# Chapter 15. Ink Jet Printing

## 15.1 General Overview

"Ink jet" is a collection of printing techniques that take small quantities of ink from a reservoir, convert them into drops, and transport the drops through the air to the printed medium (paper, transparencies, beverage containers, etc.).

Ink jet printers work by spraying a very fine stream of quick-drying ink on the paper. As with the dot matrix type, there are seven print points where the ink gets "squirted" onto the paper. Because the ink must be squirted, it must be thinner than regular ink. Many ink jet printers specify that special paper should be used so the ink doesn't run or bleed for high quality printing (more than 300 dpi). Printing should be done on the shiny side of the paper.

Ink jet technology has been implemented in a wide variety of ways. Figure 1 The ink jet tree structure provides a pictorial representation to cover most of the better known printing techniques.

At the heavy-duty high performance end, some printers can print in excess of 1000 feet per minute. A typical use of these printers would be in the printing of mailing labels. These systems, usually classified under continuous or pressurised ink jet. The ink is continuously shot out in tiny drops even when nothing is being printed. This helps to keep the ink port from being clogged from ink drying on it. To control the formation of characters on the paper, the ink is directed by magnetic fields and is selected and guided to the printed medium by electrostatic or magnetic forces. This is done in much the same way as the electron beam in a where magnetic fields are used to deflect the charged ink droplet. During the times when nothing is being printed, the ink is directed to a catcher so that it recycles back into the ink reservoir where it can be used again.

The other major classification is drop-on-demand, in which drops are formed only when required. The forces used to create and transport these drops may be mechanical, electrostatic, magnetic, or thermal.

