INTRODUCTION TO DIGITAL PRINTING TECHNOLOGY

Printing industries are increasingly adopting digital technologies to complement or replace analog ones. The terms digital and analog (or analogue) designate both types of signals for representing data and methods of print reproduction. Analog signals and computers rely on discontinuous patterned transmissions of discrete amounts of electricity of light to communicate data.

Some of the earliest electric computers were analog.

Analog printing methods reproduce images with like images. Screen printing, for instance, is an analog print method that employs film positives and negative stencils which resemble the original image to create prints. Similarly, lithography uses analogous images on plates to transfer ink to print substrates. Flexography, etching, rotogravure and other analog print methods employ other forms of analogous image transfer. All of these methods reproduce images from a master image. Unlike these analog printing technologies which use stencils or plates containing full sized images, digital printing approaches assemble each image printed from a complex of numbers and mathematical formulas. They configure images from a matrix of dots or pixels. These use digitally controlled deposition of ink, toner or exposure to electromagnetic energy such as light to reproduce images.

Market forces and the desire for digital printing's advantages are driving it's development and adoption. Print purchasers want to eliminate the risks and expenses of maintaining inventory. Batch printing and mass production are giving way for some market applications to shorter print runs and mass customisation. While analog print methods best address the needs of mass production and high quality printing, digital printing can best serve demands for variable information printing, personalisation, customisation, quick response, just-in-time delivery, and short print runs. Printers are employing both digital and analog print methods to satisfy their customers needs. They can perform complementary functions, each doing what it does best.

ADVANTAGES OF DIGITAL PRINTING

- Digital printing requires minimal press set-up and has multicolour registration built-in to its system. This eliminates many of the front-end time consuming processes and permits quick response and just-in time print delivery.
- Digital processes can vary every print "on-the-fly" i.e. while production printing, providing variable data, personalisation, and customisation.
- Most digital printing technologies are non-contact printing which permits printing of substrates without touching or disturbing them. This eliminates image distortion encountered in some analog processes such as screen printing. It also does not require as aggressive substrate hold down methods which can distort or damage some substrates such as fabrics.
- Digital technologies can print proofing; sample and short runs more cost effectively than analog methods. Digital colour printing processes offer a range of colour processes including 3 colour process (CYM), 4 colour process (CYMK), 5,6,7 & 8

extended gamut colour options in addition to some spot colours. These match growing market demand for full colour.

- Most digital print processing requires less or no colour overlap or trapping.
- Digital printing does not use film masters, stencils, screens or plates. It requires much less space for archiving text and images than analog printing methods require.
- Generally, digital printing uses less hazardous chemicals, produces less waste and results in less negative environmental impact than analog technologies.
- Digital printing is employing sophisticated colour matching and calibration technology to produce accurate process colour matching.
- Digital web printers can print images limited only by the width of fabric and the length of the bolt or roll. They can print panoramas and are not restricted to repeat patterns.
- Digital files are usually easier and quicker to edit and modify than analog photographic images.
- Designers, artists, photographers, architects, and draftspeople are increasingly creating and reproducing their work digitally. Digital processing has replaced optical and manual methods for typesetting and page composition. Telecommunication has largely converted to digital processing. One can use the same digital files for electronic media, such as Internet, CD-ROM, Video and TV, print media and multimedia.
- One can readily convert analog images and text to digital with scanning and optical character reading (OCR) software.
- Digital files are easy to transport and communicate. One can send a digital file to any digital printer on the planet within seconds. This permits distribution of design to many locations for quick response printing. Industries are adopting digitally generated and communicated art and print copy.

DISADVANTAGES OF DIGITAL PRINTING

- Most digital technologies have slower throughput as compared with comparable analog printing.
- Digital printing will often cost more per copy than analog printing for longer print runs.
- It often requires specially prepared and coated substrates.
- Most digital printing technologies deposit very thin ink or toner layers. These limits necessitate layering for applications requiring thicker deposits, resulting in slower operation.
- Digital inks and toners are limited in capacity and carry high price tags.
- Most digital devices are printing transparent chemistry which limits their use for white or light substrates.
- Some processes currently have difficulty matching colour consistently.
- This is new technology which requires investment for training as well as equipment.

