transitions.

**Teale:** Well, there's lots of other stuff, but I think we've really taken good advantage of Dan's time here because he lived it.

**Winarski:** <chuckles> I actually have one of the motors at home. I should have brought it.

**Teale:** But there's other things. We haven't spent a lot of time talking about the recording channel, which was actually in the control unit in those days because you had analog interfaces, if you recall, to the actual devices. Andy could probably talk to it if you wanted to talk about it, but we've-- we talked about recording head pretty good. We talked about media pretty good. We've threshed out the deck here pretty good.

**Winarski:** Well, another somewhat humorous story is obviously we put pneumatics back into the 3480 tape path. That required an air compressor, and of course the air compressor made noise, so they had to put all this foam insulation around it, which meant it heated up and the vanes were wearing out. So you saw the seeds there that pneumatics were necessary to make the 3480 work, but eventually they would really have to be removed, and that's where John comes in with his LTO tape head.

**Teale:** Well, Magstar MP, and then LTO.

**Winarski:** Right.

**Gaudet:** As far as the 3480 channel went – the recording channel went pretty smooth. Yeah, there were problems. We had the ASIC designs. We had the iterations, the design problems, the bugs and so on, but that's normal going through. As I recall-- and maybe I'm wrong-- but I don't ever recall the recording channel being a block for the progress. I mean, it didn't miss the schedule in terms of EVT or DVT or MPT. It was-- I don't want to take anything away. I mean, there was a lot in the cable, a lot of noise, a lot of problems that-- signal-to-noise in the channel. But I don't remember-- I mean, sure, along the way there were tweaks, but it didn't require a whole redesign, like we went through in the tape path.

**Teale:** It was a fairly straightforward architecture of the channel, as I recall, and it was a peak detection channel, I believe.

**Gaudet:** Yes. Yes.

**Teale:** So it wasn't-- the channel was one area where we were able to reuse a lot of knowledge and prior experience.

**Gaudet:** That's what I was trying to say.

**Teale:** Unlike all this other stuff that was new

**Gaudet:** it was nothing like this tape path, because if it was, we would have never made it.

**Teale:** You know, along the lines of the football not going very downfield, 160 megabytes to 200 megabytes was not much of a stretch, although we did it on a lot less tape, but the data rate only went from 1.25--

**Gaudet:** To 3.

**Teale:** --to 3, and that wasn't a big stretch either. I'm not saying the channel was a no-brainer, but it wasn't challenged the way the mechanics were challenged, the way the head was a challenge.

**Gaudet:** The technology wasn't challenged. The unknowns weren't really there.

**Gardner:** Reading and writing 18 heads in parallel wasn't a challenge?

**Gaudet:** <inaudible>

**Teale:** Yeah, there was some A-cross-B implementation. It was the first tape drive that had a true ECC that I know of. 3420 had some weird bogus recovery

**Gaudet:** The 3420 didn't have error correction.

**Teale:** Didn't really have ECC.

**Gaudet:** It just, "Hey, you got an error. You got to go back and rewrite it."

**Teale:** It had parity and it had stuff like that.

**Winarski:** But Judd McDowell was a recording channel person, like site expert, and he was on a big poster of IBM and it said, "Autograph your work with excellence." And so Judd was well thought of for his work in recording channel.

**Teale:** He's the guy described yesterday that walked on water and got all the awards.

**Gaudet:** There was very good first-level management people. I recall--

**Teale:** Al Ramirez.

**Gaudet:** --Al Ramirez. Very capable.

**Teale:** Dave Oldham.

**Gaudet:** Track following, made sure that worked -- Dave Oldham, that's another name, yes. I mean, but very, very key people that-- yeah, there were a couple hiccups, but it wasn't the showstopper.

**Teale:** In fact, we rode that relatively primitive recording channel architecture well-- all the way to LTO Gen 2.

**Gaudet:** You're right.

**Teale:** It was the first time we actually got with the rest of the world on PRML channels. We were peak detection all the way to LTO Gen 2.

