WHITE PAPER

HOW TO MITIGATE ARTIFACTS IN HIGH-SPEED INKJET PRINTING: A WHITE PAPER

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GLOBAL GRAPHICS® software

THE QUEEN'S AWARDS FOR ENTERPRISE: INNOVATION 2020

Contents

Introduction

This White Paper explains why achieving maximum quality output is so difficult, notably on high-speed single-pass inkjet printing presses but also on multi-pass inkjet presses with scanning printheads.

It examines the causes of the most common artifacts, such as streaking, mottling and banding and the steps that can be taken in software to reduce these effects using award-winning solutions from Global Graphics Software.

Under discussion are:

- Micro non-uniformity, or small-scale effects, resulting in streaking, mottling and graininess
- Macro non-uniformity, or large-scale effects, resulting in banding
- The challenges of processing data fast enough to print at high speeds

Each of these is addressed in turn and followed by an explanation of how artifacts may be resolved in software. These software solutions have been developed as a result of gaining real press time with multiple vendors who were experiencing difficulties in achieving output quality and throughput on their presses and called upon Global Graphics Software for assistance. Solutions were tested using a variety of printheads, inks, substrates, printheads and electronics and found to be effective in any workflow producing 8-bit contone raster.

All these artifacts, however, lead to one thing: that the print buyer, brand manager, printing company or converter is dissatisfied with the printed output. And that, in turn, may mean that certain jobs cannot be printed on an inkjet press, or profitability is reduced because customers demand a partial refund or simply take their business elsewhere.

If the data processing for a high-speed press cannot keep up with the full engine speed of that press it can impact profitability in another way: by preventing the print service provider or converter from entering markets requiring variable data or very short print runs. And those are often the markets with the highest margins.

What are the problems?

Most printing software assumes that a press can print a perfect grid of dots. In practice on an inkjet press there are often variations between the control system's aim point for an ink drop and where it actually lands.

This is especially true as the speed of the substrate past the inkjet heads increases. At higher speeds it's common to increase the jetting distance slightly (the separation between the head and the substrate) in comparison with a slower printer to ensure that there is no chance of the two touching. A higher jetting distance increases the distance between where a drop will actually land and the intended position for any given angular deviation. The faster substrate movement also increases air turbulence in the gap between heads and substrate.

Correcting all of these issues in hardware is very difficult, likely to be very expensive, and would also probably increase time to market and increase the cost of replacing inkjet heads in the field.

In addition, the interaction of the ink drops with the media may introduce variations. For instance, aqueous inks are absorbed into the surface of papers to differing extents depending on the coating or primer/bonding agent used, and how the driers operate to evaporate the water in the ink.

Likewise, UV-cured inks will behave differently on various absorbent or non-absorbent substrates, with variations such as the temperature/viscosity of the ink, use of corona pre-treatment or inter-color pinning (partial UV curing to "freeze" the dots), and the interval before the main UV cure exposure.

1. Micro non-uniformity

All these variables, in combination or separately, may lead to changes in the size, shape or position of each drop away from the intended ideal, which in turn often causes an apparently random coalescing of adjacent drops on the substrate surface, as can be seen in FIG 1.

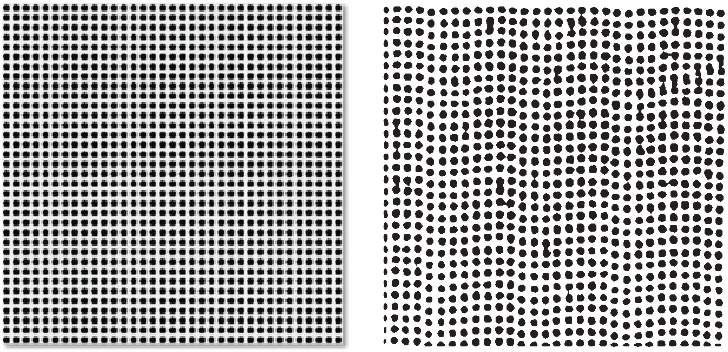


FIG 1 - A clean grid with accurate droplet placement and a grid with a less than accurate droplet placement.

