



Birth of the laser print

Talk by:
Gary Starkweather

Recorded March 25, 1997
Mountain View, CA

CHM Reference number: 102738575

© 1997 Computer History Museum

PETER NURKSE:

I'm Peter Nurkse, and I'm from Bay Area Computer History Perspectives. That's just two of us, that's me and Jeanie Treichel. Jeanie, could you raise your hand? Jeanie Treichel. Jeanie's a piece of computer history herself, since she was at PARC [Xerox Palo Alto Research Center] more than 20 years ago. I come more recently to just interest in computer history.

We've been holding these talks since 1993. I see two of the speakers at our very first talk: George Michael and Norm Hardy, here in the second row. That was one of the smaller talks at the very beginning. It was just an audience of 20. But we had in the audience Gordon Bell and Donald Knopf sitting side by side in the front row, so it was a distinguished audience. We've kept up our distinguished character, I think, ever since.

This is the first program since March a year ago, when we had Ivan Sutherland and Bob Sproul talk on the early history of virtual reality. So Jeanie and I have taken a year off, so to speak, while The Computer History Museum people have been very busy trucking over the 50 tons of equipment that you're going to see later.

For our program tonight you'll have Gary Starkweather talking on the development of the laser printer at PARC. We had hoped to have a joint program with Ron Rider too, who was also involved in the early development of the laser printer, but he's traveling constantly, and unavailable.

Was that -- Gary, I think you're already wired?

GARY STARKWEATHER:

Before I get started, I guess the one thing that's interesting is, this project, even though there were times when I wondered what in the world I was thinking of when I decided to do this, it probably was more fun than anyone has a right to expect. Like all good things, you set out to discover one thing and you discover something else which is even more exciting.

In order to cover this the right way here, it's certainly critical I think -- this would not have been possible had it not been for xerography. And of course I had the good fortune, two years out of college, to move to Rochester, and the first company I worked for was Bausch and Lomb, which was an optical company, not an ophthalmic company at the time, and I either considered Bausch and Lomb the lowest paid industrial job, or the highest paid graduate school I ever was at, and it was kind of somewhere in between.

Not unlike where I work now, Apple, Bausch and Lomb had a layoff, and I was in a group of 16 people, 14 of which got the ax. I was one of those spared; [they] probably considered me too naive to worry about, so they let me stay. Fortunately, a bunch of the people went to Xerox, and Xerox was a start-up. When I got a job offer to go to Xerox, the rule was, why would you go to a place that's making copiers -- everyone knows they make four or five thousand of those things and the market's full, so there's no future to that place.

So I said, well, there's no future here, I might as well try two places without futures, I guess, it's certainly safer. [Laughter] I went to Xerox, and of course the key to Xerox was xerography. If you're in the general world, when you talk about this process, it's called perhaps more generally electrophotography, but I am permanently wired to "xerography" -- after 24 years at Xerox, that kind of happens. It basically comes from "dry writing." The beauty of it is, is that it's a remarkable process, and I just wanted to give credit to a few people. Here you have on the left, John Dessauer, who was head of R&D at Xerox, Chester Carlson, just a wonderfully decent guy, and Joe Wilson, an entrepreneur's entrepreneur if there ever was one.

There's a picture of Joe with the first 914 copier. Interesting thing, the 914 was a seven page per minute copier, filled with relays, it sounded something like a Chrysler fluid drive shifting when it made the copies, for those of you who might remember what that was like. [Comment: This man needs a laser pointer!] That's right. The interesting thing about the 914, from which this whole company arose, and how I got there, and did this stuff, is that the -- this is the most profitable product ever produced in the world, the 914. And it sits in the Smithsonian, I think with that particular situation against it. I think it cost something in the neighborhood of five million dollars to develop. And the revenue is absolutely enormous, that this machine generated.

An interesting little story, for anyone who has ever done inventions: When Joe showed this machine off, he put an original on the platen. Audience is filled with investors. Pushed the button to make a copy, and the first sheet comes out blank. And he's going, "Oh, my gosh!" Somebody tapped him on the shoulder from behind the curtain and said, "Turn it over." He'd placed the original printed-side up. [Laughter] So the technology works, so you have to be a little careful about some of this stuff.

This is some of the early headquarters -- this is July in Rochester, for those of you who've ever lived there [laughter]. It got started in this little building, grew into the Xerox Corporation, and a number of good things got going from there, I'm not going to take you through that whole litany. One of the things was developed by a fellow by the name of Roy Lahr, and this is in 1964. Roy came up with this thing called the mobile printer. It was something that sat on the seat of a car, originally intended maybe for police and fire, plugged into the cigarette lighter for power, and would drag electrodes across a sheet of coated paper and develop it with toner, so you could actually, using FM radio, transmit information to this printer. It was considered to have no future, and hence was shut down. This is 1964 now, doing electronic printing; anyway, this was a remarkable device for its time.

Perhaps one of the neatest projects Xerox ever had was something called long-distance xerography, and this is kind of where my story came in. Long-distance xerography was a way to try and do facsimile before it was called that, I guess. What they did was the following. You had this system whereby you had a document drum, in which the original is wrapped onto it; a CRT which would line-scan across the document, pick up the reflected signals with a detector; send them over a 56 kilobaud line to another CRT, which was then modulated in proportion to those signals; and would write on a xerographic drum to make a copy at a distance. This was actually a great idea, except the CRTs almost had to be water cooled, they had them pushed right to the limit to make this work. They just happened to be one of those wonderful things Mother Nature

has designed; light sources and photo sensors to kind of be stretched to the limit in the way that they worked.

Basically it went back and forth on this raster with the CRT. The drum was doing the vertical motion in this thing, and it was about 140 dots per inch. The technology was capable of being pushed to 300.

This is a room full of these things. Not a whole lot of customers, but what they actually did in this particular area was Southern Pacific Railway, and what they did is, they'd stick one of these things out the window, and scan the bills of lading as the freight cars would go by in a distribution yard -- classification yard -- and then they could print out the bills of lading and keep the rolling stock going right on through.

The biggest problem with this thing was, no light. You couldn't speed it up. It was doomed to probably three or four pages per minute. You might get it up to six, but it just wasn't going to make it very far. There were whole projects started at Xerox using light pipes.

Well, at about this time I'm in graduate school, working at Xerox. Along came this thing called the laser. Now, those of you who've ever used early lasers, you had to get a ham radio license to run them. You had to peak the plate, and dip the grid, and everything else to get these things to light, there was really no "on" switch on this thing, it was like a class A amplifier.

The model was, could we substitute -- if I could paint with a laser, there was one simple thing in a flying spot system. It's brightness of the light source that counts, not the total power. Of course a simple calculation on a laser, you say, "Pssh -- this thing's ten thousand times brighter than a CRT. It's gotta be wonderful." The only trouble is, lifetimes were 200 hours, and so forth. So, I got this idea to try and replace the CRTs with lasers to do the facsimile, and in 1967 took a 914, and put a scanner on it -- actually I did a laser facsimile from the 914. Discovered all the wonderful problems that go with doing that.

And then got the idea, wouldn't it be neat to print with this thing. Now of course this is in the day in which a kilobyte of memory was considered a treasure indeed. So, if you do the calculations, you say, "A million bits you're going to put down? What are you going to do with that? Where are you going to get that kind of memory?"

