5. PRINTERS

This laboratory work presents the main types of printers, the general structure of a printing equipment, and the operating principle of inkjet, electro-photographic, phase-change, and dye-sublimation printers. The laboratory work introduces the *PostScript* and PCL languages used for controlling the printers, and describes the steps required to communicate with printers connected to a USB port.

5.1. Printer Types

There are several classification criteria for the printers. Part of these criteria is presented next.

A. Based on the Operating Principle

There are two important categories:

- Impact printers;
- Non-impact printers.

In the case of *impact printers*, printing is performed by means of an impregnated ribbon; therefore, there is a mechanical contact between the printing assembly, inked ribbon, and paper. The advantage of these printers is that they allow to make several copies simultaneously, but their drawback is that they are relatively slow and are noisy.

A few types of impact printers are the following:

- Selected-character printers, in which the character set is placed on a body. The body can be a drum, chain, band, cylindrical or spherical head, daisy-wheel, or thimble.
- Dot matrix printers, which can use needles or blade-hammers.

In the case of *non-impact printers*, there is no direct contact between the printing assembly and paper. In some printers, the image to be printed is first formed on an intermediary support, and then it is transferred onto the paper. The advantages of these printers are their high speed, high quality of the printed text or image, and low level of noise. Their disadvantage is that they cannot create several copies simultaneously.

Examples of non-impact printers are the following:

- With electro-sensitive paper;
- Thermal;
- Electrostatic;
- Electro-photographic;
- Inkjet;
- With microfilm.

B. Based on to the Printing Quality

There are three quality levels of the printed documents:

- Low or draft quality;
- Medium or near-letter quality;
- High or letter-quality.

C. Based on to the Printing Speed

According to this criterion, there are the following categories of printers:

- *Serial printers*, which print the characters one by one. Their speed is expressed in characters per second, and it can reach a few hundreds of characters per second.
- *Line printers*, which print all the characters in a line simultaneously. Their speed is expressed in lines per minute, and it can reach several thousands of lines per minute for non-impact printers.
- *Page printers*, which contain buffer memories for one or more pages. Printing is performed by preparing the image to be printed for an entire page in memory, after which the paper is advanced continuously during printing. Their speed may reach 50,000 lines per minute.

5.2. General Structure of a Printing Engine

The main functional blocks of a printing engine are the following:

1. Printing block;
2. Paper-feeding system;
3. Control system;
4. Interface.

In addition to these blocks, other sub-assemblies might exist that are specific to various types of printers.

The control system of complex printers may contain several processors (Figure 5.1).

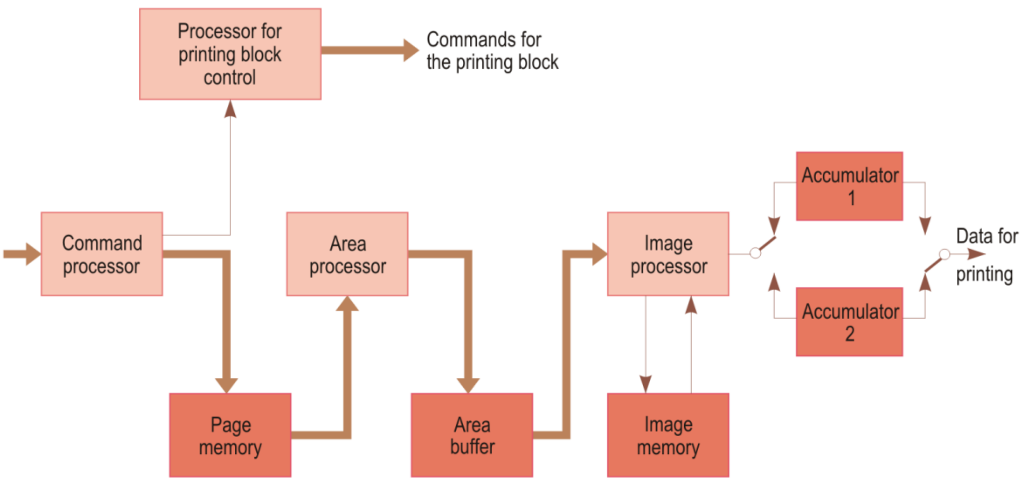

Figure 5.1. The control system of a complex printer.

The control system of a printer may divide a physical page into several areas or logical pages. Each area may be smaller or equal to a physical page and the areas may overlap, which allows to create complex pages. In addition to defining the boundaries and position of each area within the page, some processing operations to be performed on the areas may also be specified (e.g., a rotation).

Modern printers can be controlled with a command language. The *command processor* controls the data transfer between the computer and printer, interprets the commands, processes the data that describe a page, and stores these data in the *page memory*. The *area processor* performs the changes specified by the user upon the data in the page memory and transfers them into the *area buffer*, and from here towards the *image processor*, also referred to as *Raster Image Processor* (RIP). This processor defines the status of each dot of the image that will appear on the paper, based on the data received and the stored character formats.

The data prepared for printing are transferred into one of several *accumulators*. These are high-capacity memories, containing the bitmap of the image to be transferred onto the paper. To increase speed, several accumulators may be used. While one of the accumulators is used for printing, the second (or the others) may be loaded with a new page. Another processor controls the *printing block* and the paper-feeding system. This processor interprets the commands referring to the printing format, which will also determine the paper movement.

5.3. Inkjet Printers

Inkjet printers are composed of the following main elements:

- Ink reservoir;
- Ink circulation system;
- Droplet generation and acceleration system;
- Droplet guiding system.

Depending on the drop generation method, three types of inkjet printers are used:

1. Continuous jet;
2. Intermittent jet;
3. Drops-on-demand.

Each of these types uses one of the following methods for droplet guiding and placement onto the paper:

- Electrostatic deflection;
- Moving the print head or the paper and guiding the jet into positions corresponding to the dots that are to be printed;
- Selecting the nozzles of the print head.

5.3.1. Continuous Jet Printers

The droplet generation head is continuously supplied with ink under pressure by a pump. Cone-shaped nozzles are used with diameters of the order of tenths of microns, usually made from ceramic materials resistant to wear and tear (Figure 5.2).

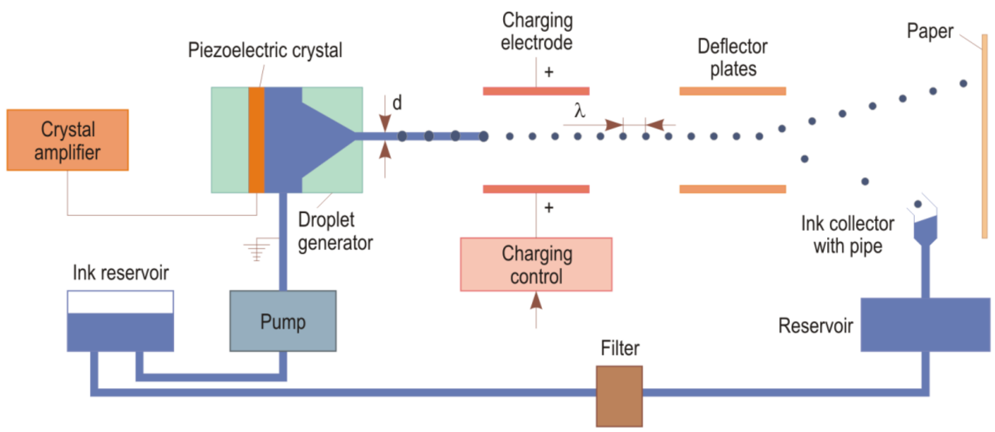

Figure 5.2. Structure of a continuous jet printer.

Due to the superficial tension, the jet tends to separate into independent droplets. This process is forced by varying the pressure on the back of the nozzle with a piezoelectric crystal. Consequently, a mechanical vibration of the ink reservoir casing is produced; if this vibration is continuous, the droplets will be generated continuously.

In addition to this piezoelectric method of droplet generation, the thermal method can also be used. Both methods are described in Section 5.3.4.

In order to guide the droplets, they are charged electrostatically with electrodes placed in the area of droplet separation. Since the inkjet is electrically connected to ground, the droplets formed are charged with a polarity opposite to that of the positive electrode. After separation, the droplets maintain their charge.

The voltage of charging electrodes is controlled by the image generation block. The charge of a droplet should vary between limits largely enough to allow later deflection over the required distance. The maximum charge is limited by the need to avoid electrostatic rejection of neighboring droplets and droplet "explosion", which may occur if the electrostatic rejection forces inside the droplet exceed the superficial tension.

The ink used should be chemically stable and compatible with the materials used for building the printer; likewise, it should be conductive, non-toxic, and non-inflammable. To prevent the ink from drying in the nozzles, additives are mixed into the ink and filters are inserted into the ink circulation system.

