Is Image-on-Image Color Printing a Privileged Printing Architecture for Production Digital Printing Applications?

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Abstract

Several different high-speed digital color-printing technologies have emerged recently after more than a decade of development worldwide. The Xerox Docucolor iGen3 Production press utilizes a unique Image-on-Image color electrophotographic architecture that is advantageous for productivity, image quality, substrate latitude, and run cost. The team developing this product and the Image-on-Image marking technology faced many design challenges on the way to market. This talk reviews the history of digital color printing technologies, the Xerox Image-on-Image marking process, the key technical challenges, how they were overcome, the performance achieved, and the potential of this technology.

Introduction

Digital color printing has experienced a rapid growth in the past decade. The advances of marking technologies, from ink jet to xerography, with dry and liquid toners, have resulted in a great span in speed and print qualities. In addition, the advancement in microprocessors enables sophisticated image processing capabilities and control of complex processes within the print engine to achieve variable data and on the fly printing. The digital color-printing offerings have since extended from home and office, up to the production printing market[1]. Ink Jet printing, either thermal or piezo, offering print quality and speed at an affordable printer cost, dominates the SOHO (small office home office) market. With special paper, it can also provide photo quality at a reduced speed. EP (electrophotographic) xerography offers expanded speed and image quality at a higher printer cost and has dominated the general office market. It has since been extended to over 100 pages per minute into the production printing market with the color run cost (consumables price/page) at the affordable range of less than 5 cents per print. The production printing industry has been dominated by offset printing. Offset printing offers excellent print quality at a competitive run cost as long as the run lengths are above 5,000 prints. For short runs, digital printing is a viable alternative due to its attractive offering of flexible run length, fast turn around, and the ability to print variable information (VI). Digital color printing is able to offer customers print quality close to offset and in some cases better, the ability to print on a range of many different substrates, and an efficient workflow in this on-demand market range.

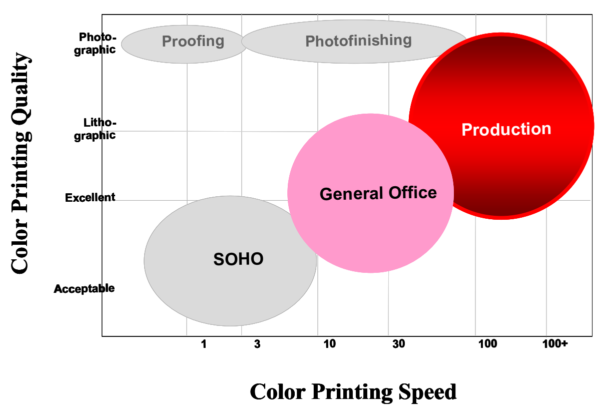

Figure 1. Market Space as a function of color printing speed and color printing quality

Digital Color Printing Architecture for Production Printing

Digital color printing technologies are still evolving to improve run cost, image quality, productivity, and expand substrate latitude for more eligible jobs. All technologies have their own niches and barriers. Ink jet printing is architecturally simple, but presents challenges in the design of a quick drying, moisture resistant ink and robust page-wide ink heads for high speed printing on a wide selection of substrates at a reasonable run cost. On the other hand, the EP xerography has already introduced several "Tandem" architectures at the speed required for this market. "Tandem" architectures are advantaged over recirculating architectures for speed in the production market. There are three types of

"Tandem" architectures that vary primarily in the way in which the color image separations are accumulated: paper, intermediate, or photoreceptor[2,3] (see Figure 2). In this paper we will use the term **tandem** to refer to tandem (either build on paper or on intermediate) and will contrast those architectures with tandem (build on photoreceptor) of which we call **IOI or Image-on-Image**.