ADVANTAGES OF ANALOG PRINTING

- Analog print technologies print many multiple copies quickly and inexpensively.
- Offset lithography and gravure produce very high resolution and image quality.
- Analog printing usually does not require expensive coated substrate to print satisfactory images as most digital printing does.
- Its inks do not require the high degree of refinement and small particle pigment sizes which most of digital printings do. Most analog inks cost less than most digital ink.
- Analog screen printing provides a wide range of single pass ink deposition thicknesses.
- Screen printing can print opaque inks which cover dark substrate surfaces.
- Analog printing can print either spot or process colours. Printers can maintain their own colour "kitchens" from which they can match virtually any colour.
- Analog methods are existing technologies installed base presses, trained operators and established markets and customers.

DISADVANTAGES OF ANALOG PRINTING

- Analog printing permits only very limited variable data printing, such as letterpress numbering.
- Analog methods require prepress set up and preparation.
- Generally, these types of printing are not cost effective for very short run printing and proofing.
- Analog printing can generate significant waste ink, chemical exposure and deleterious environmental impact.
- These printing methods use costly film for screen or plate exposure. The archiving of films, plates and screens demand considerable cataloguing, storage space and furniture. In addition, these films deteriorate with age.
- Images are limited to the size of the plate or screen image area. Larger prints require that one repeat the pattern and that the design permits seamless connection of repeated patterns.
- Many analog printing operations use ageing presses.

THE WEDDING OF ANALOG & DIGITAL

The printing industry has begun to marry the strengths of analog to those of digital printing. It has adopted digital processing for operations requiring one or a small number of images, such as art, page layout, screen and plate making, while retaining analog technology for reproducing large numbers of copies. The Heidelberg "Quick Master" combines the rapid image creation and set up of digital plate making and controls with the fast production speeds and print quality of analog offset lithography. Gerber, Luscher, Kiwo, Richmond Graphic Products Ins & Sign-Tronics computer to screen exposure masking systems also combine the strengths of digital processing with those of analog printing.

Other scenarios combine digital for printing variable information with analog for consistent data and graphics. Garment hang tags will combine analog methods, such as flexography or offset printing for logo, product identity and trademark graphics and digital methods, such as thermal transfer to print bar codes, sizing and other variable information. Still another would screen print repetitive images on light coloured garments, but would digitally print personalised or customised drop-in names of persons or places.

Whether one chooses digital or analog print methods or a combination of them for applications, one needs to measure and examine a number of parameters to effectively compare and choose among the technologies. The parameters include: image quality and resolution, production print and processing speeds, indoor and outdoor application durability, environmental impact and cost, colour and image consistency and reproducibility, and costs per print.

IMAGE QUALITY & RESOLUTION

Both analog and digital image quality and print resolution involve a complex of phenomena. One needs to understand the relationship of these to compare different printing technologies effectively. Resolution is usually indicated with terms such as lines per inch (lpi), lines per centimeter (lpc), dots per inch (dpi), or dots per centimeter (dpc). Inkjet images are composed from a grid of pixels, i.e. picture elements or dots. The number of these dots per linear inch in the x direction and the number of dots per linear inch in the y direction indicate the dpi resolution of a print. Software can usually instruct a printer to construct its lines from one or more rows of contiguous pixels. If one used 4 pixels per line on a 360 dpi matrix, one would be printing 90 output. In actuality these terms, dpi and lpi, describe only one aspect of what is termed apparent resolution, i.e. the resolution we perceive. Another factor is grayscale or gray levels. This involves the number of different sizes or grays a pixel dot in a matrix can have. In inkjet printing, this involves the number of droplet sizes per pixel dot.

Matrix cluster patterns and Raster Image Processor (RIP) algorithms can also affect apparent resolution, but these are largely software rather than hardware factors. Digital printing addresses its ink or toner to a grid or matrix. Digital software image processing can offer a large number of matrix patterns including random patterning. It also permits a single master or print image to contain multiple matrices. For instance lettering might be generated in a pattern which favours line acuity, while a photographic image is generated in a pattern which permits the desired degree of contrast and pixel gradation.
Focusing on the relationship between image output quality and print hardware factors, Rodney Shaw of Hewlett-Packard suggests “digital image-quality descriptors which allow for absolute performance comparisons between diverse imaging technologies, both analog and digital”. One of these descriptors is a digital noise scale (DNS). This model for comparison adapts electronic communication’s signal-to-noise ratio analysis. It uses a 0 to 10-noise scale, delineated in Table 1, which encompasses the gamut of conventional photographic image noise of what is commonly called graininess.

