Oral History of George E. Comstock

Interviewed by:
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Gardner Hendrie: George I'd probably like to start really far back, where you were born and grew up.

George Comstock: Well gosh, if you were to ask my wife that question she might answer that I never have grown up <laughs>. But taking it in a more literal sense, I was born in Canandaigua, New York, but only lived there for a year, so I have relatively little memory of it. My first memories really are of Worcester, Massachusetts where my parents moved when I was five years old. So I grew up in Worcester. And I was about nine years old when I got acquainted with the older brother of one of my playmates, Al Howell, they lived across the street from where I lived and he at the age of 15 was an avid model airplane builder. So he got me involved at the age of nine in learning how to build model airplanes, and that became quite a career for me during grammar school and high school. I must have built several hundred models before I was done including maybe a hundred gas models and lost a few in cumulus clouds, you know <laughs>. So that got me started on an engineering career, really, that's why I mention it, 'cause he went on to go to school at Worcester Tech (WPI), became a mechanical engineer and young George figured there couldn't be anything better to do than what Al Howell did, so I went to Worcester Tech and became a mechanical engineer, I graduated in 1945with a BS in mechanical engineering.

Hendrie: So that's how you got started.

Comstock: That's how I got started.

Hendrie: Now could you give me the background, did you have brothers and sisters?

Comstock: My sister was born when I was almost 12 years old, so I we really didn't develop much of a relationship until her adult years.

Hendrie: So you really grew up more or less as an only child?

Comstock: I was an only child.

Hendrie: Now what did your parents do?

Comstock: My mother was a traditional housewife and a fundamentalist in terms of religion. My father was a newspaper advertising salesman, and a heavy drinker, and I suppose those two kind of go together, the fundamentalist and the alcoholic. So that was the household I grew up in. My Dad was disappointed with me in many respects, he was an avid fisherman and liked to use his shotgun for hunting, and I wasn't interested in either of those activities. So we had relatively little in common, I went my way and kind of ignored what he did and he went his way and kind of ignored what I did.

Hendrie: So you got more of your inspiration to go to engineering school from your friend?

Comstock: Came from Al Howell.

Hendrie: Came from your friend.

Comstock: Yes. Who became a suspension engineer for a Mack Truck Company.

Hendrie: When do you think you decided that you wanted to become an engineer? When did that dawn on you?

Comstock: I suppose I didn't realize there was such a thing as an engineer until Al Howell went off to Worcester Tech to study to become one, and it was clear to me that my interest lay in that direction.

Hendrie: How much older was he than you?

Comstock: Well when I first met him he was fifteen and I was nine.

Hendrie: So six years older.

Comstock: Yes**.**

Hendrie: So you had plenty of time to watch him at Worcester Tech and say "Oh yeah, all right."

Comstock: Actually most of my contact with him was before he went to Worcester Tech. When he got to Tech he became deeply embedded in his homework and I saw relatively little of him. Then he discovered girls and I just saw even less of him. However, there's remained a tie in that I remained closely connected with his younger brother Harvey, and in fact just last week Harvey and his wife Debbie, who grew up in our neighborhood, and my wife and I were on a sailboat in Rockland, Maine with the two of them. So we've been in touch for a good many decades.

Hendrie: That is going back very early in your life.

Comstock: Yep! Just as an aside, the experience in Rockland, was a good test of our friendship, because we got out in a 40 foot O'Day and the first night was… we arrived late in the day and got out to a mooring in Rockland Harbor, and the next morning everything was fogged in solid, and in fact we sat there on the mooring really for four days waiting for the fog to lift which it never did and then we came home <laughs>. We did get off the mooring just twice, we did a partial foray thinking we might get over to Vinalhaven, but the GPS led us out into the middle of the waters between the two, about three miles out and we never did see the buoy that we were aiming for with the GPS. And so we turned around and did a reverse course on the compass to get back to our mooring and fortunately found it. And then another day we did a brief run up along the breakwater and into Glen Cove and then back but it was so foggy, it was just very uncomfortable, foghorns blasting all over and you never know when the ferry's going to appear 150 feet away headed straight for you <laughs>. So we discovered that we were really good friends 'cause we could endure this experience for the full four days without once not even one cruel word or <laughs>.

Hendrie: That is very good.

Comstock: It worked out well. That fog was dense enough so one time Harvey and I made our way into the town dock in our dinghy to get some supplies and we got lost trying to find the boat again. Lost in the fog <laughs>, but we stayed amidst boats so we knew we were going to find it eventually, it was kind of a random walk until we got to it. <laughs>.

Hendrie: So you majored in mechanical engineering.

Comstock: Right.

Hendrie: Any particular specialty in mechanical engineering?

Comstock: Oh yeah. I minored in aero. You see I'd been building all these model airplanes so aero was a very natural minor. And the job I accepted on graduation was at Grumman Aircraft in Long Island, and I worked there as a junior engineer for six months.

Hendrie: Now when was this?

Comstock: This was 1945, right toward the end of World War II. I'd had a deferment during most of the war as a student, engineering student deferment, and I got called up in the draft toward the end but they discovered a punctured eardrum and decided I wouldn't be suitable for the army, so that permitted me to finish the college work.

Hendrie: Were there other places you applied to and you thought of going to work?

Comstock: No, just some time during my senior year in high school I went over and had a chat with Dean Howe, the Dean of Admissions at Worcester Tech and he told me he thought I had a pretty good chance of getting in, and it worked, I graduated second in my class there. I was beaten out by a guy that got .01 percentage points above my grade point average <laughs>. He went to work for Pratt Whitney, so I guess Pratt Whitney got the cream of the crop.

Hendrie: I think Grumman had some pretty high standards in those days.

George Comstock: Anyway I stayed at Grumman for six months and I was immersed in a sea of drafting tables, and I had my own drafting table of course. I was a junior engineer. They didn't put me to work designing wing ribs or anything like that. I was assigned to an autopilot project that they had going. There was an outside inventor who had conceived a pneumatic autopilot and Grumman was trying to commercialize it. And so I was doing some experimental work with that thing, building rocking platforms and the like that we could do some testing of it before putting it in an airplane and the like. But in addition to these acres of drawing tables there were also acres of desks with desk calculators on them, each manned by a woman and the women were the computers in that company.

Toward the end of 1945 I received an offer from the Norton Company back in Worcester, my home town, to join a diamond synthesis project, the mechanical engineer designing high pressure vessels for diamond synthesis work. And that seemed so much more romantic than these acres of drafting tables that I left the aircraft industry, left it behind, and went into what would you call it, materials science. We were—I was designing pressure vessels that would work at 30,000 atmospheres with temperatures of 1,000 degrees centigrade. We were beaten to the successful conclusion of this work by GE, who adopted a different approach. They worked at pressures up to 60,000 atmospheres or so, with a much less well controlled temperature environment, but they succeeded. We had done one experiment of trying to make a 60,000 atmosphere vessel with 1,000 degree centigrade temperature, and it broke on the first run of course, and there just wasn't money or time to pursue that any further. But GE with its simpler anvil approach succeeded, and in fact in later years they used to love to demonstrate their diamond-making process by smearing a dab of peanut butter on the press's anvil and converting the peanut butter into diamonds. It was a very romantic subject, in fact a book has been written on it that even mentions the work that was being done at Norton.

So I worked on that project for three years at Norton Company, and then they were kind enough to grant me a sabbatical at pay, which at that time was like a little over $3,000 a year, and I used that to go off to Cal Tech to get a master's degree in physics. Oh and meanwhile during those three previous years Norton had permitted me to take courses part-time at Worcester Tech during the day, and I developed a BS in electrical engineering by that process. Then when the sabbatical came along I tried to tie the whole thing together with a year of study of physics, and that was really quite interesting, I loved that.

So when I came back I transferred to Norton's grinding machine division, and began developing you might say more advanced instrumentation and control techniques for their grinding machines. We answered some fundamental questions that had been topics of conversation at Norton for some time. For example they made cam grinders that would grind the camshafts for automobiles, and one of the shibboleths of grinding was that there's an optimum relative speed between the grinding wheel and the work that it's spinning over the surface of. And of course in grinding a cam, which has a large radius at one end and a very tiny radius at the other, the traverse speed of the grinding wheel over the surface of the work varies, varies substantially during the rotation of the cam and the grinding process. Well they thought that they'd get better cams if they could somehow make that relative velocity constant.

So one of the projects I did was to outfit a cam grinder with a hydraulic drive motor for the spindle rotation, to rotate the work, programmed it with a cam that would vary its speed with a variable valve, so that it maintained more or less constant traversing speed during the rotation of the cam**. It** made no difference whatever in the way the cam turned out. So we got that settled.

What's the connection with computing? Well I had to design a cam that would rotate with the headstock and would control the valve that metered oil to the hydraulic motor to control the speed. And that involved quite a serious calculation that among other things took into account the elasticity of the hydraulic pipes that connected the valve to the drive motor and so on. And the tool that I found very useful in doing that kind of computation was the Card Program Calculator, the IBM CPC, which was a fairly early effort by

IBM. It was one instruction per punch card, the machine itself was plug-board programmed, and one of the IBM techs set up a plug-board for me that had all the math functions on it, trig and so forth. So I was able to call for the sine of this angle and the tangent of that angle and multiply these and add those and store them away. The storage was a relay bank that would hold 24 numbers, and the machine went "chunka, chunka, chunk" through my deck of cards and I'd keep recycling, because of course it had to make a calculation for each degree of the rotation. And the amusing part of all this was that I had to complete my calculations in 20 minutes, I had to do a cycle in 20 minutes, 'cause that was the mean time between failure of that IBM CPC as I experienced it. IBM had a fulltime resident service engineer here on site, and I'd grind through a calculation, and then during the next one it would quit and the guy'd come over and fix it up and then I'd get through the next stage and so on. Well that was my first experience with computers per se, up to that time. At Grumman I was using a slide rule, and in the early years at Norton Company I was using a desk calculator, mechanical desk calculator.

Hendrie: That's pretty interesting.

Comstock: So where'd we go from there? That was the Norton experience. After 10 years with Norton I had designed one product that the sales department had expressed some interest in.

Hendrie: Was this a research area?

Comstock: It was called Research and Development.

Hendrie: This is Research and Development? This is where the products were developed?

Comstock: It was. Now in the grinding machine division what they were developing was grinders, and for example they built a grinder that would grind the rolls in steel mills, these were machines that were probably 50 feet long, the rolls that they were grinding were 20 or 30 feet long, and they'd be several feet in diameter, and the way they'd align the machine would be to stretch a piece of piano wire from one end to the other really tight and with a microscope having a reticule on the moving table, observe the stretched piano wire and determine whether or not their carriage is running true. And if it's not running true they'd correct it with a scraper, a hand scraper. They'd take a little bit of cast iron off the ways in the right place to get it to run straight <laughs>. So that's probably going back to the early days of constructing railroad locomotives.

Hendrie: Exactly, or something like that.

Comstock: It was fun but the one product that finally satisfied a market need was this, it was a device for lining up the table on a tool room grinder. A tool room grinder table could swivel to generate a taper on a round piece of work held between centers, so you could get it tapered by swiveling the table.

A competitor, Brown and Sharp, had come out with a gadget that put some kind of electronic measuring device on one end of the swivel table and displayed its movement on a meter, and it was micrometer sensitive, so that the operator of the machine could grind a trial piece, measure its taper, and then make

very small adjustments against an electronic needle that would tell him how much he was moving and he'd get it, well the way the machinists used to put it was get it "dead nuts."

So we thought we needed a device that would compete with that, and they had a patent on that so I came up with an improvement which put a linear variable differential transformer at each end of the table and so I was able to measure the movement at each end of this swivel table and I displayed it on a meter that Simpson built for me that was a special meter that had two meter movements with coaxial structure. So they had two needles operated around the same axis and you could see them in the same field of view, reading against the same scale. And the beauty of that was that I'm measuring the displacement at each end of this table and if the table bends during the process the needles won't move together, they'll go slightly off. So the machinists could tell not only overall how much he was moving but how much each end of the table was moving separately and if he wanted to he could straighten that out and so on and so forth. So that was my contribution to the product line up at Norton Company. Interesting, when we first completed the prototype, the salesmen had decided they didn't really need it so we put it on the shelf under the table and it was about six months later they came around and said "Well we've been losing some sales, so didn't you develop something that would help us on this table alignment thing and can we dust that off?" So I think they ultimately built something like 50 of these things, it used a twin triode to amplify the signal and so on and so forth. Well that was pretty slow progress, I was beginning to think, so when an offer came along for me to join the nascent computer industry I leapt.

Hendrie: You were ready.

Comstock: I was ready. So I went to work for Potter Instrument Company down in Long Island. They were in Great Neck, Long Island at the time, a small company, they had about 80 employees when I joined them, and I think one of the things that impressed me most about Potter was they made an arrangement, they made an appointment with me to come and see them, so I flew down to La Guardia Field commercial and Jack Potter, the president of the company, met me at the airport. Well my God, 10 years at the Norton Company I think I'd spoken to the president once and that was when I declined their pension plan, I figured I could do better just investing myself on the stock market than to put money into their pension plan, and the president said I was the first one that had ever turned down their pension plan and wanted to know what was wrong with me <laughs>. Anyway, Jack Potter met me at the airport and I was so impressed with this little company and the frenzied amount of activity going on, they had lots of projects underway and they were just getting into the front end of digital magnetic tape recording, after having built a career on electronic counters in various combinations. They had started by building a photoelectric screen system that used their counter to measure the flight time of projectiles. So for instance, the armory, oh I've forgotten the name, there was an armory that was involved with machine guns and they were measuring the speed of the machine gun bullets with this rig, and-

Hendrie: And what did it do, how did it work?

Comstock: Well the ball would pass through a first photoelectric screen, that would trigger a counter, not a counter but a frequency time counter, and so it's driven by an oscillator, a megahertz oscillator, and they'd measure how many microseconds it is before the bullet passes the second screen.

Hendrie: I see okay.

Comstock: When screen number one turns on the counter, screen number two turns it off, and there is a flight time that's measured the distance, so there's how fast it's going. Aberdeen Proving Ground, it sold three of these, three of these setups to Aberdeen Proving Ground.

One of their big applications was selling counters to zipper manufacturers, they could run a probe the length of the zipper and tell you exactly how long that-- how many segments were in the zipper, that was a good market for them, and soon . . . But they were-- they'd been asked by one of their customers to add a magnetic tape recording device to one of their counter systems to record the data automatically rather than having a person writing it down. And the only tape recorder they could find, digital magnetic tape recorder was made by Raytheon and cost them 12,000 bucks. So Jack Potter took a look at it and said "We can build one a lot less expensive than that," and so they had-- when I arrived they had created a first generation tape drive that was in three separate rack mounting panels, so there was an upper reel drive, a capstan drive, and a lower reel drive, that's three separate elements.

Hendrie: Now was magnetic tape being used commercially?

Comstock: Plastic based, Mylar based magnetic tape.

