# A Thermal Ink-Jet Printing System Design Approaches Laser Performances

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## Introduction

In May of 1993 Hewlett Packard introduced the DeskJet 1200C. This product is the first ink-jet printer to deliver black printing quality and speed equivalent to mid-range office laser printers. Additionally this printer offers high quality color printing on plain paper several times faster than traditional ink-jet printers. This allows the customers for the first time to choose a color printer without having to sacrifice black quality and performance. This paper is a summary of the technical advances that allowed these capabilities to be delivered.

## Background

When Hewlett Packard introduced the PaintJet and DeskJet printers in 1987 and 1988 respectively customer expectations of personal printers were changed forever. Customers, through these products were learning to expect quiet operation, exceptional color, and low cost with good throughput in an affordable personal printer.

These two printers combined to provide a full featured printing solution in the aggregate. However several limitations of each printer kept it from being the single desktop product for all printing needs. The DeskJet delivered high quality plain paper text with industry leading speed in an affordable printer. There were still opportunities to improved print quality when printing on a variety of papers including the newly appearing recycled papers.

The PaintJet delivered high quality color at a breakthrough price but lacked plain paper capability and the 300 dpi text which the LaserJet family had made a minimum requirement for general purpose of office printers. The DeskJet 500C introduced in August 1991 added plain paper color capability to the product line. The 500C and the two pen 550C continued the march of ink-jet technology toward the mainstream office.

The design objectives for the DeskJet 1200C were set with the overriding goal to move color into the mainstream office market using ink-jet technology without sacrificing those features which customers had become accustomed to in laser printers.

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This resulted in the following specific objectives:

- Laser speed text (4+ pages per minute) (7 p.p.m. was ultimately achieved)
- Industry leading color quality on plain paper
- Fast color throughput (1-2 minutes per page in all cases)
- Color cost per copy better than any technology at any usage rate
- Desktop form factor (< 20 inches width)
- Improved transparency and glossy paper performance.
- Product cost less than or equal to laser printers of equivalent capability
- Ink supply sensing for network or batch print jobs.

Thermal Ink-Jet technology has been extensively exploited in the single user office market by several companies, most notably Hewlett Packard and Canon.

Thermal ink-jet printers have been capable of a maximum of two to three pages per minute for delivering text printing while electro-photographic printers (EP) have typically delivered four to ten pages per minute in the office market.

Several advances were necessary in order to move ink-jet into this class of performance. These advances were in the areas of resolution firing frequency, print modes, image/character processing, and ink design.

## Product History

Table I demonstrates a history of Hewlett Packard thermal ink-jet products, capabilities and availability dates.

## Print Quality Considerations

Several attributes of text characters combine in a set of complex interactions to determine the overall quality of the output as determined by the human eye. These are:

- Character hue and darkness
- Edge smoothness/roughness
- Character edge contrast
- Presence of artifacts
- Uniformity of area fills

**Character hue and darkness** are determined by the spectral response of the combination of the materials in the ink, the paper, and the physics of deposition and curing.

**Table I.**

| Product | Year of Intro | Resolution (d.p.i) | Number Nozzles per pen | # Pens | Text Speed (P.P.M.) | Color Graphics Speed (P.P.M.) |
|---|---|---|---|---|---|---|
| ThinkJet | 1984 | 96 | 12 | 1 | 2 | N.A. |
| PaintJet | 1987 | 180 | 30 | 2 | 2 | 0.3 |
| DeskJet | 1988 | 300 | 50 | 1 | 2-3 | N.A. |
| DeskJet 500C | 1991 | 300 | 50 | 1-2* | 2-3 | 0.1-0.25 |
| DeskJet 550C | 1992 | 300 | 50 | 2 | 2-3 | 0.2-0.3 |
| PaintJet XL300 | 1992 | 300 | 50 | 4 | 1 | 0.2-0.3 |
| DeskJet 1200C | 1993 | 300×600 | 104 | 4 | 4-7 | 0.5-1 |

* One black and one color pen interchangeable by user.

In an EP engine for example the colorant is typically pigment with a polymer binder which is heated to cause fusing to the media.

In an ink-jet printer the colorant has typically been a highly soluble dye in water with capillary absorption and evaporation being the primary curing mechanisms.

**The darkness parameter** is typically communicated in optical density units with 1.2 to 1.5 being a typical range for black print.

**Edge smoothness/roughness** is a function of resolution and colorant to media interactions. Typically ink jet inks are prone to edge artifacts driven by capillary wicking along paper fibers. It is this mechanism which causes the most observable form of quality variation over the range of papers available worldwide.

**Character edge contrast** is the characteristic transfer function from white to black unique to an ink/toner and media combination. Ink-jet typically has a sharper transition than EP due to the smoothing effect of the fuser in the EP process. This sharpness however causes wicking and other artifacts to be more noticeable.

