Optimal Design of Desktop Photo Printing Systems

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Abstract

This paper will describe the process of designing a desktop photo printing system: printer, ink and media. We will compare recent technology trends in photo printers with respect to customer expectations for imaging system performance. We examine the three fundamental component processes of image printing: preparing the image for printing, putting drops on paper, and ink/media interaction. We discuss the key technology enablers of recent breakthroughs in desktop printing. We conclude that Thermal inkjet technology (TIJ) delivers the best desktop photo printing system technology today and the most promise for better customer printing experiences over the long term.

Introduction

Thermal inkjet technology (TIJ) has been the preferred method of inkjet printing since its market inception in 1985. Since then, TIJ has made rapid progress. It now challenges the print quality of electrophotography for plain paper text and graphics, and it rivals silver halide for photographic printing. It enables the highest price/performance ratios in digital printers. Its low overall system cost has helped to bring true photo printing to the desktop.

Nevertheless, competing inkjet technologies have emerged – most notably piezoelectric inkjet. While TIJ and piezo have both enjoyed market acceptance of their respective technology, TIJ technology continues to enjoy a greater unit market share for printers than any other digital printing technology and all other inkjet technologies combined.

Recently, a new class of home photographic printers has emerged. In combination with digital cameras, photo scanners, and imaging software, these products define a new market category called PC Photography [1]. At the same time, traditional desktop printer technology has seen intense focus on imaging for versatile printers. Recent versatile printing system improvements rival the photographic quality of dedicated photo printers on coated media while providing near photo quality on less expensive plain papers.

Consumer Expectations – Technology Choices

We have all witnessed a period of tremendous growth and change in digital printing. The Internet and Intranets have fundamentally changed the information available to people. Home computing is pervasive. Color is key in consumer communications, and imaging is possible - and in fact a requirement in many homes and businesses today. Printers are pervasive in the home.

This new opportunity brings with it changing consumer expectations. Photo printers and versatile printers offer a range of functionality that most never thought possible in low cost devices. At the same time, printer sales growth rates have slowed along with PC growth rates. What will be the next key growth driver? What will be the next great breakthrough? We believe it will be "the vastly improved printing experience." Our vision for what this looks like includes words like easy, fun, satisfying, cheaper, and task specific.

Desktop printing is a systems business. We create printers, but the entire printing system is what really delivers the end result to the consumer. If we deliver the right printing experience, people will print more. So how does this translate into technology choices and engineering decisions?

The engineering reality behind great printing experiences lies in driving fundamental change in component technologies and in effective packaging of those components to create printing systems matched to the intended application. For desktop printing, this means choosing print head, printer mechanism, ink, media, firmware, drivers and color management technologies to deliver brilliant image quality, high throughput, high reliability, low cost of ownership, ink and media flexibility and ease of use.

The recent competitive landscape for desktop image printers (both photo-dedicated and versatile) has been clouded by misleading claims. Some vendors would have us believe that reliance on a single metric, specifically spatial addressability or "dpi," somehow guarantees superior printing system performance. Of course, nothing could be further from the truth. This is evidenced by the fact that today's highest photographic image quality performance on the desktop is not found in the highest DPI printers. This holds true even for the competitors hiding behind the DPI label.

The truth is that system designers rely on a vast array of technology "knobs" for optimizing system performance. Pushing on just one of these without consideration of the others leads to system inefficiency and, ultimately, to customer dissatisfaction. For image printing, where traditional photographic quality attributes like graininess and color fidelity take on more importance than edge sharpness and font rendering, the increase in spatial resolution without an accompanying decrease in drop size leads to less than optimal system design. The stated resolution, in fact, overstates the "useful resolution" of the system by ignoring the effects of halftone noise and inefficiency for image printing.

As we will show in this paper, TIJ printers have a significant current and long-term advantage over piezo technology in the design of desktop printing systems. TIJ provides a broad technology portfolio with ink and media flexibility for more applications. TIJ allows for smaller drop ejection chambers and integration of electronics on silicon for higher nozzle counts and high firing frequencies. (More nozzles provide higher speed at lower cost.) TIJ enables higher quality by allowing smaller drops to be placed with high accuracy for superb image quality on more media types. TIJ has less sensitivity to air in the ejection chamber, less tendency toward nozzle clogging, and lower system manufacturing cost for better, more reliable print head replacement programs.