Even though these individual drops are very small, the coalescing commonly leads to artifacts and errors that are often visible at the intended viewing distance in the finished print. These are variously described as chaining, streaking, mottling, clustering or graininess, and are illustrated in FIG 2. These are known as small scale effects or micro non-uniformity. Added to these can be artifacts caused by missing, blocked, or misaligned nozzles.

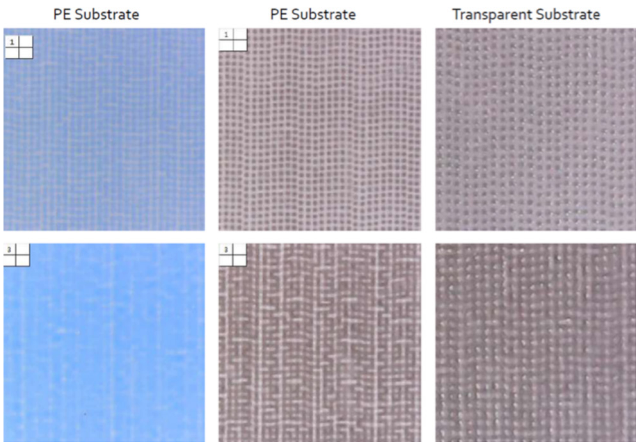


FIG 2 - Examples of chaining, clustering and mottling

Of these effects, chaining and streaking are common on reasonably absorbent and or wettable substrates, while mottling is common on non-absorbent and poorly wettable surfaces, such as metals (e.g. for tin cans) and some plastics (e.g. for flexible packaging), and highly gloss-coated stocks. Mottling is sometimes described as giving an effect that looks a little like orange peel.

Advanced Inkjet Screens

Global Graphics has worked with many different press vendors to analyze and understand the behavior of a wide variety of printheads, inks and substrates, and the impact of chillers, corona pre-treatment and inter-deck pinning etc.

As a result of that research work they have identified some significant commonality in situations that cause micro non-uniformity, which has allowed them to develop a set of screens that can mitigate those effects on the majority of inkjet presses.

These screens are called Advanced Inkjet Screens.

They're threshold screens, which means that they can be applied extremely quickly. That, in turn, means that the speed of the press doesn't need to be reduced in order to achieve maximum quality. It also means that they won't suffer from the problems with some error diffusion screens that can make small text and barcodes unreadable.

They can be applied to any workflow producing 8-bit contone raster by the ScreenPro™ screening engine alongside any RIP and other software choices that may have been made, or, within the

Harlequin RIP®. This gives a lot of flexibility for a press vendor to construct a variety of workflows with and without Harlequin RIPs, for instance, and without a significant effort in replicating screening between them.

Advanced Inkjet Screens include two variants:

- Pearl is an advanced dispersed (FM) screen, optimized for natural images on a more or less absorbent substrate. It is targeted especially at addressing chaining and streaking artifacts.
- Mirror is designed with a microstructure targeted at countering the mottling or "orange peel" effect that can be seen when solid colors are used on non-absorbent or poorly-wetting substrates such as tin cans or some plastics, such as some flexible packaging. It's also useful when dense inks such as metallics are used, or where the print should not interfere with the smoothness of the reflection from a shiny substrate.
- Opal combines aspects of both the Mirror and Pearl screens, achieving a smoother print from some printhead types. In particular, the Opal screen can help to minimize high frequency 'streaking' artifacts sometimes seen when UV cured inks are printed on difficult substrates.

In many cases Advanced Inkjet Screens are useable as supplied, but sometimes it may be necessary for the Global Graphics Technical Services team to apply additional tuning for a specific press. Even that, however, normally only takes a few days, which means that using a screen optimized for a specific press doesn't slow down time to market.