**Gaudet:** You're right.

**Teale:** And we'll talk about it tomorrow, but HP was pushing PRML. I was trying to protect my ability to implement, so I was not agreeing until I felt like I could agree and-- lot of fun LTO stories we're going to talk about tomorrow.

**Gardner:** So was it basically 18 conventional peak detectors working in parallel?

**Gaudet:** Yeah. Yeah, there were parallel--

**Teale:** There was a phase lock loop across all 18.

**Gaudet:** Yeah, there's PLL and all that, sure. Well, yeah, you have to--

**Teale:** But I think that was shared information, right? That wasn't an individual channel PLL? Wasn't it shared across all the tracks? Or was that later?

**Gaudet:** [On reading there was a clock window generated for each track which detected the presence or absence of a recorded transition. The data window timing from the Variable Frequency Oscillator/Phase Locked Loop did not respond to instantons changes like "jitter" or bit shift]. I was more focused on the tape deck, the cartridge, the media, the head. <chuckles>

**Teale:** Well, the other thing that was interesting in the evolution of tape at IBM, it was similar to the evolution of channels in disk in that, yeah, peak detection wasn't very sexy and wasn't super high-tech and wasn't PRML, Partial Response Maximum Likelihood--

**Gaudet:** Right.

**Teale:** But we were more interested in digitizing the channel than we were in having the latest, greatest technology, and we spent far more effort converting it to what became a 100-percent digital channel in Coyote [IBM 3570] B or C-- I don't remember which version-- when Bob Hutchins finally delivered the goods. And the funny part is we were landing on an all-digital channel just as disk was moving away, because disk had gone digital but then their performance requirements became so steep that they-- a lot of disk makers actually went back to analog channels just because of the performance requirements. But we got to digital and stayed on digital, and we're still on digital. I mean, there's analog components but the detection is all digital.
[Editor's note: While this statement is correct from the perspective of IBM disk drive and tape drive history, the first digital read channel was likely the Ampex DCRS tape recorder circa 1983 which

employed a 6-bit 120 MHz A/D feeding the PRML Viterbi detector.[4] Also modern disk drive read channels like modern tape drive channels do typically use 6-bit A/D conversion prior to detection.[5] ]

**Gardner:** What do you mean by the difference between a digital channel and an analog channel? What do you mean?

**Teale:** Well, in a digital channel, you have a sampling window. You're sampling the signal and you're applying a lot of mathematical algorithms to try to help you decide was that a one or was that a zero. In an analog channel, you're doing it all continuously. I'm surprised you're asking me. <chuckles>

**Gaudet:** You have to get the analog signal. You amplify it, you overdrive it, get it into a pulse, and then you--

**Teale:** So my point was that the speed of that digital channel is limited by your ability to sample, your ability to do the analog-to-digital conversion of the observation, the sample rate had to have-- there's a-- or ultimately if speed is all you're interested in, a some point digital channels can't go fast enough. But analog channels scale linearly with performance, where digital channels kind of don't.

**Winarski:** Wasn't there a key part of the 3480 write channel where they-- was it Dave Griesel who started the double write pulse?

**Teale:** We talked about writing precompensation yesterday in great detail, and what a wonderful discovery that was.

**Winarski:** Oh yeah.

**Teale:** Downstream benefits.

**Gaudet:** You basically take the analog signal itself and you overdrive it. You differentiate it. That's where your peak of the pulse sits. And then you overdrive it, so you come up with these little pulses, and you phase-lock on those, and that gives you your signal and your timing that you need to detect the information.

**Gardner:** There's probably 50 patents in the area of variations on that theme.

**Gaudet:** At least. At least. Now, PRML is different.

**Teale:** So I only pointed it out because we weren't driven by performance. Digital channels was our Holy Grail.

**Gaudet:** Right, it was.

[4] "High data rate magnetic recording in a single channel," Coleman, et. al, JIERE, Vol. 55, No. 6, pp. 229-236. June 1985 and Ampex History
[5] Based upon correspondence with R. Wood, T. Howell and D Adams. See, e.g. for description of advanced tape read channels, "Advanced tape technologies – Tape data channel" at IBM Website

**Teale:** Because now we've got a completely programmable system, but we don't have to do a new ASIC every dang time we want to tweak something.