Designing Complete Desktop Printing Systems

Optimal system design results from consideration of three essential processes: preparing the image for printing, putting ink on paper, and ink/media interaction.

Preparing the Image for Printing

Photographic image quality is achieved in a digital print when you either can't tell the difference or you prefer the digital print. The path toward this goal requires attention to traditional image reproduction attributes, specifically tone reproduction, color reproduction, process noise (granularity) and freedom from unwanted artifacts.

In a digital printing system, the finite number of native device states limits our control over tone and color reproduction. Isolated dots are sometimes visible. We would like to create a tone curve with equal spacing of levels in lightness. Unfortunately, the process of adding drops one at a time seldom results in smooth, linear, equal spacing of output levels. Our digital device states create discontinuities and non-uniformities within the color gamut. Halftone schemes designed to interpolate between directly printable colors introduce additional noise and graininess. Multiple printing passes are required to smooth out the effects of system artifacts such as banding.

To improve this part of the printing process, we need several things. We need more usable device states throughout the tonal reproduction range. We need high numbers of directly printable colors for control of color and tone reproduction and reduced granularity. We need non-visible dots. And we need precise drop positioning control, drop volume control, and ink/media dot gain control.

Putting Ink on Paper

This poses a fundamental system design question: How will we increase the number of colors per pixel and maintain low graininess and 'invisible' dots? We have three basic technology choices: high DPI binary printing with ultra-small drops, multiple dye concentrations for primary colors - some dark, some light – with multilayer dots, or multiple small dots per pixel - multilayer dots. The first approach has been successful in expensive systems such as those found in the graphic arts industry. But reliance on high DPI alone has not yielded cost-effective desktop photo printers.

Both of the other approaches have been successful in desktop printing. Hewlett-Packard and other manufacturers have succeeded in producing six-ink photo quality desktop systems [1]. These systems demonstrate Low grain throughout tone curve and true photo quality. Many consumers actually prefer the digital print. However, the systems have media & dry time limitations due to amount of ink required to create saturated colors. These systems tend to work well for their intended application: photo-dedicated imaging on special media.

More recently, TIJ technology has yielded the capability to use very small drops as fundamental building blocks of four-color desktop printing systems. In 1997, the leading systems from Hewlett-Packard printed with 10 picoliter drops. By layering up to eight drops of each primary and up to 16 total drops per pixel, these HP PhotoREt II systems create a rich palette of primary colors, lower halftoning requirements, less process noise, and more usable resolution. What's more, combinations of these small drops can be optimized for printing on different media. In 1998, we are seeing TIJ printers based on 8 picoliter drops. The piezo competition has managed to create systems with drops that are about 40% larger than the TIJ drops.

Ink/Media Interaction

The third component process of desktop printer design recognizes the vital role of ink selection and of ink/media interaction in the delivery of great printing experiences. Photo-dedicated printers must deliver media and ink sets that look like photos (accurate tone reproduction, pleasing color reproduction, low grain, uniform gloss and texture, high dynamic range) and act like photos (fade resistant, sleaveable, stackable, handleable). Recent third party testing of Hewlett-Packard PhotoSmart Photoprinter output shows that the prints have indoor fade characteristics equivalent to comparable silver halide photos. They excel in image quality and in image permanence.

While the use of specialized media is appropriate for PC Photography applications, versatile desktop printing systems must accommodate the needs of the roughly 94% of desktop printing that is done using commodity papers. This application places stringent demands on ink systems. The ink composition must be tuned to assure deep blacks, sharp edges, consistent colors, fast dry time, resistance to fading, and photo quality printing. Custom print modes adjust dot patterns for different applications on various media to deliver highest possible quality.

Key Technology Enablers

The challenge to deliver the "vastly improved printing experience" on the desktop, then, requires low cost printing systems that deliver fast throughput for text, graphics and images. These systems must produce high-quality image printing on a wide range of media and true photo quality on optimized media. As noted earlier, Hewlett-Packard introduced PhotoREt II technology in 1997 and enabled customers to begin to realize the promise of improved printing experiences. This fundamental leap forward in printing performance was enabled by several key technology breakthroughs: smaller drops for greater image quality, higher rates of colorant delivery for faster throughput, and greater nozzle packing density for lower system cost.