Continuous jet printers allow to achieve high frequencies for droplet generation (of over 100,000 droplets per second) and high speeds of the inkjet. A good printing quality is achieved if the droplets have small size and the resolution is high. At a certain maximum generation frequency, increasing the resolution will reduce the printing speed. Conversely, if the printing speed is increased by increasing the droplet generation frequency, the resolution will be decreased.

5.3.2. Intermittent Jet Printers

These printers use an ink charged electrostatically, which is supplied at a low pressure. The inkjet is generated by applying a voltage to a control electrode placed near the nozzle. Stopping the inkjet is achieved by applying an inverse voltage to the control electrode.

Droplet guiding and placement onto the paper are obtained by electrostatic deflection and print head movement. Since the droplet generation process may be controlled, and only a small number of droplets are lost at start and stop, these droplets are collected, but are not re-circulated.

Intermittent jet printers allow to achieve medium printing speeds.

5.3.3. Drops-on-Demand Printers

This method is the most used on common inkjet printers. The droplets are generated individually with the help of an electric pulse that determines deformation of the nozzles' chambers or heating of the ink. Usually, droplet guiding is achieved by selecting the nozzles of a multiple print head, combined with the movement of the print head (Figure 5.3).

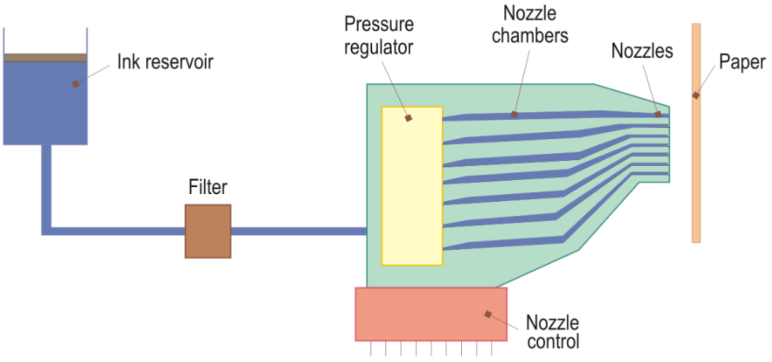

Figure 5.3. Structure of a drops-on-demand printer.

Since all the droplets are useful, there is no need for an ink re-circulation and filtering system, which leads to a constructive simplification of these printers.

The nozzles' chambers are connected to a common chamber fed by the ink reservoir. In order that the ink should not leave the nozzles when droplet generation is not demanded, the print head also contains a pressure regulator that maintains a slightly lower pressure in the common chamber. Each nozzle's chamber has a flexible casing that can be deformed with a piezoelectric crystal in order to generate a droplet. After the droplet has been generated and the casing has returned to its initial form, the chamber is refilled through capillarity. Another possibility to generate a droplet is to heat up the ink inside a nozzle's chamber.

The droplet generation frequency is limited by the need to refill the nozzle's chamber and by the fact that the ink must be accelerated at each new pulse. This frequency could be around 5,000 droplets per second. Drops-on-demand printers have lower speeds than continuous jet printers.

5.3.4. Inkjet Printer Technologies

There are several technologies that are used for building inkjet printers, depending on the droplet generation method. The most used technologies are the *thermal technology* and the *piezoelectric technology*.

Thermal Technology

The process on which thermal technology is based has been discovered at the end of 1970's by researchers of Canon and Hewlett-Packard companies. The first printer based on this technology, which is the first inkjet printer as well, was Hewlett-Packard's *ThinkJet* printer, introduced in 1984. This monochrome printer had a resolution of 96 dots per inch at a speed of 150 characters per second, approximately the same as that of dot matrix printers at that time. Later on, the technology, speed, and resolution have been improved significantly.

The thermal technology is used especially by Hewlett-Packard and Canon printers, but also by Lexmark and Texas Instruments. Other manufacturers, such as Apple and IBM, buy sub-assemblies for their printers from Canon. Canon uses the name *BubbleJet* for its thermal technology.

With thermal technology, also called bubble jet method, the print head consists of an ink reservoir with flexible casing, in which a certain pressure is maintained. From this reservoir the ink gets into the droplet generation chamber, provided with a nozzle into which the ink enters through capillarity. On one side of the chamber there is a heating element in the form of a thin film.

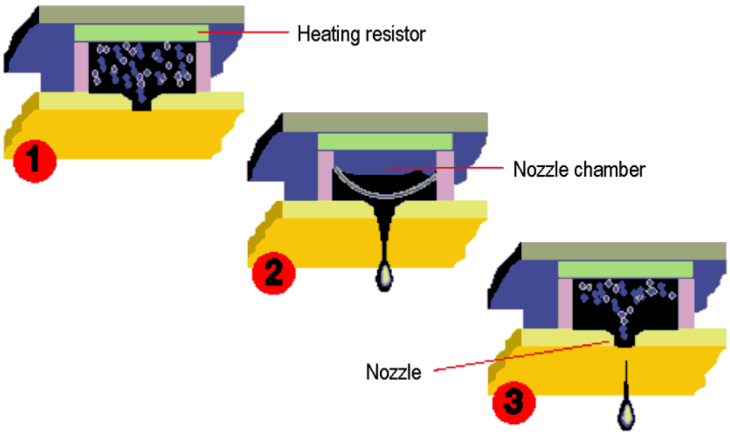

Figure 5.4. Generating a droplet with the thermal technology: (1) the ink is heated up; (2) the ink pressure increases; (3) the droplet is expelled.

Droplet generation is achieved by very rapidly heating up the ink, with a few hundreds of °C per μs. Only a thin layer of ink that is in direct contact with the heater will warm up, layer that gets to the boiling temperature. This way a small amount of ink vaporizes and the additional pressure generates a droplet, which is expelled through the nozzle (Figure 5.4).

The heating element is then cooled down, so that the ink reduces its volume and pressure, and the expelled ink is replaced with ink from the reservoir.

Thermal technology imposes certain limitations on the printing process. For instance, the ink used must be resistant to heat. The print head must be resistant to the repeated heating and cooling cycles performed rapidly. The cooling process of the ink causes a delay, which reduces to a certain extent the printing speed.

The repeated heating and cooling cycles represent the main disadvantage of thermal technology. The print head will wear out in a relatively short time, and therefore it should be replaced periodically. Some manufacturers, such as Hewlett-Packard, combine the print head and the ink reservoir into a single cartridge, so that when the ink reservoir is replaced, the print head will also be replaced (Figure 5.5). With other manufacturers, it is possible to replace separately the print head.

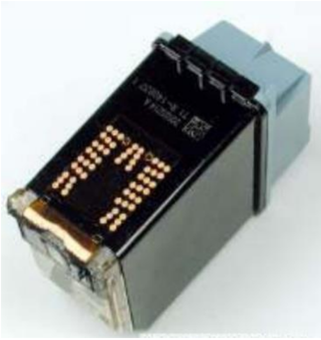

Figure 5.5. Typical ink cartridge that combines the ink reservoir and the print head (© HowStuffWorks).

The print heads of thermal printers may contain between 600 and 1200 nozzles, each with a diameter of about 70 microns. In this case, the resulting dots have diameters between 50 and 60 microns (by comparison, the smallest dots that are visible to the naked eye are about 30 microns in diameter). Nozzle density, corresponding to the printer's native resolution, varies between 600 and 1200 dots per inch. By resolution enhancement techniques, resolutions of 4800 dots per inch or higher may be reached. Usual printing speeds are of 16-30 pages per minute in monochrome mode and 16-20 pages per minute in color mode.

Piezoelectric Technology

This technology has been developed by Epson and is based on the *piezoelectric effect*. If a pressure is applied to a piezoelectric crystal, an electric voltage will be produced. If an electric voltage is applied to a piezoelectric crystal, it will suffer a mechanical deformation.

In most cases, a disk-shaped piezoelectric crystal is used, placed at the back of the ink reservoir. The disk is deformed when an electric voltage is applied to it. This deformation produces a pressure that will expel a drop of ink out of the nozzle (Figure 5.6). This way high pressures and low response times can be achieved.

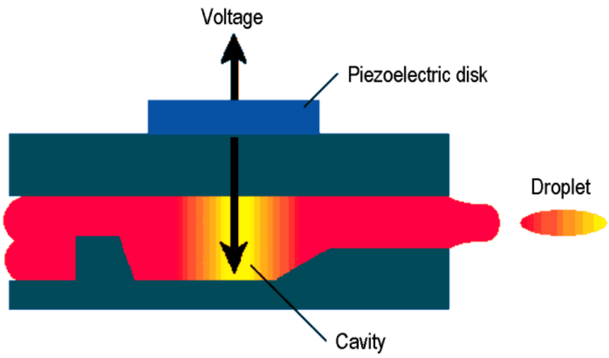

Figure 5.6. Generating a droplet through piezoelectric technology.