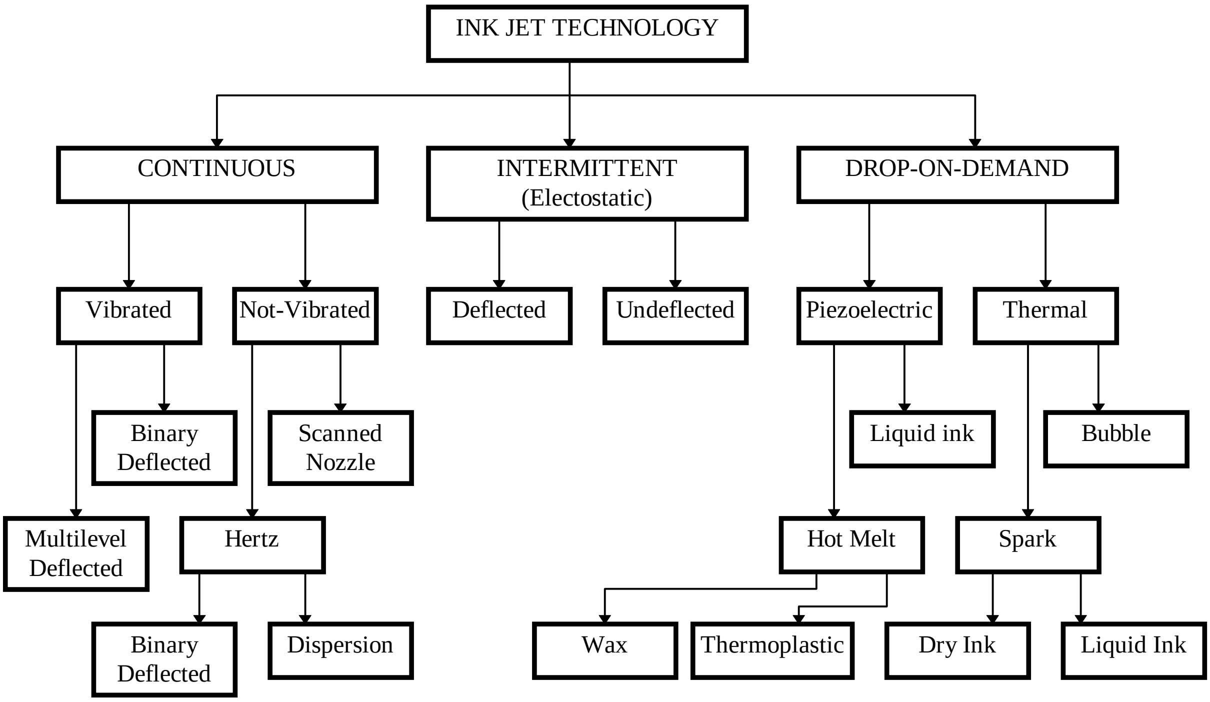



Figure 1 Ink jet technology tree

### 15.1.1 Market

The ability to combine a wide selection of important printing characteristics in a single technology make ink jet an attractive and important competitor in the printer market. These characteristics include: colour, high speed, high resolution, low cost, non-contact, low noise, and ability to print on various media. Special application areas: industrial marking; large format raster printing.

## 15.2 Technology

### 15.2.1 Continuous Ink Jet

Continuous ink jet printers can be further classified by the drop break-up method, and by their means for guiding drops to the printed medium. Typically only a small fraction of the drops is used for printing, the majority being directed to a catcher or gutter and re-circulated via a pump and filters. A primary advantage of continuous is the greater number of drops per unit time available per element.

#### 15.2.1.1 Vibrated/Multilevel Deflection:

Uniform drops are generated by applying a periodic perturbation to the jet, typically using a piezoelectric transducer. (See Figure 2 Continuous ink jet with piezoelectric stimulation of break-off and multilevel electrostatic deflection for character generation.) Drops are charged by an electrode located at the point of drop break-off and then deflected by high voltage plates to print a dot at a position proportional to the applied charging voltage.

A continuous jet is formed by applying pressure to a fluid contained in a chamber having a small opening called the nozzle or orifice. A fluid jet is inherently unstable and will break-up into drops as a result of its natural tendency to minimise surface free-energy, which is equivalent to minimising the surface area. If no forces other than surface tension act upon the free surface of the jet, it will break up quasi-randomly into drops of varying size and velocity. Applying a periodic perturbation at an appropriate frequency, typically by mean of a vibrating piezoelectric transducer attached to the chamber, results in the formation of a stream of drops of uniform size and velocity.

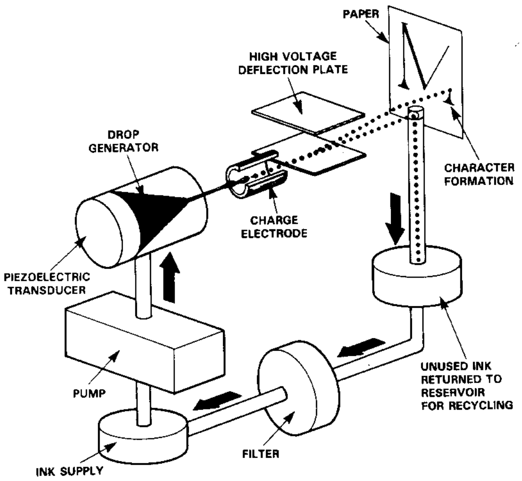



Figure 2 Continuous ink jet with piezoelectric stimulation of break-off and multilevel electrostatic deflection for character generation.

An example of continuous ink jet vibrated/multilevel deflection printer is IBM 5258. Which has 40 Positions, can print at 92 cps with resolution of 240 by 240 dpi. The nozzle diameter is 33 µm. Drive frequency at 117 kHz with a charge voltage of 200 V, deflection voltage of 3.3 kV.

##### 15.2.1.1.1 Charging

Drops are charged just before they separate from the jet by an electrode that surrounds the region where break-off occurs. One simple design is as shown in Figure 3 Simplified equivalent circuit of drop charging at break-off.

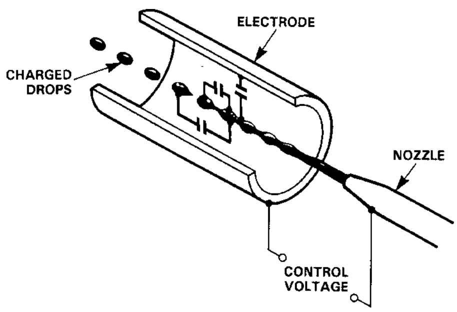



Figure 3 Simplified equivalent circuit of drop charging at break-off.