Xerox, by this point in time, had developed a higher speed machine called the 2400. That was a 40 page per minute copier. Because all this has a very interesting story that gets woven in. About this time I was starting to get a lot of flack at Xerox for working on this project, because it didn't look like a copier. That's just like -- you have trouble in any company if you're not making things like they're selling, you're immediately suspect. And so, what I was working on with lasers didn't make copies. "So, what are you working on that stuff for?"

Around this point in time something wonderful happened. I picked up the company newsletter, and there was a research center going to be in Palo Alto. I called out there, had a chance to go out there -- some people in the audience today, Bill Gunning, thank God for Bill, and John Urbach, who were there -- I called my wife and said, "Would you like to move to Palo Alto?"

We were in Rochester at the time. She said, "I'll have the furniture in the street by the time you get home." [Laughter] So it wasn't a big convincing job on that one.

And so there was a chance to actually get the technology from where it was out to California, where there were a bunch of people drawing these wonderful bitmaps on -- ready to do this on screens, had no idea how they'd put this stuff on paper. And so, here were people drawing things with electron beams, and I wanted to draw the output side with laser beams; it seemed like a natural marriage. To me it's often very interesting how technology mixes together, when the timing is correct. Had the laser printer been born ten years earlier, it might have suffered the same fate as the mobile printer. Too much demand for memory, where's the electronics going to carry it, and it might have disappeared under a table somewhere because it just didn't match right. It would be interesting to historically look at those things which might have come out different had they been born in a different time.

Inside this 2400 is some interesting stuff. In order to get it to go this speed there were 12 fluorescent lamps in here, and if you wanted to speed up even more, you can't put in 24, there's no room in this thing. The curved platen, that was also a problem. Giuliana remembered people loved those things for crushing the bindings of books and so forth, it was really wonderful as they kind of smash them over this curved surface.

The idea was that we could actually print on this drum, so in Rochester I actually tried that. The problem is this drum is only blue sensitive, and in these days it was very difficult to get lasers that were not red. This was the years of the only helium-neon laser.

They then upgraded this machine to the 3600-1, which was a "squeeze the fluorescent lamps a little harder, get another 50 percent of speed out of this thing." And then they went to something at that point in time called the 3600 Optical Character Printer, which was a 3600 and they were into electronic printing to some extent but they didn't want to change too much, so inside that box on the other end of it is a 10-inch diameter drum turning 5,200 rpm. It was a glass drum. Bill did some designs on trying to get that thing synchronized, because the way it had been designed, it didn't line up correctly -- I won't take you into the ugliness to try to get those characters to not creep on the thing as you print. 5200 rpm is a very high speed for a 10-inch drum -- 1 1/2 horsepower windage loss inside this thing. You had to glue a character mask on the outside of the drum. Occasionally it would fly off, which meant you just drained the dust out and got another one, because at that speed there was nothing left. Last thing I recall, they only made these drums with one lady in Troy, New York, who would come out of retirement to glue the film on; she's the only one who could seem to do it and not have it come off.

There were 700 of these made. The original opposition to doing the laser printer was because it put these machines out of business, they already had invested in 700 of them. Interestingly enough, people kept them once the laser printer came out, because they realized that electronic printing was authenticated. So the first rule is, customers don't care what's inside the box. It can be elves drawing the pictures, so long as it's electronic. They want just to get what they want.

Following this, or around this particular time, was something called a 7000. This has a very interesting history associated with it, because this machine was a bigger device which had

reduction built into it. Again, just a 3600 with a magnification lens inside. But what happened was, the optical design that was done to do the magnification was extremely poor. I don't know how it got designed that way. In order to rescue the project, there was a new copier being designed that had a drum which was red-sensitive, not blue-sensitive. They had to reduce the size of the exposure slit in the copier, and therefore as an emergency procedure, decided to rush this photo conductor into production to save this project. Because they did that, I could use this engine for the helium-neon laser as the base machine on which to print.

At that point in time, the project came to California, and here's Ed Glab, a technician at that time in Rochester, with a rig, testing a lens for a new copier on this engine with that special drum. So we talked Ed out of his rig for a week, and I went in and strapped a bunch of optics to it, and these -- this is again [a] simple laser scanner, just to show you. You have some type of device to deflect the beam, a laser that can be modulated, and you just synchronize the thing and paint little dots all over the surface, which is I'm sure you already know.

The question was, what to use to do the imaging. We looked at galvanometers, the little wiggling mirrors. I'll take you through that in a minute. Way too slow, not adequate. Price is right, however, but the performance isn't. There's ways of using acoustics to try and deflect things, but that wasn't so hot either. So we ended up with something ugly like mirrors on a stick, which is really what this is. The biggest problem with this concept is it's not very high tech. If this would have occurred with the interactions of stellar matter and bosons, people would have been thrilled about this thing, but it was just shiny glass, you know, going around in a circle. And that wasn't quite as thrilling as other people might have imagined.

So what we did is, we took this -- I'd put something together to try and figure out what to do, just to test it before I really committed that this was something which I thought would work. And I think we picked the polygon because it was the only one that could get you the number of spots per scan, which I needed up to 7,000, and I needed 10,000 scans per second. When I had talked to Bill Gunning, Bill was very useful in saying "Over-design this machine, because when they turn it into product, you don't want it all stressed out reaching those goals." Very wise help in that regard.

Q: [inaudible] time frame [inaudible]

A. Yeah, we're talking about 1970, this point, 1970-'71.

So we picked this, and for those of you who want to read about it, something called a merit function, which is the product of the scan angle times the aperture. Notice that a 10-facet prism, dirt-simple device, is the only one that cuts the mustard. Today, it's the only one that cuts the mustard. There's just no substitute -- been a lot of pretenders, but nothing's ever replaced it.

Again, we wanted to do from 10 up to about 70 million spots per second with this device. Now, there were people who would come out and argue with Bill and some of the others, John, and so forth, that you couldn't switch transistors that fast. This was in 1970. I mean, that's 10 nanoseconds, for goodness sakes, you know you can't go that fast. And so those arguments,

however Bill was very articulate in showing them that electrons really do move much faster than that if you just have the gates small enough. So, it would work.

The other thing that you had to worry about from the polygon -- this was one critical problem, is that I was really going to use about a three thousands of an inch spot, and at 25 inches, this says you need something on the order of one arc-second of precision to keep the spot from wobbling too much. Well, scanners which performed to that tolerance on 20 to 30 facets are \$10,000. The lasers were \$2,500, the modulators were \$10,000; and by the time you added this up, it was 50 grand for the scanner, so it's completely impractical technology. I'll show you an example in a minute of things on the laser writer near the end and you'll be able to see just how good it came out.

Nevertheless, we had to come up with a scheme here. So I came up with a scheme in which, and I can remember sitting in my office in Henrietta, New York, just prior to coming to the west coast, to look at this thing, that if you just put a lens in here you can refocus error rays back to a point. But you can't use just a round lens, you have to use a cylinder lens. And, simple as this sounds, I went to the phone and ordered one of these big long things from Edmund Scientific for five bucks, put it in there, and I couldn't believe it worked. I said, "Nah, nah, I gotta have done something wrong. Nah, nah, it can't work this way. Ten thousand dollars just went to fifty. What have I done wrong here? Nothing works that way." Well, it did work that way.

We had to look at some modulators. The only ones available in 1970 were electro-optic; we'll talk about those in a minute. Then there was acousto-optic, which was just coming up. I think it was Zenith Radio Research, in fact, in Menlo Park, that was showing some stuff doing that. We'll talk about those in a minute. [Inaudible question.] Yeah, I will in a minute. We'll get to that in the talk.