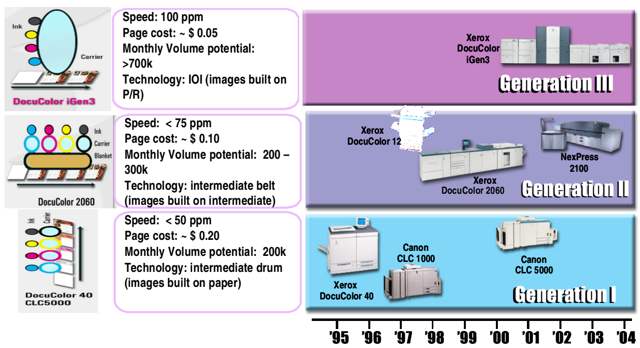

Figure 2. The Digital Color Printing System Evolution

The fundamental difference between the tandem architecture and IOI architecture is where the four-color image is constructed. The four-color image is constructed on one photoreceptor and transferred in a single step to the substrate in the IOI architecture. The complex system interactions resulting from the multiple charge and development steps on one single photoreceptor and the transfer of all four color toners in one single step demand new and unique technologies. Earlier tandem architectures avoid these complexities by separating the process into multiple steps. In the tandem architecture, the four-color image is constructed either on paper or on an intermediate belt. Each color toner has to be transferred separately from an individual photoreceptor to the paper substrate, either directly, or through an intermediate transfer drum or belt. Tandem system architecture has less image-on-image type system interactions, but has to manage multiple toner transfer and registration steps with a larger number of components. To achieve high precision registration at high speeds demands motion control systems with either large photoreceptor drums or precision belt modules. The cost of drum photoreceptors increases rapidly with the drum size and affects run cost. The precision belt module also is costly and affects product box cost. The reliability and associated run cost of these multiple components have to be managed for the Tandem architecture in order to be competitive in this on-demand market.

History of Image-on-Image Process at Xerox

Xerox has developed several generations of digital color printing technologies over the last 15 years. With the technological advances in each generation, the printing speed, the image quality, and the substrate latitude have been improved and the run cost is continuously being reduced, as shown in Figure 2.

The iGen3 product, utilizing a new REaD IOI technology, is the third generation product. The REaD (Recharge, Expose, and Develop) process is a color xerographic technology in which the color image, either spot or process color, is built on the photoreceptor in a single pass, as presented in Figure 3. The image is then transferred in a single step to paper. IOI process places toners of different colors on top of, as well as adjacent to, each other. The REaD IOI xerographic engine consists of 4 or more charge, image, and non-interactive development systems (see Figure 4), in a development sequence of magenta, yellow, cyan, and black, and one single transfer station around one single photoreceptor belt.

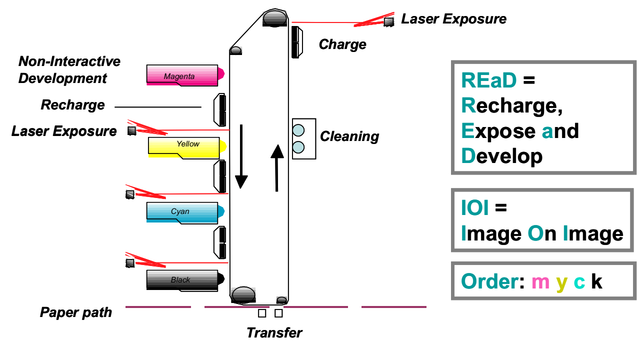

Figure 3. REaD IOI Basics

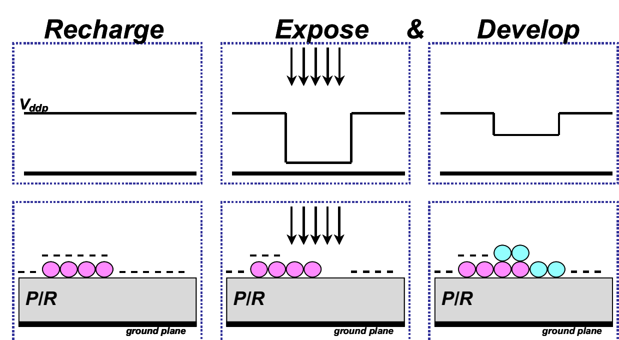

Figure 4. Basic REaD Electrostatics Surface Potentials

IOI Technical Challenges

Xerox has been developing these fundamental technologies and system architectures since 1986. Several key technologies were invented to meet the IOI printing architecture requirements, as summarized in Table 1. The REaD IOI technology depends critically on non-interactive powder cloud development to achieve exceptional image quality when building multiple images on a photoreceptor. The challenges resulting from such a simplified architecture are significant. They include the use of non-interactive development, efficient transfer of all four toner layers in one single step, the managing of the system interactions, and the engineering required for micron-level tolerances.