Figure 1: Correlation of Apparent Resolution with DPI and Gray-Levels

Adapted from: Rodney Shaw, "Image Quality Considerations for Printing Digital Photographs" in the Proceedings of IS&T's NIP 13: 1997 International Conference on Digital Printing Technologies

Higher resolution comes at the price of tone and image contour contrasts. The frequency of one's dots (dpi) is inversely proportional to the square root of the tone level. Increasing dpi to obtain finer detail and reduce matrix visibility will also reduce the picture's tone contrasts and increase the chances of false contouring and perceived image distortion. Print application viewing distance id the key factor in striking this balance. At a far distance, one needs higher tone levels but not high dot frequency for the perception of continuous tone, while one requires high frequencies and apparent resolution close up but not high tone levels. Printers have to find the balance between high resolution and high tone quality to suit each application. Billboards viewed from a distance of a 100 feet could have a resolution at of 20 dpi with a binary grayscale but appear to be a continuous tone images, while images viewed at a distance of 2 feet would require a 1000 dpi resolution with a binary grayscale. Binary grayscale means that either there is one or zero dots of one invariable size at pixel cells in an image matrix. The higher the number of possible grays (or value variations) per pixel, the higher the apparent resolution. Also the higher the number of dots or lines per inch, the greater the resolution.

TABLE 1: DIGITAL NOISE SCALE

DNS	Photo-Grain
10	Off-scale
8	Very coarse
6	Coarse
5	Moderately coarse
4	Medium grain
3	Fine grain
2	Very fine
1	Extremely fine
< 1	Microfine

For digital printing, such as inkjet, the noise level is a function of a print's dpi and the number of its gray levels. The higher the DNS number, the lesser the apparent resolution, the lower the greater. Figure 1 plots the relationship of dpi and the gray-levels against the digital noise scale.

PRODUCTION PRINT & PROCESSING SPEEDS

When comparing systems, one needs to look not only at the through-put speed of a printer, but also at the total processing time to create images including pre- and post-press time. The rate at which printing equipment produces product or adds value to it, in part, determines how much one can spend for its purchase or use.

OTHER POINTS OF COMPARISON

- Indoor and Outdoor Application Durability
- Environmental Impact and Cost
- Colour and Image Quality, Consistency and Repeatability
- Costs per Print
- Capital Equipment Costs
- Turnaround Time

DIGITAL PRINTING TECHNOLOGIES

Digital printing encompasses many technologies. These include various forms of inkjet, thermography, electrography and electro-static printing, ionography, magnetography, and digital photographic imaging and developing. None of these require a physical master but instead rely on digital data to create images.

HYBRID DIGITAL-ANALOG TECHNOLOGIES

Both analog and digital printing methods have advantages which the other lacks. Numerous opportunities exist for combining the strengths of each to garner the best of both worlds. The digital take over of pre-press analogue operations illustrates this example. Pre-press requires the generation of a single master which is best generated digitally. Once created, analogue printing can reproduce large numbers of it cost effectively. Digital can print variable information in a print job, while conventional prints the unchanging elements. Other marriages are also possible to use the best of both.

CONCLUSIONS

Inkjet technology has developed to a point where it is driving a growing multi-billion dollar industry worldwide. The development of chemistry for this printing technology is expanding its applications beyond paper printing to textile and industrial printing and fluid deposition. Other digital technologies are also providing the advantages of digital printing technologies in future articles.

Market demands for reduced inventory risk, quick response, variable information processing, personalization and customization are driving the adoption of digital imaging and inkjet printing technologies. They have grown to dominate niches and segments of the printing industry. Its expansion will continue for new applications and to replace analog printing's market share.

IT strategies projects that the greatest growth for inkjet printer sales will occur for the in-house corporate market followed by the Professional print for pay market. Current inkjet configurations cover productivity ranges from 1 to 200 square meters per hour. As production speeds and print quality increases and capital and consumable cost decrease, more print providers will adopt one or more forms of digital technology with inkjet leading the way. Trends indicate that wide-format electrostatic printing will experience somewhat slower growth. Novel digital technologies have to develop some track record before one can predict their role and market penetration. Analog printing technologies will continue to hold quality and production speed advantage for the next decade, but digital improvements will continue to erode analog market share.