Hendrie: Now was IBM using it for digital recording yet?

Comstock: Yes I believe, yes IBM was into it at that point, this is in 1955. But there wasn't much of an independent industry yet. So I arrived at Potter and I didn't actually start working on their tape drives immediately. The first project that I was assigned was a project to build a random access memory system which was one of Jack Potter's conceptions. It was a 3D selection scheme that would ultimately select a strip of tape and move it to one of 10 vertical positions and then stroke a recording head along one-tenth of the length of the tape in the desired location. And these strips of tape were mounted 10 strips to a steel frame and the steel frame was supported in a box with a series of slots cut that the frames could slide in. So the selection mechanism, oh and we stacked I think five frames in this dimension, something like 50 tape strips in this dimension, and then any one of 10 positions vertically. The big box contained a total capacity of 2,500 IBM card blocks, or 2MB data total.

When I got assigned to that project I found that they really hadn't made very much progress yet. They hadn't figured out how they were going to select and position these frames. So I went to work and designed a pneumatic positioning system using binary graded cylinders, the number required for the particular dimension of movement, and used air pressure to move each cylinder to its full stroke in one direction or the other. And the main problem was how to control the velocity at which they moved so that it would be a gentle settlement, not a slam-bang, so I went back to the hydraulic fluid stuff that I'd been doing at Norton Company, and designed these cylinders with a hydraulic component that had a variable porting system that as the piston moved it would gradually close ports, which are just holes drilled in the side walls of the cylinder, to bring it to a smooth stop in that direction. So air is pushing it but the oil was

controlling the velocity, and again that involved a fair amount of calculation. So I spent the first few weeks at Potter sitting there turning the crank on the desk calculator, the mechanical desk calculator, and I was told later that the people in that company found that a very impressive performance <laughs>, kind of cemented my career with Potter. Well this was a real Rube Goldberg of a machine, and while it worked it didn't work very well, and God knows what the reliability was going to be. So actually three of them had been built for Univac at Saint Paul, and I don't think they ever got into service, they just weren't-- it wasn't really a practical solution.

Hendrie: They fundamentally weren't reliable enough.

Comstock: Yeah. But I'd been at Potter only 12 weeks working on that random access memory project when the sales vice president came to me and said "Say George, I wonder if you could tackle another job at the same time you're working on this random access memory?" "Oh what's that Johnny?" Johnny Wilde was the guy's name. And Johnny told me that they had a trade show coming up in another 12 weeks, and that the chap who was working on a next model of tape drive for them was running pretty slow on it and he had — Johnny had pretty serious reservations about whether they were going to have a product to put into this show. So he was wondering whether I could take over on that and get something out in 12 weeks. Well sure, yes why not, I mean this is a very different environment from the Norton Company <laughs>.

Hendrie: Yes exactly, clearly.

Comstock: So I took the easy way out. I didn't change anything in the electronics of the product, but took these three panels and put all their stuff onto one piece of aluminum jig plate, so it was a one panel machine, and we added to it a handle that one could turn that would bring tension arms into a loading position that gave you a linear tape threading path, which the earlier three unit did not have. And we added a third roller to the tension arms whereas the previous ones had two, and that combination let us take the tape speed from 60 inches a second up to 75 inches a second, and made the thing generally more user-friendly and a more comfortable kind of design. And it took the same amount of rack space as the previous machine, but it was a cleaner product. So we got it out in 12 weeks and got it in the trade show and that became the Potter Model 905 Tape Handler, and we sold several thousand of those over the next couple of years. Subsequently we brought out the Model 906, and I'll have more to say about that a little later.

Hendrie: Yeah okay.

Comstock: But that was kind of my solo engineering career as it were. In 1957 the Model 905 tape drive was coming to the end of its life and we were needing a replacement for it and just about that time a most fortunate thing happened, and that is that a man named Andrew Gabor, Dr. Andrew Gabor, walked in the door and said "I wonder if you have any jobs for engineers in this company?" Well I interviewed him, I was the manager of the computer peripheral equipment side of the engineering department at that point, which involved printers as well as tape handlers. So I interviewed Andy and I was just bowled over with the guy. He was a PhD, had worked in Budapest as a radar development engineer, and appeared to

know just infinitely more about signal processing than any of the people on our staff did. And so we hired him in an instant, and the first project I gave him was to bring along the next generation of read-write amplifier for our seven track IBM compatible tape drives, which he did handle, a beautiful piece of work. On the Model 906 tape drive that we were trying to generate to replace the 905 one thing we wanted to do was to experiment with the use of silicon controlled rectifiers for the reel drive servo motors.

Hendrie: Now was the objective to have lower cost or higher performance?

Comstock: Well all of the above, and greater reliability. We had been using Thyrotrons, 2050s I think they were called, as the control element for the servo motors of the original Potter drive and also the 905. And we were reading about the remarkable SCR development that was coming along, and we decided that that was just the thing we needed to drive some beefier motors to handle the tape more effectively. And my recollection is of asking Andy to take a look at that, and he did and came up with a very successful drive. He used a one horsepower DC motor and four SCRs in an H configuration to give a bi-directional control for each motor. Now at the time we started this project the SCRs were being priced at something like $2,000 each, and we were going to put eight of them in each of our drives, the target price for the drive OEM sales price was $3,500 so you could either say we were nuts or that we had the courage of our convictions. But fortunately by the time we actually got the machine into production, which wasn't all that much later, the price had come down to a few bucks per SCR and of course once they got into washing machines and so forth they were down at 95 cents a piece. So that was a really good decision, and Andy did a beautiful job of putting together a circuit that would drive those motors very effectively. Another project that Andy took on was we were trying to get of course higher and higher recording densities, at that time the standard in the industry was the IBM seven channel, non-return to zero recording at a density of if I recall correctly 256 bits per inch. And Andy by this time was pretty familiar with the behavior of magnetic tape systems, going back to his signal processing background in radar work in Hungary. So he came to us and said "You know, I think we can get at least four times more density on these tapes than we're getting and without any sacrifice in reliability". So of course that became what we wanted to do. And the way he approached it was first of all he chose to use a one-inch wide tape instead of a half-inch tape, so we're departing from IBM compatibility, but he used paired tracks so that there'd be paired tracks based a half an inch apart, and combining the signals from the two gave him protection from tape defects. That was a major step in recording reliability. Well the net result of his work-- the problem of course was de-skewing across a one-inch wide tape, but he handled those problems very effectively and I'm sorry to say that I can't tell you how, that is the details of how he accomplished it in terms of the circuitry. But he did, and in fact we found an interested buyer in the form of Dave Evans, then the chief engineer of Bendix, Bendix Computer. Dave had been using our earlier tape drives on the G-15, and when the G-20 came along he wanted a higher density recording system and Andy's system fit in nicely. So Bendix became our customer for the Potter 1100 bit per inch high density system. And I don't remember how many G-20s were built but I know one of the first ones went to Dr. Perlis is it?

Hendrie: Oh yeah Alan Perlis.

Comstock: Alan Perlis at Carnegie Mellon,and it worked out very satisfactorily. So that was a triumph

for Potter. It took some time before IBM got up to that density but of course since then they've gone on to incredibly higher densities, that were unbelievable at the time.

Hendrie: That's interesting, so there was a significant market for something that was really high density and the IBM compatibility was not yet just something you absolutely had to do.

Comstock: Although, you know, it's possible that lack of IBM compatibility in the tapes may have crimped the commercial success of the G-20, the G-20 did not become a dominant machine in the industry, and that may have been part of it, who knows. One other project that Andy worked on at Potter was providing the circuitry for a coordinate inspection machine. Ferranti in England had produced a machine for use in inspection departments of companies building mechanical products, even including circuit boards and things like that. It had a large table like three or four feet wide and two or three feet deep, and there was a kind of gantry crane with a descending probe and you could move this thing around in three dimensions, you had both the width and the front to back and also a vertical movement of the probe, and a Nixie tube readout of what the dimension is, what the coordinate is of the point, where it's sitting. And Potter decided, "Gee, here's a perfect application for my counters, we've been in this counter technology right along and we need something to further that."

Andy worked on the circuitry to drive the counters in such a mechanical system, and we were using that is, a linear photographically produced scale with a reticle riding on it, and a photoelectric cell looking at what's happening, in fact two photo cells, with a dual pattern so that you had two signals offset by 90 degrees that you could tell which direction you were moving in. Andy developed all that circuitry. The reason I mention that is that this business of using — let's go back to a simpler, easier way for me to describe the situation at least. Back when I was at Norton Company one of the things that I worked on was what I called an electronic micrometer, and the way this one worked was that I had a round rod in which I cut threads, so it looked like a bolt, or a threaded rod, and put windings round it, two wires in adjacent V's of the thread, so I had a bifilar winding running the length of this rod, and then a thin cylinder surrounding the rod with a single winding on it of the same pitch. And by exciting the bifilar windings with two AC signals 90 degrees out of phase, we had a situation where the pickup on the moving coil would reflect its position in a phase determined manner, that is the phase of the signal coming out of the pickup would vary from in-phase to 90 degrees out to 180 degrees out and so forth as it moved along one pitch of the screw. And that principle-- the principle of a bifilar winding came into play in Andy's subsequent work. In a sense it was in play in this coordinate measuring machine, because the photoelectric grating was providing two signals, two photoelectric signals 90 degrees out of phase, and you could tell which direction it was moving in by how those signals varied, the two pickoffs. And the thing that I did at Norton Company, I wasn't concerned because I had a rotary electronic device, a rotary rotating electrical machine, a synchronous device driven from the signal so it simply followed what was happening on the pickoff, so you only needed a single pickoff, but it stayed phase-locked. But in this other type situation you're counting what's happening, like null crossings, and the null crossings are the critical point, but then you want to know—

Hendrie: You want to interpolate between the null crossings in some sense.

Comstock: Well, yes and no. Anyway in the subsequent application it's a non-interpolation thing but there's another trick that came into play that's important. Anyhow, I finally left Potter in 1964 —

Hendrie: Can we take a break right now.

<Crew Talk>

Comstock: In 1964 I received an offer to join the Friden Calculator division of Singer in San Leandro, California. Singer had acquired Friden the previous October.

Hendrie: Now Friden was just making the calculators at this time?

Comstock: Friden had been started in 1935 by Carl Friden who had been the chief engineer at Marchant Calculators, so he split off, they aren't new <laughs>, he spun off from Marchant to found his own company Friden Calculators. It became probably the leading company. There were really three in it, Monroe, Marchant and Friden. And by the 60s the mechanical calculators were under severe pressure from what was beginning to be the computer industry, and there was work being done in various places on electronic calculators, and in fact Friden hired a couple of guys out of Burrows, L.P. Robinson and George Hare to come in and get an electronic calculator program moving at Friden. Their challenge was how to lift Friden out of the mechanical age into the electronic age. And so I was one of the people that they hired to help in that process. So I joined them in May of 1964 as director of R&D for the San Leandro lab. The company had four laboratories. They had a facility in Rochester, New York, which was the former Commercial Controls Corporation that had been acquired by Friden. Commercial Controls built the Flexowriter. Now the Flexowriter had originated as an IBM product and using paper tape for input-output it incurred the displeasure of Watson Senior, and so they had spun off their Flexowriter activity from IBM to the managers who set up Commercial Controls Corporation to carry on the Flexowriter work. And Friden had subsequently acquired Commercial Controls, some time in the 50s I guess. And in fact one of the children of that marriage was a line of products called Computypers, which were a combination of the Friden Mechanical Calculator as an arithmetic unit and the Flexowriter as the IO and printing device. And the Computypers were used for simple billing accounting applications in small businesses. In a sense they were competing with the bottom end of the Burroughs line of accounting products. But it was a successful product line. They were selling several thousand Computypers a year. It was really a kludge. I mean the calculator portion of it was rigged up with solenoids to punch the buttons, and with rotary contact making pickoffs to read the contents of the accumulator out to relays <laughs>. Would you believe it?

Hendrie: Oh my goodness, that is a kludge.

Comstock: Yeah. And the Flexowriter of course used solenoids to actuate the key driving elements.

Hendrie: Many of the very earliest mini computers used Flexowriters as their IO until the ASR, until Teletype came out with the ASR33.

Comstock: It was the standard of the industry for some time. So I joined Friden in '64, with the charge of helping them continue this process of moving into the electronic world. At the time I arrived they'd already taken a giant step in that direction, in that they had just started marketing the Friden model 130 electronic calculator, which was the first U.S. designed and manufactured machine of its type. There was one in England that preceded it by a few months, but we were the first in this country. That was an interesting product. It used a coiled piano wire coil as a delay line memory for storing 1,024 digits.

Hendrie: And this is an acoustic delay line.

Comstock: Delay line, yeah, acoustic delay line. And it had a CRT screen display that put up as I recall five lines of stuff, there were four registers in the machine and they displayed the contents of the four registers plus the, what do you call the active memory element where work's being done?

Hendrie: The accumulator probably.

Comstock: The accumulator. So they were selling these for roughly $2,000 a copy, as opposed to something in the range of seven or $800 up to $1,200 a copy for their mechanical calculators. Well the pride of the Friden line in the mechanical calculators was their machine that would do square roots, that was sort of the epitome of calculators.

Hendrie: Of mechanical engineering and ingenuity yes.

Comstock: That's right. Six to eight thousand parts, and a manufacturing cost that averaged about five cents a part. So they could do a six thousand part calculator for a $300 manufacturing cost <laughs>.

Hendrie: My goodness, wow.

Comstock: One of the more interesting job titles in that company was Tweaker, well you might ask what is a tweaker. A tweaker is a person who has great skill in manipulating a screwdriver that has a slot cut in the tip of the screwdriver, and this slot could be slid down over some mechanical linkage part and given a tweak to change its length minutely. And these folks stood at the end of the production line and they'd run tests on the calculator and if it's not going quite right they'd know exactly which part to tweak to make it run correctly, and that's the way the machine got shipped <laughs>.

Hendrie: Oh my goodness.

Comstock: I'm not quite sure what the electronic equivalent of that is <laughs>, but maybe "tweaking" potentiometers come close.

Hendrie: Yes I think they come very close.

Comstock: Little potentiometers with a slot in the head-- in the end of the shaft and a small screwdriver you can drop in that shaft and you could twiddle something. There weren't any bulls-eye patterns on an

oscilloscope to help these mechanical calculator tweakers but they developed great proficiency in the art.

Hendrie: That's a great story.

Comstock: So one of the projects that was underway when I joined the company was the development of the first electronic Computyper, in which the arithmetic unit from this 130 calculator, along with its delay line, was used as the central processor. They used a second delay line for fast memory storage, and it drove a Flexowriter, and the Flexowriter's paper-tape punch reader was the IO. So it was a complete little electronic computer-like machine that was selling, well it was under design when I arrived and, you know, my recollection is that we made a decision early on to change the design of the PC boards from a transistorized version which is what was active when I got there, to using the Hex inverters that had just come on the market. You remember that one of the first integrated circuits, a caterpillar-like thing, was the Hex Inverter and we used the Hex Inverter for the main logic element to build the Model 5600 Computypers.