**Artifacts** are the unwanted visible marks on the media which are not part of the digital information in the original. In EP engines these are called toner scatter and are normally visible as a "fog" around the printed character. In Ink-jet these are spray or satellites which are artifacts of the drop ejection process (see Figure 1).

**Uniformity of area fills** are caused by a large number of technology specific anomalies. They are most noticeable in graphics, images, and large point size text. While important to the overall consideration of print quality they are not a topic of this paper.

## Technology Comparisons

### Electrophotography Overview

HP LaserJet and HP thermal ink-jet printers use significantly different technologies to image the media. Each has advantages and disadvantages. Figure 2 below schematically illustrate the functional aspects of the electrophotographic technology.

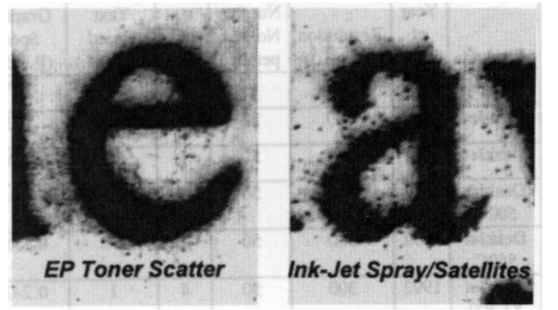


*Figure 1.*

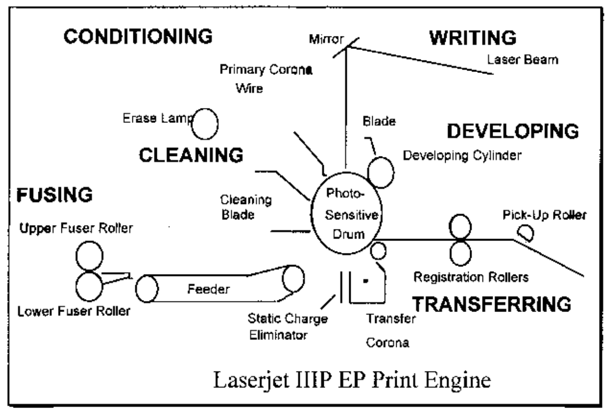


*Figure 2.*

### Ink-Jet Fundamentals

The Thermal ink-jet implementation in HP products is shown schematically in Figure 3 which is an enlarged representation of one firing chamber with the area shown being approximately 100 μ across.

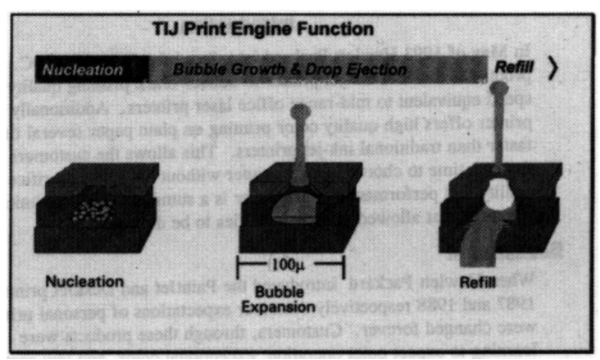


*Figure 3.*

In Hewlett-Packard thermal ink-jet all the functional aspects of the technology (ink, drive bubble, heater, ofice, and circuitry) are contained in a single disposable cartridge. The printer supplies only positioning and electrical activation to drive the drops.

**EP Advantages**

- High degree of media independence
- High speed page printing
- Dry process minimizes paper distortions
- Durable print unaffected by water and highlighters
- Excellent edge smoothness from:
  - Fusing
  - Small toner panicle size (7-15µ)
- Customer perceived reliability

**Thermal Ink-Jet Advantages**

- Low cost print engine (disposable)
- Printer mechanism simplicity
- Single pass color printing
- Smoother area fills

**Print Cartridge Design for EP Print Quality**

The design of the DeskJet 1200C print cartridge and system addresses many of the differences between the physics of ink-jet and EP to enhance the quality to EP standards without sacrificing the advantages of Ink-jet. The features and benefits are shown in Table II.

**Table II.**

| ***Design Feature*** | ***Benefit*** |
|---|---|
| Pigmented Black Ink | Higher Optical Density (1.35-1.45)<br>Improved Media Independence<br>Improved water resistance |
| Improved Resolution | 300×600 dpi.<br>Resolution Enhancement Technology (RET) |
| Heated Writing Area | Improved cockle resistance<br>Reduced paper curl from water |
| 104 nozzle printhead | Improved Speed (4-7 pages per minute) |

## Ink Design

**Carrier**

The ink carrier is primarily water. This provides the driving force for thermal nucleation and drop ejection. Additives are used to enhance resistance to clogging, promote drytime, and reduce feathering. The actual formulation is proprietary.

