Developing the Laser Printer

Gary Starkweather

Inventors usually realize that any good idea owes some debt to earlier technological developments. The laser printer is no exception. In 1938, Chester Carlson, a struggling patent attorney, needed a way to copy patents other than by hand. That led him to develop a technology now known as "xerography" from which the company Xerox was born. The word xerography comes from the Greek words "xeros" and "graphein" which mean respectively "dry" and "writing." The laser printer, as we now know it, depends on this wonderful imaging capability.

Xerox introduced the first real copier in 1959 and called it the "914," with the number standing for the largest paper the machine could copy. Despite warnings by "market experts" to the contrary, the 914 became one of the most profitable products ever produced in the Western world. Xerox started developing many different kinds of imaging machines. One of the most interesting and advanced for its time was a limited-volume product called LDX for Long Distance Xerography.

As a young engineer coming to Xerox in 1964, one of the challenges the author was given was to see if the LDX system could be made faster. The LDX system as built in the middle 1960s was a design with limited extensibility. A line scan cathode ray tube (CRT) was used with an imaging lens to scan an original document. The light was picked up by a light sensor and sent over a 56-kilobaud (kBd) line to a receiver at a location perhaps hundreds of miles away. This sort of bandwidth was not readily available but could be purchased if needed. The receiving station also had a line scan CRT whose beam was modulated to generate a variable-intensity light signal that a lens imaged to expose a xerographic drum similar to that used in a copier. The problem was that the CRT used for exposure was pushed hard to get enough light output. It took many seconds to print a document, and there was a real desire to go much faster. The immediate challenge was to find a better way.

Being a graduate student at the University of Rochester Institute of Optics, the author was using a new light source: the helium–neon (He–Ne) laser, invented in 1961. Its main advantage was its brightness or radiance. Because the laser beam was highly confined rather than a Lambertian radiator, its radiance was thousands of times higher than the CRT. The red beam was a concern for current photoreceptors in the copiers, but as a bright, deflectable light source, it had no peer. The author set about to see what might be done with the laser as an illuminator for the print and perhaps even the scan station.

A key advantage of the CRT was the fact that magnetic or electrostatic fields could deflect the electron beam on the screen. Laser beams, as someone has described them, are "stiff" and so they need something to deflect them. The only practical solution was putting several mirror facets on a rotating disk. Using 10 to 20 or more facets greatly reduced the required rotational speed. However, the mirror facets and rotational axis had to be kept within a very few arc seconds of each other while rotating at several thousand revolutions per minute. This is an exceedingly difficult requirement for a cost-effective commercial product. The author built a laser facsimile prototype with a modified 914 (720 series) copier to scan an original and print the results. His skilled colleague Robert Kowalski built electronics generating about 1000 V to drive a special Pockels-cell beam modulator. Switching 1000 V in a small fraction of a microsecond even with a small capacitance was not trivial.

The two researchers clamped, taped, and otherwise assembled a scan and print breadboard to the 720 copier with a special red-sensitive drum and made some laser fax copies in 1968–1969.

The lack of precision in the scanning mirror left bands in the images, but the demonstration showed what a laser system could do. However, a way had to be found to make a precise scanner without spending $20,000 each.

After thinking about the precision requirements for several days, the author came upon an idea while sketching the problem on a piece of paper. It looked as though a cylinder lens would solve the problem. If it would, it was puzzling why no one else had discovered it. A 12-in. (30.48-cm)-long cylinder lens was ordered, which arrived the next day by air. What was the result? Eureka! It solved the scanner problem. A scanner with perhaps 1 or 2 arc min of error could perform a task that would have required 1 arc sec precision. The scanner was now going to be very inexpensive. Today, such a simple six-sided polygon and motor system for a personal laser printer costs less than $5–$10.

About this time, the author began to wonder about an idea after talking with a couple of other people. Why not forget the input scanner and use a computer to generate the signal patterns for a print station only?

Up to this time, every part the author and Robert Kowalski had used was already part of their laboratory equipment since no spending on this effort was permitted. Furthermore, about this time a more serious, non-technical issue arose.

The author's immediate manager got wind of his idea and stated in no uncertain terms that this was a bad idea and that he wanted all work on it stopped. This was the beginning of a real challenge: To continue the project or let it go? The author decided to continue working on it less obviously. The situation was heading to a real confrontation when, one day in early 1970, the author read in the company newsletter about a new research center being started in Palo Alto, California. He called one person he knew in the starting group to ask how to tell them about the project and described what was being worked on. They decided to fly the author out to California to make a case for the new printer technology.