Here's the inside of the machine, and you can see it's very busy. The question is, how am I going to get the laser beam down among all this contraption stuff in here. And in fact, we ended up having to cut a hole in the developer housings -- the beam was able to slide through a half-inch opening -- thank God they're small -- to get them down in there to write on the drum. Because the drum isn't in here, because I'd taken it out, but you can see there's a lot of stuff in here. So there wasn't any room for real optics in here.

This is a setup taken in late 1969 - early '70, in which this thing Ed Glab had, with the big rack, we took his machine and on the rack that sits up here I mounted a polygon. It's out of focus, I apologize for that, but it was almost 30 years old here. And put a laser on a bookshelf, through a modulator, and ran it through some, you know, real expensive optical parts here. A little neutral density filter we could dial to set the exposure correctly. Hit the polygon, and went down to the drum of the machine, and there's the cylinder lens sitting down in here. A fellow by the name of Bob Kowalski -- not here today, but he's worked for me at Xerox, very key in all of this -- wired me a detector and something to run this modulator. Now, the reason it was tricky to run the modulator: we were trying to do microsecond pulses, and this was a one kilo volt thing to turn the laser beam on and off. So, quite an interesting amplifier. I remember when he came over and said, "You want to do what?!"

Nevertheless, here's the polygon, and it proved that it worked. We could actually take the wobble out of this system using that. So I came hat in hand to Palo Alto. Bill and John set up some resources for me. Those of you who ever were to the early Palo Alto facility, the windows were about this far off the ground. I don't know if they had extraterrestrials in there at one time, or what. But it was really interesting, because you had to get down on your hands and knees to communicate through these little windows. I think it was some behavioral science building at one point. [Laughter] They're probably still studying us, why we bent over, and just didn't use another building.

So this brought us then to what I call the early SLOP. Now, the reason it was called SLOP is, Scanning Laser Output Terminal. You say, why not printer? Well, because SLOP is not a good acronym, so that's why we didn't pick that one.

Here was the goal: we wanted to use an argon laser because the conventional wisdom at the time from our photoreceptor experts is (a) toner won't stick to small laser spots. That was the theoretical view. And furthermore, the spot exposure time will be so small that you'll have reciprocity failure. Now, reciprocity failure says that intensity times time is not a constant. So a three-day exposure through a small f-stop on your camera is not the same as a microsecond exposure with a very bright light. Film has a horrible reciprocity failure problem. Interestingly enough, photo conductors are linear over nine log orders, from what we can tell. They're linear from about a nanosecond to a week. So, thank you, thank you, thank you for working that way. That's wonderful capability.

We had to pick a 12,500 rpm mirror. Conventional copy lens to do the imaging -- we didn't know what the optical system would look like. And an electro-optic modulator that went to 25 megahertz. That's because we're going to have to modulate at roughly that rate. The D* stands for di-deuterium; it was a special crystal, and we'll talk again about what an electro-optic modulator does. And standard mirrors and optical parts.

This is a picture of the original slide that I used to sell the project. So this was the list of things.

This was a drawing of how it was all going to go together. I remember sitting in the office in 3180 Porter Drive and sketching that up. I don't think we actually built it that way, but it was good enough for a sketch.

Here was the whole optical system. This is again the drawing from the thing. A modulator, a little lens here which spread out the laser beam, imaged it onto the mirror, down through this correction cylinder, and onto the scan line, and what's not shown in here is a scan detector --. we'll talk about that in a minute -- for synchronization. So this is what I started out with. In fact all the original optics came out of the copier, and Edmund Scientific. So, probably, what, seven or eight dollars worth of parts in the optical system.

The other thing is, is that the way the optical system was designed, the true spot fell on an arc, while the surface of the drum is flat, or at least, it's straight. So, you had to worry about this problem of would it stay in focus. Well, the f number of the optical system is about 100, and if you do the calculation for visible light, depth of focus is about an inch and a half. That's the

diffraction depth. So it doesn't make any difference if it's curved. So that fell out of the whole system as well.

There's some cute geometry about the mirror, that I don't have time to go into, but I learned a great deal about three-dimensional geometry on a scan system like this -- all kinds of little gremlins were in there to get us -- but we solved those problems: facet-to-facet angles and things like that. The other thing is, you had to worry about the limits on a spinning disk. There's stresses that get into that. Fortunately, at 12,500, that's a reasonable speed. But we had to worry about that, specially since the first polygon was glass. And we didn't want this thing going off. Tibor Fisli, who's sitting back there, was such a help on all of the mechanical design, and the other optical design and everything else on this, said "You know, if you don't finish the hole right in there, this thing will crack and let go on you, and of course they don't warn." The other thing [is] windage losses; you've got all these 24 little paddles spinning at 12,000 rpm. So there are some calculations in there, I won't bore you with the details on that, but we'll find out about some limits here.

Here's a sample calculation about windage. If I take a 3-inch rotor, spinning at 17,500 rpm in free air, it takes about 2.7 watts. If you double that to 35,000 rpm, it take 100 watts. I discovered that quite by accident. We'd had a consultant -- you'll see some pictures of things he built -- Reno Castelli. who used to be at Columbia University, and then was part of Xerox, designed me some high speed motors, supposed to go 60,000 rpm. We put some 300 watt amplifiers so we'd have enough power, we thought, to drive these things at 60,000 rpm. At 35,000 rpm I had the amplifier wide open; everything was heating up, motor, amplifier, and we can't get the speed over about 32,000 rpm, because the windage losses are climbing astronomically out of this thing. And so there were some interesting situations that arose from this, that we had to learn about. The paddling of air. Not only that, the sound made a wonderful siren. [Laughter]

Here's the first mockup of the laser printer. We used a big 500-milliwatt argon laser, because the conventional wisdom said, "Toner won't stick to the spots. And, oh, by the way, you won't be able to expose the drum because of reciprocity failure." So John Urbach said, "Why don't we get a big enough laser, so if that's a problem, this should cover it." It sure did. I think we were capable of transferring photo conductor to the paper. [Laughter] We didn't need any toner. In reality, we couldn't put enough filters in front of this laser, because you only needed three milliwatts to do the exposure, and this thing was pumping out 500. It had a water line you don't see here running, because it's a water-cooled unit. In fact I think we had more problems with the laser than we had with anything else, trying to get this thing up and going. Inside these things, if they go wrong, you just have a very expensive aquarium, because the cooling water fills up the entire laser cavity.

Here's the electro-optic modulator. Went through some optics in here to form the beam, off the polygon, through the lens, down off a mirror, and down through a little cut in the developer housing to get to the drum. And this was the first system we actually printed anything on, to try and do intelligent straight lines, a little teeny character, whatever, to show the demonstration. Now, realize that this is running at a page a second. There's no way to slow this machine down, because it's a commercial copier that we've cut the parts out of. And you just don't slow that thing down. This was also -- one interesting thing that we learned a lot from, I certainly did -- it's

relay logic, that had 58 electromagnetic relays in it. And every time this thing would run, and have to do something, this relay would click on and off, and it was like an electromagnetic pulse going through everything here. The little scan detectors went ape, seeing these giant electromagnetic pulses going on and off. And we couldn't synchronize to anything on this thing. We managed to find -- come under control, I never learned so much about Gaussian shields in my life! I was trying to double-shield this because fields couldn't get inside. I could hear my physics instructor going "I told you, you should have known that better!" [Laughter]

This is what happens when you don't screw the glass polygon on. We started up one day, all excitement to try out a new circuit, and I turned this thing on, and it just lifted off nicely and went over to the side of the room like that; hit the wall, and went bing! bing! bing! bing! around this until it came to a stop. Bob Kowalski and I were doing a very clever dance trying to stay out of the way of this thing. [Laughter] It didn't break, what it did was just knock a chunk out of the side, so it didn't actually disintegrate due to the speed, it actually hit the wall, was what caused that. I actually still have that in my office, as a reminder of, you know, make sure everything is right before you power up.