### 15.2.1.2 Vibrated / Binary Deflection

Same general operation as above, but printing is done with the uncharged drops, while the charged drops are deflected into a catcher and are re-circulated. (See Figure 4 Multiple array continuous ink jet with quasi-random break-up. Charged drops are deflected to the gutter for re-circulation.) The primary advantage over multilevel deflection is that the complex charging schemes needed to compensate for electrostatic and aerodynamic interactions between charged drops are avoided. The primary disadvantage for a serial character printer is that one jet is needed for every vertical dot position in a character.

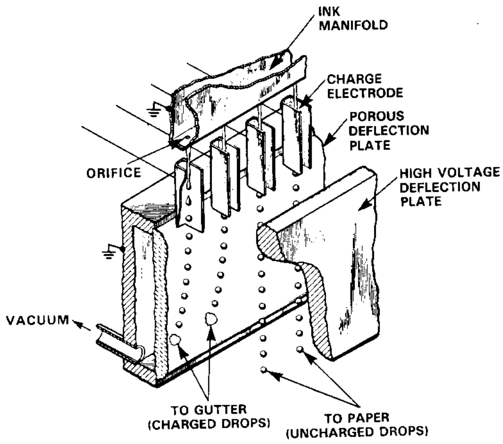



Figure 4 Multiple array continuous ink jet with quasi-random break-up. Charged drops are deflected to the gutter for re-circulation.

An example is the Diconix (Kodak) Dijit - 1 which has 64 nozzles, duplex operation with resolution of 300 by 300 dpi. The throughput is 20 ppm, performance comparable to medium speed laser printers

### 15.2.1.3 Not-vibrated / Undeflected

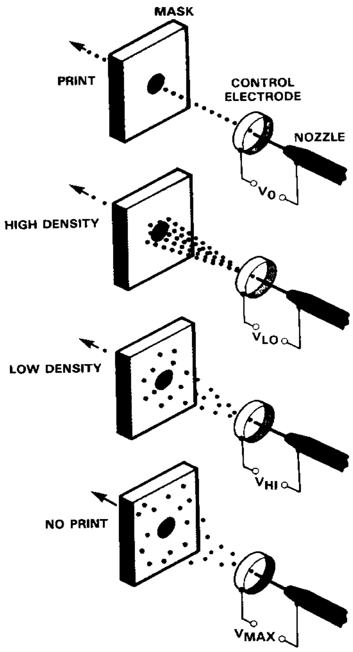



Figure 5 Voltage cause the dispersion of a charged drop stream to modulate the number of drops pass through an aperture.

Not-Vibrated/Undeflected. In this technique, drop break-up occurs quasi-randomly. A high charging voltage (100-500V) creates strong electrostatic repulsion forces which cause drops to fan out. Varying the voltage affects the dispersion and can be used to control the number of drops passing through an aperture to the paper, thus the density of the spot can be varied in an analogue fashion for halftone printing with lighter tones produced at higher voltages. For low voltages applied to the control electrode maximum print density is achieved; at the maximum voltage few drops pass through the hole. (Figure 5 Voltage cause the dispersion of a charged drop stream to modulate the number of drops pass through an aperture.)

### 15.2.1.4 Not-vibrated / Deflected

As in the undeflected case, break-up is quasi-random thus producing drops of varying size. The use of deflection plates to collect non-printing drops improves print quality; each spot may be composed of 30 drops or more. (Figure 6 Not-vibrated / Deflected ink jet. Printing is done with the uncharged drops.)

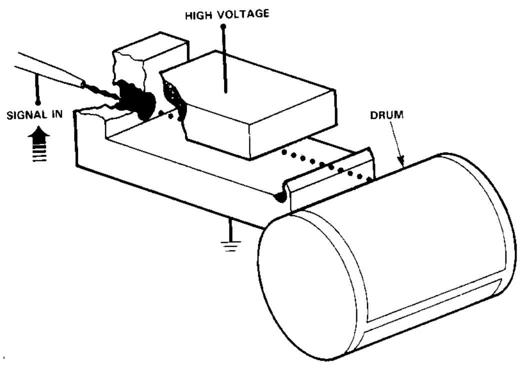


Figure 6 Not-vibrated / Deflected ink jet. Printing is done with the uncharged drops.