Small Drops

As explained earlier, the key image quality breakthrough results from the ability to print multiple layers of very small drops. The use of smaller drops in a four-color printing system enables higher print quality on all media types. It provides more usable device states throughout the tone range, higher numbers of directly printable colors for more precise control of color and tone reproduction and for reduced granularity, and tunable print modes for optimal delivery of colorant on a range of media. But the creation of small drop, four-color printing systems poses significant technical challenges that highlight fundamental differences between TIJ and piezoelectric printing technology.

Figure 1 demonstrates how TIJ works. A thin film resistor superheats less that 0.5% of the fluid in the chamber to form a gas bubble. This bubble rapidly expands (less than ten microseconds) and forces a drop to be ejected from the nozzle.

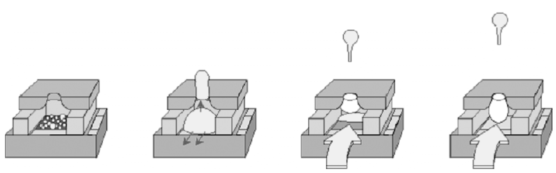


Figure 1. TIJ drop ejection sequence

TIJ print heads are constructed with materials and processes used in integrated circuits to produce the heater resistor, conductors, and some drive circuitry (in later models). The nozzle plates are made of plastic with laser-drilled openings, electro-formed metal, or etched silicon.

Figure 2 shows a typical piezoelectric inkjet print head. Ink is ejected through a similar nozzle arrangement as with

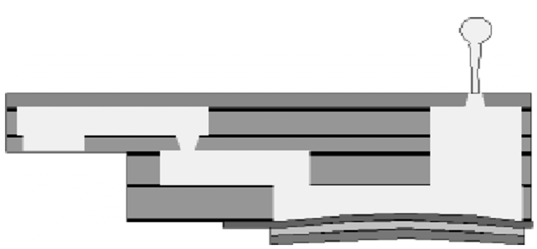


Figure 2. Cross-section of piezoelectric firing chamber

TIJ, except that the drop is formed by gradually reducing the volume in the chamber. This action is generated by applying voltage to one or more walls of the chamber being composed of a piezoelectric material. In striking contrast to the precise electro-photographic processes used in TIJ print head manufacturing, piezo systems rely on mechanical processes that make firing chamber miniaturization difficult to achieve.

Figure 3 demonstrates the fact that TIJ has consistently led piezo over time in the use of smaller drops.

Hewlett-Packard introduced TIJ products in 1997 with ten picoliter drops. Eight picoliter TIJ systems are announced for 1998. The smallest drop volume announced

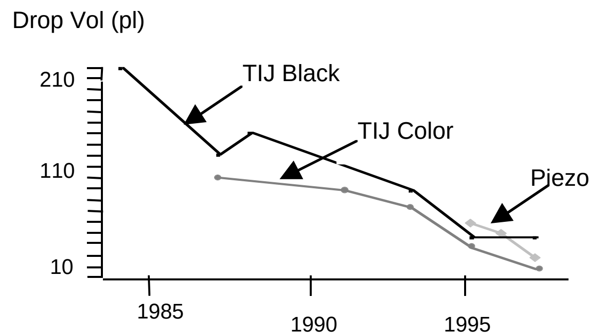


Figure 3. Evolution of inkjet drop volumes

by desktop printer manufacturers with piezo technology is advertised to deliver eleven picoliter drops.

A primary reason TIJ has enjoyed this leadership is the ability to scale down the firing chamber geometry with integrated circuit technology. Figure 4 illustrates the merging of integrated circuit and TIJ technologies. The power of this technology integration will continue to show its value as chamber sizes continue to shrink in the future. Piezo may be able to eventually achieve the smaller drop volumes required, but the author firmly believes that TIJ will continue to lead the technology in this important issue until such time as there is no need for further reduction.