Let's talk about modulators, because this was a very critical area in making this cost-effective. A Pockels cell basically uses a crystal of potassium di-hydrogen phosphate or potassium di-deuterium phosphate, and you apply the voltage across the faces of this to get the Pockels effect. The Kerr effect is across the vertical portion; across the ends is the Pockels effect, and it's linear with electric field. So what causes this rotation of the polarization in the cell, and therefore by using an analyzer and a polarizer, you can cause the light to be modulated. You cannot directly modulate a gas laser; they are not very good for the device. And if you do, you're limited to maybe a megahertz. So, this was capable of 25 megahertz; they have been operated up to as high as a hundred, 50 I think you can buy them today, even though I think they're kind of getting collector's items, to see that. The hardest thing about this is the driver, because it took -- we stacked six of these together to get the voltage down. So the voltage was 110 volts. The amplifiers had to switch this in 10 nanoseconds. The capacitance of the cell is 120 picofarads. What you have is, two amps in 10 nanoseconds going into this thing, and they had this little transistors, these little bent coils, they were twisted until they got the problems to go away, just had these little tight coils to tune this circuit so that it would work. And you looked at this amplifier -- the cell was cheap by comparison to the electronics in there, because they had these big transistors, because these things had to dump a lot of current in a very short time.

They worked, however, except there was one additional problem: the Pockels effect is very sensitive to temperature. Which meant that if the temperature changes on this, so does the plane of polarization. And therefore what you had to do was, if the data loads -- if you changed what you were printing, the cell got warmer or cooler, hence the plane of polarization changed, and the contrast would go away, so you'd be printing a page and then all of a sudden the stuff would disappear in there, because the cell would heat up. So you then had to put an autotracking circuit that would keep the temperature of the cell under control, feed back a contrast change, and after a while, you're saying "I don't think this dog is gonna hunt for a product, I mean this is just going to be a problem here."

Fortunately, about this point in time, through some work done by very many people at Zenith and so forth, was something called the acousto-optic modulator. And basically through something as simple as glass or water -- water has the problem, it's a wonderful medium, it just leaks -- using something like glass, you have a transducer, and you launch an acoustic wave through the cell, probably in the neighborhood of 80 to 400 megahertz, and it causes compression waves in the material that cause diffraction to occur when light passes through it. So you can see an optical beam, here; when it's in this position, the light is diffracted; when it's in this position, it is not. And if you put a stop in there, you can then get the light to go on and off.

One of the problems is, you can't get 25 megahertz out of these things. Because if the beam's a millimeter in diameter, and the speed of the material is 3,000 meters per second -- you can do the calculations, it's not going to work. So what you do is, you focus the beam down to a point, so that it takes less time for the sound wave to cross the optical beam. However, then there's less waves in the cell; you get poorer diffraction, so you have to crank the frequency up to shorten the wavelength, and you fortunately reach a nice workable solution at about 200 megahertz, and you can easily get to 215 to 225-30 megahertz out of these things, much higher if you really work with the technology. Interesting thing, there's very few -- the speed of sound is almost constant in most materials. I think it's 4,000 meters per second in diamond, and 3,000 meters per second in water, and in between for everything else, so it's not the variable you should try to adjust, if you're trying to design one of these things.

Here's the typical cell: the little modulator block, with a little tuning thing on here; lenses, to focus the beam in the cell -- John signed a lot of purchase orders for these things, very reliable, theoretically quite inexpensive, on the order of a couple-300 dollars for this. No contrast drift, extremely reliable devices, I mean basically it's like running a CB radio, I mean that's really all it is.

The polygon, then we also had to concern ourselves with bearings. And so Tibor had joined us by this time, he's been out there a while, and we were looking at ways of making inexpensive bearings. However, as we tried to look at where things would go, you're going to have to have higher and higher speeds. So we had Reno Castelli design us some polygons for varying speeds, and here's an air bearing unit that he designed, in which you have the rotor on an alumina shaft. And I remember asking him how do I clean that, he said simply just use a razor blade to scrape off the dirt; it will clean the alumina and sharpen the razor blade. [Laughter] So alumina is a nice thing, it's harder than steel. So it was very nice, there's no way you're going to ruin anything. This device was capable of running at 60,000 rpm; however, the amplifiers didn't want to do that because if you do the calculations, we would have been putting about 500 watts into the motor, and this poor little armature just couldn't cut that.

This is a, what we called a self-acting; you pressurize the end caps and the rest of it was self-acting: when it would come up and spin, laminar flow around the axle of the spinner would float it. This one was totally pressurized, and this was a grease bearing device that we used, so we designed three different bearing technologies to try and see how this would go. These were not intended to replace the cylinder lens, they were intended to be long-life, high speed versions of this. Above 20,000 or 25,000 rpm, ball bearings get into trouble. It's not because of the loads,

it's because the little balls are spinning so fast in the races, that they start to undergo self destruction, even though I think that's been helped a great deal by precision bearings. None of these designs ever made it into production. It was the ball bearing I think that you see there today. Fujitsu designed a printer that actually ran at 42,000 rpm, albeit with large amplifiers, but they got around this problem because they used helium environments to allow the Reynolds number to climb, so they wouldn't go turbulent flow around the axis of this thing. I don't know how many printers they built, I saw output from them, I've never seen the real printer. So I would guess keeping pressurized helium in one of these things was not the most inexpensive thing you could imagine.

This is the assembled unit here. Actually a very nice unit; you could put anything in here you wanted. Supposedly dry nitrogen was the best; we hooked it up to the house compressed air, that was available in the research center, and of course that was nice except it wasn't really all that clean. After a while it wouldn't go so fast -- there was oil, and junk, and everything else in there. So, this actually was a very good scanner but never made it into any product. Great study, however, as what makes this fly.

Here's a simple little drawing of how we were going to make this work. We were going to put the laser scanner on this copier; it had an image buffer and a computer -- see how complicated that diagram is, it would really sell today. But anyway, that was our model of how this would work. This is the same contraption with a small helium-neon laser. Bill Gunning suggested we buy a scanner from someone who could just make us a high-precision one; we could compare results. So we bought one from Speedring, in Detroit, and tested it for a while before other, less costly scanners came in and worked. I think I have a legacy with Newport Research, and Oriol Corporation -- we got all kinds of little mirrors mounted on a bed there to do that.

Here you can see one with the electro-optic modulator, the polygon spinning, nice bolts through everything, this is kind of built like a locomotive so there was no real problem here. To make things simpler we just had a microscope mounted on this thing and we could do experiments all day long. A couple of interesting problems arose. The correction cylinder lens was fairly close to the drum. And what happened is, little toner tornadoes would go around on this -- inside of this drum. That was kind of a dirty environment. If you ever opened up an early copying machine, chunks of black stuff fell out. I mean it was really kind of a dirty environment in there. It so happened that the toner would deposit itself in little particles on the lenses, and the laser beam was not moving through the same zone of the cylinder, even though it was aligned on the drum it was moving through different zones of the cylinder due to the facets being slightly different. Which meant you got wonderful little blank-out patterns where the beam would move up and hit a toner particle and back out and not be occulted again by that. So you're having little eclipses going on back and forth as this thing went on and off across the lens surface. So we redesigned the optics, moved the cylinder two or three inches away, and got away from the toner tornadoes to affect us.