With another technique, a thin glass tube is placed inside a piezoelectric crystal. When an electric voltage is applied to the crystal, it contracts and exerts a pressure on the glass tube, forcing out a drop of ink.

Epson developed a technique named *Multi-layer ACtuator Head* (MACH), in which a multi-layer piezoelectric actuator is used; this actuator vibrates and produces drops of ink (Figure 5.7). The multi-layer actuator consists of several thousands of very thin piezoelectric threads, laid in parallel with each other in a small space. When an electric pulse is applied to them, the threads lengthen and act on a vibration plate that modifies the volume of the ink chamber. This technique is used especially on the Epson printers of the *Stylus* series.

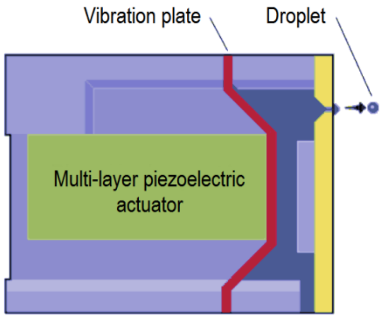

Figure 5.7. Principle of MACH technology based on a multi-layer piezoelectric actuator.

Piezoelectric technology has several advantages. For instance, the droplet generation process allows an easier control over the shape and size of droplets. The droplets may have smaller sizes, and therefore the nozzle density and resolution can be higher. Also, unlike the thermal technology, the ink does not have to be heated and cooled repeatedly, which reduces the printing time and increases the print head lifetime. Moreover, the ink can be tailored primarily for its absorption properties than for its heat resistance, which allows more freedom for developing inks with optimal chemical properties for a high printing quality. A disadvantage of the piezoelectric technology is the higher cost of printers built with this technology.

The piezoelectric technology is used by the printers of Epson, Brother, and Tektronix companies. A variant of the multi-layer technique, named *Microjet*, has been developed by the Cambridge Consultants Company. This technique provides droplet frequencies and printer costs comparable to those of the thermal technology.

The printers based on piezoelectric technology are faster, more reliable, and have lower printing costs per page compared to those based on thermal technology. On the other hand, thermal printers have lower costs, and the smaller print head allows to build more easily color and portable printers.

5.4. Electro-Photographic Printers

Electro-photographic printers (usually called laser printers) have been designed starting from the photocopiers based on the process called *electro-photography*. These photocopiers used a light source to capture an image and to reproduce it by means of a solid pigmented substance based on carbon powder, substance called *toner*. The electro-photographic process was developed by Canon in the 1960's. The first commercial application of this technology, called *New Process* to distinguish it from the older process of *xerography* used in typography, was a Canon photocopier released in 1968.

The first electro-photographic printer was a demonstration equipment made by Canon in 1975 based on a modified photocopier. The first commercial electro-photographic printer was presented in 1984, when Hewlett-Packard introduced its first *LaserJet* series printer based on the technology developed by Canon.

The operation of an electro-photographic printer is similar to that of a photocopier; the main difference between them consists of the light source used. In a photocopier, the page to be copied is scanned with a common light source, which is reflected back by white areas and is absorbed by dark areas. In an electro-photographic printer, the light source used is typically a lowpower laser beam, which is modulated by the image received from the computer. In both cases, the light source determines the selective electrostatic charge of a photoconductive[1] drum. The latent image is then developed by covering it with toner, is transferred onto the paper and is fixed.

Figure 5.8 illustrates the main components of an electro-photographic printer.

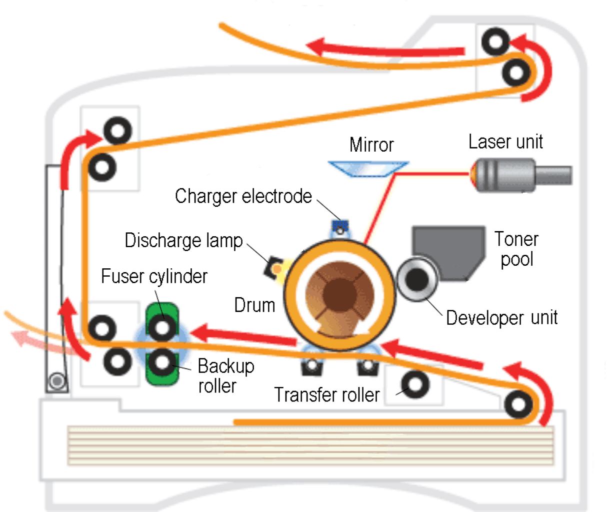

Figure 5.8. Structure of an electro-photographic printer (© HowStuffWorks).

The *drum* is coated with a photoconductive material, with the property that its electric potential changes depending on the intensity of light to which it is exposed. Initially, the drum is charged to a positive potential by means of a *charger electrode* through which an electrical current passes. Some printers use a *charger roller* instead of the electrode. By exposing some areas of the drum to light, the electric potential of these areas decreases to a lower positive value or even to a negative value, depending on the light intensity. This potential is correlated with the charge of toner particles, so that they will stick only to the lighted areas of the drum. On some printers, the drum is initially charged to a negative potential, and by exposing to light its potential increases and may reach to a positive value.

The photoconductive material used for coating the drum may be inorganic, e.g., selenium, or organic (OPC – *Organic Photo Conductor*). The selenium has the disadvantage that it is toxic. The drum must be changed after a certain number of pages (of the order of tenths of thousands).

Usually, the drum is charged electrostatically with a laser beam generated by a *laser unit*. The beam scans the photoconductive drum line by line, and during the scan it is modulated with the contents of the image memory. The beam modulation consists in modifying its light intensity. The drum rotates to pass to the next scan line, operation which is synchronized with the laser beam guidance. All the operations are therefore performed while the photoconductive drum rotates continuously.

Guidance of the laser beam must be extremely precise. For this purpose a *rotating polygonal mirror* is used (Figure 5.9). Before reaching the drum surface, the laser beam is passed through a system of lens. This optical system compensates for image distortion due to the variable distance between the mirror and various areas on the drum surface.

For electro-photographic printers a solid toner is used. The toner, stored in the *toner pool*, is composed of two main ingredients, pigments and plastic particles. The toner is extracted from the pool through the *developer unit*. In this unit, the toner particles (with a diameter of around 15 microns) are mixed with carrier magnetic particles with a higher diameter (e.g., Teflon). These particles are attached to a metallic roller, which carries them in front of the toner pool to extract the toner particles. Then the roller carries the magnetic particles mixed with toner parti-

[1] A photoconductive material has the property that it changes electrical conductivity depending on the intensity of light to which it is exposed.

cles towards the drum surface. In the light-impressed areas of the drum, the attractive force of its surface exceeds the retention force of toner particles and they adhere to the drum. In this way, the image to be printed is built onto the drum. On many printers, the toner pool, the developer unit and the photoconductive drum are combined into a cartridge that may be replaced.

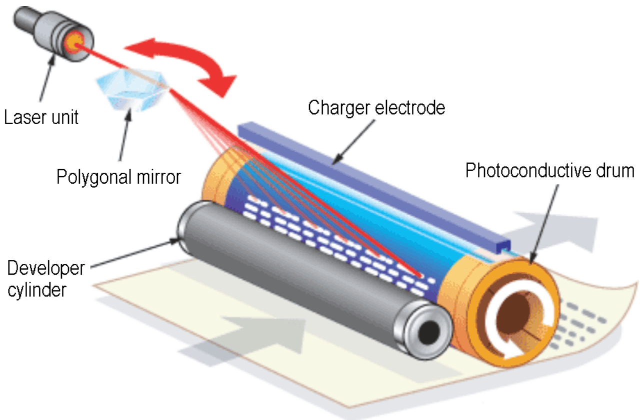

Figure 5.9. Laser beam guidance in an electro-photographic printer (© HowStuffWorks).

For transferring the image from the drum to the paper, first a *transfer roller* is used to charge the paper to an electrostatic potential that exceeds the attractive force exerted by the photoconductive drum over the toner. Then, the drum is rolled over the paper; the toner particles are attracted by the charged paper, so that the toner adheres to the paper (Figure 5.10). To prevent the paper from sticking to the drum, the paper is discharged by a discharge wire immediately after the toner is deposited on the paper. At this point, the toner is held on the paper only by a slight electrostatic charge. To permanently fix the toner to the paper, usually the thermo-mechanical method is used. The paper is passed between a heated *fuser cylinder* and a *backup roller*. In the contact area, the temperature of 150–200 °C melts the plastic particles of the toner, and the pressure fuses them with the paper fibers.