**Gaudet:** Exactly. <chuckles>

**Teale:** But disk land went digital for a very brief period of time and then their single channel screaming performance requirement drove them back to analog to get the performance. So the point is there was no synergy between disk and tape in terms of recording channel. We were multitrack, they weren't. We were analog, they were digital.

**Gardner:** I think Al Rizzi has another question.

**Rizzi:** Yeah, I have just a quick question, and it's kind of driven by one of the things Dan said having to do with the cables and DASD having write preamps on the arms, etcetera. We just had a big enough signal we didn't need that? What was the reason we wouldn't put the write preamps up closer to the heads?

**Teale:** Because we had 18 heads. <chuckles>

**Gaudet:** Yeah, it's a packaging--

**Teale:** It's a packaging nightmare. Believe me, we thought about it every time we did a different platform.

**Gaudet:** We could have. With later-later technology, packaging technology, but it wasn't available at the time to do that effectively.

**Winarski:** When did you put it in? Was it 3590?

**Gaudet:** We never did.

**Winarski:** Never did?

**Teale:** No, not even in LTO. We don't have any preamps near the heads

**Gaudet:** I don't think so, no.

**Winarski:** Wow.

**Gaudet:** I didn't think so. Yeah.

**Teale:** But we've shrunk that packaging down to where these cables are very short now.

**Winarski:** That's true. Right.

**Gaudet:** Think of it, driving that signal from the head all that way.

**Teale:** Well, first of all, this cabling is ancient crowbar technology. Remember we've got the multiple track actuation.

**Gaudet:** Was it Kapton®?

**Teale:** Kapton®, yeah. Now imagine that we're going to attempt to move this head up and down a fraction of a millionth of a meter, trying to track follow something written.

**Winarski:** With those cables.

**Teale:** Ain't going to happen.

**Gaudet:** No way.

**Teale:** So, and a modern tape drive looks nothing like this, but we've only got this because this is 3480 and not LTO. And we're not even going to really talk much about LTO implementation tomorrow because most of it is still IBM-confidential on the implementation. We can talk a little bit about the consortia and how it works, but that's about it. I don't even think we can talk about the business construct because I think there are elements of it that are not public domain.

**Gardner:** So are there any other areas of tape mechanisms, tape drives that your disk drive interrogator has left out and you'd like to share with us?

**Gaudet:** There's always memories fond and ones you want to forget, but 35 years ago, that's <chuckles>-- we just hit on the highlights I'm sure. Maybe Dan can remember everything, but I-- it had to impact me to remember it. <chuckles> So what I've said during this whole session, the sessions we've had, have been the points that really required focus.

**Gardner:** Sure. It's the high points, or low, depending upon your perspective.

**Gaudet:** Right. But you don’t remember the things that you didn't worry about.

**Teale:** One view of the evolution of tape technology that I-- I have a cut at it and I actually sent a cut to the Storage SIG once, but I don't think it saw the light of day. I talked about the seven odd things that were innovative going from 3420 to 3480. There were a couple of things going to 3490E. I mentioned them--

**Gaudet:** Yesterday.

**Teale:** I forget what they were. I mentioned them, but I don't-- but then we would go 3590 and that's the whole track-following servo story, and formatting. And one of the most significant things about track-following servo on tape is now media companies needed drive maker IP to produce media, and boy, did that change the IP game in that space significantly, because now IBM could practically pay its development bill with the media royalties that were collected from the media companies to enable track-following servo formatting of the tape at time of manufacture.

**Winarski:** And the servo writers.

**Teale:** Servo writers.

**Gaudet:** Well, you were doing your LTO stuff for free, from the royalties from tape cartridge manufacturers.

**Teale:** Basically our royalty stream just from LTO [code named after gems: Sapphire, Emerald, Ruby] alone was bigger than our development budget when I left the business.