This is the console, really sophisticated electronics. 32 kilobyte Nova 800 computer, sitting over here is a disk drive that had 2.2 megabyte capacity, had a head-per-track, I don't remember who made it, Bill probably would remember. But it was capable of providing us the data rates we needed to test this. So, here was the copier control, here, and the amplifier, which was a Harmon-

Kardon two-phase stereo amp, to run the motor, and we'd load code from the tape here and of course 32 kilobyte, you can imagine -- today they don't even use that for cache. So, as you look at this, we could put this together -- here's the modulator controls, and it's like a space launch, I mean this was really great. You know, the shuttle is ready, the cable dropped away, and you'd make a print. [Laughter] It was hardly something automatic. I know my wife came in one day and said, "You can't just say 'print'?" [Laughter] I said "Please, go, go -- would you go away?"

[Q: What year is this?] This was about 1972. The first printer came up and ran in 1971. It was interesting, because the first year at PARC, it was wonderful, because John and Bill, we worked together and we had nothing but complete time to spend working on this. When it worked, I don't think the next year I got anything done, because we had these incoming jumbo jets full of Xerox executives who had to see this thing. Some of them, the very ones who didn't think it would work, coming in, so we had visitors like mad. We had often suggested maybe Jack Goldman should have built the research center in Hawaii -- we could call it HARC -- and the trouble is, Jack often said "If I'd have done that, we'd have never kept the Stamford, Connecticut people away, because they would come there for any reason."

So, this was the console, it did a lot of useful stuff. Bob Kowalski built all this up. And this brings us to the second little problem, which was synchronizing the laser beam. We had a detector which had two pieces to it. The logic was, the laser beam intensity could fluctuate slightly, and yet you had to turn this on in something like a thousandth of an inch. The beam's three thousandths in diameter. So the idea was, you'd go from one half to the other half with a slight separation between the detectors, and you would sense crossover. This was built on an emitter coupled logic basis, and here you can see on an oscilloscope the first half, the detector, the second half, and you would basically trigger right here at this point, and [it] actually ended up a wonderful little detector system.

The other thing is, is that the time of scan on this particular model of unit was not constant, because of the facet angles. And therefore we had to make a lock-in voltage control oscillator which would look at the previous scan to see how long it was, and adjust the frequency for the next scan. That actually worked not too bad, except for the fact that you were always measuring for the one that had just gone by, which meant that you were always one late on what you were trying to do. We even tried buffers which would store up all the facets, and then correct them in order, and that didn't work any better.

You can see the effect here of doing that. Here's the start of scan -- this is about 1972 pictures here, glad Kodak fixed these as well as they did -- here's the start of scan and you can see the end of scan and see the wiggling going on there. And we did a lot of chasing on that problem; finally discovered that it was geometry, not electronic or anything else.

Thank goodness for the Alto. Many of you, I'm sure, have seen that. This is one of the deluxe versions, you had 256 kilobytes of memory. Alan Kay to this day laughs about the flack he took for wasting 64 kilobytes for the bitmap display -- what a profligate use of memory! So this device was then rigged up to be able to print to the unit as well. A fellow by the name of Bob St. John built me some buffers. I think Ron Rider had come aboard at that time and was starting to

look at the electronics issue, and far as character generation, Alan Kay had, and I think Ben Law, had built a character generator, to try and go to the screen.

There's a page printed from that first character generator on the device, and [it] actually produced something intelligible that didn't have rips and tears, and the relays weren't causing the detectors to go bananas, so you actually got a complete sheet with all the stuff on it, and at that point in time we realized the technology at least -- it may not have been "man-rated" yet but it wasn't going to blow up on the pad. [Laughter] So that was at least nice.

Now, something happened at this point. [Inaudible comment from audience.] Yes, I'm sorry? When? This is about 1973. In 1973 PARC had hired wonderfully, and we I think had filled up Porter Drive ...

[ABOUT 5 SECONDS MISSING FROM VIDEOTAPE]

... building, whose name I can't remember any more, Building -- it wasn't Building 34, it was one down on [Comment: 33] -- 33, thanks, the Singer Building, and then up on the hill they had bought another building, Building 34 I think it was called. [Comment: That's the Singer Building.] That's the Singer Building, yes. It so happened that not -- the printer and the computer science part of what was going on couldn't fit in the same building. And therefore it was decided the computer science part should go up on the hill, in Building 34, and the printer work stay down on Porter Drive. The problem is, the bits are all coming out a kilometer away, and the printer's down here at the other end, so how do we get the data to this thing?

So, we sat down one time and said, "So why don't we make an optical link?" Because we looked at doing microwave, but those were only three megahertz, and you've got to get enough FCC permission to do that, even then. So the interesting thing is there are no communications regulations on through-the-air optical communications. As long as the beam power doesn't destroy things. [Laughter] We built something called a SLOT POLOS, which is the PARC On-Line Office System, Jeanie certainly would probably remember that, so SLOT POLOS On-Line Optical Link. And how do you do this?

Well, I went to my friends Edmund again -- I'll get free catalogs for the rest of my life [laughter] -- and basically bought four astronomical telescopes. These are just simple Newtonian reflectors. And put two in a box at the 3180 building, on the roof, and two on the roof of Building 34. I put a photomultiplier at the focus of one, and a laser at the focus of the other, and we had a full-duplex optical link running at 30 megabits a second. We used helium-neon for two reasons. First of all, relatively inexpensive -- acousto-optic modulators to turn it on and off. And by using visible light, there was only one risk: fog was a bad thing, because you couldn't see through fog. On the other hand, if you used infrared, you couldn't go through rain but you could go through fog. So, made a back-of-the-envelope judgment that rain was probably going to be more prevalent than fog, and went with the visible. It was a good choice, because I think we were only down one day due to fog, in the one year that this system was up.

What would happen is, and I'll show you another picture of it here, you can see -- here we are on the roof with the box, and there's Building 34, and of course Foothill Expressway runs along

here so we couldn't run cables. CalTrans wasn't too excited about us drilling under their freeway to lay wires, and you couldn't really dangle anything over them, so that's why this worked. There was another box, way up here on the roof of this building, you can almost see it there, and I think in the next one -- there's the box. Can't remember his name, it was a woodworker guy that built all this for me; you'd lift this hood up. And this of course had to be weatherproof. The biggest downfall of this thing, both these building had flat roofs. And the alignment between these devices had to be rather precise. And so what would happen is that we'd get rains and everything kind of tilt[ed] out, and Bob Kowalski and I bought some walkie-talkies, and I tell you the number of nights we were up there, going "Do I see it? Oo, there it went! There it went!" [Laughter] And we were trying to get this flash to go by so we could line up on the sensors again. Summertime, everything stayed in dead alignment; in the wintertime every other day this thing was going in and out of stuff. So, they sat on the roof, and the telescopes were setting up the throw to this thing, and if you look very carefully, right in here's a little red dot coming back at you from the other one.

So this was one kilometer between the two of these. It took six microseconds for the beam to make a round trip. And therefore the only downside of printing this way was, there was a one-inch margin on the print you couldn't get rid of. [Laughter] No way to speed that up. You could have put in another buffer, but, I mean, this is 1973, memory's still pretty expensive at this point in time.