Hendrie: Now did this have a stored program?

Comstock: Oh yeah, misconstruing the question, it was a plug board program, yeah.

Hendrie: It had a plug board program okay.

Comstock: So an outgrowth of that work was a more ambitious project that we got started a year or two after I joined the company to build a multi-user Computyper. In fact it turned out to be one of the early mini computers for business application, and this is being developed in the timeframe around 1967 or so. It was intended to support up to 20 operators sitting at their own individual Flexowriters, and I remember one of the big issues in designing it was do we use a 6-bit character or do we use an 8-bit character, memory being expensive in those days. And this was going to semiconductor memory, rather than delay line memory. So the decision was made in favor of 6-bit organization to keep it—

Hendrie: To keep the cost down.

Comstock: Keep it economical. And in fact we did succeed in making a product out of this and it went to market in 1969 and the big problem was supporting it with software, course nobody else was providing software for this machine so Friden had to develop its own accounting software and all the application stuff, not to mention an operating system and so forth. Oh one other detail of the—this ultimately was sold as the Singer System 10, a multi-user, multi-tasking office mini computer, Singer System 10.

Hendrie: With not a plug board program, this had it internal?

Comstock: That's right.

Hendrie: Internally stored?

Comstock: Yes. One of the amusing details of its design was that a certain amount of memory could be allocated to each user terminal and it was allocated with a hardware jumper that was soldered in place. So whenever somebody wanted to change the configuration of his office, the Friden technician would have to come out and resolder new jumpers in to effect the proper memory allocation-<laughs>. Now I believe that Singer and Friden Singer succeeded in selling some substantial number of these in the U.S. and perhaps approaching 1,000. But in the unwinding of Friden which took place in the mid-70s this product line of the Singer System 10 was sold off to ICT in England, and what I've heard is that they sold another 1,500 of them before the product was declared obsolete. So a fair number got distributed around the world. Well not large in comparison with the number of computers today, but for the time it really-- it was a respectable thing. One of the needs for that machine was for mass storage, and the system architect on it who was an ex-Burroughs man was all excited about buying a horizontal spindle fixed disk drive from Control Data, and—

Hendrie: Horizontal spindle, yes.

Comstock: With a disk on each end of it, and very expensive I might add.Well it was at about this time that I had a phone call from Andy Gabor saying that he was interested in finding out whether we had any work for him, he left Potter shortly after I did, and joined Honeywell in-- what's the town in, it's not Braintree but-

Hendrie: No. He worked I believe in Waltham.

Comstock: Waltham, okay.

Hendrie: Yes, that’s where I first met him at that time.

Comstock: That's where you met him. Okay.

Hendrie: That's where I met him.

Comstock: Well he was working on disk drive developments I believe under Mario Chu, was it?

Hendrie: Chuan Chu.

Comstock: Chuan Chu, that’s it, okay. And I guess he felt uncomfortable in that environment for reasons that I don’t fully understand

Hendrie: It was an extremely political environment.

Comstock: Okay, that would rub Andy the wrong way <laughs>. Andy is the kind of person who has just incredible powers of concentration. When he's given a task he just devotes himself single-mindedly to it. One of the consequences is that you simply cannot persuade him to work on two projects at once, it's just not done. But he will apply himself so diligently to that one project that he produces an absolutely superb

result every time. And I guess the political thing you're talking about probably was yanking him around so much at Honeywell that he couldn't stand it. So sure, I thought here is a perfect opportunity for us to get a disk drive. He's had some disk drive experience at Honeywell, and I asked, “Andy could you design us something along the lines of a 2311 disk drive from the IBM line using the six -disk pack?” “Sure.” So he joined us in 1967 I believe it was, and went to work on building this 2311 clone. He took a rather different direction in that work from the IBM design concept. IBM used a hydraulic recording head positioner and the machine was, the 2311 was famous for dribbling oil all over the floor. In fact when the insurance companies installed acres of these things they were careful to put an oil pan under each, an oil catch pan under each <laughs> disk drive. So Andy joined us at Friden and set to work designing an all electronic equivalent of a 2311. Really the only things that were IBM related were the heads—the recording heads, and the disk pack, and everything else was unique.

Hendrie: So you were going to use their disk pack?

Comstock: Yes.

Hendrie: And their recording heads?

Comstock: Well no, by then it was an independent industry, Jugi Tandon for example was starting to produce IBM disk heads, flying heads <clears throat>. Well Andy designed a disk drive in which he used a DC motor for positioning the heads. The shaft of the motor was elongated. Here's the motor, the shaft sticks out, and a pinion gear is ground in the end of that shaft, oh it's, you know, half an inch long pinion. And the head carriage has a mating rack that engages this pinion under a light spring pressure, it's a heavy enough spring pressure so that the torque of the motor won't cause it to skip teeth, but it's a light enough pressure so that it doesn’t wear. And by having this spring engagement it's a zero backlash construction, so that by placing a position transducer on the other end of the shaft of the positioning motor you can measure angular position which translates through the rack and pinion to linear position of the head and in that way locate the tracks. Now the transducer that he used for the positioning was one of these bifilar type devices, it was actually a printed circuit card a couple of inches in diameter, that had a pattern of u-shaped conductors with one complete cycle of that u-shaped pattern for each track on the disk, and a second set of these u-shaped things interleaved with the first set to form a bifilar winding. And then a pickoff that is scanning this thing, and observing, well the two-- the bifilar windings are excited from the oscillator at some reasonable frequency, I don’t remember what frequency he used, it may have been above the audio range but I'm not sure. It must have been because I never heard any squealing coming up <laughs>, and I wasn’t old enough at that point to blame that on my ears <laughs>.

So with this pick off system he had a zero crossing of a particular polarity at each track location. And he servoed on that zero crossing to put the track, put the heads at the right location, the center part of the track. Now, the signal that he’s actually working with is a sinusoidal signal coming out of the transducer so he can go from track to track by counting zero crossings, uses a counter to do that. But when he is on the portion of the track right near the zero he’s got kind of a linear position signal and he can use that in his servo to home in on the precise location. Now the problem is that the servo system that does that is unstable if all you’re giving it is position information. It’ll just go into wild oscillation. In the Friden design

he added another element to the bottom of this servo motor shaft in the form of a DC tac generator, a little DC motor 1-1/2", 2" tall which generated a DC voltage proportional to the speed at which it's rotating. And that gets fed back into the servo as a stabilizing element in the servo amplifier design and lets the thing come right in on zero without any– without, you know… It stabilizes the system. And without it it'll just oscillate wildly. So this resulted in a mechanism that did not dribble oil on the floor. The height of the whole structure was maybe 8" or so, 10" maybe.

At Friden we mounted it in a cabinet that looked just like the IBM cabinet, it was a floor standing cabinet, and brought the working platform turntable as it were, it's not really a turntable but brought the cone of engagement up to a waist height so operators would feel perfectly comfortable, it's something they're familiar with. But it was all empty space down below instead of hydraulic pumps and tubing and so forth. The other thing is that in the IBM positioning system with the hydraulic actuator to ensure that the heads are located properly on the tracks, they had a- kind of a rack like device and a spring- a spring detent that would detent it to force the final position to be accurate. Andy's designs did not require a detent. The precision of this zero crossing from the transducer and the stability of its servo drive was such that he could just home right in, that's the track, and the electronics holds it in position. No detenting. So net result, a reliability that's infinitely ahead of the mechanical reliability of the IBM machine.

So Andy designed this disk drive over a period of a year and a half or so and I recall well in January 1969 we had a staff meeting with the new president of Friden who had been sent in by Singer reviewing all of the R&D projects and which ones should we keep and which ones should we drop for economy reasons. And the guy who was the systems architect for this System 10 computer that we were developing made an impassioned plea that we should drop this disk drive project because it was an unproven technology, nobody could be sure it was going to work, it was going to be very expensive to build something like that. The manufacturing VP piped up that gosh we've never built anything with that kind of precision in this shop, our parts tweakers won't know what to do with it, I'm not sure we can build the damn thing. So it went around the circle of about 10 managers and I was the only one that was sticking up for that project. So the president, Bob Campbell who had come from Link Aviation, another Singer acquisition, said, "Well, we're going to drop that project." Oh I was really heartbroken. It just didn't make any sense at all. So that night I went over to Andy's house; my wife and I went over and sat down with Andy and his wife and said, "Don't you think we can do better on our own?" And he said, "You know, everywhere I go, large corporations are awful." He had the Honeywell situation; prior to that he had political issues at Potter; now here at Friden he's back in the same kind of morass. So he said, "If you can find a way of guaranteeing me a salary for a couple of years I'll go with you." So that's what it took. So we decided at that point we'd write a business plan and go looking for money so on and so forth. We still weren't willing to abandon the project at Friden. And Andy completed the machine. It was just about finished at the time of that meeting. His engineering.

Hendrie: Prototype, yeah, engineering prototype.

Comstock: Yes it was a little more than a prototype. It was really a—it was not quite a beta machine but it was well beyond an alpha machine. And we'd hooked it up to Friden's IBM 360 and it worked perfectly. And the accounting guys were saying boy that's pretty nice, it's quiet, it doesn't drip oil on the floor. So

that gave me an idea. I called Harvey Goodman. Harvey was the highly publicized president of a computer—of a company called Data Processing Financial and General, DPF&G, based in New York that was one of the early companies in the computer leasing business. And he had hundreds of IBM computers scattered around the world with people asking him for more disk drives which he had to buy from IBM. So he got—I told Harvey about this project and this product and asked him to come out and talk with us. So he said, "I will do that." And he came out and Andy spent a morning with him demonstrating how this alpha beta model was working on the 360, and then in the afternoon we go in to meet with this president Bob Campbell. It was—by now we're up into late February or so of that year and Bob Campbell says, "Well I understand that you've seen the disk drive product, I'd be interested in hearing your opinion of it." And Harvey drew himself up and he said, "That's the best god damn engineering project I've ever seen in my life and I was responsible for keeping an eye on all the engineering projects at IBM for x number of years." Campbell said, "So well, is this a project that would be of interest to people like you in the computer leasing business?" "You're damn right it is." "Well, would you be interested in buying some of these?" "Son I'll give you an order for 1000 of them right now. How soon can you supply?" I hadn't prompted this guy at all. I mean he was just very enthusiastic about what he had seen and he didn't have any hesitation about…

Hendrie: And he had enough of a technical background to understand how clever what he'd seen was and how it worked and how ingenious it was.

Comstock: So that shook Bob Campbell loose a little bit and Bob called in a senior technical advisor, a guy named Dr. John Hunt who had been on the staff at Link Aviation with him and whom he really trusted, and John came in and took a look at it, same sort of thing as Harvey—Harvey's look. And his report to Campbell was just the same as Harvey's. Fantastic that this project went to so well, that the result is so good, blah, blah, blah. So the net result of all that was that Campbell decided, well we'll rescind the cancellation and we'll complete this project. Andy then he figured he needed until June to get it all wrapped up and get the loose ends tied up. And meanwhile we're working on a business plan…

Hendrie: You still hadn't given up your idea.

Comstock: Well at that point I leveled with Campbell and said, "Look, we'll stay here long enough to finish this product and make sure that it's in good shape but Andy and I are looking for money to start a company." "Okay, fine." So we had an amicable sort of agreement on that. We're both staying on the payroll and so on. So then we started looking for money. Now our first—our first business plan contemplated building a small, a thin version of this disk drive. And whereas the mechanism in the Friden drive was tall, it was mostly air, and Andy felt that given the linear nature of this signal from his transducer around the zero crossing that if he could differentiate that signal and develop a velocity term that way for his servo that he could dispense with the tach generator and that would shrink our height of the mechanism a couple of inches. So we wrote a business plan around this concept of a disk drive and we could see the minicomputers coming along and so we slanted it toward the single cartridge idea, single platter cartridge. Just by way of illustration <inaudible>, here's a pretty good picture of it. This was a product flier put out by our Japanese licensee and it shows the IBM 2310 cartridge, that IBM used in their 2315 single cartridge disk drive that was incorporated in such products as the 1130 computer. And that

was the cartridge we decided to use and was incorporated in this business plan. And this is in fact the Diablo disk drive that was the outcome of this effort. It's 6-1/2" tall as compared with the, well…

Hendrie: Exactly.

Comstock: Oh yeah, here's a picture—here's the Diablo disk drive sitting in a cabinet that was designed by Mohawk Data Sciences, one of our customers, and they wanted a cabinet that would resemble IBM, so they got this really quite compact disk drive sitting at the top end of a very empty box. By the way, there are several of these scattered around the computer history museum collection. So let's see where were we? So we put together the business plan and started carrying it around to the venture capital community.

Hendrie: Now this must be when, 1970?

Comstock: No this was spring of '69.

Hendrie: We're still in '69, okay, yeah.

Comstock: Yeah, spring of '69. And we got nothing but ho-hum response to it. They just didn't see the commercial potential and why all this hullabaloo was, you know, big disk packs future, lots of storage capacity.

Hendrie: Even though you could clearly show that this was going to have a much lower cost than anything IBM was building.

Comstock: So the final shot at that stage of the plan was a trip to the east coast to visit with a company in Connecticut called Electronic Capital Corporation. And we spent a Saturday morning with their chief honchos and all they could talk about was the mobile home company they had just acquired down in South Carolina and they weren't the least bit interested in hearing our disk drive story. So on the flight back home Andy and I looked at each other and said this just isn't going to fly is it? And it was at that point that I offered what I think was a very valuable suggestion. I said, "You know, Andy, if you could use these positioning techniques that you have perfected for the head positioning and especially this new idea of yours of developing a velocity term without another piece of hardware on the drive mode, motor, then you might be able to build a printer this way. If you could use that technique to position a daisywheel printing element as opposed to an IBM golf ball, which has two coordinates of motion**,** but chose a daisywheel with only one coordinate of motion and also use the same technique for positioning a carriage, the print carriage that carries it, we might have a really good product." "Well," he said, "that sounds interesting. How fast would it have to go to be salable?" I said, "Well the competition will be the IBM Selectric Typewriter and they advertise the Selectric as running at 15 characters a second." Of course it really doesn't run at 15 characters a second because every time they do a shift operation that steals a cycle and if they were doing all shift operations it would run at 7-1/2 characters a second. So its true average speed is somewhere between 7-1/2 and 15 depending on the application. I was very conscious of this because by then I'd become the Vice President of Engineering for all of Friden and I had

responsibility for the lab in Rochester as well and deeply embedded in Flexowriter stuff. <Inaudible> How do we make the Flexowriter run at 12 characters a second? It had been running at 10 characters a second since it was designed. And if we can only get it up to 12 characters a second maybe we can compete with this IBM Selectric thing. So I said to Andy, "You know, if we could run a daisywheel printer at 30 characters a second, twice the advertised figure of the IBM Selectric, we would have a world beater." So he said, "Well let me think about it." Now I know when Andy's thinking you don't talk to him. So he sat with the back of an envelope and a pencil and a calculator for about a half an hour then he turned to me and said, "I think we could do it." So generation two of the business plan adds a daisywheel printer running 30 characters a second, twice the IBM advertised speed. And we decided that even that might not be enough. I mean we'd seen how hard shelled these VCs were. So we said the printer and the disk drive by themselves are going to be OEM products and maybe the VCs are afraid of companies that have to rely on other companies to sell their product. So perhaps we should put an end user product into the kit at the same time so we got the waterfront covered. So we added a third product, namely a word processor that would incorporate our mass memory device and our printing device. So we'd be building most of the guts of this word processor; get ourselves into the end user business. Word processors were kind of interesting to people in those days because the IBM magnetic tape– they called it the IBM magnetic tape Selectric typewriter was doing very well. A lot of people were trying to get in on it, figure out what they could do to take advantage of that same market opportunity. So we redid our business plan that way and within a few weeks we had found a backer, which meant that…

Hendrie: Who did that turn out to be?