Table 1. iGen3 Evolution Milestones in Xerox

Year	Major Event
1986	Non-interactive development invented
1987	HSD (Wire Scavengeless with Hybrid Two Component Housing)
1988	REaD Image-Next to-Image (INI) Spot Color
1992	First REaD IOI process color prints
1992	Split recharge invented Vt
1994	iGen3 initiated
1997	First iGen3 Technology Breadboards built
1999	iGen3 technology readiness demonstrated
2001	First iGen3 customer

HSD Non-interactive Development

A non-interactive development process was invented in 1986. Hays and Wayman[4] discovered a single component development technology, coupled with a set of AC biased wires on top of the donor roll caused the toner particles to jump through an air gap with a controlled toner cloud. Later in 1987, the single component loading of the donor roll was replaced in favor of a more reliable two-component development system. The marriage of donor rolls from single component development and the magnetic roll of two-component development earned the name of HSD[5] (Hybrid Scavengeless Development).

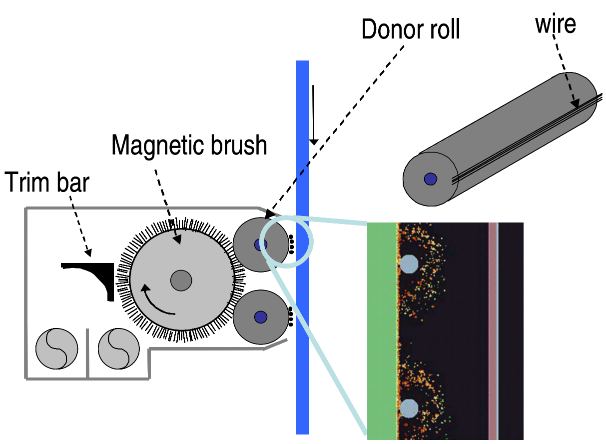

Figure 5. HSD Development Housing

A HSD developer housing, as is used in iGen3, consists of a two-component developer sump, a magnetic brush, two donor rolls, and a set of development wires in contact with the donor rolls and adjacent to the photoreceptor, as indicated in Figure 5. An AC biased field applied to the wires creates a uniformly concentrated toner cloud around each wire for non-interactive development. The toner particles are first tribo-electrically charged by their interaction with soft-magnetic carrier particles in the developer sump. A uniform layer of toner particles is then developed to the donor rolls by a magnetic brush. Near the photoreceptor, high AC electric fields between the wires and the donor rolls alternately attract and repel the charged toner particles, causing them to form a cloud in the vicinity of the wires. The toner particles from the cloud are then developed to the photoreceptor under the influence of the electric field from the latent image (see Figure 6). The non-contact nature of the development system insures that previously developed images are not degraded, while also providing excellent line fidelity and solid density.

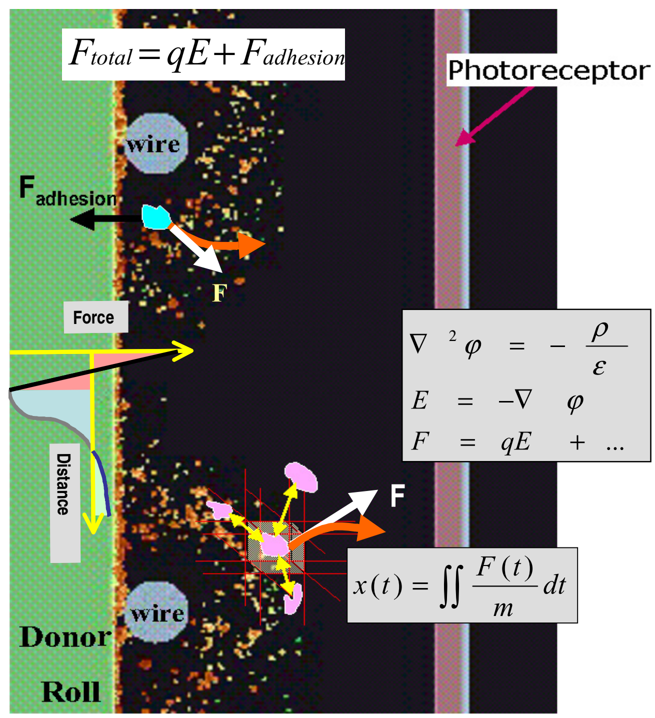

Figure 6. Development Physics

Single Pass Transfer

Having completed the development of all four separations, the toner layers are transferred to the paper in a single step at the transfer station. The advantage of a single step transfer is that it eliminates at least 4 opportunities for image mis-registration or disturbance and transfer efficiency loss, as shown in Figure 7. The total toner mis-registration on paper is the product of all mis-registrations at each transfer step. The more transfer steps, the more difficult it is to maintain high accuracy of total registration. The single transfer approach in the IOI architecture enables the image registration accuracy to be on the average less than 40 microns.