Selecting drop sizes

With multi-level screens (see Appendix 1), the smallest ink drop sizes are used for the lightest tones, and the largest drops for the dark tones through to solids. Simply dividing the tonal range from 0 to 100% ink coverage by the number of drop sizes the heads can deliver doesn't yield good results, however. In practice 100% coverage of the lightest drops usually produces a tone that's darker than 50% of the tonal range, sometimes up to 80%. If three or four drop sizes are used, then the three larger sizes will normally all be used for the tones that are darker than 50 to 60%.

The tonal range for which each drop size is used is also overlapped fairly broadly, with some coverage of the larger sized drops being introduced before the maximum coverage of the smallest drop size is reached. If the tonal ranges are not overlapped there can be a visible change in texture at the point of transition from one drop size to the next. Careful tuning of tonal ranges and overlaps is therefore key to avoiding visual artifacts such as banding in graduated tints, and to generating a smooth overall tone reproduction curve that enables color management to achieve accurate, stable and repeatable output.

Global Graphics has put considerable development effort into generating screen patterns that work well in high-speed inkjet presses, and in technologies to use those screen patterns with the best overlap characteristics.

2. Macro non-uniformity

Another common objectionable visual issue is a lack of tonal uniformity across the printed result, which causes banding along the output on a single-pass press, or across it for a multi-pass press.

For the purposes of this White Paper we'll use the terminology "cross-web uniformity" for both of these and for equivalent situations in print sectors where there is no continuous web of substrate through the press, e.g. when printing on ceramic tiles.

The unevenness is caused by variations both within and between inkjet heads along the print bars in the press. Variation within a single head is often called a 'smile' and is usually caused by ink pressure or voltage changes across the head. Variation between heads may be caused by differences in manufacturing.

Certain types of head/ink combinations also wear with use; the more drops that are emitted, the more the head wears. This can cause both variation between heads, and additional variation over time.

The traditional method of correcting for a lack of cross-web uniformity is to adjust the voltages at various points within each head to change the drop size emitted from each nozzle, but this is not an ideal solution, because:

- Not all heads have enough adjustment points to correct the smile or wear.
- It's often time-consuming work for a trained technician, which increases the time and cost of installation or head replacement because it's not readily automated for closed-loop correction.

Manual adjustment is especially difficult in head overlap/stitching regions. Or when multiple interleaved print bars are used for redundancy or to increase resolution. And it's often completely impractical to apply sufficiently often for those heads that wear with use.

- It can reduce jetting stability; anecdotally it can also reduce head lifetime. It's especially risky to tweak heads beyond warranty limits, because that raises costs and complications when heads fail.
- It can cause ink pressure and timing/drop speed variation, which degrades the quality of the print in other ways, including risking triggering ink coalescence that introduces objectionable micro non-uniformity artifacts.

PrintFlat™

Global Graphics Software has launched an option in ScreenPro, called PrintFlat™, which applies cross-web calibration as rasters are screened, to ensure a uniform tonal response across the print. It uses measurements from printed output to identify where tones are non-linear, and by how much, and then compensates for those artifacts on the fly as the data is screened.

Applying cross-web calibration in software, in parallel with screening, enables a rapid and automatable solution, greatly reducing the cost and time for building a new press or field replacement of heads and enabling correction for cases where heads wear.

It can also address every nozzle independently, which avoids issues in stitching regions and when multiple print bars are in use. And it doesn't cause any timing or stability issues.

