Pixel-Pixel Electrical "Cross Talk" Through Liquid Toner Developer and Resultant Image Degradation

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Abstract

One normally conceptualizes and analyzes electrophotographic liquid toner development as proceeding strictly between an electrically-biased developer electrode and a photoreceptor, with a more or less "perpendicularly-constrained" development current flow. That is, one typically ignores the "local lateral conduction" through the liquid toner near the photoreceptor surface which tends to "short-together" the closely-spaced, adjacent image pixels which are at different surface potentials. In this paper, an analog electronic circuit model is used to analyze dynamically the local lateral electric currents through the liquid toner[1,2] close to the photoreceptor surface, driven by adjacent image pixels at different initial potentials. This is herein termed "pixel-pixel cross talk." It presents a quantitative and comprehensive, dynamic "picture" of the lateral current transients (cross talk currents) as the image pixels traverse the development nip, along with the resultant edge degradation and "single-pixel-fill-in." It predicts and demonstrates the effects of development gap, liquid toner conductivity, photoreceptor thickness, process speed, etc., and whether changes in these parameters will ameliorate or aggravate the image degradation. The circuit model results are in excellent agreement with experiment; give powerful additional insight into the transient dynamics of the cross talk effects, and suggests ways to reduce the degradation.

Introduction

The liquid toner modeling undertaken herein is related to a high quality liquid electrophotographic printing process, designed as a computer color printer, shown schematically in Figure 1. The photoreceptor is charged, exposed to a scanning laser, and developed with a liquid toner. It is rapidly and sequentially recharged, exposed, and developed with at least 3 more color liquid toner stations before the composite color image is transferred *en masse* to an intermediate transfer blanket, from which the image is again transferred to the final paper or transparency receptor. While the toner nip conductance profiles have been measured,[1] and the overall process has been electrically modeled,[2] the subject of this paper focuses on some additional detailed, and important electrical dynamics within the liquid toner development nip. The parameters and details are generalized enough to form the basis for modeling most liquid toner processes.

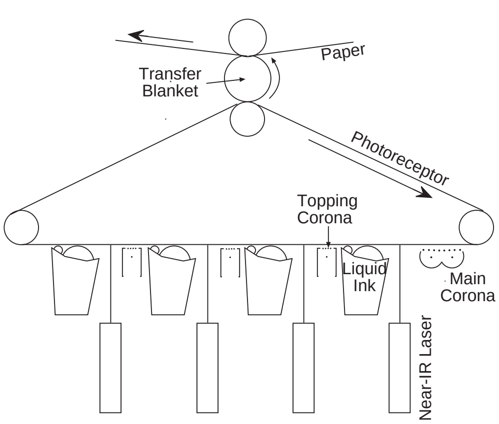

Figure 1. Diagram of Printing Process

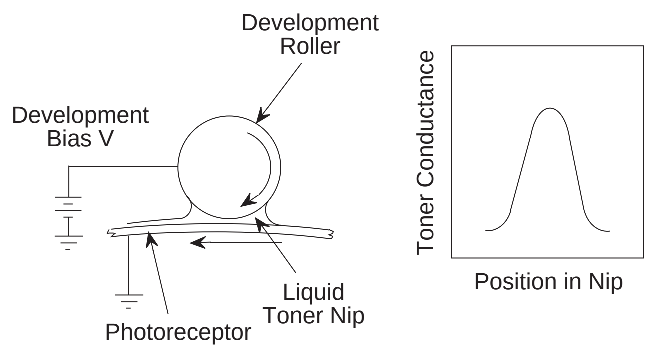

Figure 2. Liquid Toner Nip (Inverted) and Conductance Profile

Figure 2 is a representation of the liquid toner "nip" region between the developer roller and the photoreceptor surface. Since the process utilizes discharged-area-development, which is common for printers, the developer roll is biased to a development potential, e.g. 500V, which is less than the photoreceptor surface potential of the unexposed background areas, 600V in this example, but considerably more than the residual potential of the exposed image areas of the photoreceptor, e.g. 125V.