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BINARY CONTINUOUS INKJET

The advantages of binary inkjets are their speed, proven track record, high reliability, and a large range of available chemistry for many applications. The disadvantages are initial systems cost and lower resolution of some current offerings than drop on demand printers, the need for low viscosity electrolytic inks, and the need for refiltration resulting in some waste ink. Hertz binary continuous inkjet, such as those from Stork and Iris, offer high resolution but with slow image production speeds, drum-limited format, and high capital and consumables costs.

MULTILEVEL CONTINUOUS INKJET

The now defunct technology application development company, Enblene, developed a demonstration T-shirt printing device employing the Imaje continuous inkjet heads and UV curable water-based pigmented inks. The first direct digital garment printer could image on cotton, linen, rayon, silk, wool, polyester, polyamides, Lycra, and sponge. The printed images altered the character of the fabric's hand so slightly as to be indistinguishable. In addition to the UV inks textile inks, Toxot, the research and development arm of Imaje, developed a water-cased pigment-loaded thermally cured inkjet color ink which exhibits greater color density, wash fastness, and adhesion that it's water soluble UV curable predecessor. The Emblene team established that the Imaje heads and UV ink could print textiles. Continuous inkjet heads can cost about $5,000 per head, piezoelectric heads range from about $30 to $3,000, and thermal inkjet heads about $20. Continuous heads offer very high reliability and resistance to failure commensurate with their cost.

Continuous inkjet heads are hand assembled while the production of thermal inkjets and the Epson multi-layer Stylus systems are automated. A few tens of thousands of continuous inkjet print heads satisfy worldwide demand each year. While companies, such as Hewlett Packard, Canon and Lexmark produce drop on demand inkjets by the millions. Large scale productions of many drop on demand print heads keep their costs very low. Their reliability is considerably less than continuous printers. This makes CIJ effective for high volume, long term print running.

Emblene had produced commercially acceptable T-shirt prints with a set of four CYMK scanning Imaje/Toxot inkjets operating at 120 dpi. Theoretically, a configuration involving dedicated arrays of Imaje/ Toxot continuous inkjets could print bolt textile at a rate of 600 running meters per hour at 180 dpi. For 1.5-meter wide bolts of fabric, this would yield production rates of 900 square meters, or about 9,000 square feet, per hour. (Toxot is currently constructing a 120 dpi 6 color multilevel CIJ array capable of printing two meter widths of floor vinyl at production rates of 2,400 square meters per hour.) Though still falling short of rotary screen printing's cruising production rates of 60 to 90 meters per minute or 3600 to 5400 meters, it is considerably faster than drop on demand inkjet printing capability. In addition, rotary screen printers usually print elastomeric and other dimensionally unstable fabrics at slower speeds of about 20 meters per minute. For print jobs which could accept its resolution, continuous inkjet could compete with rotary screen printing for short to medium production runs, elastomeric fabrics, and for on-demand printing.

The advantages of multilevel continuous inkjets are their speed, their ability to cover a larger band width print area with one pass, reliable operation and long print head life over thermal or piezo drop on demand printers, proven track record, and available chemistry.

The disadvantages of multilevel continuous inkjets are that they initially cost more than drop on demand printers, they currently operate at resolutions lower than most drop on demand printers, they are limited by their requirements for inks with extremely low viscosity between 3 to 6 cp. and electrical conductivity that usually involves the addition of soluble salts.

In general, the initial cost of CIJ heads currently prohibits their use for low volume applications. Binary CIJ and multilevel CIJ systems currently offer the most cost effective and reliable means to digitally print larger volumes.

AIR JET DEFLECTION – MILLIKEN MILLITRON

These printers have proven successful because they operate at profitable production speeds (about 20 running meters per minute, with print resolutions acceptable to the market. They permit customization, personalization and on the fly design and color changes. This type of inkjet also prints carpets better then analog technologies due to its ability to vary dye delivery pressure so as to penetrate color into different carpet pile types and thickness. Due to their larger orifice and drop size, carpet printers deposit a larger volume of ink with somewhat higher viscosity than other inkjets. The rug dying inkjets use ink with viscosity in the 100 to 400 cps ranges, while other inkjets use ink in the 1+ to 30 cps ranges. This enables the printing of durable intense colors which do not wick excessively with less expensive dye chemistry. Since most rug yarns are coarser than apparel yarns, carpet inkjet output with coarse resolution in the 20 to 30 dpi range do not encounter customer resistance, because the coarseness of carpet inkjet printing matches that of the carpet yarn.