**Colorant**

The black ink in the 1200C is a pigment based ink. A block copolymer manufactured to a very tight molecular weight range is used as a dispersant. The dispersant must adequately disperse the pigments in a manner to withstand the repeated temperature cycles in the print head where the resistor cycles from ambient to 500C+ in a few microseconds millions of times during the life of the pen. Additionally the ink survives transportation and storage for several years. An enlarged sample of a typical pigment particle is shown in Figure 4. The ink was a co-development between Hewlett Packard and a major chemical company in the U.S.

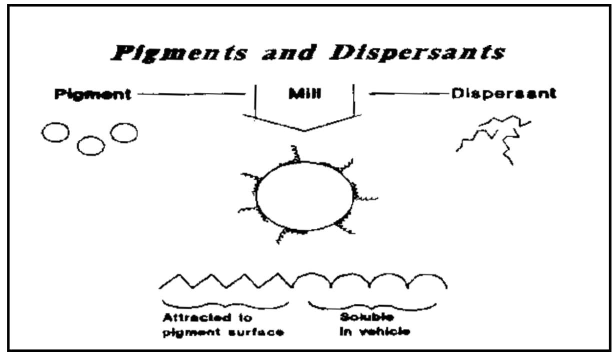


*Figure 4.*

**Tradeoffs**

The design of the ink must trade-off properties which affect many performance variables. Over eighty performance variables are tracked during development and evaluation of ink designs and manufacturing processes. A few of the most significant are print quality, kogation, crusting or clogging, drytime, and shelf life. The DJ 1200C ink provides print quality essentially equal to HP's LaserJet IIP series on a majority of the available worldwide papers. A comparison is shown in Figure 5.

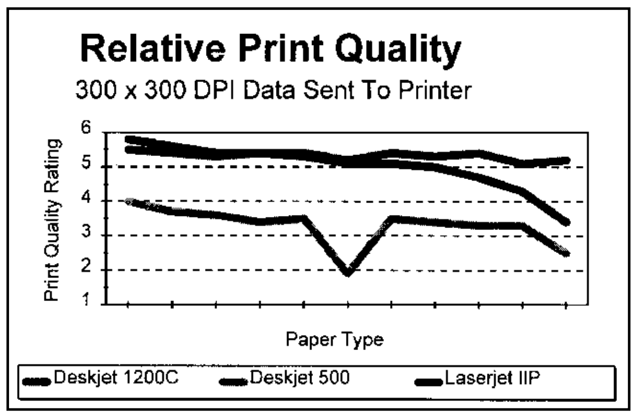


*Figure 5.*

## Printer Techniques

**Mechanical Considerations**

Within each print mode, a variety of writing system designs affect print quality. The effect of the main heater is enormous. It is located directly below the print zone and functions to dry the ink quickly. The heater prevents objectionable bleed and paper cockle (out of the plane puckering of the paper caused by the aqueous nature of the ink) while increasing throughput.

The heater consists of a wire element which, when heated, radiates in the 3 to 5 micron range. This is the optimum range to excite and evaporate water molecules. The element is suspended within a three sided reflector which directs the radiation to the printing area. When the ink is dried quickly, the water does not have a chance to swell the paper fibers and produce cockle, nor to mix with an adjacent wet drop of ink and produce color to color bleed.

If there is a data interruption or an I/O delay, the heat from the main heater runs the risk of discoloring (browning) the paper or causing a hue shift where a given swath of printing is dried for longer than the previous or succeeding swaths. To prevent these objectionable print quality errors, the printer constantly monitors the data buffers, and begins to ramp down the print speed and turns off the heater when buffers deplete. In this way, the hue shift is hidden by making it appear more gradual, and browning is prevented.

When paper is heated water is driven out and it shrinks. If paper is allowed to enter the heated print zone without being preconditioned, the paper will shrink during printing. In single pass printing this shrinkage shows up at the swath boundaries as a misregistration. In multi-pass printing, the errors will show up as individual misregistration of dots. In an area fill, this appears as a white haze. Different environmental conditions and different media types will affect the amount of error that occurs. Humid conditions and heavy bond papers will produce the largest misregistration.

The DJ1200C preheater is designed to precondition paper evenly before it enters the print zone. The heater consists of a flexible polyimide laminate with etched copper traces. The power is regulated by the resistance of the preheater itself which eliminates any cost of supplying a pulse width modulated or other regulated supply. If the preheater is cold when the printer receives a print job, the cold preheater draws approximately 45 Watts. As the copper traces become hot and the resistance builds, the preheater consumes power at a much lower steady state. See Section View in Figure 6.