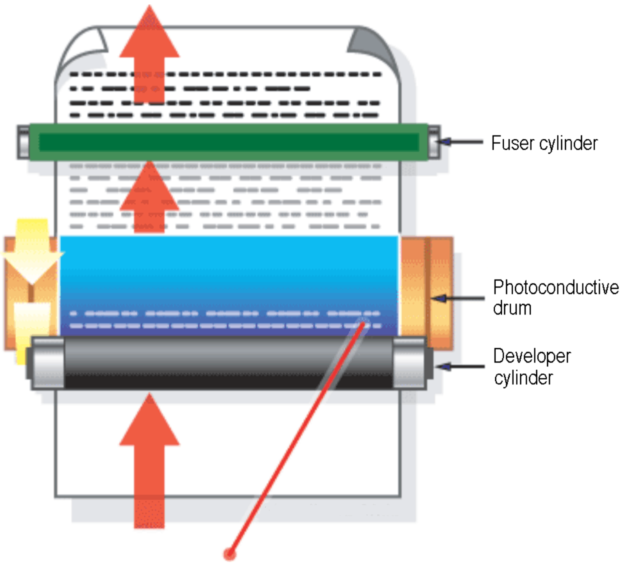

Figure 5.10. Transferring and fusing the image to the paper in an electro-photographic printer (© HowStuffWorks).

For a new printing cycle, the old image is cleared by exposing the entire drum surface to the light of a *discharge lamp*. The toner particles that remained on the drum are removed with a cleaning blade or brush and are collected in the toner pool. The drum surface is then charged to a positive potential with the charger electrode. Early electro-photographic printers used drums large enough to hold the image of an entire page. Modern printers use smaller drums and the image for a page is formed as a continuous process.

Instead of using a laser beam for charging the drum electrostatically, some printers use a row of light emitting diodes (LEDs). This technique was invented by Casio, and is also used by Oki and Lexmark. The advantage of this method is its lower cost, since the laser unit and the complex guiding system for the laser beam are replaced with a row of LEDs placed above the drum. The main disadvantage of this technique is that the horizontal resolution is fixed by construction and, while some resolution enhancement techniques can be used, they are not as efficient as the techniques offered by the laser technology. Moreover, the lifetime of these printers is shorter than that of printers using the laser technology.

The liquid crystal display (LCD) printers operate similarly, using an LCD panel placed between a constant light source (which is not a laser beam) and the photoconductive drum.

Usually, electro-photographic printers have resolutions of 600 or 1200 dots per inch. In most printers, the resolution is fixed primarily by the raster image processor (RIP), which translates the printing commands into the bitmap image to be printed. Another element that may limit the resolution is the size of printer's memory. By changing the RIP and extending the memory, it is possible to increase the printer's resolution. Nevertheless, higher resolutions also require a toner with an adequate quality, since at high resolutions the size of toner particles may limit the image clarity.

The *Resolution Enhancement Technology* (REt) increases the apparent printing quality within the limits of a certain available resolution. This technology, introduced by Hewlett-Packard in 1990 with the *LaserJet* III printer series, consists in altering the size of toner dots at the edges of characters and diagonal lines to reduce the aliasing effect. Thus, by using this technology the on-paper resolution remains at the printer's rated value, but the images will appear sharper.

Compared to inkjet printers, the main advantages of electro-photographic printers are their higher speed and precision. Common printing speeds are between 20 and 50 pages per minute, but complex printers may have much higher speeds. For instance, some sophisticated models may have speeds of 200 pages per minute or higher. The diameter of the laser beam is constant, so that it is possible to achieve a high precision of the dots from which graphical images are built. Furthermore, the solid toner does not diffuse into the paper pores as the liquid ink does, and therefore the printing quality is dependent to a much smaller extent on the paper quality. Although the cost of electro-photographic printers is higher, their cost per page is lower than that of inkjet printers. However, color electro-photographic printers are not as widely used as color inkjet printers.

5.5. Color Printers

5.5.1. Generating Color

Unlike color monitors, which use the additive color synthesis, color printers use the subtractive color synthesis. With monitors, a color is generated by combining the three primary additive colors, red, green, and blue; the standard used is called RGB (*Red*, *Green*, *Blue*). Printers use pigments with the three primary subtractive colors, cyan, magenta, and yellow; the color system used is called CMY (*Cyan*, *Magenta*, *Yellow*). *Cyan* is the complementary color for red, *magenta* is the complementary color for green, and *yellow* is the complementary color for blue. For instance, to print in the red color, a pigment should be used that is colored magenta (which absorbs green) and yellow (which absorbs blue), reflecting back only the red color.

More often than not, printers use a fourth pigment as well, colored black; this color system is called CMYK (*Cyan*, *Magenta*, *Yellow*, *Black*). Although, theoretically, black can be created by the superposition of the three primary subtractive colors (CMY), in practice creating the black color is difficult by such superposition, because it is difficult to create absolutely monochromatic pigments (for instance, there might exist traces of cyan in the magenta pigment, etc.). In such cases, the black obtained will have shades of green, blue, or red. On the other hand, creating the black color by superposition of three pigments is not economic.

To get a large number of colors, the three primary colors used by printers are mixed in various proportions. This mixing can be physical or optical. The *physical mixing* of colors is only possible with liquid inks and it implies that two or more colors of ink actually mix together before drying. Since printers use inks that dry rapidly, the colors to be mixed must be applied to the paper simultaneously or in rapid succession. Only a few printers are based on the physical mixing of inks to increase the number of colors they generate.

The *optical mixing* of colors can be performed in one of two ways. One pigment of a certain color can be applied over another, or the colors can be applied in adjacent positions. Applying successive layers of pigments requires that the inks have a certain transparency. Most printer inks used today are transparent, which allows using them on both transparencies and on paper. The hue obtained by applying a transparent ink is, however, dependent on the color of the medium used.

When the colors are applied in adjacent positions and are not superposed, by placing dots of different colors in very close positions, the eye will not distinguish them as separate colors, but as a new color, the mixing being performed on the retina. This procedure is known as *dithering*. Most printers use this procedure to create a large number of colors. By this procedure, a pixel of the image is not represented by a single dot, but by a group of dots that is termed *super-pixel*. The problem that occurs with this method is that the perceived resolution of the color image will be lower. This resolution is limited by the size of super-pixels rather than the individual dots. For example, to print an image using eight bits for each primary color, the printer must use super-pixels formed by 8×8 dots. The resolution will be reduced accordingly, so that a printer with a resolution of 600 dots per inch will have a resolution of 75 dots per inch for color images.

The quality of color printers is indicated by resolution and number of levels or tones that can be printed for each dot. Generally, the higher the resolution and number of levels per dot, the higher the printing quality. In practice, manufacturers choose either a higher resolution or a higher number of levels per dot, depending on the main destination of the printer. For instance, for general applications it is more important to have a high resolution, while for graphic applications it is important to provide a photographic quality, with a high number of colors. Depending on the possible number of levels for each dot, there are two types of color printers: binary or with continuous tone.

With *binary* printers, it is not possible to have intermediate levels for the colors from which a dot is made. For a certain dot, the cyan, magenta, yellow and black dots are either active (on) or inactive (off). Therefore, each dot may have only 16 different combinations of toner or ink. Moreover, the black color combined with any other color will appear black, so that eight from the 16 combinations will appear the same. This means that each dot may only have nine distinct colors, plus the white color. The colors that cannot be represented directly are simulated by some form of color interpolation. These printers have a lower quality and a considerably lower cost than those that may vary the number of levels for each dot.

Continuous tone printers can generate many intermediate levels for each color a dot is made of. For instance, if the printer can create 256 different levels for each of the cyan, magenta, and yellow colors, then it can generate up to 16.7 million colors. In practice, the number of colors that can be generated is lower. These printers can create photographic quality printings.

5.5.2. Color Inkjet Printers

At present, the most widely used color printers are the inkjet printers. On these printers, generating colors is simpler than with other technologies, because it is possible to mix small amounts of liquid inks even after they have been deposed onto the paper to create intermediary tones. This way, it is possible to create a large number of colors and to achieve high quality prints from the viewpoint of color saturation.

Color inkjet printers allow both monochrome and color printing. The way the switching between the two operating modes is achieved varies between different models. Simpler printers may be equipped with a single cartridge, either for the black ink or for the colored inks. To change from monochrome mode to color mode or vice versa, the cartridges must be swapped over. When the black color has to be used on a color page, it will be generated by composing the three primary colors, with high ink consumption. More complex printers may be equipped with two cartridges, one for the black ink and one for the color inks. Other printers may contain separate cartridges for each primary color.

On most color inkjet printers, the speed of color printing is much slower than that of monochrome printing. This is because, many times, there are no separate print heads for each of the primary colors, but a single print head for the color inks. Usually, color printers have a separate print head for the black ink. Figure 5.11 illustrates the print heads of a Lexmark color printer. Monochrome printing is performed on a width of 56 dots, while color printing is performed on a width of 16 dots. Printing a line of color the same width as one in monochrome requires multiple passes.