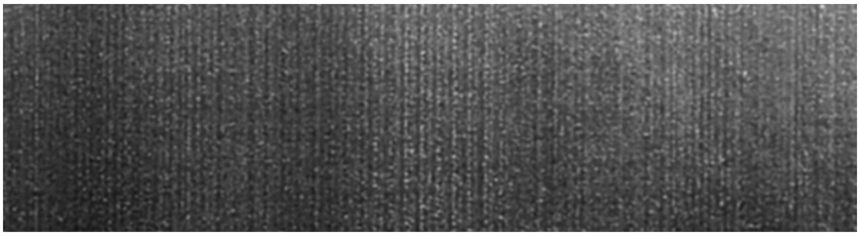


FIG 3 - Photograph of typical inkjet print showing variation in density

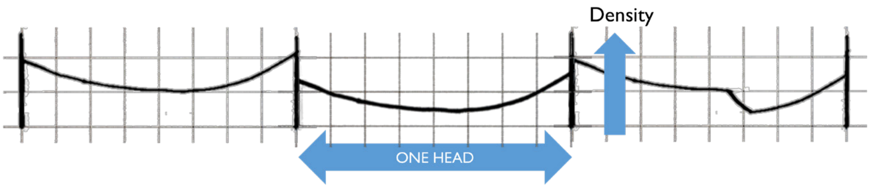
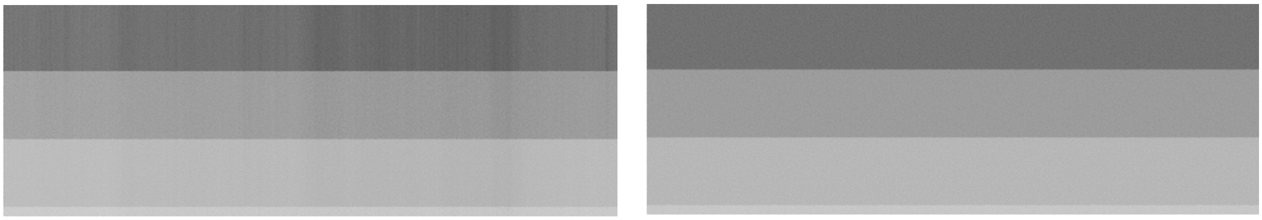


FIG 4 - Variations in density within and between print heads

In those cases where the heads are unaffected by wear the precise density pattern across the web is usually very stable, which means that a single calibration may be applicable until the press is deliberately changed, e.g. when a head is replaced. Obviously, the density pattern must then be re-measured so that it can be applied for subsequent prints.

For those head/ink combinations that do wear the density pattern will change with time; exactly how often the system requires re-calibration depends on the precise wear speed occurring and on the quality threshold applied by the press vendor or printing company. Global Graphics is working with vision system suppliers to develop in-line solutions for continuous, closed-loop calibration; contact us now to ensure that Global Graphics includes your preferred vendor in those discussions.



Uncorrected *Corrected*

FIG 5 - Example of adjustments to output density to correct uniformity

3. The challenge of printing at high speed

One of the obvious challenges of screening for a high-speed inkjet press is that the screening itself must be done at high speed. If a job is ripped and screened once, and then printed tens of thousands of times or more the performance of the RIP and screen processes may not be critical because each job must be processed in the time it takes to print all of those thousands of copies of the previous job.

But that's not typically the kind of job that will maximize margin and profitability for the print on a digital press. Shorter run lengths and increasing variability (even if that variability is just a serial number) often lead to higher margins. But they also increase the demand on ripping and screening. In the extreme, if every item printed is different, then every pixel in the output must be ripped and screened at full engine speed.

There are three main approaches to specifying a halftone screen definition: spot functions, threshold tables and error diffusion screens.

Spot functions define the shape of a halftone dot within a cell algorithmically. They can be very good for an 'AM' screen as used for offset, flexo or screen printing. But they're not an efficient way of specifying a screen for inkjet, which will normally be a form of a dispersed or 'FM' screen (see Appendix 1).

A threshold screen, sometimes called a table-based screen, also defines the order in which the pixels within a cell are marked. That cell is then tiled across the output to apply the screen to the whole job.

Applying a threshold screen can be extremely fast as there is no complex calculation to perform, and it is becoming faster and faster with every new computing development because it corresponds extremely well to the optimizations that are being built into new computer chips and compilers.