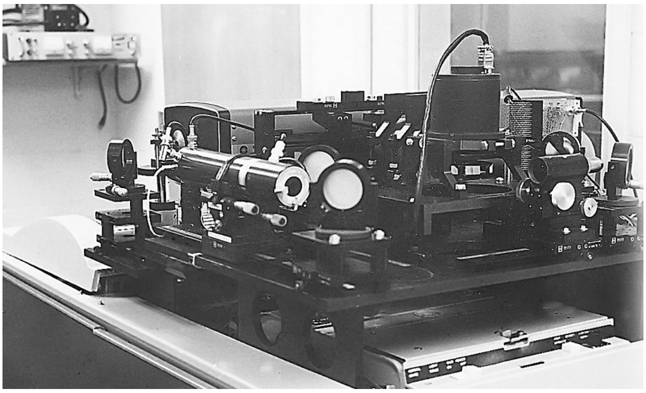
The trip was a rousing success. A group also becoming part of the new Palo Alto Research Center (PARC) was working on a personal computer that "bit-mapped" text and graphics onto a display much like today's Macs and PCs. They needed a way to render their pixel-oriented screen image to paper. The new laser printer was a natural fit to their needs. They were willing to take the author into their organization, but there was one "problem": management in Rochester would have to approve a transfer. The author promised to find a way to get this done.

Upon the author's return to Rochester, his manager refused to permit the transfer to PARC. Technically, this was a violation of company policy. After some stressful discussions the author took the issue to a more senior level. Eventually, after some tense but productive discussions, George White, an energetic and future-oriented Xerox vice president, approved the transfer to PARC, and the author moved his young family to California in early January of 1971. Thus began work in earnest on the laser printer.

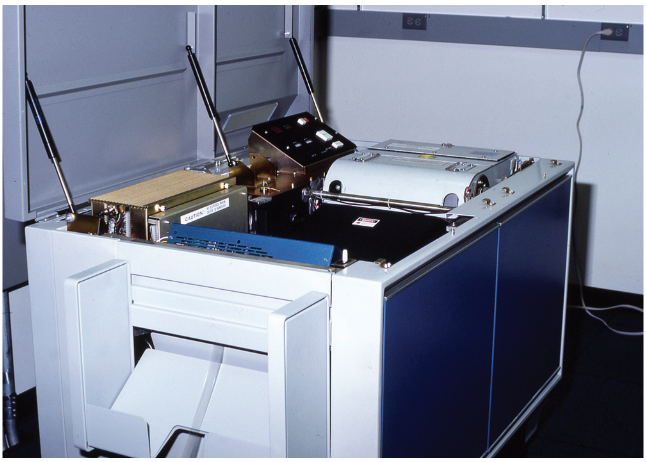
Spearheaded by the visionary genius of Jack Goldman, PARC was a great place to build this machine as well as being a font of other great technologies. The invaluable Bob Kowalski from the Webster, New York, Xerox facilities was hired. John Urbach, now deceased, provided a lot of encouragement as well as financial support. He reported to one of the best managers and mentors anyone could have, Bill Gunning, who helped the author set realistic and important goals for the first printer and provided very wise counsel.

The group decided to build a prototype that would print at one page per second and at a spatial density of 500 laser points per inch in both the fast and slow scan directions. A solution to the poor red sensitivity of standard Xerox photoreceptors emerged from a major optical system design error in the Xerox 7000 duplicator that did not show up until early production. The only practical way to remedy this optical system problem was to replace the usual blue–green-sensitive photoreceptor with one more sensitive in the red part of the spectrum on the drum of the 7000. This error was a truly fortuitous event allowing the laser printer work to proceed. It is unlikely that the printer would have had the necessary backing if it alone had required a special photoreceptor.

The Xerox 7000 with the red-sensitive drum was going to be used to print one page per second using a He–Ne laser. This meant generating at least 20 million points per second from the scanner. The



▲ **Fig. 1.** First PARC prototype laser printer.



▲ **Fig. 2.** Dover printer with covers open.

scanner was more than capable of doing this, and the author designed an optical system that would scan a 60–75 μm spot across an 11-in. page in under 200 μs. Bob Kowalski and others began building a test-pattern generator that would produce grid patterns and some character forms that would drive the laser modulator at the required data rate. The actual operational data rate was closer to 30 Mb/s due to scan inefficiencies and other factors in the prototype.

In November 1971, after putting together the prototype shown in Fig. 1, the group was able to print grid patterns and some simple text lines at one page/s.