Comstock: That was Itel Corporation. They were a group in San Francisco that started with the former San Francisco IBM branch manger, a guy named Gary Friedman, and his sidekick, his buddy, Pete Redfield who had been a manager—Vice President for IT for large companies. And they had teamed up to set up a computer leasing firm to compete with this fellow Harvey Goodman and called it Itel Corporation. And by the time we started working with them they had branched off and were beginning to lease shipping containers which turned out to be quite a business. And in fact that was a highly computerized business in that the fundamental strategy of the business appeared to depend on deciding which jobs to turn down. You don't want to send a shipping container off to someplace where it's going to sit with no return load for months at a time burning up your capital. So they had computerized this whole operation in such a way that they had tighter control of what goes where and when you say no on a possible sale. Very bright guys. They subsequently got in trouble but that's not an uncommon story. So they were interested; they were doing all this computer leasing, they were interested in having a hardware capability for their conglomerate so they decide to finance Diablo. The financing was arranged through a Palo Alto venture capital firm Sutter Hill. Well that got us started and I've got some crib sheets up here if you'll tear off the first crib sheet up to where we are. Just rip it out. Thanks. Well the first note on the next crib sheet reminds me of something that I left out in the Friden story. The question was how did I happen to think of a daisywheel printer on this airplane ride?

Hendrie: Yes I was going to come back to that.

Comstock: Well I'm sorry to steal your thunder. Well, in 1966 or so—well first of all when I joined Friden,

I found that Friden had a secure laboratory that was working on a classified stuff primarily for NSA as a customer. And…

Hendrie: Excuse me, I think we ought to pause just for a second.

Comstock: That's fine. I want to go back to Friden a bit. We had- when I arrived they had this secure lab that was electro magnetically shielded, the whole bit, and was doing classified work at the highest level for NSA revolving around Flexowriters and calculators and so on and so forth. Well, we got an invitation—no I'm jumping ahead. In 1966 or so we had a visit from Fred P. Wilcox who lived in New Canaan, Connecticut. Fred had been a vice president of Fairchild Camera and Instrument stationed back east. I don't think he had anything to do with the semiconductor at that point. But he was an inventor. I visited him at his home at one point in our interactions, a home that had been built as a model home by one of the glass companies and had been designed by a famous architect, Phillip Johnson or somebody, or Edward Stone maybe. Anyway it was quite a fabulous, very modern house, spacious grounds in New Canaan and out back he's got a machine shop, a complete model shop, every tool you could imagine: milling machines, grinders lathes, saw. And out there he personally fabricates each part for each thing he makes. I asked him, "Well, do you have a machinist that works with you?" "No I– it's too much trouble to tell them what I want and they never get it right anyway." So he Makes everything himself. Yep. He had built a daisywheel printer that printed on a 40 column wide format and he was trying to interest the Los Angeles police department in putting this into their police cars so that the officers would have a written communication to work with instead of what they thought they heard on the radio to reduce errors, improve efficiency, blah, blah, blah. But things were going slowly down there and he's wondering whether he could get some company like Friden that obviously had a need for printers and printed calculators and all that. In fact one of the neat printers we developed was for the electronic printing in the adding machne version of our electronic calculator. We did a disk printer, it had a character disk in which the characters were displayed around the periphery of this disk but in a spiral- a helical format offset one column width between the beginning and the end of the disk. And this disk was caused to move continuously across the face of the printing document in synchronism with its rotation so that each rotation would have every character appearing in that column position.

Hendrie: And then when it shifted, it's over one.

Comstock: You see the wheel was moving continuously in both dimensions. It was continuous movement. But the characters were steady here and then jumped to steady here and then jumped to steady. I thought it was kind of a neat concept. So we built that into our printing calculator and then I got the guys in Holland to make a full character printer out of it with 96 characters around the rim of that thing. And they successfully did that to use as an output for a modern computyper. Well, that's another whole story. But Fred P. Wilcox brought his daisywheel printer in to show us; he had a model of it. He had used a jeweler's saw to carve out each spoke of this…

Hendrie: Of a wheel. He had a disk of metal and then a jeweler's saw and carved it out. And this case of course the characters are not on the edge, they're positioned up at the edge just like a daisywheel. It's just like this.

Comstock: He made a metal daisywheel. He carved it in aluminum and I've forgotten how he put the characters on the end but he got the characters on the ends of each spoke and had this thing as a demonstration device. Well he explained the principle to us. This thing works by spinning the wheel continuously and translating it piece wise from column to column. So it would go to a column and sit there and it's spinning and as the desired character comes into printing position the hammer makes an impression of that character and the thing moves onto the next one.

Hendrie: From the rear?

Comstock: Yeah, the hammer is in the back and there's a ribbon and then the paper. And so that's how he prints it. And because the character is out on the end of this spoke and because in a printing device of this kind the contact time of the character against the platen, which is when the printed image is being formed, is only something like 50 microseconds or so. If you calculate how much the spring that supports that character is going to deflect due to the rotation of the hub during those 50 microseconds, it's small enough so there's very little stress in the spoke. That's the underlying theory of his printer. So we were thinking boy this thing really has some potential.

Hendrie: Yes, so there's no smear, it just deflects a little bit for the time it's physically in contact.

Comstock: Yes, that's right.

Hendrie: And it doesn't have enough- it has enough bending that it doesn't smear.

Comstock: The character remains in contact without smearing and it has one of the advantages of the IBM chain printer. Remember before the chain printer it was all drum printers like the Annalex printer and the galloping Gs for example were a problem. The characters would move up and down all over the place depending on what pattern was being printed. So he overcomes that in the same way the chain printer does. The motion is this way so if there's a little bit of smearing it doesn't produce wiggles up and down that your eye is very sensitive to but it may produce a little bit of horizontal dither or smearing that you're much less sensitive to. And this daisywheel printer would do that same thing but with a lot less smearing than you would have from a rigid medium or print bearing-character-bearing medium. So we got quite excited about it and offered Fred a licensing deal where we'd pay him a substantial amount of money in the hundreds of thousands of dollars for a pre-paid royalty and then royalties subsequent to that on flow of product. Well he said he'd give that careful consideration and when we heard back from him he said well sorry but he'd sold it to IBM, that IBM seemed very interested in it and IBM obviously had more resources than Friden did so he decided to sell his patents to IBM. So that was a big disappointment to us. It was a year or two after that that the US Army Signal Corp, Fort Monmouth is it, came out with a bid request for a forward area teletype system that would comprise a keyboard, paper tape input output, and a printing device that could be deployed in forward areas. And their aim was to minimize electromagnetic radiation that could be picked up for code snooping. And that they wanted very high reliability and they wanted minimum number of moving parts and so forth. They'd been using teletypes and they just weren't satisfactory. So we decided to bid on it. And our competitor in the bidding

was Kleinschmidt. Now Kleinschmidt was building a drum printer with a single hammer that would traverse the length of the drum and pick off the characters in each column position. And we proposed our– we proposed- we were planning to propose a daisywheel printer a la Fred Wilcox. So I called Fred and I said, "What do you suppose IBM's reaction would be if we were to inquire with them about bidding this- your printer principle in this Signal Corp job?" "Hey, that would be terrific," he said "and I don't care a hoot about IBM. You know, what they've done? Those bastards have put my invention up on the shelf cause they don't want it competing with the Selectric typewriter so they're not doing a thing with it. I can't even get in the front door of their plant down in South Carolina where they do this work." He was mad as hell at IBM…

Hendrie: So they bought it to…

Comstock: They bought this...

Hendrie: They wanted to mothball it.

Comstock: They bought- that's it. They bought it to mothball it.

Hendrie: They bought it to get it off the market.

Comstock: Yep, yep and Fred was mad as a wet hen. He said, "I don't think IBM would give you the slightest trouble. Is IBM going to be suing the US government for using classified equipment out there?" He said, "Go ahead and use it, you have my full support." So we bid it to the Signal Corp that way and the Signal Corp was so puzzled over these two contracts, two bid proposals, that they awarded the contract to both of us. That is separate contracts to each of us. And so we set to work and we built a forward area teletype machine that used a photoelectric keyboard for reliability, used a photoelectric tape reader for reliability. We couldn't get away with- lasers weren't advanced to the point where we could cut holes in tape with a laser, and a daisywheel printer. Well, by the time I left Friden in 1969 it had become painfully clear that this wasn't going to work. We could not get decent life out of those daisywheels. There was a little error in this 50-microsecond calculation. As we dug into it and began looking at things with a microscope and a strobe light we were able to see that as soon as the hammer had contacted the character the characters stopped rotating. The acceleration of that hammer was so great that it glued the character to the face of the hammer which carried it for the rest of the probably the 150 milliseconds travel time to get it into contact with the paper. So instead of a 50 microsecond bend, we were dealing with a bend that was many, many times larger than that. So these machines were spoke breakers. They would last a few days <laugh> but it just wasn't a go. We delivered our products to the Signal Corp; we got paid for them. We had put more money in it than they paid us but that was all right, that's the way it goes. So, on that airplane with Andy, trying to figure out what to do about our business plan…

Hendrie: You've had a lot of experience with daisywheel printers.

Comstock: Yes. It was clear to me that if his servo techniques had the ability to stop that character on position and then print it that we would have a machine that would not be a spoke breaker.

Hendrie: Right. As opposed to just…

Comstock: The constant rotation. So it was as simple as that. It was- let's stop the character to print it and the question is can it be done. Can you do it? So he did some scratching on the back of the envelope and said I think we can run it at 30 characters a second. Yeah, I loved it too. So Pete Redfield and Gary Friedman financed our company, Diablo Systems, and we opened the doors for business in August 1969. And Andy set right to work designing the Diablo Series 30 disk drive. And we did that one first because he had the most– he had recent relevant experience. He'd worked on them at Honeywell, he had done the one at Friden with the tach generator and now the innovation is getting rid of the tac tach generator and packaging it in a much more compact form. So that was kind of duck soup for him rolling off a log as it were. And we shipped our first series 30 disk drive just about a year after we opened the doors; a one year gestation period.

Hendrie: And what were the specs on that?

Comstock: Say it again.

Hendrie: What were the specs?

Comstock: It had a capacity of 1.1 megabytes where IBM was using that same cartridge with a capacity of 750 or so kilobytes. It had a latency time. Track-to-track latency was 20 milliseconds. The disk spun at 1500 rpm. And it had virtually an infinite life expectancy. One of the neat things about this product in terms of selling it was a demonstration that we could make. We had it rigged up for demo purposes with recording and playing back stuff and showing error an error count. And it would run there for, you know, days at a time without making an error. And that was in itself impressive. But what really turned on prospective customers was where the drive—disk drive is sitting on the counter. Lift up one corner of the drive about 2". Now of course that's putting a twisting strain on it. No errors. And then we'd take our finger away and the thing would crash down on the table. No errors. Then they'd say well, shit there's something wrong with your sensing device. So then we'd go in and bring our finger near a point in the playback lead wires and the error rate goes wild, you know…

Hendrie: Yes, that's a great—demos like that are wonderful.

Comstock: That was a terrific demo. Well we shipped the first of these about a year after we started the project and guess who we shipped it to? Well of all the people that were involved in minicomputers who do you think might have been the most likely to want to try this out?

Hendrie: Digital?

Comstock: Yeah. And guess who was in charge of peripheral equipment at Digital.

Hendrie: Grant Saviers.

Comstock: Grant Saviers was our very first customer. I am not kidding about it. He'd been following the project for several months, had been visiting us to see how it was coming along and so on. We had appointed a regional sales manager named Dick Harrison back in New England and he had—he was acquainted with Digital people and had been talking this up to Grant and Grant had come out on several visits. So he kind of followed it through its incubation. And they ordered 600 of them from us and that was enough to tide them over till they were able to build their own.

Hendrie: And that gave them—that gave you…

Comstock: That gave us our start. And our second unit went to our UK licensee. We had established a licensee in the UK, Data Recording Instrument Company, and for a number of years they were producing our stuff over there.

Hendrie: Now what year was this first shipment?

Comstock: That'd be 1970. So it was early, probably early fall 1970 that that went to Grant.

Hendrie: Did you ever sell any to Data General?

Comstock: Yes. Data General became– Data General replaced DEC as our most important customer. And they didn't build their own either for a long time or ever I don't know which.

Hendrie: I don't think they built that product. When they got started doing vertical integration I believe they built the 10 platter- the washing machine.

Comstock: Oh yes, 2314.

Hendrie: Yes, with the replaceable, removable disk pack.

Comstock: One more—that reminds me, one more comment on the disk drive, the 2311, that Andy developed at Friden. Two more comments. One is a contract with Harvey Goodman never materialized because the 2314 came in and we were at 2311. So he did us a very good service but didn't end up as a customer. But I bumped into a guy named Roger Johnson who had been—who was the manufacturing VP at Friden. I bumped into him at the airport two or three years after we had gotten Diablo fired up and I asked him, "Hey Roger, how did the disk drive that Andy designed at Friden work out?" Now this guy was the one that was sitting in that group of 10 or 11 people who killed the project in January '69 and he said, "You know, that thing was a real surprise." He said it was the easiest product to put into production that this company had ever seen. He said it just sailed right in. There was no problem, that it was really clean. Yes it had—the cost of manufacture was low, everything was perfect about it. Roger Johnson went on to become the CEO of Western Digital I believe. We've got a bunch of interesting alumni from these companies. Like our—the sales manager we hired, sales and marketing VP at the outset in Diablo… Well let's see. I guess I was talking about Roger Johnson who subsequently was CEO at

Western Digital, was with them for many years, very successful business. We had another fellow at Friden, Farouk Arjani was in the product planning department when I was there and he started a word processor company and did very well with that. There've been quite a few. At Diablo the first man that headed up Diablo sales and marketing was Sam Wiegand whom we got out of Honeywell. He'd been Western regional manager for Honeywell but had left Honeywell to join some smaller company in Colorado. He loved skiing. But I guess that hadn't worked out to his satisfaction so he came back to the Bay Area and joined us at Diablo. He subsequently became the marketing VP—marketing and sales VP at Tandem Computers, worked with Jimmy Treybig and was instrumental in achieving their $4 or $5 billion success. And my manufacturing VP at Diablo was Bob Marshall who also joined Tandem and became one of the three members of the troika at the head of Tandem. So we had some fairly illustrious alumni. One of them that I'll talk a little bit about later is David Lee who was a young engineer that joined us at Friden while I was there and subsequently came over to Diablo and worked on the printer at Diablo. And then a year after we sold Diablo to Xerox he left us and then started a company called Qume that copied the daisywheel. He made quite a success out of that.