The quality achievable by a threshold screen is almost entirely dependent on the skill with which the threshold table itself is created. Many aspects of the halftone definition must be carefully tuned, including even basic parameters such as the size of the cell.

Error Diffusion Screens (EDS) have been widely used in the wide format market and in the slower end of the industrial print market. They involve examining every pixel with its neighbors in the raster and determining programmatically whether each pixel should be marked or not, and (for multilevel screening) with which drop size.

Output quality from EDS can range from very poor to very good depending on the algorithm used, but the amount of computation required means that EDS is much slower to apply than a threshold screen would be. And that computation is of a type that is not being accelerated so much by recent improvements to computer hardware and compilers. As an example, it's not usually possible to process multiple pixels in parallel when applying EDS, while it's easy to do so for threshold screens.

At least some EDS implementations can also suffer from a tendency for the tone of graphical elements to spread slightly, often towards the bottom and right of the output. In photographic images this doesn't usually matter. But highly detailed graphics such as small text and barcodes may be damaged sufficiently that they become unreadable

Driving data directly to the inkjet press electronics

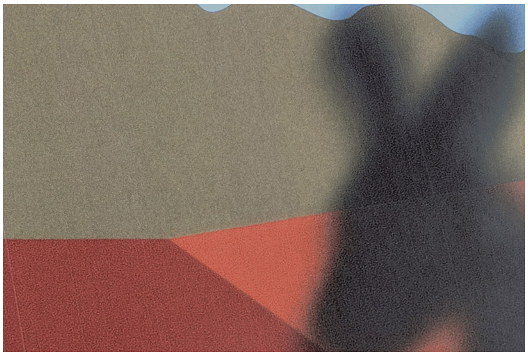
For applications where the high-speed printing of variable data is required, when variable data means that every page or label is different and therefore unique, the optimal result is achieved by driving the data directly to the electronics. Typical examples are of printing labels with variable data barcodes, one copy of a book or personalized advertising.

ScreenPro Direct is an inline component that drives the press directly and screens as it prints. Print quality is optimized with no loss in performance even with additional print bars to support extended gamut colors.

Such use cases require the workflow to adapt and instead of preloading a page to be printed multiple times the data needs to be sent to the press electronics as fast as the printheads are printing dots on the media. With faster web speeds and increased resolutions this has a cumulative effect on the data, moving from 600 dpi to 1200 dpi is four times the data. This soon becomes a problem with the design of the press and the workflow, in order to keep up with press speeds. There are networking issues, disk access, not to mention the data processing required by screening. Failure to address these issues results in "buffer underrun" which presents itself by elements not being printed, gaps in the print and operators having to drive the press at low speed i.e. at the speed the data can be sent rather than at the speed the press can run.

Many of these issues can be solved by hardware. For networking bottlenecks high-speed ethernet can be used, optical links, bar splitting and having two data feeds. Disk access can be helped by using RAID drives. However, the only real solution is to not write the separation to a file and to use the screening engine to write directly to the print electronics. This places further stress on the data processing required by the screening. Code optimization is absolutely necessary as is the tuning of the hardware, and load balancing the screening engine with other process running the press.

Before



With PrintFlat

FIG 6 - PrintFlat

Custom screening for challenging presses

While the Advanced Inkjet Screens and PrintFlat are applicable for the majority of inkjet presses, it's inevitable that some presses may have different characteristics, perhaps because they use unusual inks or substrates.

Global Graphics Software Technical Services team offers BreakThrough services, making experts available in print workflows, RIP integration, color management and halftone screening to augment an OEM's own engineering resources. The experience and expertise of the team means that a better product can often be developed and be brought to market faster.

Amongst the services offered by Global Graphics Software is the creation of custom halftone screens for those unusual presses.