**Winarski:** Wow.

**Teale:** But of course the accountants wouldn't let us view it that way.

**Winarski:** Yes.

**Gardner:** So Dan, your perspective on your years, both as a developer and then as a licensor? Could you summarize your perspective on things?

**Winarski:** Well, that's a good point, because IBM had such fundamental patents for reel-to-reel technology, having the first of that product, that we would go out and actively license companies to the media technology, the tridecyl stearate lubricant, the tape cartridge, the leader block, the take-up reel. So there are a lot of key components that became an active revenue stream for IBM regarding the patent licensing, and IBM had an open policy to license people -- some people use patents as a monopoly. We didn't. We would go out and license companies in a fair-and-reasonable way -- and the idea was we didn't want to alienate any companies because we still regarded them as partners, even though they might need our patents in one area. So you get into the concept regarding these patent licenses of a balancing payment. We might need some of their patents. So we'd look at the relative royalties. But again, the whole concept of whatever we did was to maintain the business relationship.

**Gardner:** Were you actively involved in your licensing career with licensing of 3480?

**Winarski:** Oh yes. I got to visit my good friends at STK. <chuckles>

**Gardner:** Must have been quite an experience.

**Winarski:** Yeah. And so they were using-- and I forget what model-- it was an older model tape drive of theirs-- but yeah, they were using-- their take-up reel looked remarkably like ours with the mini doors, and they were using of course a leader block in their tape cartridge, and I forget what other patents. But yes, so clearly the 3480 not only-- it was great working as an engineer, but as a follow-on career as a patent licensing person, 3480 helped me along.

**Teale:** We worked with a gal in San Jose that I think worked across tape and disk named Sofia Laskowski.

**Winarski:** That's right. Sofia was my second manager [in patent licensing]. I forgot to mention her in the-- Joanne was my manager briefly for about a year, and then she, for whatever reason, had had it with patent licensing. So <chuckles> I remember being introduced to Sofia as her powerhouse for doing proof packages of infringement. I think that was largely due to all the other people had left <chuckles> along with Joanne. I was the one surviving member. But no, it was great. Made a lot of trips to Japan, like Fuji Photo Film and-- not only did we do licenses for revenue bearing, sometimes we just needed a cross-license with a company, be it Tandberg Data or Fuji Photo Film. It was more like, "Hey, we need your patents, you need our patents. Let's document this so that we can maintain a business relationship." And so there was a certain amount of work in just tracking patents and who owns what to make sure that everything was on the level.

**Teale:** Yeah, I remember traveling to Tandberg with Sofia to negotiate a sliver license-- you may have been on that trip--

**Winarski:** Oh, definitely.

**Teale:** --on something that impacted the actuator that we didn't feel we could design around in a timely fashion or even do a better job. Tandberg, like many European companies, was very reluctant to negotiate a sliver license with us because it just wasn't in their culture. It wasn't in their business plan. They tended to use patents to protect their IP, not to share it. We eventually negotiated it, but only-- we were successful for one reason and one reason only. We were not only Tandberg's biggest customer, but we were approximately their only customer. <chuckles> We bought quarter-inch cassette drives from them and qualified them for System 400 series. So they cooperated. <chuckles>

**Winarski:** That's right. That was like the best patent licensing trip I was ever on, because you made the reservations well in advance. I could take my wife, and so we got to see Oslo, got to see "The Flying Dutchman" presented in Norwegian. Or no, in German, but with Norwegian subtitles. But it was a grand time.

**Teale:** Got to eat some reindeer maybe.

**Winarski:** Oh yes, and caribou stew.

**Teale:** Yeah, the Laplanders farm reindeer as a food source up in-- Laplanders meaning they go across Sweden, Norway and Finland. They're nomadic basically.