Figure 3 shows conceptually the development "dynamics" within the liquid toner nip. [The charges and voltages shown on the photoreceptor (pc) are the initial conditions after exposure for simplicity, rather than the final charge distribution after development, which would appear more confusing.] The applied electric field between the development roll and the discharged areas of the pc surface causes positively charged (in this example) toner particles to "electrically plate" on the pc surface in direct proportion to the positive current integral per unit area of pc surface. This toner plating is represented by the large arrows in the figure. "Counter ions," negative in this example, flow in the opposite direction from the positive toner particles, represented by the small arrows. They are typically colorless, small and of high mobility. They are necessary in all liquid toner systems to maintain overall charge neutrality in the toner "soup." In undischarged pc areas, those areas initially at higher potentials than the development roller, which will result in undeveloped pixels in the final print, colorless counter ions (negative) are plated on the pc surface, while positive toner particles are "backplated" onto the developer roll opposite these areas. Most discussions of liquid toner development systems forget or ignore the counter ions, but they are extremely important and their properties can result in success or failure of a real process. Hereinafter, for simplicity, I will only refer to the plating of positive toner particles on the pc, but always keep in mind the counter ions flowing in the opposite direction from every toner particle. The sum of the motion of these charged particles constitutes the development current (ignoring negligible "free charge").

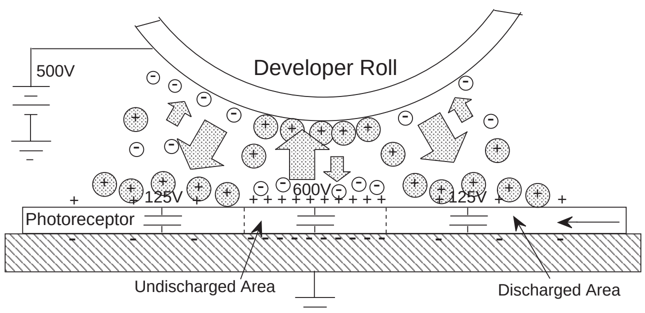

Figure 3. Liquid Toner Development Dynamics, Conceptual Representation

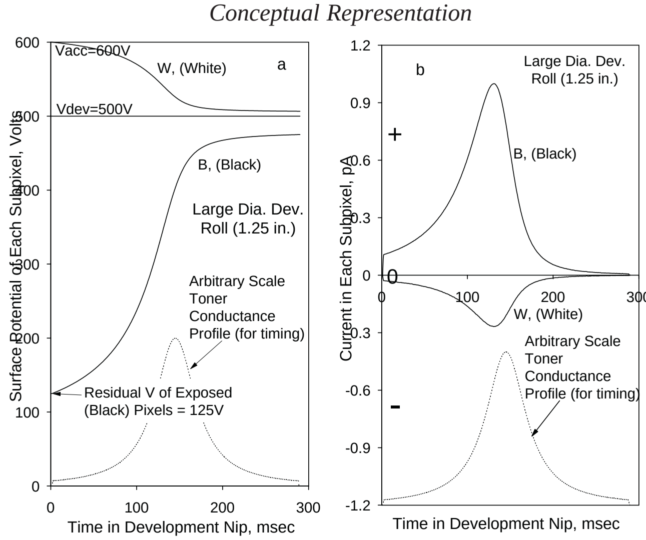

Figure 4. Typical Voltage and Current Transients for a White and Black Pixel; Non-Cross Talk Case