The advantages of air deflected continuous inkjets are that they can print continuously at production rates on 3-dimensional surfaces reliably. Their disadvantages are their low resolution and that they generate waste ink.

SIDE SHOOTER THERMAL INKJET

In 1977, Canon received its first patent for the side-shooter thermal bubble jet. Soon after Hewlett Packard received patents for its roof-shooter thermal inkjet technology. These companies cross licensed their patents to each other. IBM licensed rights to produce and develop the HP technology. When IBM sold its printer division, these rights transferred to the new company, Lexmark. Hewlett Packard produced the first commercial thermal inkjet printer in 1984. Other thermal inkjet head manufacturers include Olivetti and Xerox. Many other companies have fabricated printers using print heads from these head manufacturers.

REAR SHOOTER THERMAL INKJET

The wide-format thermal inkjet manufacturers include Encad, Hewlett Packard, Calcomp, Xerox, Colorspan (formally LaserMaster), Mutoh, Maechatron, and others. They can direct print flexible substrates, such as paper, vinyl and coated canvas for use as banners. The flatbed versions can print rigid surfaces. The Mechatron and other XY plotter based printers can also mask printing plates and screens for imaging.

Canon extended the limits of its Bubblejet technology with its development and refinement of the Canon Bubble Jet Textile Printer. It introduced this printer at the end of its joint development venture with Japanese textile printer Kanebo in Vienna, Austria, June 1996. This device prints cellulosic fibers with fiber reactive dyes; synthetics with disperse dyes, and nylon and protein fibers with acid dyes. These printed fabrics require conventional post processing including steaming and washing. Canon extended the life of its print heads from 8 to 14 and then to 130 hours of continuous operation, which it guarantees. It achieved this with the addition of a head cleaning mechanism and the reformulation and refining of its inks too. The Canon Bubble Jet Textile Printer delivers 360 dpi resolution, 8 color capacity, over 1,000 nozzles in 16 print heads and prints up to 1.65 meter widths at the rate of 1 linear meter per minute. The high force associated with droplet ejection from Bubblejet heads provides the advantage of fabric penetration and the disadvantage of increased ink splatter. Some coarser, deeper pile fabrics benefit from its advantage while hiding the splatter, while tightly woven fine fiber fabrics reveal splatter.

Canon, Hewlett Packard and Lexmark have continually advanced thermal inkjet technology. They have developed printheads with more nozzles capable of higher droplet generation and print resolution. For its BJC 7000, Canon developed a 480 nozzle printhead. Hewlett Packard refined its 800 series printheads with a new more reliable 192 nozzle configuration. On older models, each can generate 10 pl. droplets at 12,000 drops per second (12KHz). Lexmark developed a printhead capable of 1,200 x 1,200 resolution. All of these printheads have been incorporated into printer systems which deliver photographic quality images.

The advantages of thermal inks are:

- Their lower equipment cost
- Very large installed base
- Available inks and ink development
- The development resources and guarantees of giants such as Hewlett Packard, Canon and Lexmark

Their disadvantages include:

- Limited head life due to kogation and resistor failure
- Limitations of their low viscosity inks.

PIEZOELECTRIC

Piezoelectric printheads can be grouped into one of the following types based on the way electrical current deforms the piezoceramic activator plate: shear mode, bend mode, push-piston mode, and squeeze tube. In addition, one device is a hybrid combining two of these modes in the same printhead on separate piezoceramic plates. Piezoelectric driver plates are almost universally Lead-Zirconium-Titanate (PZT).

PIEZOELECTRIC SHEAR MODE

Shear mode print heads use an electric field perpendicular to the polarization of the piezoelectric PZT driver. Electric charge causes a shearing action in the distortion of the PZT piezoplates against the ink causing the ink to eject from the nozzle opening in