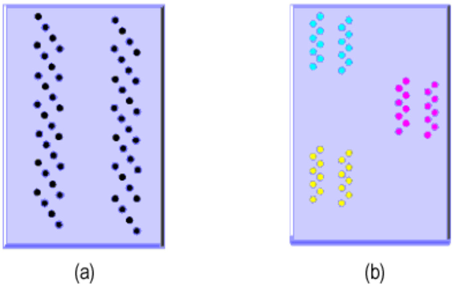

Figure 5.11. Placement of nozzles in the print heads of a color inkjet printer: (a) for monochrome printing; (b) for color printing.

To increase the range of pure colors that printers can generate, some manufacturers have designed six-color inkjet printers. These printers use two additional inks beyond the four common inks. Generally, the additional colors used are orange and violet. This results in a more realistic reproduction of photographs and less need to use other techniques for color extension, such as dithering.

Printing quality for inkjet printers in general, and color printers in special, is determined to a large extent by two elements: *ink quality* and *paper quality*. There are two types of ink that are used. The first type is slow-drying and it is used for monochrome printers. The second type is fast-drying and it is used for color printers. On these printers, since different inks are mixed, they need to dry as quickly as possible to avoid color alteration by merging of adjacent dots.

In general, the inks used for inkjet printers are based on pigments diluted in water, which may create some problems. On earlier generation printers, paper stain was a frequent problem, but later considerable improvements were made in ink chemistry. Although manufacturers have also made progress in the development of water-resistant inks, the results are not yet satisfactory. Some manufacturers offer inks that are not water-soluble or papers that allow fixing soluble inks to prevent altering the print results.

One of the manufacturers' concerns is the development of inks that allow printing on a wide range of media. The research aims to improve the dyes and pigments used for the inks, in order to ensure the quality of printing on various types of media, without the need to use special papers, with high costs.

Generally, dye-based cyan, magenta and yellow inks are used, with small molecules (less than 50 nm). These have high brilliance and allow to achieve a large color range, but they are not enough water-resistant and fade-resistant in time. Inks based on pigments with larger molecules (between 50 and 100 nm) are more waterproof and fade-resistant, but they cannot deliver an enough range of colors and are not transparent. For that reason, currently these pigments are only used for the black ink.

Ink fading represents another problem. The ultraviolet light or the ozone may attack the pigments, which may lead to color or hue changes. Among the inks used on inkjet printers, the black ink is the most stable, especially if it is based on carbon pigments. Color inks based on dyes are, however, less stable, and some hues may fade in a short time. Regular color inks are rated for only a few years. Some manufacturers, particularly those offering photographic printers, have designed permanent inks based on pigments whose color is rated for more than 100 years.

The type of paper used determines at a great extent the quality of printed images. It is possible to use a plain paper, but this does not allow to get high-quality color images. Currently, most inkjet printers require using a special coated or glossy paper to achieve photographic-quality reproductions. Such a paper reflects most of the incident light in the same direction, unlike a regular paper, which reflects the light in different directions. The cost of various types of special papers is high, so that manufacturers try to get high-quality images using a regular paper. This quality has been improved considerably over the last years, but using a special paper is still needed to achieve photographic quality. Some manufacturers, like Epson, have their own proprietary paper that is optimized for their printers using the piezoelectric technology.

One of the factors that determine the quality of paper is the absorption degree. The paper should absorb the ink only to a limited degree, since otherwise the ink dots will change their shape and the image clarity will be significantly reduced, especially at the borders of objects and text. To eliminate ink absorption, various types of special papers have been designed, which are coated with a thin layer of a material based on wax, gelatin, or polymers. On such papers, the ink will dry almost solely by evaporation and will diffuse only to a limited extent into the pores of paper, but the drying time will be much longer. The low absorption degree of these types of special papers is essential for achieving high resolutions.

5.5.3. Color Phase-Change Printers

Phase-change printers use a variant of the inkjet technology. Instead of using solvent-based inks that are fixed (that dry) by evaporation or absorption into the print medium, phase-change printers use inks that change state from liquid to solid.

The ink used by these printers is initially in the in form of solid wax sticks of different colors. The print head will melt a certain amount of wax from each color, and these are maintained in liquid state in four reservoirs inside the print head. The liquid wax is then transferred onto an intermediate drum with a system of nozzles, in a similar way to the ink in inkjet printers. From the intermediate drum, the image created is transferred onto the paper in a single step. The wax droplets, which are no longer heated, cool rapidly and return into solid state. Because of using solid ink, these printers are also called *solid inkjet* printers.

The first printer that used the phase-change technology was the *Pixelmaster* printer of the *Howtek* Company, introduced in the late 1980’s. Establishment of this technology has been made by Tektronix with the introduction of its *Phaser III PXi* printer in 1991. Tektronix, which was acquired by Xerox in 2001, has improved the phase-change technology to achieve higher quality. While for the *Pixelmaster* printer plastic-based inks were used, which formed little lumps on paper and sometimes clogged the print head, for the *Phaser III* printers wax-based inks were used and an additional step was added to the printing process, for flattening the solidified wax droplets with a roller.

Compared to inkjet printers, phase-change printers are less sensitive to the print media. The cost of these printers is lower than that of color electro-photographic printers. The quality achieved is high, but not as good as that of photographic reproductions.

5.5.4. Color Electro-Photographic Printers

Color electro-photographic printers have appeared later than color inkjet printers, because the technology used by monochrome printers poses a few problems to the color variant. The colors used are the same, cyan, magenta, yellow, and black. First, the primary colors of the image are separated and the image corresponding to each fundamental color is built sequentially on the photoconductive drum. After building the image of a certain color, the toner with the corresponding color is placed on the drum and the partial image is transferred either to an intermediate surface or directly to the paper (Figure 5.12). Forming a complete image thus requires four (sometimes, three) passes of the electro-photographic process.

In some electro-photographic printers, the paper makes four turns over the photoconductive drum; thus, each primary color is printed separately. In this case, the drum must be cleaned after printing each color, and the alignment of the paper must be rigorously maintained for all four passes. In other printers, the paper passes only once over the drum. The drum, however, must make four complete turns, while the toner is placed on the drum separately for each primary color. After placing the last color (black) on the drum, the final image is transferred onto the paper. Single-pass printers do not improve the printing speed, but they have the main advantage that paper alignment is no longer a problem. Only the proper alignment of the drum between the four passes must be maintained, which is easy to perform.

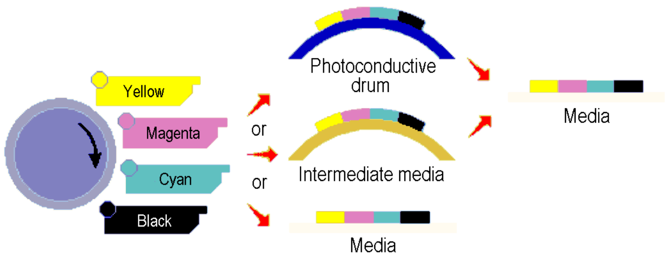

Figure 5.12. Principle of color electro-photographic printers.

Because of the multiple passes required to form a color image, the printing speed of color images is reduced to one-third or one-quarter compared to the printing speed of monochrome images. For example, a printer with a speed of 24 pages per minute for monochrome printing may have a speed of 6 pages per minute for color printing. Nevertheless, color electro-photographic printers are faster than other types of color printers.

There are color electro-photographic printers in which the processes of building the images for each primary color are performed simultaneously. The first printer of this type was the *Lexmark Optra Colour 1200N* printer, based on the LED technology. On this printer, there are four photoconductive drums for the four colors, and above each there is a LED array. The paper is passed in succession before each drum and each time the color corresponding to the particular drum is added. The advantage of this solution is that the color printing speed is nearly the same as the monochrome printing speed.

In addition to their speed, another advantage of color electro-photographic printers is the durability of their print result. This is due to the toner that is chemically inert, unlike most inks. Since the toner is fused onto the paper's surface and not absorbed into it, the print quality is higher than that of inkjet printers even when regular paper is used. Furthermore, by controlling the temperature and pressure during the fusing process, various prints can be obtained, from matte through glossy.

5.5.5. Color Dye-Sublimation Printers

Dye-sublimation printers, sometimes called *dye-diffusion* printers, allow to achieve photographic-quality prints. Initially, these printers have been used in demanding graphic applications and photographic applications. The advent of digital photography led to the spread of dye-sublimation technology, this technology being used in many photographic printers that emerged in the second half of the 1990's.

The printing process of these printers consists of applying dyes from a plastic film, which is kept in the form of a roll or ribbon. The film contains consecutive stripes of cyan, magenta, yellow, and black dye. The film passes across a thermal print head consisting of thousands of heating elements. The heat causes the dyes to sublimate, that is, turn from the solid state directly to the gaseous state, without passing through the liquid state. The gaseous dyes are absorbed by the paper. The amount of dye transferred is controlled by varying the intensity and duration of the heat.