Figure 4 shows typical voltage and current transients (time plots) as two different tiny unit areas, or pixels, of the pc traverse the development nip. [The graphs refer to "subpixels," which will be described in the modeling section, following.] In Figure 4a (voltage transients), the initially discharged pixel, B (hereafter referred to as a "black pixel") rises from its initial residual potential of 125V in this example, toward the development potential of 500V as toner particles plate on the pixel. This plating current direction is here defined as a positive current. An initially undischarged pixel, W (hereafter referred to as a "white pixel") begins dropping in potential from its initial voltage of 600V, usually called Vacc, toward the 500V development roll voltage as negative current, or "reverse current" (counter ions) flows toward the white pixel. If enough nip time is allowed, both pixels will reach the 500V development voltage and current flow will stop. This is referred to as "development to completion" since no more toner can be plated unless a higher development voltage is applied. Figure 4b shows typical current transients for the same black and white pixels, where the "bell" shape arises from the conductance profile of the toner nip. These two pixels are considered part of "large" black and white areas so all their "neighboring" pixels are at the same initial potentials. Thus there is no tendency for lateral current to flow from pixel to pixel through the liquid toner soup close to the pc surface as they traverse the development nip. In this example, the white pixel receives only negative current flow, and a negative current integral results (colorless counter ions). The black pixel receives only positive current and a positive current integral results, which is directly proportional to the toner mass deposited per pixel area. These pixels within large areas of like potential are those represented by the simple development "picture" of Figure 3, above -- that is, the NO-cross talk case. These can serve as "benchmarks" with which to compare the following cases involving cross talk currents.

However, if the two pixels at different initial potentials were neighboring pixels, cross talk or lateral current flow could occur from pixel to pixel, through the liquid toner close to the pc surface as the pixels enter the toner nip, as depicted in Figure 5a. In this case, the two pixels are very close to one another relative to the rather remote developer roll. The differing pixel voltages result in local electric fields which cause toner plating from the higher voltage white pixel toward the lower voltage black pixel. While this may seem inconsequential at first, a moment's reflection reminds one that the initial pixel voltages are really very finite initial charges on the pc pixel capacity, which changes rapidly as local pixel current flows. That is, each pc pixel with its initial charge constitutes a tiny "wimpy battery" whose voltage collapses or rises rapidly as current flows into or out of it. The "danger" depicted in Figure 5b, is that these local lateral cross talk currents will cause the white pixel to rapidly drop below the 500 V development voltage as it supplies current to its black neighboring pixel(s), and thereafter be "mistaken for a gray pixel" by the 500V development roll as the pixels proceed through the nip. In this case, the development roll will plate toner on the "white-pixel-now-turned-gray" as it traverses the remainder of the

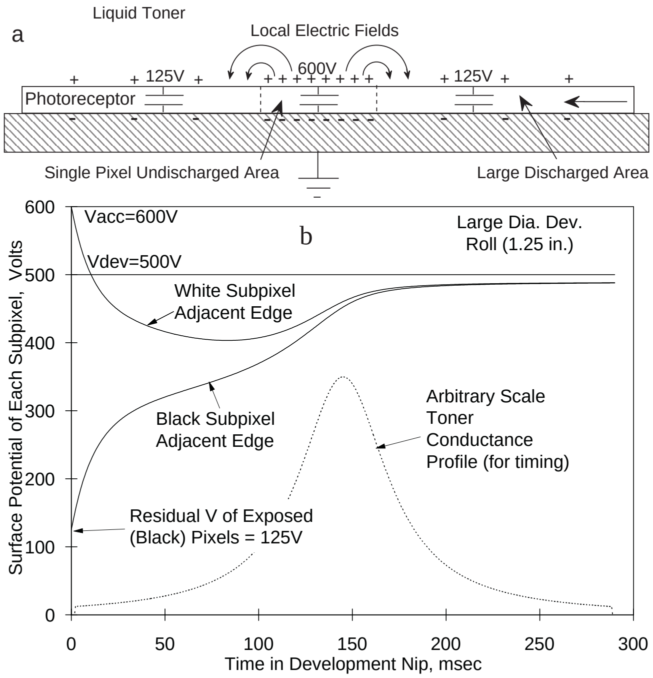

Figure 5. Voltage Transients; Pixel-Pixel Cross Talk Through Liquid Toner

nip. Clearly, this cross talk will begin the moment the adjacent pixels at different potentials enter the liquid toner nip. This is precisely the region where the development roll is the "most remote" -- in the lowest regions of the bell-shaped conductance curves. (The bell-shaped conductance curves represent conductance from the roll to increments of the pc surface.[1] As regards the cross talk lateral currents, the liquid toner soup in the nip is assumed to exhibit a more or less isotropic conductance, which is supported by measurements.)