Hendrie: Let's see, so where are we?

Comstock: Yes, where are we? We've finally got Diablo financed; we got the first product out, the Series 30 disk drive shipped to DEC. And in the fall of 1970 Andy was sufficiently free from responsibilities of designing the disk drive to turn his attention to the printer question. So this is where the back of the envelope analysis was going to be checked out. And his first step in looking at the printer was to arrange to get a computer in-house at Diablo. And Gary Friedman's brother happened to have an 1130 that he had purchased and was no longer using. He had an accounting business. So he leased us his 1130. That led to some ruckus with the IBM service department: were they going to honor the service contract on it because they didn't own it. And it took a regional manager at IBM to get that straightened out but they did. Well one of the amusing things here was that as Andy started trying-- well no just trying to install this 1130 turned into a bit of a marathon. Each time they'd start it up it would run for a little while and then smoke would start to come out of it. And that happened a couple of times before a higher level service person was brought in. What was happening was that the voice coil actuator for the single platter 2315 drive—disk drive of the 1130 was being toasted. Now why would a voice coil in a disk drive get toasted? The answer turned out to be that the accountant had installed his computer with a line printer but we didn't need a line printer so we had just decided to use the- our console serial printer, an IBM Selectric typewriter, and dispense with the line printer expense. Well it turned out that the software didn't get changed accordingly and consequently when you turned the thing on the disk drive would spend its time looking for the software that controlled that printer that wasn't there. And after some length of time, an hour or two or whatever, the voice coil was hot enough that it burst into flames. Smoke came pouring out and so on. Took them a little while to find that and they had to replace—they did three replacements of voice coils before they got it straight.

Hendrie: But it clearly was not– so that drive you could write a program.

Comstock: Oh yeah.

Hendrie: For that drive that would burn up– for that computer that would burn up the drive.

Comstock: Yes. We were very happy to be able to say that point that that was not possible with the Diablo Series 30 disk drive. You could work it as hard as you wanted and it would never burn up. Well, after doing a couple of months of work with the 1130 Andy brought a print out which was set up as a curve into my office, plotting margin– safety margin versus print speed. And at 30 characters a second it was showing about a 40% safety margin. And it was crossing the zero safety margin axis at somewhere around 55 characters per second. So from this we concluded that we had done well in choosing our target spec speed for this printer: 30 characters a second, double the advertised rate for the Selectric, more than double its actual speed and still plenty of safety margin. And if we needed to later on we'd probably be able to push it up to higher speeds if competition set in but at that point there was no competitive pressure to do that so we stuck with 30 characters a second as our design goal and Andy buckled down to designing the product. Subsequently some people did put out daisywheel printers advertised at speeds up to 55 characters a second but they didn't last on the market very long. So I think everybody was flirting with that same limit. Now, I've already described the essential elements in Andy's design of that high type printer really. It used his digital servo with the bifilar type pick off for positioning based on the zero crossings. And that just translated over into the printer very nicely. In the case of the print wheel we had 96 positions so it had 96 cycles of the pattern on the little printed circuit card. And in the carriage positioning—you know, I've forgotten just exactly how finally that was subdivided but it was the same sort of thing. So it was the same servo principles in both cases and in both instances it used, successfully used the differentiation of the linear portion of the sinusoidal curve to get the servo stabilization. We didn't have the weight of the tach generator to foul up the positioning of the print wheel or to slow us down on positioning the carriage. It was just great; everything worked out. And the net result of it all was that we had maybe a dozen moving parts in this product whereas that IBM Selectric typewriter had something like 600 moving parts in it. So an IBM Selectric in a high intensity application like a word processor that's banging away hour after hour or computer console printer that's generating long reports hour after hour mostly– they were lucky to get a few weeks operation out of it before the thing really needed serious service attention. But the daisywheel printer with these electronic positioning methods would run for years without requiring service.

Hendrie: So when did you ship the first one of these? When did this product get finished?

Comstock: As I said, Andy started the design on it in November 1970, and in February 1972 we had a press party at the St. Regis Hotel in New York City where we demonstrated it to the public for the first time. And it was a big hit. It was a big hit. Now I say that we demonstrated it to the public for the first time at that press party but there was one sneak factor on that. In the plane in which we were flying east to do this demo, sitting across the aisle from me was Bob Noyce. And Bob was working on a big sheaf of papers that turned out to be related to a first IPO, an IPO for Intel. I think if I remember correctly they were doing something like $20 or $30 million a year revenue at that point getting read for an IPO. So we had interesting conversation along the way. "What are you going to New York for?" "To talk with financial types." "What are you going to New York for?" "To do a press party on our new printer." "Oh, tell me about the printer." So we said so long at the airport, Kennedy, and we get to the St. Regis Hotel and as we're registering Bob Noyce walks in. He's also in the St. Regis Hotel. So we said, "Hey we're going to

be setting up this demo; soon as we get settled in our rooms why don't you come on up." So around 10 or 11 o'clock at night he comes up to the ballroom where we're setting this stuff up, he got the first public demonstration of the daisywheel printer. And that's my claim to fame. It turned out in later years that he was an avid pilot, airplane pilot. Yes, he had an Aero Turbo Commander- Turbo Aero Commander. And it turned out in conversation with him at various industry events that he was also very interested in seaplanes. And I had bought a twin engine seaplane in 1973, I guess it was, '73, a 1954 Piaggio Royal Gull. It was a five-place amphibian, fabulous airplane. There's a picture of it in the room here somewhere. Well anyway, so we had fun exchanging views on seaplanes and he was very interested in a Republic CB. There was a conversion that had been developed by- an engine conversion that had been developed by a guy up in Seattle with double the power of the thing and so on. So one day we– he and I got together and we met out at the Concord Airport. He flew his Turbo Commander over and I had my seagull– flying- Royal Gull there and we swapped flights. So he let me fly his Turbo Commander for a bit and I let him fly my seaplane for a bit one Sunday morning. Yeah, that was fun.

Hendrie: Well, you know, Reed Dennis is– was a great flyer.

Comstock: Oh wasn't he though. Yeah he's got a Grumman Albatross.

Hendrie: Yes, exactly. Which is an amazing classic. I've never gotten a flight out of him.

Comstock: My connection with Reed Dennis is that we have the same barber, Steve Cervelli, and that barber has introduced us and I got a loan of the videotape that Reed did on his round the world flight. And some day Reed's going to take me for a ride in his Albatross but I don't know just when. Anyway back to– yeah. Where are we?

Hendrie: Well we have just announced the printer.

Comstock: That's right and started shipping the following month. Now we had had some inquiries about printing technology from Xerox. Our first contact was in December of the preceding- December '71. And it had all the flavor of developing into an OEM type of relationship. So we were nurturing it and sworn to secrecy and all that. They were sworn to secrecy; we were sworn to secrecy and so forth. But after we made our public announcement, Xerox opened up and said we really don't want an OEM arrangement, we'd like to buy your company.

Hendrie: Okay. Now you were not public at this point.

Comstock: No, no. Our– Itel Corporation at that point held about 65% of the company. Sutter Hill had 5% as a finder's fee. And the rest was distributed among employees. Well it turned out that Itel had gotten into some financial difficulty. They had acquired another company. Oh god I can't remember its name maybe it'll come to me later. It was a company that had been building small computer machines like the computyper—all electric computype, and word processors and were selling primarily in Europe. It was an American company, US company. And they had quite an extensive field service organization. You know, products that had the Selectric typewriter in them had to have a pretty extensive field service

organization. So these fellows had something like 275 people in their service group and that was of great interest to Itel, so Itel had acquired them at a point when they– when that operation was losing something like $1/2 million a month. And Itel being formed from people with a very strong IBM orientation had felt that by putting an IBM trained manager in charge of it they'd be able to straighten out the mess.

So they hired IBM's branch manager in Seattle to come down and take charge-- Dura Business Machines was the name. So they hired I've forgotten his name from Seattle to take over as president of Dura and over several months he got it to the point where it was just about break even. But then there was a turn down in general business in '71 and by the end of '71 this Dura business operation was losing something like $1 million a month: back in the loss column. And when the annual audit was done it turned out that there was a huge inventory problem that apparently Dura US had been shipping product to Europe and treating it as a sale and Europe had been warehousing it. It's a very famous accounting problem that so many companies run afoul of: when is a sale a sale? Yeah, well they were in it in spades. So the accountants were saying to Pete Redfield, you know, you've got something like $12 million of goodwill on your balance sheet from the acquisition of Dura and we don't think we're going to be able to give you a letter unless you can clean that up. So Pete's solution to that was grab this Xerox offer. We'll sell Diablo to Xerox. Our 65% of the proceeds will more than cover the $12 million and we'll be free of that onus. They could just shut down Dura. Yeah. So that's– that was the thrust at that end of the equation. We'd love to sell you guys. So we had a management meeting among our VPs in Diablo saying do we want to go along with this or not? Well, what could we do to stop it? The only mechanism we could think of to stop it, the reasoning was, if we don't want to do it we'd go on strike, that we'd- we'd hand in a mass resignation if they were going to sell the company. That would probably stop it. Yes, Xerox would decide not to buy it and get the team.

Well we were debating this point in this group and our financial VP John Dougery who had come to us out of Price Waterhouse, he'd been six years a tax accountant, now he's really enjoying this start up environment. It was really a fun company. They were 150 of us at this point and it was going like gangbusters; it was good. That's the fun time of the company. John draws himself- John subsequently became a venture capitalist, Dougery Wilder and something, Dougery Wilder Jones or whatever. John drew himself up full height said, "You guys are absolutely crazy to consider selling this company. In another three years it's going to be worth so much money that you're crazy to consider letting it go at this point in time." Well at the other end of the spectrum was my partner Andy Gabor. Remember Andy had left Hungary at the end of the freedom- he was a Hungarian - he was a radar expert in Budapest, then the Hungarian revolution came along and he starts toting a submachine gun and he's a freedom fighter. Then the Russians move in with their tanks; Andy and his wife escape. They swim the Danube River with just the shirts on their backs and manage to get over here. So Andy has never had a penny in his life except day to day what he can earn. So the prospect of converting this piece of paper that he had into a substantial amount of money was very attractive to Andy and he stood up full height and said, "The trouble with you entrepreneurs is that the bird in the bush is worth two in the hand!" So anyway, we decided to be good boys and not offer a mass resignation if the thing- the transaction went through. It closed– I think we signed the papers in April and stuff went into escrow and all that and by August I had Xerox shares instead of Diablo shares.

Hendrie: August of what year?

Comstock: '72. And Andy was very pleased to have achieved some financial security for the first time in his life. But Andy and I had been having some personal differences and we told our new boss at Xerox, a guy named Bill Brown who was senior vice president in charge of the special products divisions of Xerox, which included the SDS acquisition that they had down in El Segundo, included a company that was into mammography building machines- Xerox mammograhpic equipment.

Hendrie: I think we're going to have to stop now.

Hendrie: Yeah I had interrupted you, you were working for this guy and Diablo was one of his special projects.

Comstock: So Andy and I approached Bill and said it looks as though we're having difficulties that will make it difficult for us to continue working together under the same roof, and we hope you can find a solution to this problem. So Bill asked for two or three weeks to work on it, and the ultimate outcome was pretty good I think. Andy transferred to Xerox PARC, he became a staff person associated with PARC under George Pake, and I was left running Diablo. Let's follow Andy's career from there.

Hendrie: Okay that would be good.

Comstock: Andy I think-

Hendrie: What was the tension between you and Andy in terms of outlook?

Comstock: Yeah I think it was the personal chemistry had gone sour, I think that was, you know. And if you were asking who to blame I think you'd have to say we were both to blame. Anyway…

Hendrie: Okay so let's follow Andy.

Comstock: I think Andy functioned in kind of an advisory role, consulting, internal consulting role on a number of things throughout Xerox for a period of a year, or two or three. I know that one of the people he was fond of and who they worked together was John Urbach, John Urbach was doing pioneering work on optical disk recording, and Andy with his disk experience, at least in terms of positioning stuff and that sort of thing, well plus his signal processing know-how, was a good colleague for John to work with. So I think that type of thing occupied him for some time. But then ultimately the product planning people at Xerox decided that the development work that Xerox was doing in the word processor field, which had been taken away from Diablo and was centered in a new organization setup down in Dallas, was covering the word processor part of the field but that they still needed an executive typewriter to complete the office products portfolio. So they asked Andy whether he could develop a silent equivalent of the IBM Executive Typewriter, which is a fairly noisy thing.

Hendrie: The Executive Typewriter being the golf ball?

Comstock: Yeah. So Andy undertook that project with pleasure, he set up a skunk works in a small building over in Hayward that had been occupied by us as Diablo headquarters for a while. He occupied that building. By the way at this point Diablo had grown to something like 2,500 employees and we had about 500,000 square feet of floor space in Hayward. Well that's where it was when I left Diablo in 1977, and it was a year or two later that Xerox consolidated, Xerox dropped the disk drive product line, and consolidated all the printer work in a new building that they put up down in Fremont. That was a 500,000 square foot building, and I think their sales level was up in the $400 million range.

Hendrie: But your CFO was absolutely right, this is going too well, this is going to be worth a lot more money.

Comstock: He was absolutely right, and there was further proof of that that I'll mention a little later.

Hendrie: I wanted to ask you one other question if we can just roll back for a second, what did you end up was the value of the Xerox stock when the acquisition?

Comstock: Xerox bought it for 30 million.

Hendrie: For 30 million?

Comstock: Yeah, which was puny compared to what it could've been worth a few years later. But on the other hand it was between five and six times prior year sales <laughs>, so that's not too shabby.

Hendrie: No that's not too shabby.

Comstock: So in one way it was a pat on the back but in another way it was a steal. So Andy went to work in his skunk works, he pulled in about 25 engineers, several of whom were former Friden alumni, and over the course of the next several years developed a noiseless version of his Daisy Wheelprinter that compared very favorably with IBM's Executive typewriter. It was twice the speed and noisless. The culminating event of this saga was that they held a press party in New York City to introduce the new Xerox Silent Typewriter, I'm not sure it was in the Saint Regis. It probably wasn't.

Hendrie: It probably wasn't, but they did.