drops. Shear mode piezoelectric printheads include those from Spectra, and those based on Xaar's patents, such as Xaar, Nu-Kote MIT, Brother, and Olympus.
LaserMaster, now ColourSpan, employs Spectra sheer mode heads for its hot melt DisplayMaker Express. Polaroid uses them for its DryJet Color Proofing System. Luscher and Kiwo employ them for their computer to screen printers. 3D Systems manufactures prototype building devices which print dimensional prototype models using Spectra shear mode printheads. These print systems melt thermoplastic resins which Spectra heads shoot layer upon layer to form models. Spectra heads have the advantage of high reliability, proven performance, robust capability, wide ink choice, and can process inks in the 20 to 25 cp. (centipoise) range, which is relatively high for piezoelectric inkjet. Spectra manufactures a number of head versions made if materials varying from sintered graphite to stainless steel. Spectra Inc. has advanced shear mode with the use of CNC machined sintered polycrystalline graohitic carbon as the structural print head base, the placement of a filter between the piezo pumping chamber and the nozzle, and the edge shooting placement of the piezoelectric transducer. The shear mode action makes it possible to achieve tightly packed assembly of many jets in a printhead with just one piece of piezoelectric plate. Although these heads have the disadvantage of high sticker price, printheads developed with shear mode technology can deliver lower cost per jet at higher speeds with superior jet uniformity for jetting various inks on a wide variety of substrates.

The Xaar type of this technology is also known as shared-wall shear mode. Its electrodes are exposed in the ink channel in their native unpassivated mode. Water-based inks corrode these electrodes unless they are passivated, that is coated to prevent corrosion. Without passivation, these heads must use non-corroding solvent-based inks. Xaar, Brother and others have successfully passivated the printhead electrodes to permit the printing of water-based inks. The Xaar piezoelectric print technology is termed shared wall because each of the piezoelectric activated membrane walls is shared with its neighboring ink channel. This means that only every other chamber can fire simultaneously. In actuality, one can only fire every third chamber due to the possibility of accidental droplet generation from the chambers immediately adjacent. By adjusting the angular orientation of the printheads to the direction of substrate movement, one can achieve a workable pattern of ink deposition to compensate for this head firing limitation. The Nu-kote/MIT version of the Xaar print heads can print either 200 or 360 dpi depending on the angle of orientation.

A number of OEMs employ Xaar shear mode printhead technology. Using the MIT version are Raster Graphics fir its PiezoPrint 5000 and 6000 printers, and Daniel Instruments Limited of Winterthur, Switzerland for its Polijet Digital Inkjet Print Systems (DIPS). These systems use three rows of precision positioned printheads to enable continuous line printing. Xerox employs the Olympus version of Xaar technology in a two row array producing up to 720 dpi resolution. Mechatron is also using an array of Xaar piezo printheads for use with its XY flatbed plotter systems tool head. Xaar heads typically have the advantage of relatively low cost. They have improved in performance, but still suffer from limited reliability and the restrictions of in channel electrodes and shared-wall activation.

"COUPLED" PIEZOELECTRIC CRYSTALJET

The Calcomp Topaz CrystalJet printheads are a hybrid or "coupled" piezo technology, which combine shear mode with bend/normal technology to squeeze and push ink through its nozzles. Three PZT side walls and roof collapse in on the ink channel to eject its droplets. They use separated rather than shared walls and can generate a number of different drop sizes per pixel for 12 gray levels to be expanded to 16. They consist of 256 nozzles per printhead with one printhead per color. This produces 180 dpi with one pass, 360 dpi with two passes and 720 dpi with 4 passes. These are relatively fast and robust printheads which can use a range of ink types. They have the advantages of relatively fast processing speeds and the ability to produce variable droplet sizes and gray levels with higher viscosity inks than thermal inkjet. They own the disadvantage of a short track record.

PIEZOELECTRIC BEND MODE

Tektronix, Sharp, Epson, and On-Target Technologies print heads also employ piezoelectric bend mode, in which its electricity excited piezoceramic plate expands placing pressure on the ink forcing some through the nozzle thus forming ink droplets. The electrical field between its electrodes is in parallel with the piezoplate polarization. The piezo transducer plates are bonded with the printhead diaphragm which is opposite the nozzle plate. Printers which use this form of piezo inkjet are Tektronix's Phases 300 and 350 color phase change inkjets and the Epson Color Stylus 400, 600, 800, and 5000 inkjet printers. The Tektronix printheads and print system produce very good saturated color which makes excellent overhead transparencies. Rather than printing directly to a print surface, they print to a transfer roll which in turn prints the surface. These systems are more complex and expensive than the Epson systems.