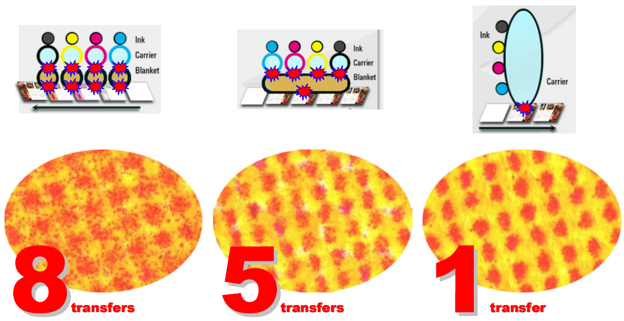

Figure 7. Advantages of Single Pass Imaging

A single step transfer process also ensures a high toner transfer efficiency, typically 95%, to prevent image degradation. However, the transfer of multiple toner layers is technically challenging. The transfer field has to overcome the adhesion force between the toner particles and the photoreceptor surface. That is especially difficult for the bottom toner layer in contact with the photoreceptor surface because it has been recharged multiple times. Such a difficulty is overcome by applying both electrical and mechanical forces to the toner layers. The electrostatic field created by the transfer charging devices is the primary driving force. Mechanical pressure is also applied between the paper and the imaged photoreceptor via a blade to ensure that the paper is in intimate contact. The transfer of the toner layers can be further assisted by the application of acoustic energy to the toner particles in the case of rough or textured substrates.[6,7] This unique combination of electrostatic, acoustic, and mechanical forces applied simultaneously through the transfer step, as shown in Figure 8, provides high image quality over a broad range of media from coated to uncoated, textured to smooth, and heavy to light weight paper.

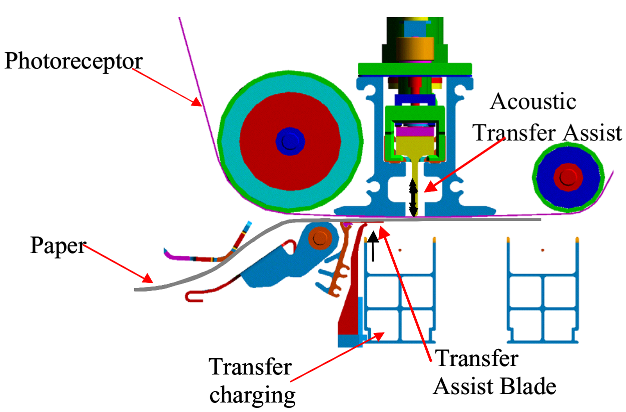

Figure 8. Transfer Blade and Acoustic Assist Transfer Assembly

Managing System Interactions

Several complex system interactions are unique to the IOI process and have to be managed in order to produce good color images. As successive toner layers are built up on the photoreceptor surface, they can affect the subsequent latent image uniformity due to the toner layer residual voltage, the increased dielectric thickness (combined thickness of the toner layers and photoreceptor), and the exposure loss caused by imaging through toners. A split-AC recharge[8] system comprised of DC and AC devices is used to charge the toned layers and the photoreceptor uniformly in preparation for the next exposure and development steps. The DC device raises the average potential while the AC device improves the resultant charge uniformity while neutralizing the residual toner charges in the previously developed layers. The latter reduces the voltage drop across the toner layer that would otherwise negatively impact development of the subsequent layer(s). A thick thirty micron photoreceptor and thin toner layers developed from the high fidelity powder cloud development mitigate this dielectric thickness change issue. The loss of exposure through the toner layers is eliminated by the arrangement of colors in an optimal order for light absorption, the use of IR lasers for exposure, and an IR sensitive photoreceptor. The discharge level is also tuned to beyond the knee of the PIDC (photo-induced discharge curve) to ensure total discharge. With all of these combined, the charging and discharging uniformity throughout the ten-pitch photoreceptor belt is maintained to be less than ten volts to give good color uniformity.