Comstock: Andy is very good at making public presentations, he's very good at that, and so he introduced the new typewriter. And what he did was he stood behind a lectern and gave a brief lecture on how it was developed and what some of the technical principles were that enabled him to achieve the kind of performance that they had obtained, which included among other things the surprising--the paradoxical idea of making the hammer heavier, not a lighter hammer, but a heavier hammer, which pulled the frequency-- the frequencies came down rather than going up or something like that. But the other very important element was very tight paper control to avoid having the paper act like a loudspeaker. So anyway he completed his remarks and then turned to a pedestal that was next to his

lectern that had a cover draped over it, pulled the cover off and here's an IBM Executive Typewriter and he punches a GO button and the thing starts clattering away, it's making a hell of a racket, and he turns to the left of his lectern, removes the cover, and just stands there, and after half a minute or so one of the guys in the front row says “Well aren’t you going to turn it on?” and his answer was “It's been running during this entire presentation.”

Hendrie: I love it, he has a sense of drama too.

Comstock: Doesn't he <laughs>. Superb.

<Crew Talk>

Comstock: Well it turned out as a product that it was just exactly what Xerox had asked for, but nobody was buying these Executive Typewriters anymore, at least in this country. I've heard that they sold something like 60,000 of them in France, but that was about the only market they found for it.

Hendrie: So it was a great implementation of a technical marvel that wasn’t needed.

Comstock: Yeah, you could paraphrase the old expression. It was too much, too late. Not too little, too late.

Hendrie: That's too bad. And why don’t we finish up because you and Andy don’t cross again right?

Comstock: Well yes we do.

Hendrie: All right then.

Comstock: It was several years ago, it was some time in the late 80s that I got a phone call from Andy. And the gist of it was “Hi George, I've been thinking about the fact that most of us have relatively few really close friends, and we shouldn't throw them away. Can we get together?” <sounding tearful>. So, you can see how it moves me. To go back to Potter, when I left to go West, Andy came in to say goodbye. What he said was “When you're gone George who am I going to have to talk to?” I mean it was that close.

Hendrie: Yeah it was that close.

Comstock: So I've seen him most recently a few weeks ago, basically based on your questioning, to see whether he'd be able to do this interview and he felt he just didn't have the time, he concentrates on one thing at a time.

Hendrie: When you told me that earlier in this interview I related it to he's focused on something and he's got to make that happen.

Comstock: And he's very disciplined.

Hendrie: Well where should we go, did you want to follow the rest of Andy's career after Xerox, then we'll go back to you?

Comstock: Yeah we can wrap that up. After the Executive Typewriter, I believe it was after that typewriter that Andy basically took retirement. Maybe he did a little consulting after that but basically he retired, and he's devoted himself to two matters since then. One is best described perhaps by mentioning one of his observations about United States society. When he first came here from Hungary, he tells me, he was very, very disappointed to discover that there was not a string quartet on each block. Now he's a violinist, and approaches the music with the same dedication and veracity that he approaches technical problems, and it really was a very big disappointment to him to find the paucity of musical performing interest in our country. Now he did succeed in finding a quartet that he joined, he was living in Danville and I'm not sure, I think he may even have had to go into Oakland to find this quartet, but he ultimately got situated and played at least weekly with these folks. So he got a partial solution to that problem. But he's had medical issues that have been a problem for him, in fact it's kind of ironic that a lot of his work in these positioning systems, like the head positioner, have revolved around stability issues, the tach generator, the differentiated slope of the curve and so forth, to stabilize the servo. Well in playing the violin he began to develop a nervous tremor in his bowing arm that would incapacitate him after a half an hour of play. And he consulted with all kinds of neurologists and so on and so forth and basically was not able to find a solution to that problem. So he switched to the viola, and he found that the dynamic of bowing the viola was enough different from the bowing of the violin that he was able to postpone the development of a similar tremor for several years. But he had a problem. Viola music is written in a different clef or musical format notation from violin music, so he couldn't play the damn stuff reading the music. So he spent some time developing a computer program that would accept viola music and translate it into violin notation. Now he could play the viola perfectly. <Laughing> Isn't that wonderful? This guy is a genius <laughs>. He is one of the few genuine genius level people that I've known.

Hendrie: He can attack any problem and he will think about it and come up with a solution.

Comstock: That's right, that's right.

<Crew Talk>

Comstock: Well I've told you about Andy's transition to the viola, but after a few years of viola playing the tremor reappeared now tuned to viola dynamics. And so yet another transition was made, he went to the mandolin, and today he's playing the mandolin. My mind isn't clear on whether he's had a similar shift of notation to struggle with or not. But he also developed a middle ear problem, that affected balance, and he's devoted a lot of attention to studying the dynamics of these systems and has worked in a collegial fashion with some neuro scientists at San Francisco-- what is it, University of San Francisco Hospital on these questions and apparently has made significant progress in understanding the dynamics of what's going on. But the observation you made earlier about his ability to dedicate himself to a problem and dig deeper than others have explored, is just evident in each of these experiences. Fantastic person.

Hendrie: That is wonderful.

Comstock: There's one more chapter for the Diablo story that I'd like to mention. And that is it actually starts back at Friden. Some time in the mid '60s, oh maybe around '66, '65 or '66, a young fellow walked in the door looking for work, his name was David Lee, and he seemed like a very bright young mechanical engineer. He'd graduated from the University of Montana, I believe, with a mechanical engineering BS, and had worked for two or three years with NCR in Dayton. But he explained, maybe not at the time of the interview but later, that he wanted to get to the West Coast because he had met a young Chinese woman at U Cal Berkeley and would like to be closer to her, geographically. So we hired him, and I remember the first job I put him on was really not a very practical task. We were designing a new adding machine, a mechanical adding machine that was going to replace the 20 year old design that Friden had. This is a priority job from the product planning department who had the salesmen consulting customers about what they needed in a new adding machine <laughs>. And so one of the then fairly elderly designers of these mechanical products was going to work on his drafting table, designing this new adding machine, and I was keenly conscious that a similar project had been underway when I arrived on the scene to develop the next generation square root calculator, under the aegis of one of the old time designers who used to work for Carl Friden, and that project had just bogged down, it was—now one of the problems here is that in preparing one of these mechanical calculators for production they used to spend literally millions of dollars for class A tooling to bang out these parts in order to achieve the nickel a part cost that I mentioned. And spending 10 million bucks for the tooling on a new product was not at all-- they were completely adjusted to doing that <laughs>, it was just the standard practice. So here's this new adding machine coming along, with the prospect of another $10 million tooling bill, and I would like to make sure the thing really works before we release it for production. So I asked David Lee to sit down and analyze the tolerance loops in the design. Well he was discovering, you remember this play "Six Degrees Of Separation?"

Hendrie: Yes.

Comstock: Well in the case of the tolerance loops in this adding machine, he had like 30 degrees of separation. And when you go through and add up the tolerance of the parts on that it's very easy to conclude the machine will never work. So I guess that's part of the reason for the tweakers <laughs>. They'll take a particular unit of production, regardless of what the tolerances are and adjust those tolerances in effect. Well, so David worked on that for probably several months, and we finally decided to abandon the project 'cause it would only produce negative bad feelings <laughs>, it wasn't worthwhile. And then I put him on developing the printing electronic calculator printer that I mentioned earlier, that had the helical print wheel, and he brought that along. Oh he had been working at NCR on printer hammers, so that kind of tied in with that nicely. Anyway when we were ready to start designing the—converting Andy's design for the printer into hardware, we hired David from Friden who joined us, and I remember one of the first tasks Andy gave him was to study a variety of means for converting the rotary motion of the servo motor for the carriage positioning into the movement of the carriage over an 11 or 12 inch range. And the conclusion was that the best deal would be to use a steel cable, one of these multi-filament steel cables and of course the challenge was to pick the right cable and the right diameter of

pulley for it to run around and wrap around, and that was David's assignment. So he tested out, did fatigue testing on probably a dozen different versions of the cable and tested several different wheel diameters and so forth, got a good workable answer to that question. And the other major issue that we assigned him was to go to work on the print wheel. There were two elements involved, one was to find somebody that could create the plastic injection mold that would have the characters engraved and all that, and to pick the right material to use, which would have to have good injection molding properties, would have to have good physical parameters in terms of strength and stability and so forth, and it would have to have reasonable wear resistance, we didn't want the period wearing out after the first few strikes. So he spent some significant time working on that, and he also helped rig up the lab bench setup where we put this, how many spokes is it, half a dozen spoke sample wheel on a servo motor and--

Hendrie: And watched it.

Comstock: Watched it to see how much the spokes jittered and how long it would take to settle down when that was positioned and so forth. So those are the kinds of things that David was doing. Meanwhile we had a crew of two or three electrical engineers working, or designers really, working under Andy's direct supervision to do the circuitry for the printer, and we had another group of mechanical designers, some of these old calculator designers joined us, doing the physical structure for the chassis and the ways and all those things. So that was David Lee entering the picture. Now in 1973, about a year after Diablo had been acquired by Xerox. David came in and told me that he wanted to resign, that he was planning to team up with another of our colleagues from Friden who was still at Friden, a chap named Lon Israel. Lon was a mechanical engineer and had previously worked for Whirlpool, so he had some really good high volume production experience behind him. So the two of them set up this new company called Qume, and I recall David phoning me shortly after they had set it up and assuring me that they had no intention of building a daisywheel printer, they were going off in some other direction. Well that was good news from David. So a year or so later when they announced their Qume daisywheel printer I'm a little disappointed in David. Now it turns out that Andy had I think there were two patents that revolved around the positioning stuff and I'm not sure whether those also included the application of those positioning techniques in a daisywheel printer mechanism or not, but in any event there were at least two patents that read pretty clearly on what was happening. So when we learned that David was building a daisywheel printer we sat down and chatted with the then CEO of the company, oh Sutter Hill had financed Qume, which was a bit of an irritant, because they had arranged financing for us, and one of their senior partners had been on our board of directors up to the point of the Xerox acquisition.

Hendrie: Who was that?

Comstock: Paul Wythse. Do you know Paul?

Hendrie: Uh-huh.

Comstock: So we were a little put out with them, but anyway discussions with the Qume people about our patents didn't seem to make any difference to them so we sued them, for patent infringement. And that thing was grinding along. Ultimately Xerox decided rather than making a big court case out of it,

which probably would've bankrupt Qume, in fact the Sutter Hill people told me that they were really trying to figure out how to keep Qume alive because this whole litigation thing was so oppressive to them. But Xerox may have been feeling quite a bit of pressure from the consent decree that they had had to sign up to with respect to their copier stuff a decade earlier, well whatever period of time. And so in any event they granted an appropriate license, a royalty bearing license to Qume, and collected royalties ever since. Now one element of this story is that again a few years later I bump into a Xerox vice president in the airport <laughs>-- airports are great places for meeting people <laughs>, especially if you live at a crossroads. So I bumped into one of their vice presidents and I asked him about how the daisywheel printer had played in Xerox's financial fortunes, and he told me that Xerox had collected more dollars in royalties based on Andy's patents than they had from all of their copier patents, than the royalty dollars they'd collected on all their royalty patents over the years. Well it was a surprise.

Hendrie: That is a surprise.

Comstock: But they had something like 50 or more licensees around the world and yeah.

Hendrie: Well clearly he did a thorough job of doing patent coverage.

Comstock: Well interestingly enough when Diablo was independent we had used a patent firm in San Francisco to file our applications, and after we teamed up with Xerox I had some serious conversations with the Xerox patent people back East, headquartered in Washington, saying that we really needed a patent attorney onsite at Diablo, and finally after several months of harangue they did assign a guy named Barry Smith to us. And Barry took a look at the then existing patent applications and concluded that there was more that could be done with the inventive subject matter, and so he re-filed one or two of these cases and substantially increased the coverage that we had over the coverage we had obtained through the local law firm. I think the difference there probably is that when a local law firm is working on this sort of thing for a company their goal is to get it done as quickly as they can and at a reasonable level of expense for the client so that he'll keep coming back to them and getting the patent is more important than getting a perfect patent. But when you've got a company employee like Barry Smith his career is going to depend on really getting the broadest coverage and making the most of that patent. So he discovered some really substantial improvements that could be made in that patent structure and achieved them and that contributed to the result I've described. Now why am I going into all this? Because unfortunately-

Hendrie: Aren't you going to tell me about what you did after Xerox?

Comstock: Oh yeah we'll get to that.

Hendrie: Okay good.

Comstock: But I wanted to complete this David Lee story. I'm kind of irritated with David, and in the first place David's-- I always thought David was a neat guy, I enjoyed him personally, I enjoyed working with him, I thought he was a fine engineer. The girlfriend at U Cal Berkeley didn't last long and his parents

who were then in Argentina heard about it, they flew up here and said “We are going to select a bride for you, we'll give you an appropriate bride, not just some pickup at the University of California,” so they did, they arranged for a bride to come over from Taiwan and she arrived on day one and on day two she and David were married in the church in Hayward <laughs>, that’s the Chinese way. And they're still happily married as far as I know and they live in a very fine house a couple of miles over this way on a ridge and <laughs>, but there's one thing. I'm disappointed with the PR people that David fell in with, because they over the years have promoted the idea that David was the father of the daisywheel printer. And I can illustrate that with a paragraph from this recent publication, this is the book by Iris Chang called “The Chinese In America.” It's really quite a book, it gives you a horrifying story really of how America treated this foreign population that began flowing in here in significant numbers around 1840, and who subsequently became the key to getting the Transcontinental Railroad built and going on since then, they're really an oppressed people. They’ve got lots of reasons for feeling very badly about the way they were treated. However, this is a section of this book that touches on David Lee. The author has interviewed him, or his PR agent, “In 1969 several employees at Friden,” and they’ve misspelled Friden, “left to form their own company Diablo, and Lee decided to join them.” Well Lee joined us in early 1971, not in 1969 when the company was founded. “It was a radical move at the time,” well at the time he joined us we had one hell of a hot product line in our disk drive that had produced the revenues which multiplied by six gave us the price that Xerox was willing to pay for the company. “It was a radical move at the time for the majority of Taiwanese arrivals in the early 1960s aspired to become professors, a career deemed both prestigious and secure. Those who did not plunge into academia tended to work as scientists or engineers at large commercial companies like IBM or Bell Laboratories. In David’s memory there were perhaps no more than a thousand Chinese American engineers in Silicon Valley and most of them were wage earning professionals, not capitalists, very few dared to create their own companies. At the Diablo startup Lee developed the first daisywheel printer for mass production. In 1972 the Xerox Corporation avidly seeking a product to compete with IBM ball printers bought Diablo for 28 million, turning David into a multi-millionaire.” Now that is bullshit. That is bullshit.

Hendrie: He didn't have enough stock.

Comstock: He didn't have enough stock to get that kind of money, and he did not develop the daisywheel printer. Now you could be generous to David and say well he developed it for mass production, so maybe finding the right cable was a contribution to mass production. But the essence, the essence of this machine is the positioning technology that made the daisywheel a practical printing instrument, and that was Andy Gabor’s contribution. So I'm very resentful that David promotes stuff like this that detracts from Andy’s rightful-

Hendrie: Rightful position yeah. That he figured out the scheme for doing it.