An example of a product is IRIS Graphics 2044 which has an unvibrated glass capillary nozzle 15μm in diameter is pressurised by high pressure (650 psi) pumps producing a stream of droplets at a rate of about 1 ,000,000 per second. Each printed spot contains about 30 droplets. Four colour printing is done in a single pass at 240 dots per inch on E-size sheets (34 by 44 inch) and can be made in 30 minutes. A draft quality mode at 120 dots per inch can be printed in 15 minutes. A lower cost, smaller format printer, the IRIS 2024, was introduced in September 1986 and produces 18 by 24 inch colour plots in 12 minutes.

## 15.2.2 Drop-On-Demand (DOD) Ink Jet

### 15.2.2.1 Piezoelectric Pressure Wave / Liquid Ink.

Piezoelectric Pressure Wave - Liquid Ink. Two basic configurations are in use: one with a tubular transducer and the other with a planar transducer (see Figure 7 Cross-section of Silionics style drop generator showing motion of rectangular piezoelectric transducer during drop ejection.). In the former case, a cylindrical piezoceramic element is used to abruptly compress the enclosed volume producing a pressure wave which causes ejection of a drop at a nozzle. In the planar configuration, a flat plate of piezo-ceramic material forms one wall of the ink chamber.

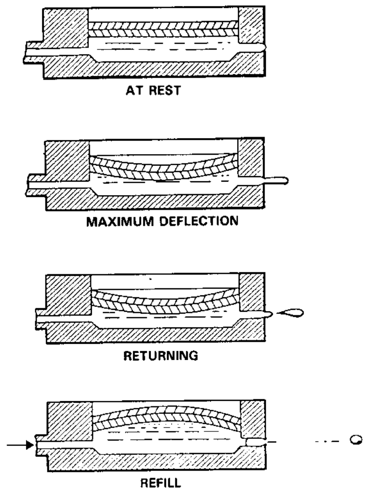



Figure 7 Cross-section of Silionics style drop generator showing motion of rectangular piezoelectric transducer during drop ejection.

A example is the Tektronix 4692 which has 40 μm nozzles, operated at 20 kHz with resolution of 154 dpi.

Another configuration is the Epson piezoelectric compression technology. See Figure 8 Epson piezoelectric compression technology

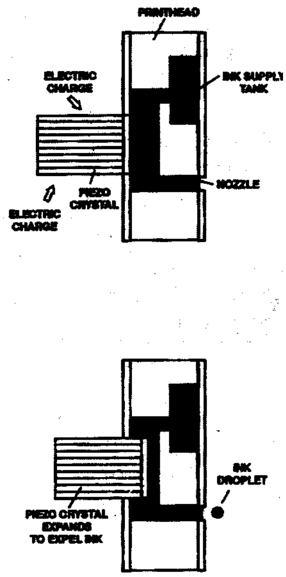



Figure 8 Epson piezoelectric compression technology

An example is the Epson Stylus Pro printer, which has 64 black nozzles and 16 X 3 colour nozzles for magenta, cyan and yellow. Which has bi-directional printing with resolution at 720 by 720 dpi with MicroDot.

There are also piezoelectric-solid ink printers. These work basically like a liquid ink system, since the "ink" is melted both in the head and in the ink reservoir when the printer is in operation. The ink, however, is solid when loaded into the printer and solidifies on contact with the printed medium. The advantage is that thick solid ink gives good saturation. An example is the Howtek PixelMaster. Which has 32 rotating nozzles, can print four colours. At 30 kHz Operation with resolution of 240 by 480 dpi. The throughput is 4 mins per page.

Currently most higher performance Ink-Jet Printers use piezoelectric transducers to eject either liquid or solid ink.