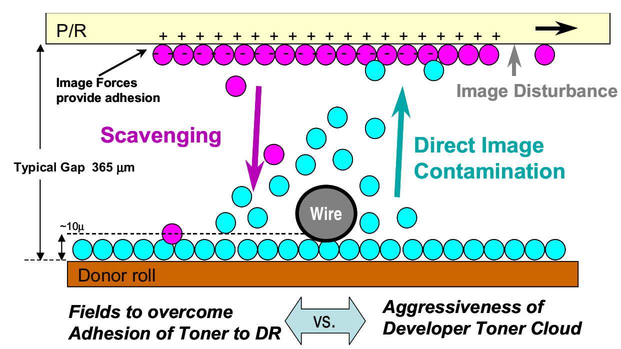

Figure 9. Electric Field for Toner Detachment vs. Interaction

The wire voltage in the HSD development is also carefully tuned to reduce contamination in the development sump and in the imaged area on the photoreceptor by the different color toners. Such contamination can cause color shifts in the image, as indicated in Figure 9. This could happen if the toner particles impact a prior separation with excessive force. If the impact is strong enough to release the previously developed toners from the photoreceptor surface, the released toner particles can be scavenged toward the donor roll surface and end up in the toner sump of a different color. The space left behind on the photoreceptor surface could also cause a color shift. The electric field between the wire and the photoreceptor surface determines the gentleness of the toner cloud. A lower field would reduce such a contamination problem. However, the field has to be strong enough to overcome the adhesion of the toners on the donor rolls to generate the required toner cloud for proper development. Therefore a balance has to be reached in applying voltages on the wire, donor rolls, and photoreceptor to obtain good development without causing color shifts.

Managing Microns

In order to maintain a 40-micron image registration and control uniform fine line development, many of the key components are engineered to be within a 50-micron tolerance. The gap between the HSD donor roll and the photoreceptor is maintained close to 365 microns with high precision donor rolls and the photoreceptor belt. The uniformity of the photoreceptor coating is within ± 1-micron. All the supporting backer bars and rolls for the photoreceptor belt in the belt module are also engineered to be within micron tolerances. The HSD housing has the ability to translate in both x and y directions and rotate in all 3 axes with compliance in 5 degrees of freedom. With such an adjustment, the development gap is well maintained and controlled to provide uniform and consistent color image development even when opened and closed for customer maintenance. The 40-micron color registration is achieved by well-controlled belt motion to within 30 microns in both process and lateral directions. The repeatability is 2 microns over 4-belt revolutions. Dual drive motors power the belt module and the gear train is engineered to be less than 1-micron accuracy.

Conclusion

Image-on-Image printing is a conceptually simple architecture based on modular REaD stations. It is capable of offset print quality due to its gentle powder cloud development system and single point transfer. The arc hitecture relying on large circumference photoreceptor belts is easily extended in process speed to capture more of the production printing market. On the other hand, Image-on-Image technology is complex relative to Tandem architecture and demands very tight control of manufacturing processes and tolerances. Though a considerable effort was required to gain mastery of these design rules, the result is a privileged extensible architecture that will be difficult to emulate. The DocuColor iGen3 Production Press, built on the Xerox REaD IOI technologies, provides our customers with unequalled print quality, reliability, flexibility and economics.

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Biographies

Rick Lux is currently a Vice President managing the Xerographic Competency Center responsible for all xerographic engineering within the Production Systems Group. He holds a Ph.D. in Engineering from the University of Rochester. Rick has worked at Xerox for 24 years and during his career, he has managed both product development teams and corporate research laboratories.

Huoy-Jen Yuh is currently a staff member in the Xerographic Competency Center within the Production Systems Group. Huoy-Jen holds a Ph.D. in Chemical Physics from the University of Chicago. During her twenty-year career in Xerox, she has worked primarily on photoreceptor related research, product development, manufacturing, and benchmarking. In particular, she has focused on the understanding of the effect of binder polarity on charge transport and the dispersive nature of charge transport in molecularly doped organic systems. She has also led multiple teams in delivering various organic photoconductors for several Xerox products and recently their integration in the iGen3 print engine. Huoy-Jen holds 60 US patents and is a certified Lean Six Sigma Black Belt.