At that point we decided that the technology looks stable enough, we should build a printer that serviced PARC. So we built something called EARS - Electronic Array Raster Scanner. Ron Rider was a big designer in that, built a very sophisticated character generator for this device, I think it would do 20,000 characters a second. It would even rotate one character in a word for you, doing a data stream, so it was, feed a data stream to this device, it would in real time generate the bits for you, and this particular device was used by over a hundred users, I think it was in service for four years, it made 20 billion prints -- 20 billion revolutions of the polygon, and this thing ran, and ran, and ran, and ran. I think what really sold a lot of Xerox executives is, they'd come out, and we were all using this thing to get our work done. It wasn't, "Oo, start it up, so-and-so's going to come out." We used this thing in our daily work.

At that point in time it was decided, "Why don't we make a simpler version of this device, so that we can propagate these machines around, not just one of them, kind of a Mount Olympus model of printing?" So that gave rise to something called Dover. John Ellenby named it that, and what we wanted was a fast printer for the masses. Same 7000 machine -- this thing really got its work cut out for it -- in fact, they were by this time off lease. No one was using 7000's any more so we could buy these things out of the warehouse for \$700. In fact, we proposed making a product based on this. There were 25,000 machines off lease at that point, and for something like a thousand or two thousand dollars you could completely refurbish this page-per-second machine. It was made like a Sherman tank, it would just never break down. To make a long story short, these machines ended being cut up for scrap in the Los Angeles warehouse and never saw the light of day as a product. Too bad.

So we built 35 of these things. You see a Dover [1 word missed] there, and I'll show you some of the things so you can come up later and take a look at it. Same 7000, but we got the ugly stuff

off of it. Fellow by the name of Gary Swager did a digital interface to this; we finally got rid of the clicking and clacking of the relays so we didn't have 58 little antennas all the time going off inside this machine.

You can see what the inside of this scanner looked like. These little rods are supposed to show what the light path is; this one shows what it looks like when you illuminate the rods. It's very fortuitous that light is a weakly interacting material; it can actually cross itself without causing deflection, which is really nice, because there was a lot of that going on here.

We also went on and built some other machines. This was a 3400 copier with a laser scanner built onto it, using a helium-cadmium laser -- one of the more ugly devices ever designed by mankind. Tons of noise, 42 percent beam intensity fluctuation in this particular laser. I think the lifetime was well over 50 hours on most of these things. [Laughter] And you'd better make sure you're ready to print, because it didn't have long to do it, once you turned it on. [Laughter]

Notice on most of these things we always retained the copying feature. The reason was, that's a smart thing to do in a company like Xerox. You know, if it copied, it still is [Laughter] Obviously it was a useful function, but this gave rise to the concept, what if we made printers which had copying capability with them? They would be called "multi-function". How could you go wrong? You want to print, you print; you want to copy, you copy. So this gave rise to a number of things, not the least of which was a modification to the 9200, which was by this point in time [a] just released machine, two pages per second, had a belt photo conductor, still blue sensitive, so we didn't have the red sensitivity any more. We decided that we'd modify this thing so that we could actually take the platen glass, where people copied, and you could have a rig which would swing onto the surface, and print through the copy lens.

[We] tried that, and it worked, but then went to a subsequent modification in which we decided we would wrap the optics around the base of the machine, and electrically insert mirrors in front of the copy lens when you want to make a copy. It was seven seconds: you pushed the button, you could make prints in seven seconds or push the button and you could make copies again. Ron Rider worked with this, a number of people -- Tibor did a tremendous mechanical design of getting this stuff in here. You can see, we put little boxes around here, so it would tend to look nice.

You can see how this thing all folded out and snapped together. So there was the RCA helium-cadmium laser, all kinds of brass stops to make sure that this thing aligned when you closed the doors, I think this is one of the more exciting things Tibor and the shop ever did was to build this particular rig. You can see a scan detector here, here's the motor which inserts mirrors in front of the copy lens. And when it was all done it looked like that. And indeed printed at two pages per second, and you could make copies at the same time.

Also, a key thing in these developments, we never changed the materials package in the copier. Same toner, same photo conductor, because it was understood this would be a useless expense to modify this materials package. Everyone else who worked on laser printers always had a special materials package, to work just with printing. So this was considered a "right, white" system --

you painted away all the charge that you wanted to get rid of. You didn't just write the areas that you wanted to have the toner stick to.

A product actually came out using copying and printing, it was called the 5700. I think there were probably, what, six sold, something like that. It wasn't just us: IBM had one called the 6670 Information Distributor. The nice thing about these devices is that we found out a lot about systems, because if you ever saw any one of these machines, there was one of two signs on it: "Please don't use me as a printer" or "Please don't use me as a copier." And therefore you could never trust that when somebody would walk up and say, "Oh, I'm just going to make copies." "No, no, don't do that -- I just sent some stuff to it." Or vice versa. And therefore, the concept of having a device which could both print and copy had an exciting but very short life, in all of this.

In 1976-77 Xerox introduced, using basically Ron Rider's character generation technology, and the optics and scanning systems devised at PARC, to produce something called the 9700. This was a 9200 machine with a scanning system built into it, which printed at two pages per second at 300 dots per inch. It was a cut sheet machine, eventually it was capable of printing duplex. The most significant feature -- remember the other machines introduced at this time, which were both by IBM and Siemens, had fanfold material going through them. The problem with fanfold is if you screw up on a page, you get the page. And you've got to burst it anyway, in fact 50% of all the failures that ever occurred in fanfold machines were bursting the paper. It didn't happen here. The other thing is, this machine was just fortuitously architected by the copier people, that you could completely write the image on the photo conductor before you had to commit to the sheet of paper. And therefore if you made a fault, you could just hold the sheet and rewrite the photo conductor. Hence you never had to get bad output.

Since it was cut sheet, you could feed things in different orders, and you were able to print books. The biggest concern in this device was, it had to print 300,000 pages a month to break even. Early on, the laser failures were stupendous. I mean, they were air freighting these things in, these helium-cadmium lasers. They finally switched to argon, which would have been the better choice in the beginning anyway. Argon is much more complicated than cadmium. It just works. It isn't how simple it is, it's how simple it is when it works. I often think of internal combustion engines -- have tons of stuff going on inside. From a beginning standpoint you'd say "Why would anyone ever build anything like that?" Well, but it does work. And that's key.

So when this device -- they finally got those problems fixed, and the average monthly print volume was one and a half million prints.

[PORTION MISSING FROM AUDIO TAPE]

Anyway, to get them on the hook, and this device eventually went to 600 dots per inch; went to 135 pages per minute. This is an interesting chart -- you may not be able to see it very clearly. But it shows what happens to the printer bandwidth if you go to four pages per second and 500 dots per inch, you're up to 100 megabits per second. Today people are running routinely, in the higher speed machines, at 50 to 60 megabits per second.

This is a picture of the 9700 sitting in its full glory. It's now been retired. It's 22 years old. Amazing, I can't believe this product is 22 years old already. Currently, probably the best example of this is the DocuTech machine today, 135 pages per minute at 600 spots per inch. It's just like printing off anything you'd want, duplex, 11 by 17, folding, and in fact, these do come in color versions.

You can come up and take a look at these afterwards if you want. It's not a commercial for Xerox, but nevertheless, this is a 40 page per minute color printer, running at 400 dots per inch. You can come up and take a look at this. This is tremendous output. So 40 pages per minute, in color. Here's a booklet done on this device, stapled, finished at the output, from the Triple A. Printed in real time, they can customize them for you. So, what's exciting is the vision we had, at the time we started this was, electronic printing at where you are. And indeed that has come to a realization.