When the dyes are absorbed by the paper, they tend to diffuse into the paper pores. The diffusion of dyes allows creating continuous tones of color as the result of blending together dyes of different colors. Because each of the three primary colors can have a large number of intensities (for example, 256), the color range is very large.

The cyan, magenta, and yellow dyes are applied successively to the paper. Over the print a clear coat is added to protect against ultraviolet light. With this technology, very high-quality results may be achieved. However, the procedure used is not economical. For instance, even if a particular image needs none of the pigments, the corresponding ribbon segment is still consumed.

On some dye-sublimation printers, the size of the printable area is limited. The print result is qualitatively similar to a color photograph. Many photographs are printed on paper using this type of printers. For example, Kodak uses dye-sublimation printers for the color prints it processes.

5.6. Printer Commands

5.6.1. Function of Commands

In order for the texts and images to appear on paper similarly to the way they are displayed on screen, the programs must sent various commands to the printer. These commands may specify all the basic operations to be performed by a simple printer, or may select various features of a more complex printer. The commands must be included in the data stream sent to the printer, and therefore the printer needs to distinguish one from the other the data that must be printed and the commands that specify how the data are to be printed. The commands are sent via the system driver of the printer.

In the simplest mode, to print a text the stream of ASCII characters from which the text is formed is sent to the printer. To specify the character set (the font) to be used for printing, the size of characters, their style, the spacing between characters, or the spacing between two consecutive lines of text, various commands must be sent to the printer before sending the characters of the text. Without these commands, the printer will use its default settings.

When the printer receives an ASCII code representing a character to be printed, it will read the bitmap representing the shape of that character from a ROM or RAM. The ROM contains the available character sets of the printer, and the RAM may be used to extend these character sets by downloading them from the computer. Based on the character bitmap, the printer's controller will guide the print head to generate that particular character. Many times, the controller has to perform scaling operations of the character size, because the character memory only contains the shape of characters of certain sizes.

To distinguish the commands from the codes of characters to be printed, either special control characters, with codes different from the codes of common characters, or character sequences preceded by a special character can be used. Usually, the special character that precedes these sequences is the *Escape* (ESC) character, and this is the reason why they are called *Escape sequences*.

5.6.2. Control Characters

Some commands, intended to peripherals in general and to printers in particular, are frequently used, reason for which they were included into the ASCII control character set. There are two groups of control characters. The first group contains the characters with codes between 0 and 0x1F, and the second group contains the characters with codes between 0x7F and 0x9F. The most used are the characters from the first group, which are recognized by the majority of equipment. Many printer manufacturers use the codes from the second group to print some special characters in various languages, so that these codes cannot be used as control characters on all printers.

Table 5.1 contains the ASCII codes of the control characters and their meaning. Not all the characters shown in the table are used for the printers.

Table 5.1. ASCII codes of control characters and their meaning.

Hex Code	Control Code	Abbreviation	Meaning
00	Ctrl-@	NUL	Null
01	Ctrl -A	SOH	Start of Heading
02	Ctrl -B	STX	Start of Text
03	Ctrl -C	ETX	End of Text
04	Ctrl -D	EOT	End of Transmission
05	Ctrl -E	ENQ	Enquiry
06	Ctrl -F	ACK	Acknowledge
07	Ctrl -G	BEL	Bell
08	Ctrl -H	BS	Backspace
09	Ctrl -I	HT	Horizontal Tab
0A	Ctrl -J	LF	Line Feed
0B	Ctrl -K	VT	Vertical Tab
0C	Ctrl -L	FF	Form Feed
0D	Ctrl -M	CR	Carriage Return
0E	Ctrl -N	SO	Shift Out
0F	Ctrl -O	SI	Shift In
10	Ctrl -P	DLE	Data Link Escape
11	Ctrl -Q	DC1	Device Control 1
12	Ctrl -R	DC2	Device Control 2
13	Ctrl -S	DC3	Device Control 3
14	Ctrl -T	DC4	Device Control 4
15	Ctrl -U	NAK	Negative Acknowledge
16	Ctrl -V	SYN	Synchronization
17	Ctrl -W	ETB	End of Transmission Block
18	Ctrl -X	CAN	Cancel
19	Ctrl -Y	EM	End of Medium
1A	Ctrl -Z	SUB	Substitute
1B	Ctrl -[	ESC	Escape
1C	Ctrl -\	FS	File Separator
1D	Ctrl -]	GS	Group Separator
1E	Ctrl -^	RS	Record Separator
1F	Ctrl -_	US	Unit Separator

5.6.3. Escape Sequences

The number of control characters available is low compared to the number of functions that modern printers may perform. To extend the number of control characters, *Escape* sequences are used. These sequences begin with the ESC control character (ASCII code 0x1B or 27). This character indicates that the following characters in the sequence must be interpreted as commands rather than printable data. In the simplest case, a single character follows after the ESC character. It is possible to abandon an *Escape* sequence with the CAN control character (ASCII code 0x18 or 24).

The sets of *Escape* sequences are specific to different types of printers. The major printer manufacturers have imposed certain standards regarding some sets of Escape sequences, sets that are also used by other printer manufacturers. This ensures the compatibility of smaller manufacturers' printers with the printers of important manufacturers, that is, emulation of some command sets that have been imposed as standards. The advantage is that the same drivers can be used for compatible printers. Often, printers emulate several command sets of other printers.

An example manufacturer who imposed a standard in the area of command sets for printers is Epson. The Epson command set had become a standard language for printers, and it is called Esc/P. In 1992, when Epson introduced its high-resolution inkjet printers, it extended the Esc/P set to include support for scalable fonts, graphic images, and page settings; the result was the Esc/P2 command set. Many modern inkjet and electro-photographic printers have emulation modes of the Esc/P2 command set. Table 5.2 contains command examples from the Epson Esc/P2 set.

Table 5.2. Example *Escape* sequences from the Epson Esc/P2 command set.

Sequence	Hex Code	Function
Esc (C	1B 28 43	Set page length
Esc (G	1B 28 47	Select graphics mode
Esc @	1B 40	Initialize printer
Esc 0	1B 30	Set line spacing at 1/8 inch
Esc 2	1B 32	Set line spacing at 1/6 inch
Esc 4	1B 34	Enable printing with italic characters
Esc 5	1B 35	Disable printing with italic characters
Esc *l* n	1B 6C n	Set left margin to column n
Esc Q n	1B 51 n	Set right margin to column n

5.6.4. PostScript

Page printers, such as electro-photographic printers, create an image of a full page before printing it. Nevertheless, describing a page as a raster or other form of bit image and sending this description to the printer is not efficient, because many pages contain mainly text. Moreover, it is difficult to make a description that will generate a printed page identical with the page on the screen (the concept known as WYSIWYG – *What You See Is What You Get*). To describe document pages efficiently and independently of the device, Adobe Systems developed in 1985 a specialized page description language, called *PostScript*. This is a programming language, derived from the *Forth* language, which specifies to a printer (or to other peripheral) how the text and graphics should be arranged on a printed page.

The *PostScript* language contains commands and code sequences that describe graphics elements within a page and indicate the position into which they should be placed on the printed page. These commands describe the page contents in vector form. The commands are sent to the printer through its driver, and the printer interprets the commands and generates the rasterized image to be printed. Hence, the graphic operations are performed by the printer, which is optimized for implementing these operations. On the other hand, the printer must contain a powerful processor to interpret the commands and to execute them in a short time.

The advantage of the *PostScript* language is its versatility. The language uses outline fonts, which can be scaled to any size. In addition, the language is device and resolution independent, which means that the same code can be used for a printer with a resolution of 300 dots per inch and a typographic typesetter with a resolution of 2400 dots per inch, producing the highest possible quality images at the available resolution.

In 1990, Adobe Systems announced the second version of the language[2], called *PostScript Level 2* (the first version was later called *Level 1*). The new version introduced several enhancements. The interpretation speed of the language increased four to five times because of a new font rendering technology. Version *Level 2* contains a new generalized class of objects, called resources, which can be pre-compiled and transferred to the memory of a *PostScript* peripheral. Furthermore, the memory is managed more efficiently, because it is no longer required that programs pre-allocate memory for downloaded fonts and graphic images. In addition, the language has built-in compression and decompression features, so that large graphic images can be transmitted faster to the printer in compressed form.

Version *Level 2* of the *PostScript* language also enhanced font handling. While the first version limited font sizes to maximum 256 characters each, the second version allows defining composite fonts containing an unlimited number of characters. Larger fonts are particularly useful for languages that do not use the Roman alphabet and for those that have many diacritical marks.

A newer version of the language is *PostScript Extreme*. This version is intended for printing systems with very high performance, such as digital typographies.