### 15.2.2.2 Thermal Ink Jet/Bubble Jet

Commonly known as Bubble Jet by Canon of Japan and Thermal Ink Jet and ThinkJet by Hewlett-Packard. When heating a thin film resistor causes sudden vaporisation of a small portion of the ink vehicle; this displaces fluid in the ink chamber causing drop ejection through an adjacent orifice. Figure 9 The process of ink ejection with thermal heating

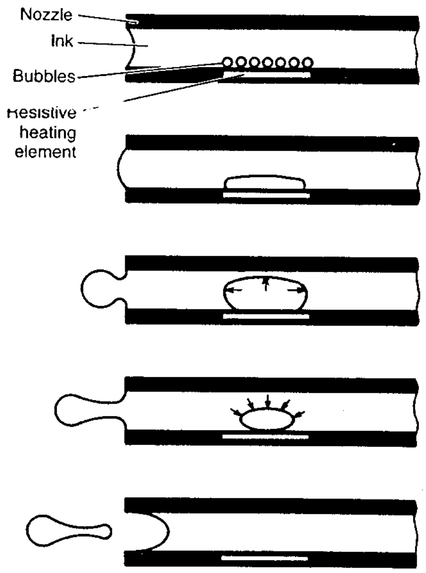



Figure 9 The process of ink ejection with thermal heating

| | HP DeskJet 500 | Canon BJ-330 | Epson stylus Pro |
|---|---|---|---|
| Nozzles | 50 | 1 x 64 | 1 x 64 |
| Speed | 4Khz | 300 cps @ 10 cpi | 3 ppm/1.5 ppm colour |
| Resolution | 300 dpi | 360 x 360 dpi | 720 x 720 dpi |
| Noise | | 45 dbA | |

To expel a drop, the temperature of the thin film heater resistor is rapidly increased by the application of an electric current. The typical pulse duration (of 3 to 10 µsec) is too short for convection to influence heat transfer. The rate of change of temperature is in excess of 30 million degree C per second. Heating cause tiny vapour bubbles to be formed. Further growth is supported by stored heat in the superheated ink layer. When the bubble become a big pillow-shaped, ink will eject at the open orifice. As the stored energy is consumed, bubble starts to collapse and the ink replenished.

### 15.2.2.3 Thermal - Spark.

Solid ink and liquid ink configurations have been developed. An electrical discharge through a conductive ink vaporises one or more of its components. The expanding gas propels some of the ink particles toward the paper. Figure 10 Dry spark ink cartridge, where an electrical pulse at 4-6 µsec at about 4 kV, then at 400V to maintain the spark. In Figure 11 Liquid spark ink jet cartridge, where an electric arc vaporise the ink and expel a fine spray, similar to thermal printer. These type of technologies have the disadvantages of smudging, noisy and problem that are associated with electric arcing.

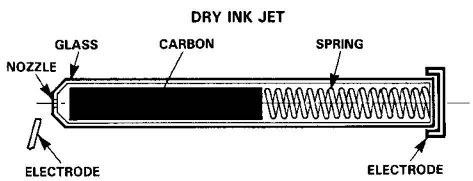



Figure 10 Dry spark ink cartridge

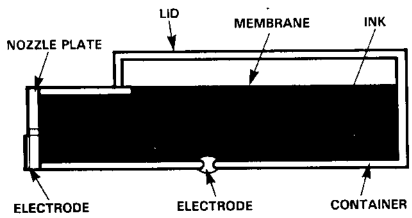



Figure 11 Liquid spark ink jet cartridge

### 15.2.3 Intermittent (Electrostatic Pull)

#### 15.2.3.1 Undeflected.

The ink is under slight positive pressure (about 1 cm of water) to form a convex meniscus. High voltage (about 2 kV) on a gating electrode just outside the nozzle overcomes the surface tension and allows a stream of drops to emerge which are all equally charged. Drops are further accelerated toward the printing surface by an additional high voltage (about 7 kV). This method has been used for facsimile recording. (See Figure 12 Intermittent (electrostatic pull) ink jet without deflection)