Let me turn this off and show you one thing. Because today when you hear people talk about, can't do that with a flat panel because it's too expensive, I look at that. The 9700 production cost of the scanner was about \$5,000. This is from an eight page per minute laser printer today: the polygon, diode laser -- no modulator now, you just modulate the diode -- some glass optics, plastic holder, a mirror, a scan detector. You can come up and take a look at this. What do you think this costs? Thirty eight dollars, complete. [Laughter] Now, if any one of us, in PARC, had suggested to Xerox management that it would ever get to \$38, we would have been cashiered at that point because we would have clearly, our senses would have left us. I would never have been so bold as to suggest this would get to \$38. Maybe the polygon [would] get to \$38. They make these by the, 25-30,000 a month. The polygons are \$6, including motor. It has roughly, except for eight pages per minute, it's got all the performance the original scanner ever did. So you can see, a little hard work takes you a long ways, and to me the exciting thing is, you can't imagine enough, even for technologists. When we think we're on the edge, we're not on the edge. We tend to set our own limits, because we're afraid people won't believe us. And so, as I look at things like this, I think I was one of the luckiest people on earth, to have a chance to work on this. And I certainly want to thank Bill, and John, and so many of the others who helped me in all of this. And coming to the west coast, I can't imagine I even contemplated was this a good career move. [Laughter]

I'll tell you one other interesting story. Dave Kearns, who was CEO of Xerox, came out to visit us on our tenth anniversary. I told him, I said "You know, Dave, when I came to Xerox PARC, I had some people whispering in my ears, saying 'Dangerous move. They might close this place. Xerox is prone to do that, and you'd be left on the west coast.' And I said, 'Some fate!'" [Laughter]

So anyway, thank you very much for coming, I'll entertain questions if you have any. [Applause]

Q. Are you still working on laser printing? Are you following the work of...

A. I follow the laser printer work, but it's now basically just taken off en masse, and when I thought, I mean out of the 30 or 40 patents that I had, I thought we had completely wrapped the optical system, there was no more to do. Every month I see 15 - 20 patents. People coming out,

they put the lens this way, put the lens that way, so there is no end to how you can innovate on that.

Q. I was wondering if you're following what they call digital paper, or virtual paper?

A. Oh yes, sure, absolutely, [inaudible comment] and I'm just very excited about what can be done, because, why not eliminate that? And to argue that it can't be done is silly, because you cannot believe the studied arguments that were presented on why this will never work. Unfortunately I didn't know that, so....

Q. One of the things I remember, and maybe you could comment on this, there was an early machine, I think was based on the 3400, that had a microprocessor controlling it. I believe it was a 6800 microprocessor. And one of the dangers of this machine, which was outside of my office, was that if the microprocessor failed while the paper was in the fixer, it would catch on fire, and there was a fire extinguisher that was specially built to spray on the thing when it happened.

A. Yes. Well, yeah, there was a machine called the 3600 model 3. I showed you the [model] 1, and the 7000. There was a 3600 model 3 that was capable of printing pictures. Now, that might sound silly to us today, but it was impossible to print pictures in the early days of xerographic imaging, because we didn't know how to get toner to stick to large areas, or how to do it in a production sense. So this machine was built with a special system to do that, and to make the copy quality so high that it fed the print past a very bright light to fuse it. Trouble is, certain times the copy would catch, or curl, and go up in the lamp house, which caught the copy on fire. So there was a smoke detector that looked down the axis of the lamp house, and would turn on the CO2 extinguisher to blow the fire out. So far, so good.

Trouble, one problem. The buzzer would sound when you had a fire, the key operator would open the doors. When you open the doors, Underwriters Labs requires you to shut down the power, and the fire extinguisher went off. [Laughter] And the machine started up again, and so that time, you closed the doors, it has to go through a warm-up cycle before the power is applied again, and there was some of them that got smoked. So the usual rule was, if you hear the buzzer, wait until the hissing stops, don't open the doors. What they did was to rewire the machines to fix it. But there's a case of intentions gone awry. We elected never to touch that machine with a laser printer. So actually that went into history as only a copier, so that's what you remembered.

Q. I used to work at Xerox, I used to [inaudible], basically 4500s and 6500s, did you have anything to do with those boxes?

A. Well, I had worked on the scanners, it's always questionable whether one should admit to having had a chance to work on those. The 6500 was Xerox's early attempt to do color, actually a very brave reachout, and a remarkable concept to do full color copying in 1975. The trouble is, the machine was quite unreliable. It had 99 -- you could actually make 99 copies; I don't know anyone who ever got past nine without a problem. So we made some digital printers based on that, and it was a good way to clear our ideas on how it was working, and I actually tried very hard. But it was a good idea that just wasn't quite ready. Today the secret is, merging microprocessor technology with the xerographic process has taken all the wrinkles out of the

system. So, those were the days of electromechanical solutions. Now today we use electronic solutions and that's the difference. If you ever go inside a Canon color copier and turn off the microprocessors, it looks like a 6500 coming out.

Q. You mentioned color, it's interesting -- in 1966, when I interviewed with Xerox, in [placename inaudible] they said they were working on color. That was '66. You mentioned '75. What was the first working model of color copier?

A. That was 1975, it was called the Epic machine. But there was always work going on inside. The question was, how do you wire this into it? And basically they took a 914 and just stuffed it full of three-color housings -- cyan, magenta and yellow developer, and made the first color copier that way.

Q. So it took them another nine years.

A. Yeah, well, it was difficult, because you had to develop the toners, you had to learn how to fuse them, you had to learn how to make them mix correctly, and, remember, picking colorance was very difficult in the 1960's. You had no computers to do this with. So you had to take all the CIE numbers and multiply them long hand, or if you were so lucky, you had a Marchand calculator -- zzz, zzz, zzz, zzz, zzz and there's one number. This could take you days to get through a filter design. So it was a lot of time, and then you'd have to find out that didn't work, you'd do another one. [They] used to have rows of people: Senior Filter Calculator, and Junior Filter Calculator, and all that kind of stuff. [Laughter]

Q. Where did the XGP fit in history?

A. The XGP was the print end of an LDX, with a higher performance CRT in it, in an attempt to try and make a printer out of that. And there was a special design, I think Jim Rees did it in fact, with some light pipes, to try and capture twice as much light, and help it a little bit. But when you're within a factor of two of burning out, there's not much you can do. I will say, there was one model of thing I didn't mention, but since you've raised the question, it was called the Allegro Project. This was a stroke driven CRT, of which the intent was to draw the characters on the face of the CRT. Since you didn't have to rasterize, you could get the brightness way up, and these were running very bright CRTs. The trouble is, I had my two or three person crew, and John was supporting us, and they had 30 people on their project in Rochester. So, how do you decide which one to use? So I decided to invoke a contest: we'll agree on a certain set of prints we have to make, and one of them was graph paper. Well, try and get an electron beam make a right angle. And I mean, magnetize your watch on the way around the corner! [Laughter] So, it didn't work, and they could not pass muster on graph paper, and the thing fell out of favor, and the laser scanner got the nod to go ahead.

Q. In your describing all these wonderful machines that came out of Xerox, you didn't mention the thing that I remember as, 123321 and the 720.

A. The 123321 never actually made it to product. This was a machine that was intended to reduce copy down onto an electronic accounting machine card. So it was 3-to-1 reduction to

make your card, so you could literally file the card with punchouts, and then put the image back in and blow it back up. It was quite good but it was ever only a prototype. The toner was small, and it never worked. [Inaudible] as a product, it was not ... [Comment: You were trying to sell it to us!] Oh yeah, right. [Laughter] Why should that stop them?