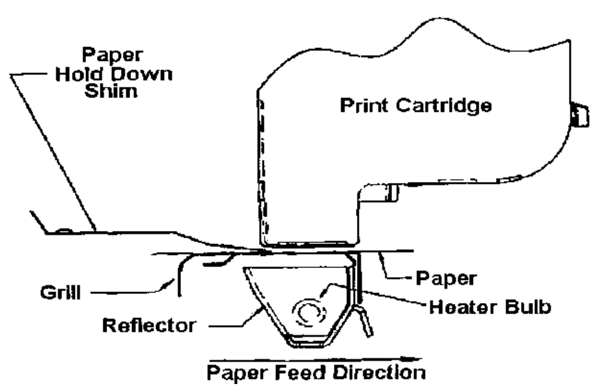


*Figure 6.*

**Print Methodologies**

There are three print modes in the DeskJet 1200C. These are fast, normal and high quality. These modes are chosen from the front panel or from a dialogue box from within the application. Choosing a print mode commences a complex decision process on the optimum set of printing physics invoked which is depended upon the media, the print sample (text, graphics, monochrome, or color) as well as densities and inter swath boundary conditions.

The Table III below demonstrates the primary choices made by the printer.

**Table III.**

| Mode | Text | Monochrome Graphics | Color incl. Images | Speed P.P.M. |
|---|---|---|---|---|
| Fast | 1 pass bi-directional | 1 pass uni-directional | 1 pass uni-directional | 7/1/1 |
| Normal | 1 pass * bi-directional | 3 pass interlaced | 3 pass interlaced | 6/.5/.5 |
| H.Q. | 1 pass * bi-diretional 300x600 (RET) | 3 pass interlaced | 3 pass interlaced | 4/.5/.5 |

*Printer selects unidirectional when required by swath boundaries

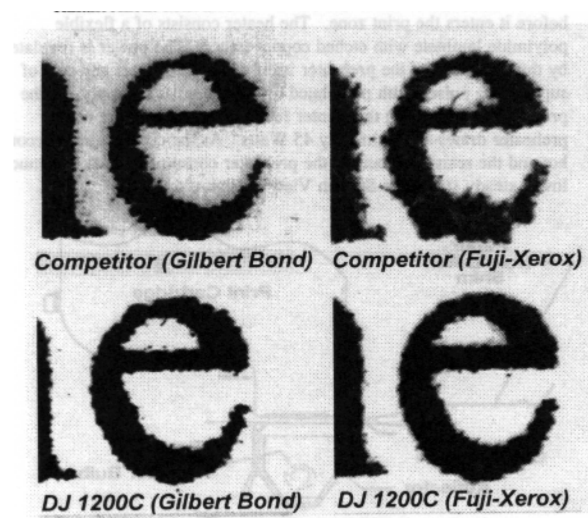


*Figure 7.*

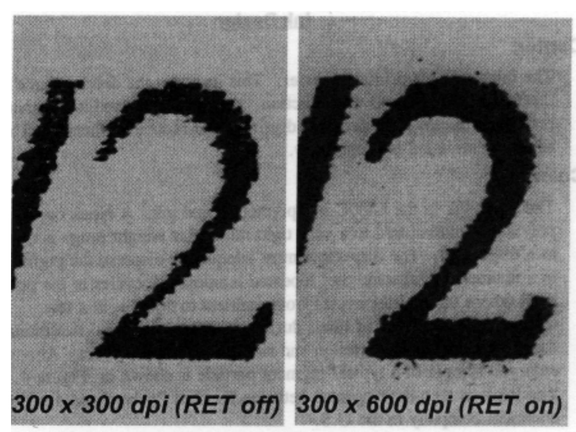


*Figure 8.*

As the reader can discern a complex page of mixed black and color text and graphics achieves variable throughput results but delivers quality consistent with the mode chosen by the user.

Figure 7 shows the relative print qualities attained on a sample of media.

In Figure 8 a comparison is shown between the 300 d.p.i. normal mode and the 600 d.p.i. high quality mode with resolution enhancement activated.

**Achieving Laser Speed**

To achieve laser speed the while delivering high quality the firing frequency of the printhead was extended to 8 kHz. This allows a printer carriage speed of 26.67 inches per second at 300 d.p.i. and 13.3 i.p.s. at 600 d.p.i. Coupled with the 104 nozzles for each pen E.P. speed is achieved. Additionally, the product carries an additional motor to pick and feed the following page while printing the current page. This minimizes non-printing time.

## Conclusions

A significant set of new technologies were developed, refined and integrated to deliver for the first time in a color inkjet product the ability print text at a speed and quality equivalent to EP printers in the low and mid performance range. Through advances in inks, print head architecture, control software, and mechanism design the of office user can now have his high performance text printer and color in one affordable printer.