**Gardner:** And so Andy, do you have any summary remarks on tape past and present?

**Gaudet:** I summarized it at the beginning, that the job that was done was a combination of a lot of good work from a lot of good engineers, a lot of technology, lot of insight that you've seen today from Dan and John. But it all came together, and that's what gave us the 3480. Without talent like this, it just doesn't happen, and we were blessed with it. It worked out great. Going through it day by day was hell, but coming out the other end, it was phenomenal. <chuckles>

**Gardner:** The six-year war ended successfully.

**Gaudet:** That was it. John started with that, yeah. Right, exactly.

**Winarski:** We'd also like to remember both Fred Froehlich and Joe Bullock.

**Gaudet:** <gasps> Froehlich's finger. You remember it?

**Winarski:** No, but I remember his long cigars.

**Gaudet:** <chuckles> No. John, you talked about that yesterday.

**Teale:** I remember it vaguely.

**Gaudet:** About the stick for keeping the tape off the head.

**Winarski:** Oh, I remember the Froehlich finger now. Yes. [The Froehlich Finger was a Rube-Goldberg mechanical "pull the tape away from the tape head" mechanism to keep the tape from sticking to the recording head when the tape was not moving. It caused threader problems and was replaced by the pneumatic puffer-head. Source: email with Winarski]

**Teale:** And we had a mechanical--

**Gaudet:** Anyway, Fred was a great guy.

**Teale:** I summarized yesterday, so let's close.

**Gardner:** Okay. I think that is a wrap.

**Winarski:** Thank you so very much.

END OF INTERVIEW

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Editor's process notes:

First pass review completed by Gardner on July 17, 2016, as 102738021-05-01_IBM_Tape3_3480_TEG.docx.

1. Comments by received from:
   a. Winarski on August 27, 2016, as 102738021-05-01_IBM_Tape3_3480_TEG_DJW.docx
   b. Gaudet on August 29, 2016, as 102738021-05-01_IBM_Tape3_3480_TEG_GAUDET.doc
   c. Teale on October 31, 2016, as 102738021-05-01_IBM_Tape3_3480_TEG_DJW_Gaudet_Teale.DOC

2. Final draft completed December 30, 2016.

3. Subsequent changes:

  

a. Changed session name from “3480 Tape Drive Details Panel:” to “IBM Tape History – Session 3: 3480 Tape Drive”.
b. Changed associated session file name from “102738021-05-01_3480_Tape_Drive_Details.docx” to “102738021-05-01_IBM_Tape3_3480.docx”
c. Changed associated video file name from “3840 Tape Drive Details_FIXED.mp4” to “IBM_Tape3_3480_FIXED.mp4”
d. Moved Appendix 1 into session
e. Revised introduction

4. Memorabilia offered by interviewees and accepted into the museum’s permanent collection have CHM Lot Number’s X7617.2016, X7620.2016, X7677.2016, X7678.2016 and X8091.2017.

5. All unknown or uncertain names, dates, places, products and other facts were verified to the extent possible. A collection of more than 100 pdf documents collected in conjunction with editing this transcript was provided to CHM as Incoming Receipt A2017.5820.

  

## APPENDIX 1 – eMail from Teale

From: John Teale <lobo1976@gmail.com>
Sent: Thursday, October 08, 2015 3:19 PM
To: Tom Gardner
Subject: Fwd: 3480 Technogical Innovations

Hi Tom here is the list of stuff that was unique to 3480 at the time.

Solid state data buffer
- Elimination of vacuum columns
- Reduced tape acceleration
- Smaller reel to reel motors

Thin film write head
- Harder substrates for longer head life (no metal)
- Higher frequency operation improving linear density

Center tapped shunt biased magnetoresistive read head
- Reduced tape velocity - signal amplitude independent of tape speed
- Smaller gap length / improved gap length control for higher linear density
- Reduced track width footprint for higher track density
- Harder substrates enabled
- "Free" common mode noise rejection

Write equalization
- Vastly improved write coil life
- Improved read sensor linearity
- "Fee" signal equalization

Chrome dioxide media
- Higher coercivity for higher areal density

Cartridge media
- Reduced tape damage from handling
- Improved volumetric density (smaller data centers)
- Automation enablement

AxP ECC
- True error correction

Recording channel
- ?

etc.