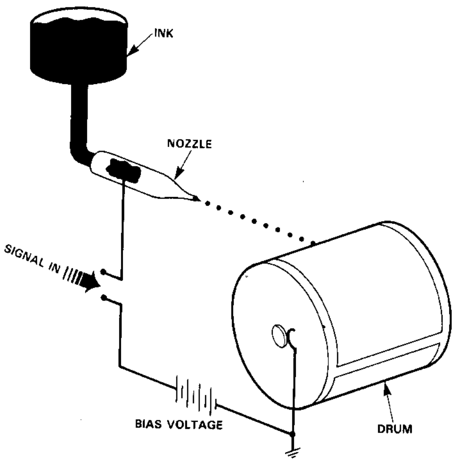



Figure 12 Intermittent (electrostatic pull) ink jet without deflection

Deflected. Drops are extracted by the technique described above. Deflections in vertical and horizontal directions are controlled by two orthogonal sets of electrodes. (See Figure 13 Intermittent (electrostatic pull) ink jet with both vertical and horizontal deflection)

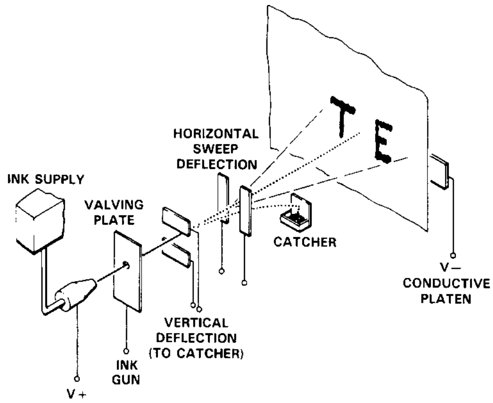



Figure 13 Intermittent (electrostatic pull) ink jet with both vertical and horizontal deflection

## 15.3 Halftone Printing

Images reproduced in books and magazines are generally printed using halftone techniques in which continuous-tone artwork, such as a photograph, is converted to a pattern of dots of varying size and shape. It is interesting find out how few dots are required to reproduce some recognisable detail in the image.

For most of today's printers which use dot patterns rather than fully formed characters, 300 dots per inch has become a standard and 600 dots per inch or higher is now getting popular; 150 dots per inch resolution for an image may seem anomalously low. In reality, the information content of a halftone image (and its perceived quality) goes beyond being described by the simple notion of resolution; the number of different dot sizes and even the shape of the dots must be taken into consideration:

$$\begin{pmatrix} Quality \\ Index \end{pmatrix} = \begin{pmatrix} Picture \\ Element \\ Density \end{pmatrix} * \left[ \begin{pmatrix} Halftone \\ Level \end{pmatrix} - 1 \right]^{1/2}$$

Halftone techniques provide an alternative to higher resolution for improving image quality. Higher resolution increases cost and complexity. For example, doubling the resolution requires twice the number of nozzles and associated drivers operating at twice the drop frequency to maintain the same print speed; memory requirements will increase by a factor of four. A four level halftone, at the original resolution, will provide similar image quality with only twice the memory required, but will be less accurate in rendering the finest level of detail in the .

Three techniques are used in ink jet printing to vary the average optical density of a pixel: (1) drop volume control, (2) dye dilution, and (3) pixel pattern techniques.

### 15.3.1 Drop Volume Control

For continuous ink jet, for example the Not-Vibrated/Undeflected printers, charge electrode voltage can be varied to control the amount of ink spray passing through an aperture; For vibrated binary deflection systems, it is possible to direct a controlled number of drops to a given spot and thus vary the spot size under digital control.

For piezoelectric drop-on-demand printers, varying the pulse height or pulse width can vary spot size on paper by controlling the drop volume. A four-fold increase in dot area can be achieved as the pulse width is varied from 10 µsec to 50 µsec in NEC using their micro-valve head design. Cannon using Bubble jet devices bubbles of varying size by varying either the pulse height (from 30 to 50V) or the pulse width (from 4 to 15 µsec); this causes varying amounts of ink to be ejected.