Q. What about the 720?

A. The 720 was just a double-speed 914. Putting a faster pulley in, that's all it was. And then there was a 1440, by the way, in which they put an even smaller pulley in. But after a while, you just can't go bang bang bang bang with the scan line only so often, and then that didn't work.

Q. I remember our experience with the 720 was that [it had] a far superior image to the 914.

A. Well, you have to understand the 914 was built on a shoestring. Joe Wilson literally bet his entire personal wealth on getting that product out. Every firm you can imagine -- marketing firm -- IBM, Kodak, 3M, all said this is a dumb idea. And Joe said -- I remember he told us the story -- he said, "I sat in my house one night and said 'I think they're all wrong. I'm going to go ahead with this.'" And so the 914 was basically what they could afford to do, and the 720 then was a polish up on that. You learned by doing. And so the 720 was a cleaned up version of that.

Q. This is more a comment than a question. It wasn't clear from your slide that the EARS [Electronic Array Raster Scanner] which we had in the early to mid '70's was actually a 500 dot per inch machine, [A: Thanks for mentioning that.] and I was finishing up my thesis at Stanford at the time, and my hardest problem with one of my readers, who was a statistician, was giving him this stuff that looked like it had been Xerox-copied out of textbooks, and say, "Ignore the form, look at the content, which is junk!" Because it was so pretty; nobody had ever seen this stuff.

A. That's right, we did do 500 dots per inch at a page a second, and that was at Bill Gunning's insistence, because the 9700 was 300 dots per inch, and we were able to relax the mechanicals back to a less demanding situation. But 500 dots per inch -- the other thing was getting enough memory to drive this thing, so we were reading from a disk and going to a FIFO buffer. Because you couldn't get 500 dots per inch density for a full page of stuff. You couldn't -- the memory would fill a room.

Q. I thought the Dovers ran at like 384.

A. They did. And there were some other things that -- that was another situation as well. Yep. Dovers were reduced, and that was because of the issue of the Alto. The Alto couldn't push 500 dot per inch data rates.

Q. As you probably know, there was a much earlier computer printer based on the Xerox 914, done at MIT Lincoln Lab. That probably would have made a pretty good product, if Xerox could have been convinced to manufacture it. I don't know if the word of that ever got anywhere within the management.

A. Sure. The problem was is that the way products were designed in those days, it was copy volume that drove the product, and 914s were way too slow, seven pages per minute. And you say, “What makes personal printers so useful then?” The reason is, it’s consumables. If you were to pour the toner in a laser writer with a bottle, you could save a lot of money. Except on dry cleaning. And therefore, people elected to spend the money on the cartridge; it’s probably three times as expensive to use a cartridge, but you don’t care, because you want a clean hands operation. In those days that was not understood, and it was copy volume that won over. Remember, the 9700 was shown on a business plan not to be useful until you could cross 300,000 a month. [The] 914, if you ran 24 hours a day, you couldn’t make that many.

Q. Incidentally, that printer shared with your later product the tendency to catch fire and burn; they initially had a fire extinguisher next to it. It used it up very quickly, and switched to having an output paper tray that was made out of metal, with a lid that you could put on and just let it burn itself out. [Laughter]

A. Yeah, that’s right. The fuser was a radiant fuser, as it was called. That was the technical name for it, actually referred to as a pizza oven by those of us who had to actually use the thing. And this thing would come up and glow, and God forbid the paper stopped in there, it was poof! and it was gone.

Q. One of the reasons it was called a pizza oven was the earlier flat plate camera at Xerox, we actually heated pizza in it. [Laughter]

A. I never knew that! That’s great!

Q. One comment about the 5700. I worked on the 5700 for a couple of years with Ron Rider. One of the things that was fairly innovative about the 5700 was the use of the Alto bitmap display for the entire user interface at a copier, and that was one of the things that Kearns just adored about it, and there was this huge war inside of Xerox, against the electromechanical twisting knobs type guys back in Rochester. That’s one of the reasons why, when the 5700 died, it was like it got killed by politics because of them. And the DocuTech system, also, there was a first beginning where we used to use color for the user interface, and all the shading on the buttons and all that, and all the ergonomic things. There was another successor product to the 5700; they were codenamed Xenia Verde, and they were mostly these card reader things with all those weird IBM magnetic strip cards and all that. We used to use the printer quite a bit in El Segundo with Rider and company, but it was more of a political product that it was a market driven product, because it was against that IBM product, and they felt they were really going to lose huge market share, even though there was an enormous amount of work done on paneling halftones, and integration of halftone imagery and all those other things.

A. Yes, it’s an interesting story because today, people still talk about multi-function. You can see them today, in ink-jet or laser form. There are still the same system issues. I mean, they can give you the functions, but what do I do when I’m trying to receive a fax and I was just trying to make a copy? Well, you’ve got to put in a lot of control logic to say, please hold the call, or buffer the data, or something. So that’s still a problem today, on the system handling of all of this. It hasn’t

really hurt the sales, perhaps, all that much, but it's by no means a runaway success. If you read the Multi-Function Printer Report every month, as I do, you'll find out it's still a good idea, trying to find -- it's a solution in search of a problem.

Q. It seems that it would be more appropriate in a single-user sort of situation, because you're less likely to be trying to do multiple things. [A: That's true.] Is that positioned so it could be like a consumer product?

A. Now, it is, however there are ways to do multi-function. For example, if you take a Canon 500, or a Xerox Splash machine, you hook them to a Fiery [Electronics For Imaging - EFI] controller. The Fiery controller will spool the data stream, rasterize the images while you're making copies, so you can just interrupt it and do that. So what you have to do is have a sophisticated controller that doesn't push the people who are trying to send data off the net and say, "Excuse me, I'm not available right now for some reason." It just takes their data, and for all they know, things are getting done. And so it basically acts as a buffer, and that's been a successful characteristic of those devices. But those are \$30,000 boxes, and so that's a little out of my personal range. But you're right, that's a good point.

Q: Who was the [inaudible]?

A: Well, it's interesting, because in those days it was perceived that Kodak and IBM were the two key competitors we had to worry about. IBM introduced the 3800 in July of 1975, it was a wonderful machine, but it was basically a line printer replacement. It did 180 by 144 dots per inch, which was good enough for a line printer, but it wasn't the 300 dot per inch square that the 9700 did. So we worried a lot, I certainly did, about what IBM was doing. Unbeknown to me, I had two neighbors working on the 3800, and unbeknown to them, I was working on that. We later laughed at barbecues about all the sweat that we had. But, guess what? The one person we didn't pay attention to, and no one would have guessed, was Hewlett Packard, who's the big kahuna in printer volume at this point in time. And so, while we were all watching each other, up a little farther on Hillview, some people were getting some bright ideas on working with Canon. I think it's remarkable, in the history of this thing, that an instrument company ends up dominating in the -- I don't know quite where you'll cut it, but say 20 pages and below. They own two thirds of the market. So we worried about the wrong people. I mean, IBM got out of the business, formed Lexmark which is doing okay. Now IBM looks like they're getting back in. But, you don't get to pass Go, you go to Jail, and you get to start back up the hill again on that one.

I really appreciate everyone turning out. This was, I say, more fun that I'd ever be able to imagine. [Applause]

If you want to see a technology revolution, there's some up here on the table.

END OF TAPE

Transcribed by John Amos, a volunteer for The Computer Museum History Center
San Antonio, Texas January, 1999.