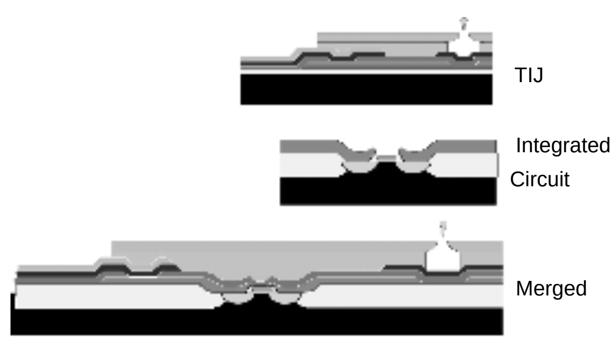


Figure 4. Merging TIJ and integrated circuit technology

Figure 5 shows a reduction in heater resistor and ink channel geometry on two TIJ printheads. This reduction is necessary for reduced drop volumes. Unlike piezo systems, TIJ technology benefits from the use of standard photolithographic processes for the definition of firing chamber geometries. Note that further scaling is possible without violating established integrated circuit design rules.

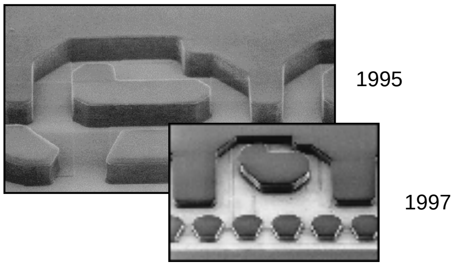


Figure 5. TIJ firing chamber size reduction

High Rate of Colorant Delivery

A natural benefit of reducing drop volume is an increase in firing frequency. As the firing chamber is scaled down, each drop requires less energy. Since TIJ systems can use simple "square wave" drive pulses, higher frequency firing is more easily controlled than in piezo systems that require complex pulse shaping to drive drop ejection. With TIJ technology, many nozzles may be added to an existing design without adding electrical connections to the printer. The power of this electronic integration will become even more important in the future as higher frequencies are required.

TIJ has also been leading the way in nozzle count per printhead. Figure 6 shows a comparison of TIJ and piezo by examining current products on the market. The nozzle count is multiplied by operating frequency to determine rate of colorant delivery.

Total K Drops/Second [K(f x n) + Color(f x n)]

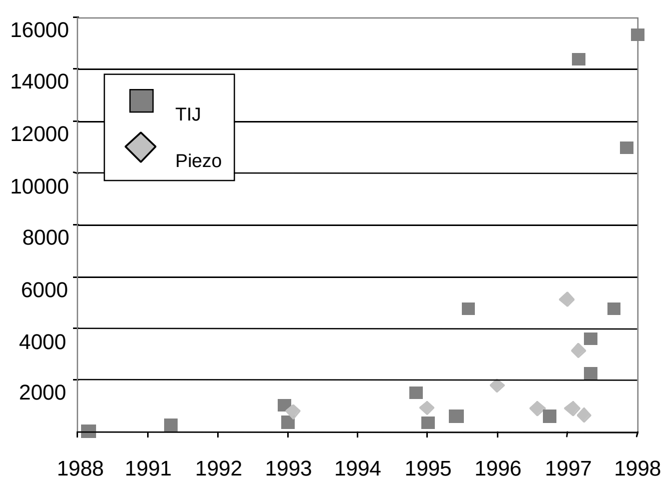
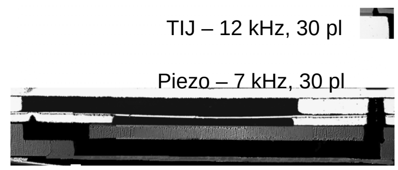


Figure 6. TIJ vs. piezo print engine performance – K Drops per second capability

In addition to high nozzle count and high operating frequency, single pass resolution is a key determinant of print speed. Single pass resolution is defined as the DPI (in the paper advance axis) that the print engine can achieve in a single pass. In desktop printing, TIJ is the leader at 600 DPI, with piezo at 185 DPI. In other words, the leading piezo printer requires more than three physical passes of the printhead to achieve the resolution of the leading TIJ printer. Figure 7 shows actual firing chamber cross-sections of the leading TIJ and piezo printers. This figure reveals the much larger chamber volume and cross-sectional area required by piezo. Both of these printheads shoot approximately 30 picoliter drops. TIJ can approach a chamber to drop volume ratio of 2:1, over an order of magnitude better than piezo. This packing density advantage will be even more important in the future.