Use of the *PostScript* language requires to pay license fees, and this is the reason why many interpreters of the language have been created. Such an interpreter is the *GhostScript*

[2] Each version of the *PostScript* language has numerous sub-versions.

program. Other interpreters are built in various printers or may be added later on memory cards. However, not all of these interpreters are fully compatible with the original *PostScript* language.

The *PostScript* language is most efficient in describing pages containing texts. In describing graphic images, *PostScript* (as well as other page description languages) may slow down graphic printing, especially color printing. To print a graphic image, the computer must first translate the image into commands of the page description language. Then the printer must translate these commands into the image raster that will be printed. This double conversion requires time. If printing is performed via a specialized software driver of the printer, only the bitmap of the image is sent through the printer interface. Then the printer can quickly rasterize the bitmap image, and the printing time can be decreased. The disadvantage is that each operating system requires its own software driver.

5.6.5. PCL

Overview

PCL (*Printer Control Language*) has been developed in the late 1970's by Hewlett-Packard for their dot matrix printers, and has been used after that for their inkjet and electrophotographic printers. After its introduction, the language has been extended and improved; currently, the sixth version of the language is used, PCL 6. The aim of developing this language was to provide an efficient method to control various types of printers. Unlike the *PostScript* language, PCL is not a page description language, its commands being *Escape* sequences.

PCL is specific to Hewlett-Packard (HP) printers. Practically, the language is used by all HP printers, but the different versions of the language are not always fully compatible with the previous versions. However, usually the printers will ignore the commands that they do not recognize.

There are six major versions of PCL. These versions were created in accordance with printer technology developments and application software improvements. The first versions, PCL 1 and PCL 2, were used by dot matrix printers and inkjet printers that existed in the early 1980's. Most of the *LaserJet* series printers appeared later also support these versions of the language. The PCL 1 and PCL 2 versions only allow printing texts, specified by ASCII characters.

Version PCL 3, released in 1984, was the first version that included commands for printing graphic images. This version was first used by the *HP LaserJet* series printers and then by the *HP LaserJet Plus* series. PCL 3 allowed for the use of bitmapped fonts and graphic images, quickly becoming an industry standard. Printers manufactured by other companies emulated the PCL 3 commands of the *HP LaserJet Plus* printer.

Version PCL 4 was introduced in 1985, at the same time as the *HP LaserJet II* series printers. As improvements, this version of the language added the capability to use macros, multiple fonts on the same page, larger bitmapped fonts and graphics.

Version PCL 5 represents a significant enhancement of the language by the ability to use scalable fonts, outline fonts[3] and vector graphics. Vector operations are based on HP-GL (*Hewlett-Packard Graphics Language*), language that has become an industry standard for commanding plotters. This version has been introduced in 1990, and has been initially used for the *HP LaserJet III* series printers. This is the most widely used version to allow compatibility between different types of printers, including manufacturers other than HP. Version PCL 5 has been developed for complex desktop publishing, office, and graphic design applications. The results obtained by using this version of the PCL language are qualitatively comparable to those of *PostScript* printers, with the advantage that the use of the PCL language does not imply license fees. The disadvantage is that PCL is not device independent.

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[3] Outline fonts represent individual characters by mathematical descriptions, which define the outline of characters. Thus, characters are not defined by dot models. Based on the mathematical description of a character, the image of the character can be generated for any required size.

PCL 5E (*Enhanced*) is an enhanced version of the PCL language, used by the numerous variants of the *HP LaserJet 4*, *HP LaserJet 5*, *HP LaserJet 6*, *HP LaserJet 8000*, and *HP LaserJet 9000* series printers. The enhancements included to this version comprise the possibility to select from a wider range of fonts and the capability of bidirectional communication between the computer and printer. Version PCL 5C (*Color*) added commands needed for color printing, and it was intended for various HP color printers.

Version PCL 6 is very different from previous versions of the PCL language, with this version the language becoming modular and object-oriented. Introduced in 1996, version PCL 6 was initially implemented on the *HP LaserJet 5* series printers. This version was intended for applications requiring intensive graphics processing, providing a set of graphics primitives that accelerate the printing of complex graphic images. In addition, this version reduces the processing to be performed by the computer, reduces the amount of data that must be sent to the printer, and provides WYSIWYG printing. Version PCL 6 ensures compatibility with prior versions of the PCL language.

PCL contains three types of commands: control characters (similar to those described in Section 5.6.2), native PCL commands, and HP-GL vector commands. In addition to these functions, the PCL commands allow to set parameters that control subsequent functions, for example, selecting a particular font. After setting a parameter, the setting remains in effect until the same parameter is set again, another command alters the parameter, or the printer is reset. For this reason, applications usually reset the PCL printers at the beginning of each print session in order to operate with known parameter settings.

Types of PCL Commands

PCL commands must be sent to the printer in the proper order. This order results from a command hierarchy and the arrangement of commands into several groups. The command groups of the PCL language are described next.

Job control commands are sent at the beginning of a print job and remain in effect throughout the entire print job. These commands contain information such as the position where the image should appear on the page, the paper bin to use, or the measuring units that will be used for the page description.

Page control commands set the characteristics of the page used for printing a document, such as: page size, page orientation, left and right margins, or line spacing.

Cursor positioning commands initialize the coordinates of the point of reference for printing text, point of reference called the *cursor*. The PCL cursor is similar to the cursor on a monitor screen, indicating the position the next character will print. The position specified for the cursor may be the absolute position on the page or the relative position to the previous position.

Font selection commands allow to change the character set in use. In the PCL language, a font is identified by several of its characteristics such as: font name, character style, spacing type, height, or pitch. The style of the characters can be normal, bold, italic, or bold and italic. Considering the spacing type, fonts can be proportional or monospace. In a *proportional font*, each character occupies a horizontal space that is proportional to its width (for instance, letter *i* occupies lesser space than letter *m*). A *monospace font* is one in which the characters occupy the same horizontal space, regardless their width (Figure 5.13). The character height is indicated in typographical points; this unit of measure is equal to 1/72 inches (approximately 0.35 mm). The printing density (*pitch*) is a characteristic used with monospace fonts, indicating the number of characters per inch (cpi). Usually, each of these characteristics requires a separate PCL command. To increase processing speed, PCL printers keep two active fonts simultaneously, one primary and another secondary; switching between these fonts is accomplished with a single command.

Figure 5.13. Illustration of proportional and monospace fonts.

Font management commands control the downloading and manipulation of programmable fonts. These commands allow transferring a font from the computer into the printer's memory, to select it to be used for printing, or to remove fonts from memory.

Graphics commands indicate to the printer how to build raster images or specify operations such as filling a rectangular area with a certain pre-defined pattern. Generating more complex graphic shapes requires the use of HP-GL vector commands.

Print model commands are graphics commands that allow to fill images and characters with a certain color or pre-defined pattern, depending on the operation supported by the particular printer.

Macro commands reduce the number of commands that must be sent to the printer to perform the most frequent tasks. For example, a single macro can be used to describe a complete page format. Macros can be temporary or permanent. Resetting the printer erases temporary macros, but leaves permanent macros in memory. Switching off the printer erases both types of macros.

PCL Command Structure

Each PCL command represents an *Escape* sequence comprised of two or more characters, from which the first character is ESC. Some PCL commands contain a single character after the ESC character. This character may have an ASCII code between 0x30 (48) and 0x7E (126). Other commands contain one or more parameters in the character string; these are called *parameterized commands*. In general, parameterized commands have the following form:

`ESC` *`X Y`* `#` *`Z1`* `#` *`Z2`* `#` *`Zn`*

- *X* represents the *parameterized character*, which identifies a command and indicates that additional parameters follow. The code of this character may be comprised between 0x21 (33) and 0x2F (47).
- *Y* represents the *group character*, which indicates to the printer the type of function to perform. The code of this character may range between 0x60 (96) and 0x7E (126).
- *#* represents a *value field* and specifies a numerical value of one or more characters in BCD code. That is, the field is formed of ASCII characters with codes between 0x30 (48) and 0x39 (57). The numerical value may optionally be preceded by the + or – sign and may contain the decimal point. If a command requires a value field and this field is missing, the printer will assume a value of zero.
- *Z1* and *Z2* specify the *parameter* associated with the preceding value field. Each parameter may be a character with an ASCII code in the range 0x60 (96) to 0x7E (126). Although in the preceding example two parameters are illustrated, a PCL command may contain one or several parameters.
- *Zn* is the *termination character*, which specifies a parameter for the preceding value field, like a normal parameter, but at the same time notifies the printer that the *Escape* sequence has ended. The termination character may have an ASCII code between 0x40 (64) and 0x5E (94).