Techniques for piezoelectric and thermal ink jet drop-on-demand for ejecting groups of drops to implement spot size modulation can also be done. (Figure 14 Dot size modulation is obtained by using a burst of pulses to control the amount of ink in each pixel.)

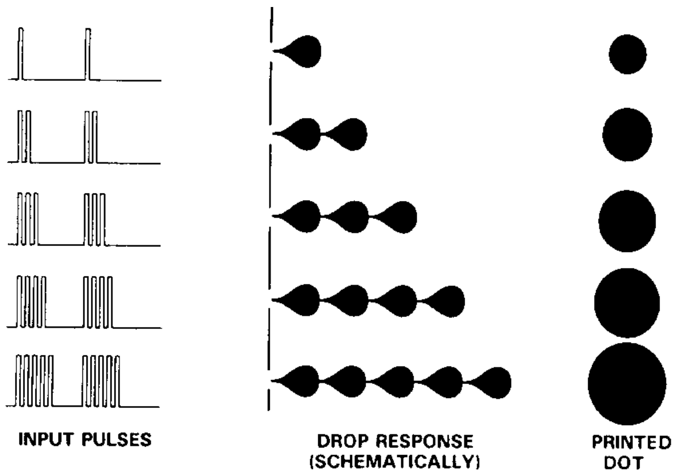



Figure 14 Dot size modulation is obtained by using a burst of pulses to control the amount of ink in each pixel.

### 15.3.2 Dye Dilution Method

Canon and NEC have also worked on printers which use the dye dilution method to increase the number of grey levels achievable. Usually dye dilution method is combined with modulation of the drop volume to produce hybrid systems.

### 15.3.3 Superpixels and Other Processing Techniques

Most hard-copy devices are able to produce only a single size dot. These printers can simulate halftone printing at the expense of resolution by grouping together a number of basic picture elements, commonly called pixels, into a "superpixel". Figure 15 Superpixel patterns used to obtain multiple intensity levels. (a) 2X2;(b) 3X3. illustrates how 2 X 2 and 3 X 3 superpixels may be used to achieve multiple intensity levels; more levels are achieved by defining a larger matrix. Grey tones are perceived because of the visual averaging that occurs over several black and white pixels.

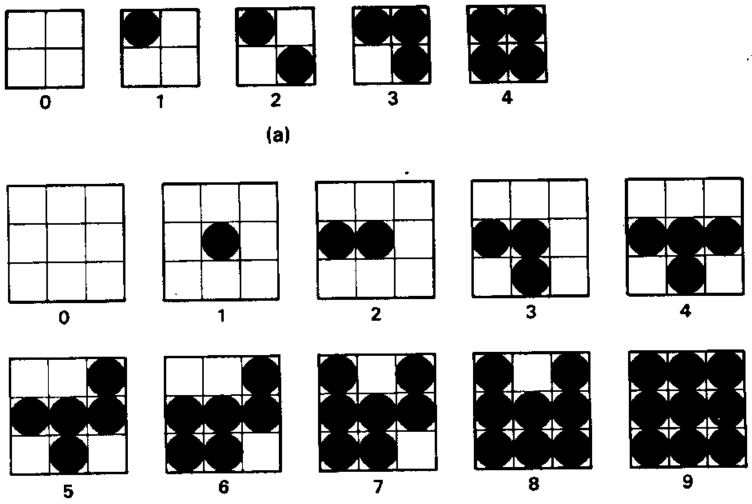
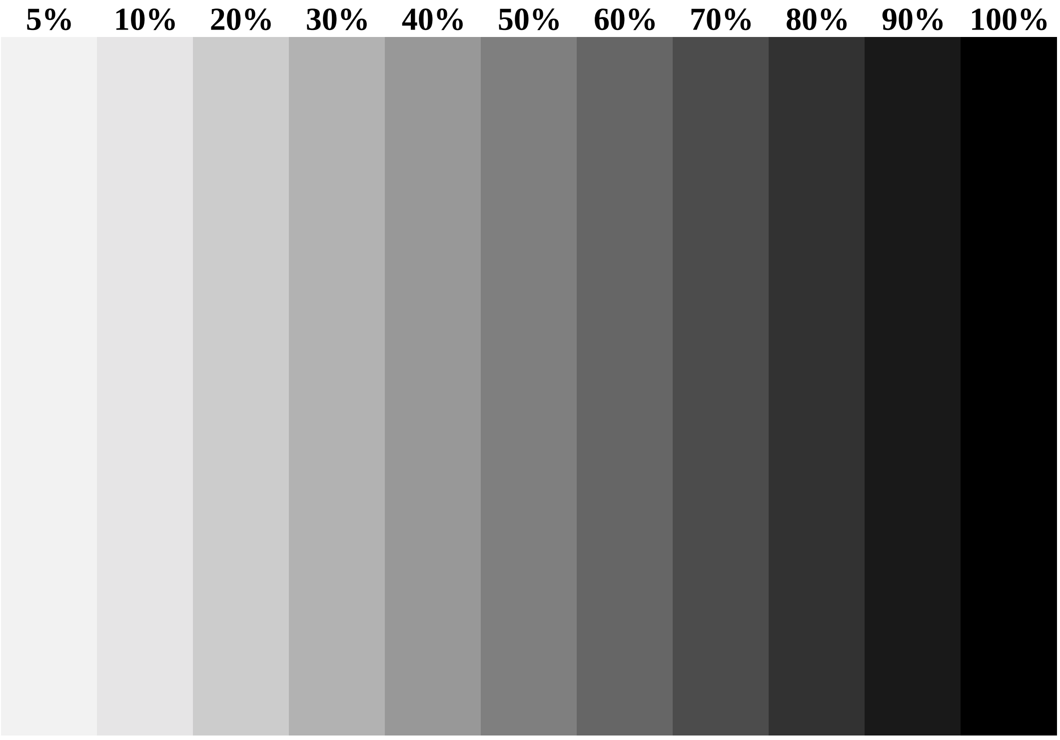