Global Graphics will first carefully discuss the requirements for image quality with the press vendor. The optimization process is normally carried out during site visits by skilled Global Graphics technicians. During the site visit, a series of test patch charts are printed on the press and analyzed by a combination of an optical test instrument to provide objective numerical readings and expert visual examination to determine the effect and likely cause of the errors. Customers' own test sheets and, if relevant, customer jobs can also be examined to help analyze the print quality and the likely cause of any problems.

After measurement and assessment, the results are used to guide the team in generating a new optimized screen for the test patches, which are then printed and measured once more.

Screen optimization may involve any one or more of:

- Creating custom halftone dot shapes that are designed to counteract artifacts created by the specific way the ink drops strike the substrate, interact with each other and are dried or cured

- Tuning the tonal ranges, overlaps and calibration curves within each range for the different drop sizes.
- Using sophisticated screening technologies, such as mixing error diffusion screening for some specific tonal ranges with a table-based (threshold) screen for the rest.

After several iterations of test printing, measurement and re-optimization, the best achievable screen for that individual press, ink, media and speed combination will be reached.

Optimization can be carried out for any number of speed and media combinations; most press vendors will start by picking the most commonly anticipated combination and optimizing for that.

The resulting optimized screen can then be applied in a workflow using Global Graphics' technology.

Appendices

Appendix 1. What is half-tone screening?

Halftone screening, also sometimes called halftoning, screening or dithering, is a technique to reliably produce optical illusions that fool the eye into seeing tones and colors that are not actually present on the printed matter.

Most printing technologies are not capable of printing a significant number of different levels for any single color. Offset and flexo presses and some inkjet presses can only place ink or no ink. Halftone screening is a method to make it look as if many more levels of gray are visible in the print, by laying down ink in some areas and not in others, but using such a small pattern of dots that the individual dots cannot be seen at normal viewing distance.

Conventional screening, for offset and flexo presses, breaks a continuous tone black and white image into a series of dots of varying sizes and places these dots in a rigid grid pattern. Smaller dots give lighter tones and the dot sizes within the grid are increased in size to give progressively darker shades until the dots grow so large that they tile with adjacent dots to form a solid of maximum density (100%). But this approach is mainly because those presses cannot print single pixels or very small groups, and it introduces other challenges, such as moiré between colorants and reduces the amount of detail that can be reproduced.

Most inkjet presses can print even single dots on their own and produce a fairly uniform tone from them (with some exceptions, especially aqueous ink on uncoated, unprocessed paper). They can therefore use dispersed screens, sometimes called FM or stochastic halftones.