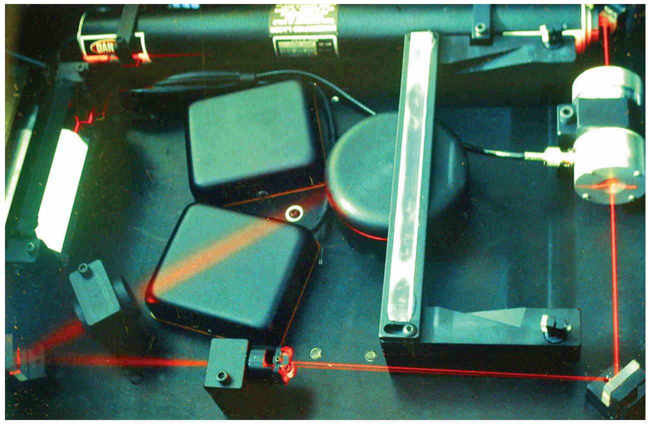
The results were exciting. There were some competing efforts using other technologies for computer printing, but the laser printer won out as it used what George White liked to call "zero dimensional" imaging. When you print with points, you can print any arbitrary pattern at quality levels the technology will permit. No more fixed letter formats as in a typewriter or line printer. Alan Kay and others built an experimental character generator to drive the prototype printer through a cable running from the character generator in the computer science lab to the laser printer lab because the character generator also had other uses.

PARC's expansion as the prototype was developed further created another problem. The computer science lab was moved to a newly acquired building half a mile away, and with a freeway in between, no cable could be run directly between the character generator (CG) and laser printer. How could the system be tested in the next one to two years before the group was all back together again in the new PARC facility on Coyote Hill Road? Fortunately, there was a clear line of sight between the two buildings. Four 8-in. astronomical telescopes were bought, and two were placed in weatherized boxes on the roof of one building and two on the other. That way, a modulated He–Ne laser at each end sent signals between the laser printer and the CG. For over a year the printer sent the start of the scan signals to the CG and the CG sent us data back in synchronism with the critical start of the scan signal from the printer. A 6-μs delay in the light travel time yielded a 1-in. (2.54 cm.) extra margin on the printed sheet, but that was quite tolerable for the development work. The group was back in business for the year they were apart. In California, rain actually cleared the air, and measurements of the path transmission efficiency showed improvements when it rained!

Once the group was back together in 1973, a new laser printer was built for general employee use at PARC, called EARS, for Electronic Array Raster Scanner. Ron Rider designed a hardware character generator remarkable for its speed and capability. Everyone with an Alto computer at PARC could have their documents printed on this machine at 1 page/s. Over the 15 to 18 months or so that it was in service, over four million pages were printed.

The next big step after EARS was to take advantage of the novel image generation capabilities of the Alto II computer and develop a 60-page/min. laser printer named Dover built on the same 7000 copier base in 1976–1977. Figure 2 shows a Dover printer with the top covers open.

Figure 3 shows the Dover laser head with the laser beam light path. This machine ran with a software image generator combined with a novel hardware board resident in the Alto computer itself. Data were printed at a spatial pixel density of 384 pixels/in. This permitted a much lower cost system, and 35 of these machines were built for selected users in conjunction with Electro Optical Systems in Pasadena.



▲ **Fig. 3.** Dover printer laser head.

The Dover printers had digital controls rather than the relay logic of the 7000, yielding a streamlined design and a reproducible configuration at a modest price for a machine with such novel capabilities. One of these machines can be seen in the new Computer History Museum in Mountain View, California.

In 1977, Xerox introduced the 9700 Electronic Printing System, which printed 2 pages/s at 300 pixels/inch. The paper supplies were big enough to permit over 40 minutes of printing without paper reloading, and the paper trays could be refilled while printing. Xerox management had hoped that these printers would generate at least 250,000 prints per month on average. In actuality, they averaged well over one million prints per month! Now that the technology has come down in cost, one can readily buy low-cost personal monochrome or color laser printers. Fast, high-end color laser printers now challenge traditional ink-on-paper printing technologies. In fact, digital copiers today are really a return to the original laser fax idea. Some things just seem to require time and patience to properly unfold.

It is hard to be thankful enough for the opportunity of working at Xerox and PARC in developing this technology. These were exciting times in a beautiful location. What was once a nearly career-limiting idea has become commonplace. A statement by Michelangelo is pertinent:

"I saw the angel in the marble, and I carved until I set him free."