The PCL language allows combining two or more *Escape* sequences into one, provided that both the parameterized and the group characters (*X* and *Y* in the previous example) of the sequences are the same. In the new sequence, all the letters, except the termination character (`Zn` in the previous example), must be transformed into lower case. To combine multiple commands into one, the first three characters of every command are eliminated, excepting the first command, the remaining characters of every command are concatenated, and all the letters are transformed into lower case, excepting the termination character. For example, the sequences `ESC ( s 0 P` and `ESC ( s 9 H` may be combined into the sequence `ESC ( s 0 p 9 H`.

5.7. Communication with USB Printers

For printing files to USB printers, system functions such as `CreateFile()` and `WriteFile()` can be used. This assumes that a USB printer is attached to the computer and its driver is installed. Before using these system functions, several steps should be performed in the user application. Some of these steps are the same as the steps required for establishing communication with HID-class devices, described in Section 4.11 of the laboratory work *Universal Serial Bus*. The steps required for a *Windows* operating system are described next.

1. Define a GUID (*Globally Unique Identifier*) for USB devices:

   ```
   static GUID GUID_USB = GUID_DEVINTERFACE_USB_DEVICE;
   ```

   This definition replaces the call to the `HidD_GetHidGuid()` function and the definition of the GUID structure for HID-class devices. The definition requires to include the initguid.h and usbiodef.h header files.

2. Call the `SetupDiGetClassDevs()` function to get information about the USB devices attached to the computer. This step is similar with the same step required for HID-class devices, except that the first parameter of the function should be the pointer to the `GUID_USB` structure. Display an error message if the function returns the value `INVALID_HANDLE_VALUE`. In this case, the communication with a USB printer cannot be established and the operation is completed.

3. Steps 3-9 must be repeated in a loop for each USB device; the iteration count may be set, for instance, to 30. Call the `SetupDiEnumDeviceInterfaces()` function to get information about the interface of a device from a list of USB devices. This step is similar with the same step required for HID-class devices, except that the third parameter of the function should be the pointer to the `GUID_USB` structure. After calling this function, if the code of the last error is `ERROR_NO_MORE_ITEMS`, exit the loop with a `break` instruction and continue with Step 10.

4. If the function call in Step 3 has been successful, call the `SetupDiGetDevice-InterfaceDetail()` function to retrieve detailed information about the interface of the device selected in Step 3. This function should be called twice; the first call is performed identically with the same call required for HID-class devices, with the third parameter set to `NULL` and the fourth parameter set to zero. After the first call, memory with the appropriate size for storing detailed information should be allocated, and the `cbSize` member of the `SP_DEVICE_INTERFACE_DETAIL_DATA` structure should be initialized, operations that are also performed identically with the same operations required for HID-class devices. Before the second call to the same function, declare a variable of type `SP_DEVINFO_DATA` and set the `cbSize` member of this variable to `sizeof (SP_DEVINFO_DATA)`. For the second call, replace the last `NULL` parameter with the pointer to the variable of type `SP_DEVINFO_DATA`. After calling the function, the `SP_DEVINFO_DATA` structure will contain information about the device; this structure will be required in a later step. If the function returns `FALSE`, display an error message, free the memory allocated for the detailed information, and continue with the next iteration from Step 3.

5. Call the `CreateFile()` function to open the communication with the device. For calling this function, set the second parameter (access mode) to `GENERIC_WRITE` and the third parameter (share mode) to `FILE_SHARE_WRITE`. If the function returns the value `INVALID_HANDLE_VALUE`, display an error message and continue with the next iteration from Step 3.

6. Free the memory allocated in Step 4 for the detailed information about the device interface.

7. If the `CreateFile()` function returned a valid file handle, determine the descriptor string of the device by calling the `SetupDiGetDeviceRegistryProperty()` function. The parameters of this function are the following: the handle returned by the `SetupDiGetClassDevs()` function in Step 2; the pointer to the `SP_DEVINFO_DATA` structure; the `SPDRP_DEVICEDESC` option to specify that the function should return the descriptor string of the device; `NULL`; the pointer of type `PBYTE` to a buffer defined by the user into which the function will store the descriptor string; the length in bytes of the allocated buffer; optionally, the pointer to a variable of type `DWORD` that will receive the size of the buffer that is required to hold the requested property. When the call is successful, the function returns the value `TRUE`.

8. Compare the descriptor string obtained in Step 7 with the descriptor string of USB printers, "USB Printing Support". In some cases, the descriptor string of USB printers is "USB Composite Device" or, depending on the printer driver, a different one. If the strings match, exit the loop with a `break` instruction and continue with Step 10. If the strings do not match, continue with Step 9.

9. Close the file opened in Step 5 by calling the `CloseHandle()` function, increment the device index, and continue with Step 3 to get information about the interface of the next device.

10. Call the `SetupDiDestroyDeviceInfoList()` function to release the memory allocated for the information about the devices. At this point, the operation to establish the communication with the printer is completed.

After establishing the communication with a USB printer, an application may send to the printer the contents of a .prn file generated for the particular type of printer by calling the `WriteFile()` function. For calling this function, the handle returned in Step 5 by the `CreateFile()` function should be used.

5.8. Applications

5.8.1. Answer the following questions:

a. What are the advantages and disadvantages of inkjet printers?
b. What are the advantages and disadvantages of thermal technology used for inkjet printers?
c. What are the advantages and disadvantages of piezoelectric technology used for inkjet printers?
d. What are the advantages and disadvantages of electro-photographic printers?

5.8.2. Create a *Windows* application for establishing communication with a USB printer. As model for the *Windows* application, use the AppScroll-e application available on the laboratory web page in the AppScroll-e.zip archive. Perform the following operations to create the application project:

1. In the *Visual Studio 2022* programming environment, create a new empty *Windows Desktop* project with the *Windows Desktop Wizard*. Check the *Place solution and project in the same directory* option to avoid creating another folder for the solution.

2. Verify that the active solution platform is set to x64.

3. Change the *Character Set* project property by opening the *Properties* dialog window. In this window, expand the *Configuration Properties* option, expand the *Advanced* option, select the *Character Set* line in the right tab, and choose the *Not Set* option.

4. Copy to the project folder the files contained in the AppScroll-e.zip archive and add all the files to the project.

5. Copy to the project folder the files from the Printers.zip archive, available on the laboratory web page. Add to the project the SetupAPI.h, initguid.h, and usbiodef.h header files.

6. Specify the SetupAPI.lib file as additional dependency for the linker.

7. Open the AppScroll-e.cpp source file, delete the `#include "Hw.h"` directive, and add `#include` directives for the SetupAPI.h, initguid.h, and usbiodef.h header files (in this order).

8. In the `AppScroll()` function, delete the sequences for initializing the HW library with the `HwOpen()` function and for closing the HW library with the `HwClose()` function.

9. Select *Build* → *Build Solution* and make sure that the application builds without errors.

In the AppScroll-e.cpp source file, write a function to establish communication with a USB printer attached to the computer. The function returns the value `TRUE` if communication with a USB printer has been established and the value `FALSE` otherwise. Follow the steps described in Section 5.7 for writing the function. For details on the parameters of a function, access the Windows Hardware Developer documentation by placing the cursor inside the function name and pressing the F1 key.

After writing the function, include the call to this function in the `AppScroll()` function and display a message showing whether communication with a USB printer has been established. Connect a printer to a USB port of the computer, and then verify the operation of the function.

5.8.3. Extend Application 5.8.2 by writing a function to send the contents of a .prn file to a USB printer. For generating a .prn file, open a text file with a text editor such as *Notepad* and select the *File* → *Print*... option. In the *Print* dialog window, select the *Samsung CLP-310 Series* printer, check the *Print to file* option, and select the *Print* button. Enter the file name in the *Save Print Output As* dialog window and select the *Save* button. The input parameter of the function is a pointer of type `PCHAR` to the character string representing the name of the .prn file. The function returns a value of type `int`, as described next. The function calls the `CreateFile()` function to open the .prn file for reading. If opening the file was unsuccessful, the function returns the value 1. Otherwise, the function performs repeatedly, in an infinite `while` loop, the following operations:

1. Call the `ReadFile()` function to read from the .prn file a number of bytes corresponding to the size of a read buffer; this buffer should be declared of type `BYTE`.

2. If reading from the file was unsuccessful, the function closes the .prn file and returns the value 2. If reading from the file was successful and the number of bytes read is 0, which means that the end of the file has been reached, the function closes the .prn file and returns the value 0.

3. Otherwise (if reading from the file was successful and the number of bytes read is not 0), the function sends the bytes read to the printer using the `WriteFile()` function, with the access handler returned by the `CreateFile()` function called in the function for establishing communication with the printer.

4. If the call to the `WriteFile()` function was unsuccessful, the function closes the .prn file and returns the value 3. Otherwise, the operations in the `while` loop are continued.

After writing the function, include the call to this function in the `AppScroll()` function, after the call to the function for establishing communication with a USB printer. Connect the *Samsung CLP-315* printer to a USB port of the computer and verify the operation of the application.

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