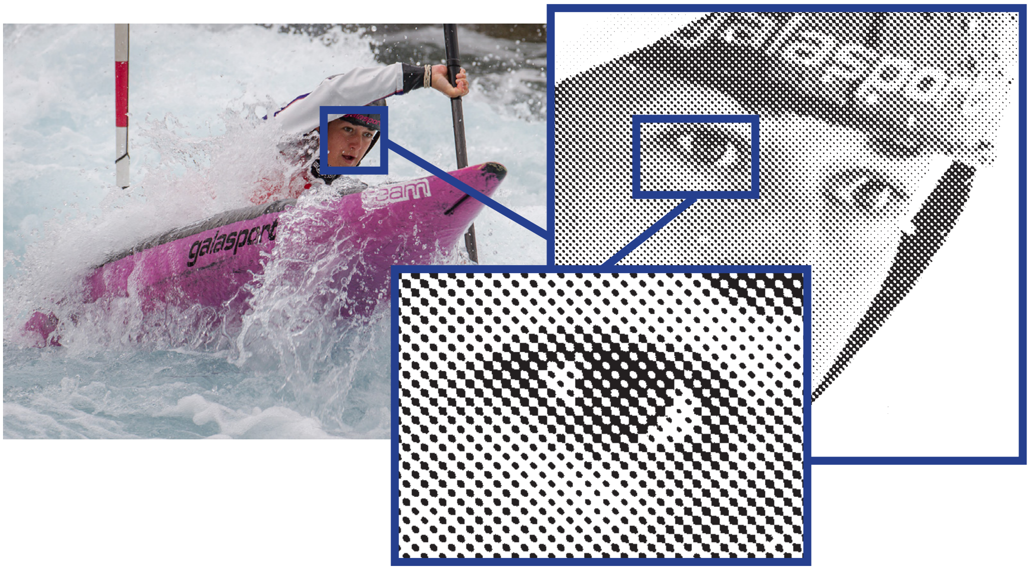


FIG 7 - A simple halftone screen

A dispersed screen uses dots that are all (more or less) the same size, but the distance between them is varied to give lighter or darker tones. There is no regular grid placement, in fact the placement is more or less randomized (which is what the word 'stochastic' means), but truly random placement leads to a very 'noisy' result with uneven tonality, so the placement algorithms are carefully set to avoid this.

Inkjet is being used more and more in labels, packaging, photo finishing and industrial print, all of which often use more than four inks, so the fact that a dispersed screen avoids moiré problems is also very helpful.

Dispersed screening can retain more detail and tonal subtlety than conventional screening can at the same resolution. This makes such screens particularly relevant to single-pass inkjet presses, which tend to have lower resolutions than the imaging methods used on, say, offset lithography. An AM screen at 600 dots per inch (dpi) would be very visible from a reading distance of less than a meter or so, while an FM screen can use dots that are sufficiently small that they produce the optical illusion that there are no dots at all, just smooth tones. Many inkjet presses are now stepping up to 1200dpi, but that's still lower resolution than most offset and flexo printing.

Appendix 2. Where is screening performed in the workflow?

Halftone screening must always be performed after the page description language (such as PDF or PostScript) has been rendered into a raster by a RIP … at least conceptually.

In many cases it's appropriate for the screening to be performed by that RIP, which may mean that in highly optimized systems it's done in parallel with the final rendering of the pages, avoiding the overhead of generating an un-screened contone raster and then screening it. This usually delivers the highest throughput.

Global Graphics' Harlequin RIP is a world-leading RIP that's used to drive some of the highest quality and highest speed digital presses today. The Harlequin RIP can apply a variety of different halftone types while rendering jobs, including Advanced Inkjet Screens.

But an inkjet press vendor may also build their system to apply screening after the RIP, taking in an unscreened raster such as a TIFF file. This may be because:

- An inkjet press vendor may already be using a RIP that doesn't provide screening that's high enough quality, or process fast enough, to drive their devices. In that situation it may be appropriate to use a stand-alone screening engine after that existing RIP.
- To apply closed loop calibration to adjust for small variations in the tonality of the prints over time, and to do so while printing multiple copies of the same output, in other words, without the need for re-ripping that output.
- When a variable data optimization technology such as Harlequin VariData™ is being used that requires multiple rasters to be recomposited after the RIP. It's better to apply screening after that recomposition to avoid visible artifacts around some graphics caused by different halftone alignment.
- To access sophisticated features that are only available in a stand-alone screening engine such as Global Graphics' PrintFlat technology, which is applied in ScreenPro.

Global Graphics has developed the ScreenPro stand-alone screening engine for these situations. It's used in production to screen raster output produced using RIPs such as those from Esko, Caldera and ColorGate, as well as after Harlequin RIPs in order to access PrintFlat.

Appendix 3. Modern single pass inkjet presses

Inkjets work, as the name suggests, by jetting ink. Current printheads generate drops of ink with very fine control over their size/volume, speed and timing of ejection.Originally all inkjet printheads were binary, meaning they only generate one, consistent size of drop. Binary in this case means all or nothing – there's a full-sized drop on the media, or nothing at all.

More recently, many printhead developers have created multi-level printheads that can place any one of several different amounts of ink at a single location on the media. This can be done by generating single drops of different sizes, or by jetting multiple drops onto the same location. Different heads and different configurations can deliver a variety of different amounts of ink; from two levels upwards, although the maximum common number is about five.