Comstock: So I'm very happy to have this opportunity to put that feeling on the record. Thank you very much Gardner Hendrie, and thank you very much Computer History Museum for making that possible.

Hendrie: Okay good.

Comstock: Okay, if you'll tear off that sheet up here we'll get into the rest of my life if you're interested.

Hendrie: Yes.

Comstock: Well after five years with Xerox-- oh I've got another missing story.

Hendrie: Okay great.

Comstock: We closed the deal with Xerox, signed the papers, it was about a foot high stack of papers, today they're probably 10 feet high but in 1972 it was about that high, we signed those papers at the Itel offices in the Embarcadero Center building in San Francisco, on a Friday afternoon. On Monday morning about 9 o'clock I get a call from the front desk at Diablo saying "There's a gentleman from Rochester here to see you, he says he has an appointment." Well I look at my appointment book, I don't have any record of an appointment with anybody from Xerox, so I say, "Well, I don't see that I have an appointment but I'll come out and get the guy and see what he wants." So I go to the lobby and this guy introduces himself as the Manager of Records Retention for Xerox situated in Rochester, where their principal production facilities are located, headquarters are down in White Plains. Well he's got a manual that's as thick as this notebook of mine that has my patents in it, and that's the Xerox procedures relative to record retention, and he's going to go over this manual with me and make sure we understand every detail of how we're to do things now that we're part of Xerox. So I said "Gee, I don't have any record of your having an appointment, and I am very busy this morning, I'm not going to be able to spend much time with you but if you like I'll take you on a little tour of our plant." Well he thought that was generous, so I gave him a 10 minute tour of the plant and walked him to the front door. My next move was to call Bill Brown, my new boss at Xerox and say "What the hell is going on here?" <laughs>, so Bill got that fire damped down. The next fire was the Andy Gabor - George Comstock question. <laughs> That took a little longer.

But that was an interesting introduction to the life of Xerox, and what I found over the next few weeks or months was that take as an example a product planning meeting, at Diablo, independent Diablo we'd sit down, there'd be four or five of us around the table talking about what does the market want and are we able to do that, how much is it going to cost and so forth, and we'll reach a decision. Well that wasn't the situation at Diablo Xerox. We'd sit down at a much larger conference table with 20 people around it, or 30, and we'd have a long far-ranging discussion about all the factors that are involved and agree we'd meet again in a week to have further discussion. And that would go on and on <laughs> and on, you've been there <laughs>. So after about five years I think Xerox was fed up with me and I was fed up with Xerox so they offered me a position of Senior Vice President for West Coast Affairs or something like that, which would've been some kind of a consulting liaison communication role, and I said, "no thank you". But I said instead what I want to do is start yet another company, and we have an idea for a product that would be a self-contained word processor product of quite modern design, and if Xerox would have any interest in financing such a company I'd be willing to consider that. Well the answer is "Yes, we'd be very interested in looking at that. What we'd like to have you do is to go down to, it's not El Segundo, it's Santa Monica, at 9200 Sunset there's the offices of the Xerox Development Corporation, headed up by

Abe Zarem, who had made a big name for himself in some optical reconnaissance work in a company that had been acquired by Xerox. So I go down and talk with Abe and he's all full of generalizations about how wonderful it would be to work together and so forth, and I want you to sit down with my lieutenant, I've forgotten his name, and work out the details. Well about five months later <laughs>, I had four other guys involved in this with me, we had a chief engineer, a manufacturing guy, a sales guy, and an HR guy, and the five of us were gung-ho about doing something about this, and we said let's forget it. So I went back to Sutter Hill, talked with Bill Draper, and said we'd like to start a new company to build-- we'd changed our objective, instead of building a word processor which was of great interest to Xerox but not generally speaking, we'd like to build a small business computer, ideally suited to running a company with five, 10, 15 employees, and we think we can package it in such a way that it will not be as threatening to that user as computers are today, multiple boxes scattered around it and blah-blah-blah. And Bill Draper said "Gee, yeah, I think we can finance that," so we left a copy of the business plan and two weeks later we had our bucks <laughs>. So that's how we got Durango Systems started in 1977. And we opened the doors for business I think it was July or August of '77 and began designing a product, one of which is sitting right there. That's the Durango F85 computer. Why don't you take a picture of it?

Hendrie: Well yeah.

Comstock: Voila, the Durango F85, the little adhesively adhered name plate has fallen off it, some day I'll-

<Crew Talk>

Comstock: We were talking about the Durango machine over here just before we broke but let's leave that to the end of our session and meanwhile thanks for the dinner at Flea Street Café. That was very nice. We were on the startup of Durango, we raised our money and got going and in that case it took us another 15 months to start shipping product, and-

Hendrie: How much money did you raise?

Comstock: Well we had an initial infusion of a million and a half and then we subsequently added three-quarters of a million to that. Now the Durango effort was directed toward taking advantage of the microprocessors and in fact we used the Intel 85, 8085 for our machine, and built a unit that was really substantially ahead of IBM technology, by a big margin. For example, we had five inch floppy disk drives in it that we designed our own read-write system for and we were putting almost a megabyte on a five inch floppy at a time when the industry standard was 160 kilobytes and some of the machines were only doing 80 kilobytes, so we were way ahead. We built our own dot matrix printer for the machine, 165 characters per second in draft mode, 35 in (NLQ)- near letter quality mode. One of the interesting sidelines on that was that we decided to use a ribbon cartridge that Hewlett Packard was using in one of their printers, so we adopted their cartridge. After we got into production there was a question whether Hewlett Packard would supply those cartridges to us on an OEM basis, and I finally got a green light on that by talking with Paul Ely, E-L-Y, who is vice president of HP in charge of their Boise, Idaho operations where the cartridges were built, and he agreed to OEM'ing those cartridges to us, which we proceeded to

do for a year or two but then ultimately we tooled up and began building our own, manufacturing our own cartridges.

To make a long story short, we had bitten off more than we could chew really, we had not only the entire hardware system to put together and we were building our own printer, but we also had to develop our own software, we put out a contract with a group in Southern California for an operating system and they just didn't perform for us. So we wrote our own DOS, and then we needed to have BASIC on it, well we wrote our own dialect of BASIC that took advantage of our operating system, and then we needed some application packages. So we bought a set of packages that had been designed for one of the smaller members of the Data General product line and modified them to run on our machine, and we designed our own word processor, built our own word processor software package, and so on. Ultimately we did add CP/M to the machine so that foreign software could be brought over onto it. Course this was starting in 1977 and well, there just wasn't a lot of stuff available when you got down to it. We got a spreadsheet through the CP/M route that I just mentioned. One of the things that's come back into my mind from time to time as I think back over this error concerns a certain airplane flight, it seems that in 1981 a team from IBM's Boca Raton operation flew out to Monterey, California, to visit with Gary Kildall, who was running, what was it, Data--

Hendrie: Digital Research, yes.

Comstock: Digital Research, and he had the CPM operating system, and IBM was going to talk with him about putting CPM on their not yet announced PC. Well Gary was an avid amateur pilot and flew a Pitts acrobatic biplane which was kind of the A plus ultra of biplanes in those days, and it turned out that the day these IBM'ers were going to be arriving was absolutely perfect weather, and my understanding is that he went flying that day and left one of his subordinates to deal with IBM. What I've heard is that they were so insulted by this that they just turned around at the front door, marched back to their corporate jet and flew up to Seattle to visit with the son of a woman who was on their board of directors, I believe that was the connection, to talk with him about an operating system, and he said oh sure he could supply them with an operating system knowing that a friend of his across Puget Sound somewhere had something that he thought he could buy that would probably be able to go into the thing. Didn't he pay $75,000 for that? The son of the director was Bill Gates.

Hendrie: I don't know how much he paid.

Comstock: That was the software package that got Microsoft really on the map.

Hendrie: Yeah it turned into DOS.

Comstock: Well what's the thought that runs through my mind. Here was an airplane flying practically overhead when we were on North First Street, San Jose with Durango, and seated in that plane were four or five people who had they landed at the San Jose airport and taken the four or five mile ride up to our plant on North First Street, would've seen a disk operating system that didn't require a "Go to a numbered" statement, it could go to a literal, and had lots of other advantages <laughs>, and not only that

it was not a dream in somebody's eye, it was actually operating on a machine, it was controlling disk drives, we had a hard disk on the machine at that point, I mean that would've been a perfect solution for IBM <laughs>. My gosh, we might've even sold the company to them for the price that Xerox paid for Diablo <laughs>. So that was one of the ironies in my life at Durango, we just didn't stay close enough to the pulse of the industry, is my excuse for it, so we didn't know what was going on. And a year or two later that elephant foot of the PC really squashed us at Durango. In spite of all that Durango did manage to produce and sell something approaching 10 thousand of these machines, and last time I talked with a chap who was our service manager, Terry Purcell, he still had several of them running out in the field, and that's what well 15, 20 years later. So it was a product that we could be proud of, and it was also a company we could be proud of. Our peak employment got up to about 150 people and it was one of these low politics situations, in fact there have been several reunions of Durango folks to get together for a weekend just to see each other and enjoy each other and talk over old times and so on. So it was kind of a lasting phenomenon. Finally it was a very lasting phenomenon for me because at about the time that we turned profitable at this company-- oh by the way, one of the things I'm really very pleased about in looking back over the years, is that in both the case of Diablo and in the case of Durango we ran those businesses within one percent of what we had been predicting in our business plan for expense and revenue for the first couple of years,we really tracked perfectly what our predictions had been. How many companies can make that claim? And we achieved-

Hendrie: Venture business plans never do that.

Comstock: We achieved profitable operation at precisely the month predicted, no I'm wrong about that, in the case of Diablo we had predicted profitability at 24 months, and in fact we had a huge loss at 24 months, after a meeting of our board, Paul Wythes pulled me aside and said "Look, this is a very serious situation, we've got to really cut expenses to the bone here, I mean this thing is going downhill very rapidly." And I said "Paul, please don't worry about it, next month you'll see that everything is all right," and sure enough the following month we had our profit, and it was one month late on achieving profitable operation. What was the reason? Well we had filled up the postage meter <laughs>, and a number of other things, to put the expense into the 24th month instead of the 25th month, because of some obscure contract condition that I've forgotten right now but there was an advantage for us <laughs> in having it turn out that way. So Paul worried unnecessarily about our profitability. Anyway both these companies did very well in that respect.

When Durango turned profitable, as expected, we had a problem that many of the people who had joined us had accepted what you might call less than fair market value wages for their job, in the expectation that when we turned profitable we'd correct that situation. And so we set about correcting it, but we quickly discovered that some of these folks had very unrealistic expectations. So we thought someoutside help would be desirable, and one of our people in the HR area, Kay Cooper, had worked just previous to joining us with a very bright woman, Pat Hillman Gill, who was heading up HRD activity at ESL, and whom Kay knew was planning to start her own private practice. So she recommended that we talk with Pat about coming in to give us a hand. To make a long story short she came, we successfully got over the hump of the problem of having profitable operation and she married me <laughs>. That was a number of years ago and it's the best thing that happened to me in my life

<laughs>. So I think that kind of winds up the story, well no not quite.

Durango did well, it operated profitably for about a year, and then the arrival of the PC and also pricing pressure where people expected to pay like $1,500 such as an Apple cost, instead of paying the $7,500 to $40,000 that one of our systems cost, made life very difficult for us. So it gradually slid down and ultimately the venture capitalists decided I wasn't the person to run it anymore, they brought in a new guy from Memorex, poured a lot more money in it, a year later folded it into another company that was having trouble that they owned and a year after that that all went down the tubes. So we suffered the fate that's not uncommon in this entrepreneurial stuff. Well I'm going to put in another plug for me, I've worked for four startup situations in my life, one was Potter, they were 80 people when I started and 800 when I left, and went on growing another four times after that, then there was Diablo that I started, Durango that I started, and I'll also make a brief mention of Network General which was the last company I worked for, where I was employee number four and enjoyed a very pleasant and wonderful five years with Len Shustek and Harry Saul in that environment. It was a great experience, a wonderful way to polish off a career. So I had four startup situations and for me three of them were successful, so I like to claim I was batting 750 and that's not too bad.

Hendrie: That's not bad at all in the multiple startup world

Comstock: I joined Network General as employee number four in 1986, a few months after they had opened the doors for business. I came in at first as a volunteer consultant to help them get started.

Hendrie: Now how did you get connected with them?

George Comstock: Oh Harry [Saal] had interviewed Angie Lux, our VP for Software Development from Durango (one of the first women, I believe, to have filled the VP role in that position in the computer industry) and was calling me on a reference check, and we had a really interesting phone conversation and decided to have lunch, we had lunch several times over the course of the next couple of years and then I didn't hear from him for several months. I did get a call then in which he said, "Hey, I've started a new company, would you like to come over and see our product?" Of course, so I went over to have lunch with him which was pizza with Harry, Len [Shustek] and Harry's wife Carol, and a view of the first Sniffer, which was there in a compact suitcase luggable package, they had put their own network-- they had put an Ethernet network card in and had put their own software on for the Sniffer function, and they demonstrated it to me. I didn't know a thing about networking, but this felt like a chance to learn something interesting Networking. So I said, "Harry, I've had some experience with startups, if you could use another pair of hands around here a day or two a week for the next two or three months I'd be glad to pitch in pro-bono." Well he was a little bit puzzled about this offer, is this guy a spy or something <laughs>, but after a little consideration he said well why not, come on. So I joined them and the one or two days a week quickly turned into five days a week and I was setting up their sales operation using manufacturers reps which was a bit off the track at that point, but it worked out very well, in fact they ended up buying out about half of their reps and converting them into direct sales officers, this is two or three years downstream. But after I'd been there for a couple of months Harry said, "Look, we'd like to have you join us as our VP of sales and marketing." Well why not. It's a lot better than being president

<laughs>. You can concentrate on something. So I did, and it was just a wonderful experience working with those people. And it was a wonderful company, you know, they started it, they opened their doors in May 1986, had shipped our first Sniffer to a customer in September '86, we turned profitable on a month to month basis in January '87, now isn't that something. Course the fact is it was a software company, their added value is software, they bought the "suitcase" machine, they bought a network interface card from 3Com, plugged them together, there's a manufacturing cost that's on the order of $2,600, loaded their software onto it and sold it for $20,000. So I mean that was a very fine kind <laughs> of business. 87% gross margin. They were profitable in January '87 and continued profitable every month from then on and they were characteristically operating with a 15 percent net after tax and doubling sales every year. I finally retired from Network General in 1991 I think it was, yeah I was there five years, and by that time they were doing 50 million a year and still 15 percent net after tax. It's interesting, the last year or so I was with them I was functioning as what's called Business Development Manager, meaning I was out looking for acquisitions and mergers, and one acquisition I recommended they consider was acquiring McAfee, McAfee Virus, anti-virus stuff. And McAfee at that point was if I remember correctly doing something like 15 million a year, Network General meanwhile had gone public and had an enormous valuation, and it seemed like a good deal 'cause it would sell to the same customer and in a sense a related kind of phenomenon, fixing problems. But they felt kind of uneasy and too big a thing to take on, it'd be difficult to manage and so on, so they didn't. But, you know, 10 years later McAfee bought Network General, and paid 1.4 billion for it <laughs>. I was no longer with the company and by then I had sold all my stock <laughs> so, you know, the principle of diversifying your investments.