Figure 15 Superpixel patterns used to obtain multiple intensity levels. (a) 2X2;(b) 3X3.

Ordered dither is a widely used, easily implemented technique in which a continuous tone or multi-level image is converted to a binary representation by comparing each pixel intensity with a predefined value in a threshold matrix whose elements repeat periodically in both dimensions. Where the intensity of a pixel exceeds the threshold corresponding to that pixel, a dot is printed; where it is less than the threshold value, no dot is printed. The simplicity of the technique results in low computer processing and memory requirements.

In order to minimise contouring and texture visibility, while maximising the retention of detail, proper selection of values in the dither matrix is important.

Error diffusion is a technique for further increasing the number of tone levels achievable by additional computer processing of the data. Data from a multi-level image is compared to a selected threshold level; the difference between these values generates an error value which is then distributed (with different weighting factors) to neighbouring pixels. The error value may be positive or negative and can continue to propagate to other pixels or may be truncated.




## 15.4 Page Description Languages

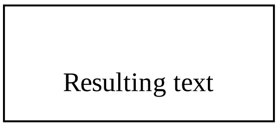
Portability between printers allowing them to use output data in some common format is an attractive characteristic, but the number of different printers is large. It is not practical to describe the desired result at the bit level, as used in dot matrix printers, since different printers work at different resolutions, from less than 70 dpi to over 2000 dpi.

As in portable programming languages, a higher level of description is required. A page description language (PDL) such as PostScript specifies what is required in terms of lines, shapes, fonts and characters and leaves it to the printer to map this to its own characteristics.

PostScript was developed by Adobe Systems Incorporated and is a device independent programming language specifically aimed at describing text and graphics. An example is shown in . The complete set of facilities provided is far too large to be described here and the reader is referred to the books in the further reading section of this chapter.

```
0 0 moveto
0 40 lineto
90 40 lineto
90 0 lineto
closepath
stroke
/Times-Roman findfont
12 scalefont
setfont
l0 l5 moveto
(Resulting text) show
showpage
```

(a)




(b)

Figure 16 PostScript: (a) source text; (b) what it produces

For other printer language, such as that employed by HP in their ink-jet and laser printers, refer to the lab manuals of HP deskjet 500C.