The main effect is that for the same nozzle pitch, native resolution and speed, it is possible to print drops that give different image densities on the substrate.

Assuming a colored ink, small drops generate "light" tones and larger drops generate "darker" tones. A common industry description for multi-level printheads is "grayscale heads," which describes the effect of printing black ink with different sized drops: the smaller drops appear gray, and larger drops give progressively darker grays until black is reached. However, note that grayscale heads can be used to print any color, or indeed clear, white and other ink types.

The same effect can be achieved by jetting from multiple nozzles onto the same location on the substrate, either producing the same drop size in all nozzles, or using combinations of nozzles that jet different sized drops.

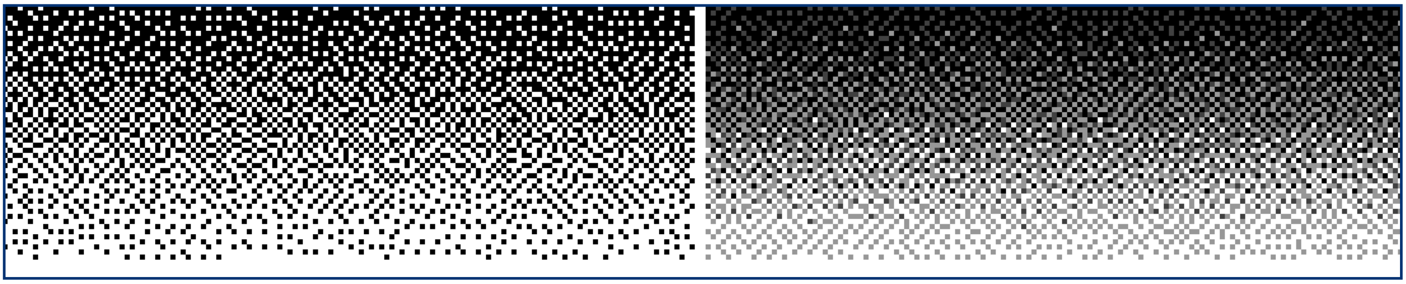


FIG 8 - Inkjet screening. Left: 1 bit per pixel (1 drop size). Right: multi-level screening (3 drop sizes)

And, of course, a similar effect results from passing the same head over the same location on the substrate multiple times in a "multi-pass" printer. This technique has been used in wide-format printing for many years but is too slow to scale to meet the needs of high-volume digital presses in many print sectors.

Using multiple nozzles to address a single location, or grayscale heads, together with a high-quality multi-level halftone increases the perceived image quality and smoothness, compensating for the comparatively low resolutions of many inkjet presses. More recently there has been a move to use grayscale heads at higher resolution, often 1200dpi, which does appear capable of delivering very high quality, when paired with appropriate screening technology.

Even though several different tone levels can be achieved by jetting different amounts of ink onto the same location, halftone screening is still required to achieve enough tonal levels for smooth gradations and images. Screening in this situation is more complex, because those different amounts of ink must be calculated for each location, but sophisticated multi-level screening technologies are available in both of Global Graphics' Harlequin RIP and ScreenPro screening engine.

It's worth noting however, that not all head vendors have opted to develop grayscale heads. The most notable exception is Memjet, who has, instead, chosen to produce higher resolution (1600dpi) binary heads. Global Graphics' screening technology, in both Harlequin and ScreenPro, is also applicable to this case.

About Global Graphics Software

Global Graphics Software http://www.globalgraphics.com/software is a leading developer of platforms for digital printing, including the Harlequin RIP®, ScreenPro, Fundamentals and Mako. Customers include HP, Canon, Durst, Roland, Kodak and Agfa. The roots of the company go back to 1986 and to the iconic university town of Cambridge, and, today the majority of the R&D team is still based near here. Global Graphics Software is a subsidiary of Hybrid Software Group (Euronext: GLOG).

GLOBAL GRAPHICS® software ™

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