Print Engine Cost per Unit Throughput



Piezo chamber length = 19 X TIJ
Piezo face area = 248 X TIJ

Figure 7. TIJ vs. piezo: actual firing chamber cross sections

In this paper, we have argued that the challenge to deliver the "vastly improved printing experience" on the desktop requires fast throughput for text, graphics and images, high-quality image printing on a wide range of media and true photo quality on optimized media. We have shown that dramatic progress in printing performance has been enabled by breakthroughs in drop size, in the rate of colorant delivery, and in the number and packing density of nozzles on each printhead. The true current and long-term superiority of TIJ technology is seen in one final attribute: lower print engine cost per unit throughput.

TIJ printers make extensive use of integrated circuit technology to reduce system costs. This level of integration is not available in piezo systems. Drive electronics for temperature, dot timing, and positional control are all possible with integrated processes in a TIJ system. For a given overall system cost, this integration allows TIJ printers to have more "intelligence" in the print engine. For a given cost, TIJ systems can provide more total nozzles, higher nozzle packing density, lower drop volume and higher firing operating rates.

Much of the cost of adding nozzles for higher printer throughput comes from the electrical interconnects. This is especially true for those applications where several printheads are ganged together. As shown in Figure 8, TIJ has continually reduced the number of interconnects to the printer while adding nozzles.

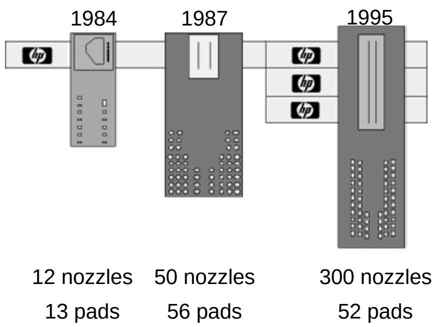


Figure 8. TIJ trends in printhead electronics integration

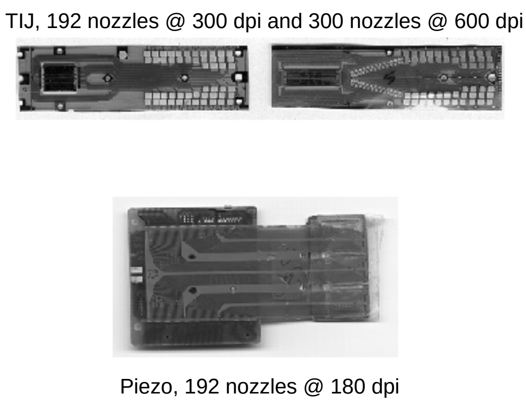


Figure 9. TIJ vs. piezo: relative packaging efficiency

This trend in efficiency is only possible when integrated circuit technology can be utilized. The monolithic integrated processes that have been developed by TIJ manufacturers demonstrate clear superiority for lower cost, higher performance systems. Figure 9 (to scale) illustrates this point.

Long Term Technology Advantages of TIJ

We have shown that today's desktop photo printing systems based on TIJ technology have superior performance on the key attributes required to enable the "vastly improved printing experience" for customers. These are ink performance, minimum deliverable colorant, rate of delivery of colorant, and print engine cost per unit throughput.

Technology trends for the foreseeable future will require even greater print engine performance at ever lower costs. Drop volumes will continue to decrease while operating speeds increase. Drop volumes smaller than two picoliters have been successfully jetted with experimental TIJ print engines in the lab. TIJ firing frequencies above 100 kHz have been achieved. Pigment-based black and color TIJ inks already show superior plain paper performance to those in piezo systems and rival laser quality for text and graphics. TIJ photo inks have permanence characteristics that challenge silver halide prints. Future TIJ ink systems will enable higher performance through faster dry times and better water and smear resistance. Finally, the trend toward higher levels of nozzle and electronic integration will enable wider arrays of nozzles, the use of redundant nozzles for error masking in single-pass printing, and higher throughput rates. All of these trends will make TIJ technology the clear leader for most desktop and many workgroup and commercial printing applications.

References

1. F. Bockman, IS&T's NIP 13: International Conference on Digital Printing Technologies, Seattle, 1997, pp. 670-674.