So that's my story, and since then I've just been engaged in various volunteer activities and I love to do: woodworking, I gave up private flying about three years ago, I love that, I'm doing some sailing these days, that's very enjoyable, and I've gotten into politics, I'm the vice mayor of Portola Valley right now <laughs>, and presumably I'll be the mayor next year. So, you know, what do I feel best about myself having the 750 batting average on entrepreneurial startups or being the mayor of Portola Valley <laughs>, I'll put my money on the startups. So I hope this has illustrated the principle I started off with that there's a thread that runs through everything, and this thread started with meeting Al Howell when I was 9, then bifilar precision pickoffs and that ran all the way through the Diablo story, and I'm not sure whether there's such a thing in this Durango machine or not. If you'd like to take a look at the Durango machine we could do it now.

Hendrie: Okay before we do that I just want to thank you for taking the time, a generous amount of your time to tell your story for our Oral History Project at the Computer History Museum.

Comstock: Well thank you Gardner, I suspect I've enjoyed it more than you have, you can see I do like to spout off <laughs>. So thanks for the opportunity.

Hendrie: Well let's look at the machine, and I think you may have some other things you want to show me over there.

Comstock: Well possibly. Oh here's a picture of the consultant that came in to help us with our profit problem at Durango, and we've been married 22 years now and it's been a wonderful experience. This is

the Durango F85 computer, uses an 8085 processor, and I already mentioned one of the ways that was ahead of the industry was that in this five-inch floppy disk drive, in this-- well should we start over again?

Hendrie: No there we go.

Comstock: This is the Durango F85, it was well ahead of the industry. For instance in the five inch floppy disk drive here we designed our own read-write stuff and put 947 kilobytes on a disk at a time when everybody else was doing either 80 kilobytes or 160 kilobytes. We originally had two floppies in it but we very soon replaced one of the floppies with a hard drive, we started with a five megabyte hard drive, and then went to a 10 megabyte hard drive. We built our own printer. This is a dot matrix printer. Here's the dot matrix head, and that's a ribbon that just fell loose there. We started with the HP ribbon cartridge and then ultimately tooled and manufactured our own. This paper feed mechanism could handle both continuous form fanfold side-punched sheets, or what's the opposite of sheet? Continuous form. Or this mechanism could handle individual cut sheets. So it was quite a versatile printer and it would handle wide format so you could do accounting reports quite nicely. We had some auxiliaries, I don't know whether you can see it, but this is an auxiliary dual five inch floppy drive that could be plugged into it. But more than that, if you were to look around at the back side here you'd see a bunch of connectors, we could connect up to four auxiliary terminals, we bought the terminals from, oh what was the name of the company, AD, I've forgotten the name. It was the guy that became chairman of Long Island Lighting Company that was running it. So you could put four terminals with their keyboards connected into the back of this thing and have one to four external terminals plus, this built-in keyboard, you could have as many as five people doing different jobs at the same time on this machine, and sharing a printer.

Hendrie: It had a relatively small screen, was that sort of the standard with it?

Comstock: Yes, this was the standard screen, it was a nine inch screen that we used just a pure character based presentation. It was legible 'cause you're sitting reasonably close to it, and this swiveled around so you could get a viewing angle.

Hendrie: It was a completely integrated physical package.

Comstock: That was the point.

Hendrie: You didn't have to plug anything together.

Comstock: Our aim was to try to make it look enough like a typewriter so that people wouldn't be scared of it because it was a computer. Well that was great psychological theory but it wasn't enough to overcome the appeal of an IBM name tag on multiple pieces of equipment. So that's the Durango system, and I wish that plane had landed at San Jose <laughs>.

Hendrie: Do you have anything over there that you'd like to?

Comstock: I think we've already looked at some of this stuff yeah. This was the-- we sold the Diablo

drive in three different configurations, this was just a single drive, this is two drives in the same box, both interchangeable cartridges, and this is one where we denatured the lower drive so you couldn't remove the cartridge, that became our antidote to a machine such as Iomec built that had one removable and one fixed on the same spindle. I didn't mention competition but when we went into this business there were three competitors, one was Iomec, whose sales and marketing function was headed up by Avery Blake, a former colleague of mine at Friden, of the Friden alumni. Another one was Calux I've forgotten what their antecedents were, and the third one was a company I believe in Phoenix, Computer Memory Technology, or something like that. And each one of them had one significant customer, Calux had Burroughs as a customer, Iomec had, I think they may have had HP as a customer, and CMT, I think it was CMT, had Data General I think as a customer. But once we came on the market none of them were able to get another major account, we just dominated it. One interesting point is I mentioned the business plan that we had created and then tracked very accurately, in predicting the market we had listed 10 major account potentials, and for each one of them our percent assessment of the likelihood of our closing them as a customer. And looking at that after two years it turned out that we only closed one of those accounts, up to that point, but nevertheless we made our numbers.

Hendrie: But you made your numbers anyway?

Comstock: Yeah. I think we already took a quick look at this; this is our Japanese distributors' sheet showing the cartridge and how it fit into the Diablo machine. This was a brochure on the daisywheel printer featuring the daisywheel with its characters on the tips of the spokes. This is a brochure on the Durango machine. We even demonstrated how light in weight it was by having one of our secretaries carry one of the machines, she was able to hold it just long enough for the picture.

Hendrie: Did not have a giant power supply in it.

Comstock: Right. That's pretty much it. I talked about Computypers at Friden, this was a Computyper, here's the Flexowriter, with paper tape reader and punch, here's some reels for managing the tape and down inside here is the central processor, there's plug board not visible here that's used for programming it, and Friden was selling these at the rate of several thousand a year, and in a sense that was kind of the seed planted to generate the Durango idea. So that's about the story.

Hendrie: Are those your patents down there?

Comstock: Oh this notebook, yeah this is a collection of my patents over the years, my own patents, there are about 40 of them in there.

Hendrie: 40 patents?

Comstock: Yeah, there's only one of them that really collected much in the line of royalties and I guess it generated about five million dollars worth of royalties for Potter Instrument Co.

Hendrie: That's okay, very good.

Comstock: Ampex was one of the payers.

Hendrie: Thank you very much and we'll sign off now.

Comstock: Okay Gardner, it's been a pleasure, thank you.

END OF INTERVIEW

REFERENCES

John T. Potter — ELECTRONIC MEMORY DEVICE
US Patent #2,620,389 — Filed Sep 1, 1948; Issued Feb 2, 1952

John T. Potter — THREE DIMENSIONAL MEMORY DEVICE
US Patent #2,674,728 — Filed Apr 26, 1949; Issued Apr 6, 1954

John T. Potter — ELECTRONIC MEMORY DEVICE
US Patent #2,650,830 — Filed Apr May 19, 1949; Issued Sep 1, 1953

John T. Potter — ACCESS MECHANISM
US Patent #2,862,389 — Filed Nov 24, 1951; Issued Dec 2, 1958

The combination of a plurality of mechanical displacement elements, means for adding their displacements, each said displacement being one member of a binary proportioned sequence of steps in ratios of 1, 2, 4, 8, etc. relative to the length of the first step in the sequence.

This claim covers the positioning air-hydraulic cylinder strings employed in each of the three positioning axes of the Potter 3D RAM.

George E. Comstock — MICROMETER ADJUSTOR
US Patent #2,855,688 — Filed Jul 11, 1953; Issued Oct 14, 1955

Differential screw threads for precision adjustment of a tool room grinder's swivel table.

George E. Comstock — TAPER GAUGING DEVICE
US Patent #2,863,222 — Filed Nov 4, 1955; Issued Dec 9, 1958

Dual LVDT electronic measuring system for setting the taper angle on a swivel-table tool room grinder.

George E. Comstock — CAM GRINDING MACHINE
US Patent #2,801,505 — Filed Nov 4, 1955; Issued Aug 6, 1957

This precision automotive camshaft grinder was my first application of "Fluid Power Control" technology. The object was to vary the rotational speed of the shaft being ground to maintain approximately constant relative surface speed of the grinding line of contact as the cam radius changes during the rotation of the camshaft in the grinder, thereby producing a more uniform surface finish on the cam.

My next application of FPC was in the digital positioning mechanism for the Potter 3D RAM.

George E. Comstock — TAPER GAUGING DEVICE
US Patent #2,863,222 — Filed Nov 4, 1955; Issued Dec 9, 1958

Dual LVDT electronic measuring system for setting the taper angle on a swivel-table tool room grinder.

George E. Comstock — VACUUM LOOP TAPE HANDLER
US Patent #3,016,207 — Filed Dec 15, 1958; Issued Jan 9, 1962

The Potter Instruments Co's "Pucker Pocket" tape stabilizer embodied in its Model 906 reel-to-reel, tension arm tape drive.

Andrew Gabor — DUAL TRACK HIGH DENSITY RECORDING SYSTEM
US Patent #3,217,329 — Filed May3, 1960; Issued Nov 9, 1965
1100 Bit/Inch system first used in the Bendix G20 computer when standard density was 256 bpi.

Frederick P Wilcox — DATA TRANSMISSION SYSTEM AND PRINTER
US Patent #3,461,235 — Filed Aug 17, 1960; Issued Aug 12, 1969

Wilcox's mobile communications system incorporating a constantly revolving daisy wheel character-bearing element.

George E. Comstock — ELECTRONIC CALCULATOR
US Patent #3,854,124 — Filed Nov 21, 1967; Issued Dec 10, 1974

An electronic printing calculator with a FIFO memory function. The application was denied by the US Patent Office because none of their examiners could understand the disclosure, which was submitted as a FORTRAN program controlling a simulation of the invention by an IBM 1620 computer, backed up by appropriate logic diagrams, etc. The US Court of Customs and Patent Appeals directed the Patent Office to perform a proper appraisal of inventive content, and issue a patent if found worthy. It did.

Andrew Gabor — CONTROLLING THE POSITION BETWEEN TWO RELATIVELY MOVABLE MEMBERS
US Patent #3,663,880 — Filed Sep 14, 1970; Issued May 16, 1972

One of the patents fundamental to positioning printer daisy wheels and print carriages.

Andrew Gabor — HIGH SPEED PRINTER WITH INTERMITTENT PRINT-WHEEL AND CARRIAGE MOVEMENT
US Patent #3,954,163 — Filed Sep 11, 1974; Issued May 4, 1976

The second fundamental daisy wheel printer application

Michael C. Weisberg — COMPOSITE PRINT WHEEL

Mike's US Patent #4,037,706, filed on May 6, 1976
Used on the Xerox OPD Word Processor daisy wheel printers.

Andrew Gabor — QUIET IMPACT PRINTER
US Patent #4,681,469 — Filed Jun 11, 1986; Issued Nov 13, 1994

Andy's Xerox PARC "Skunk Works" development of the ultimate typewriter, the silent Xerox 630, a "Knock-OFF" for the IBM Selectric "Golf Ball" (noisy) Executive typewriter.

William H. Draper, III, "The Startup Game," Palgrave/Macmillan, 2011

Bill's Tales of Silicon Valley Venture Capitalists should not be missed! He and Paul Wythes founded Sutter Hill Ventures in Palo Alto in 1964, raised money for Diablo Systems in 1969, for Qume in 1973, and for Durango Systems in 1977.

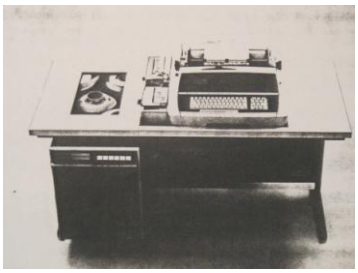
Robert M. Hazen, **"The DIAMOND makers,"** Cambridge University Press, 1999

A compelling drama of scientific discovery.

Film CLIP, "Tthe Potter 3D Random Access Memory." 1957

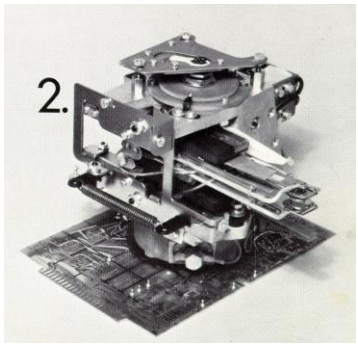
A four miniute titled, silent video showing the mechanical design and actionof the machine, to be available on the computerhistorymuseum.org soon, possibly 2015 or 2016.

Photo Gallery


The Friden Model 5610 Computyper

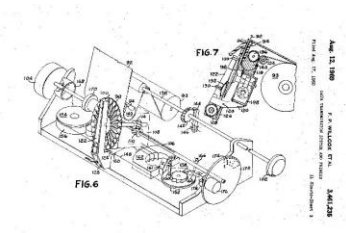

Dr. Andrew Gabor


Andy's Friden 2311 IBM Clone

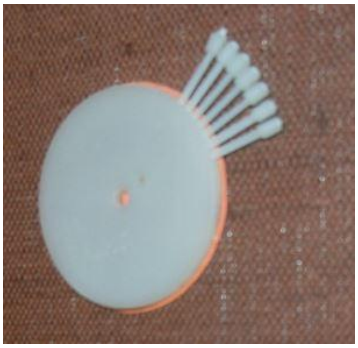


Diablo R/W Head Positioner - 1970

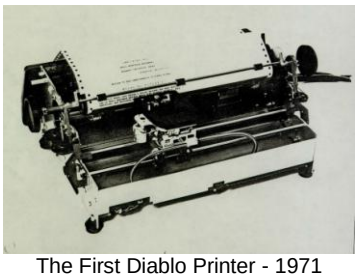

Diablo Model 30 Drive – Hanover, Messe -1970



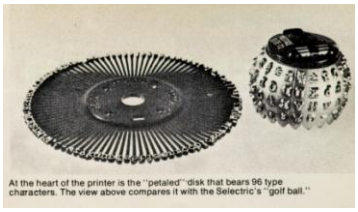
Fred Wilcox Patent Drawing - 1969



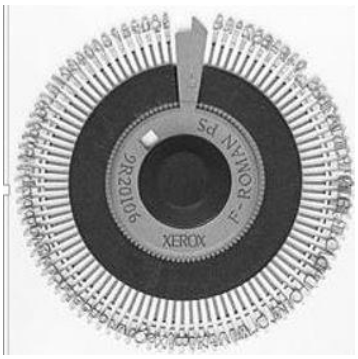
Diablo's First Daisy Wheel



The First Diablo Printer - 1971



Daisy Wheel, IBM Golf Ball - 1971



Mike's Metalized Wheel - 1975

Durano F-85 Computer - 1978

Requiem - Diablo 630, ca 1988