In 1997, Epson changed its multi-layer piezo design to bend mode technology for use on its Color Stylus 400, 600, and 800, 3000 and 5000 inkjet printers. Epson has combined its multi-layer vertically laminated piezoelectric disk technology with its Microweave algorithm to eliminate banding and ultra-fine ink for uniform ink droplets and improved print quality.

Epson provides piezoelectric print heads to Original Equipment Manufacturers (OEM) Minaki Engineering, Raster Graphics, and Roland Digital Group for the manufacture of wide format color printers. These include the Mimaki's JV-1800, Raster Graphics PiezoPrint 1000 and Roland's CammJet series of printers.

Those printers which are capable of 1440 dpi, such as the 400, 600, 800, 5000, use Epson's MicroPiezo refinement of its multi-layer technology. The advantages of these Epson heads are that they form very accurate circular droplets, and they are mass produced and low cost. Their disadvantage lies in their delicate multi-layer piezo louvers which can only tolerate extremely low viscosity inks of about 1.6 to 3cP.

PIEZOELECTRIC PUSH MODE

Push mode is similar to bend mode in that the electrical field between its electrodes is parallel with the piezoplate polarization, and that the piezoceramic pushes against a transducer foot which places pressure on the ink to eject droplets. Dataproduct, Trident and older Epson printers use this technology. It is relatively high energy process which ejects droplets which are more elongated and may form satellite droplets. These companies have considerable experience with these printers and have steadily improved them.

The idanit 162Ad and other large high production digital print devices employ the Dataproducts heads. Trident has been serving the major marking and coding companies and their industry for a number of years. Its high energy droplet ejection level can be an advantage or disadvantage, depending upon its application and the need for penetration. They are relatively robust and can use inks in the 10 to 20 cp. ranges. Satellite droplets, however, usually compromise image quality.

Multi-layer piezoelectric technology refers to Epson's technology which first employed push mode for its Stylus Color (1994) and Stylus II (1995) printer printheads. These push mode heads contain 64 nozzles per printhead.

PIEZOELECTRIC SQUEEZE MODE

Squeeze mode refers to technology which S.L. Zoltan of Clevite Corporation developed (1970 announced, 1974 US patent) and Seimens used in its PT-80 printer (1977). In this mode, electrical charge deforms a piezoceramic tube so that it squeezes the ink within the tube forcing it out through the nozzle end. Seimens successfully marketed this technology for office printing.

SUMMARY OF PIEZOELECTRIC

Hot melt, also known as phase change, technology currently piezoelectric print heads. Teletype Corporation probably initiated hot melt technology in the late 1960s using continuous inkjet technology. Exxon claimed invention of this technology using piezoelectric inkjet. Dataproducts developed the first commercial application of this technology for monochrome printing. In 1987, Dataproducts acquired Exxon's rights. Howtek introduced the first color printer using hot melt piezo. Tektronix of Wilsonville, Oregon owns the phase change trademark and manufactures a number of phase change printers. It uses the bender mode piezoelectric driver. Spectra developed its own version of hot melt and licensed Dataproducts rights as well. Brother has also been active in hot melt piezoelectric printing.

The time it takes to refill the ink firing capillary or chamber is the primary factor limiting the speed of a piezoelectric printhead and not the response time of the piezoelectric transducer. Transducers in continuous inkjets operate at hundreds of thousands of cycles per second. Drop on demand printers are constantly stopping and starting the flow of ink, whereas CIJ print heads receive a continuous flow of ink and do not have to overcome inertia constantly as do drop-on-demand print heads. Continuous inkjet also can guide ejected droplets with electrical force, while drop on demand piezoelectric inkjet relies on the force and direction of expulsion and gravity as its only droplet guiding forces.

The advantages of the more robust Xaar, Tektronix, Trident, Calcomp, Dataproducts, and Spectra piezoelectric printheads are their ability to print higher viscosity inks, a wide variety of inks with different solvents, heat sensitive inks and colors, and hot melt thermoplastic and paraffin. Piezoelectric printheads generally have high reliability and will last for months to years of operation. Piezoelectric inkjets generally deposit consistent ink droplets which result in sharp images.

The disadvantages of piezoelectric inkjets have been speed and cost. New configurations of these heads are producing throughput which is much greater than that of comparable thermal inkjet printers as evidenced by the Calcomp CrystalJet, Raster Graphics PiezoPrint 5000 and the Xerox Xpress 36 & 54, which are 2 to 3 times faster than Encad or HP thermal inkjet wide format printers