Modeling

To model the effects of pixel-pixel cross talk, consider two extended black areas (initially discharged) separated by a line of white pixels (initially undischarged), one pixel wide as depicted in Figure 6. Here, 720 dpi (dots per inch) are used, giving pixel sizes of 35.27 µm square. This results in a quasi-one-dimensional "worst case" problem (for white pixels) for simplicity, easily extendable to two dimensions. For better

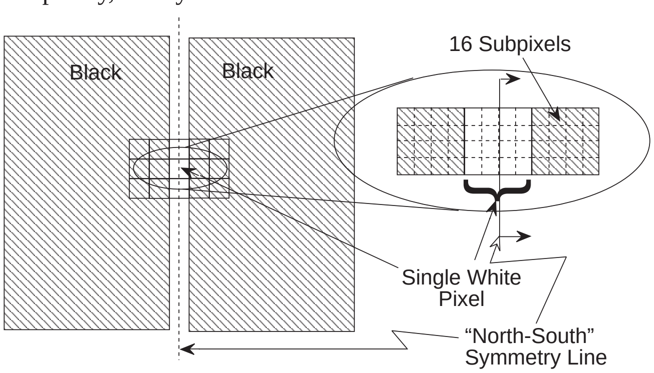

Figure 6. Representation of Region to be Modeled

"resolution," consider each 35µm pixel as subdivided into 16 subpixels of 8.8µm square each. This allows investigating details within each pixel, such as an edge subpixel relative to an interior subpixel. Since there is "east-west symmetry" about the central "north-south dividing line" bisecting the line of white pixels, one needs only analyze the "east half" or the "west half" of the cross talk currents -- the other half is identical and independent.

Figure 7 depicts a simplified version of a very useful analog electronic circuit model to investigate the cross talk cur-

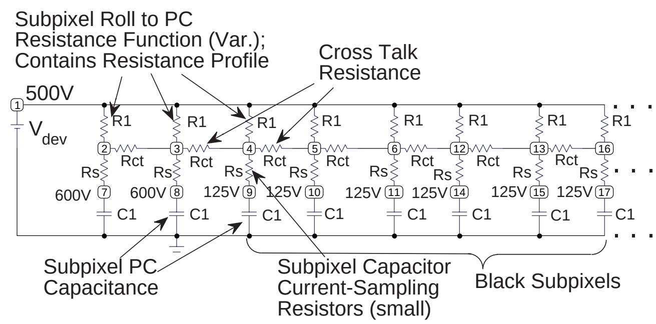

Figure 7. Simplified Analog Circuit Model

rent transients. C1 represents the pc capacity of each subpixel. The node voltages shown are the initial voltages, prior to running a transient. The 600V capacitors are the white subpixels, and the 125V ones are the black subpixels. R1 represents the developer-roll-to-pc resistance for each subpixel capacity. R1 contains a time-dependent factor which generates the proper bell-shaped toner resistance curve, -- a unique one for each roll diameter and roll-to-pc spacing under consideration. Rct represents the subpixel-subpixel cross talk resistance between adjacent pc subpixels, which is calculated under a set of assumptions, including toner resistivity, ρ, and various "cross talk depths." Rs is a current-sampling resistor of very small value to sample each subpixel current independently.

Figure 8 shows the resulting voltage transients for the modeled single line of "lonely white pixels" sandwiched be-

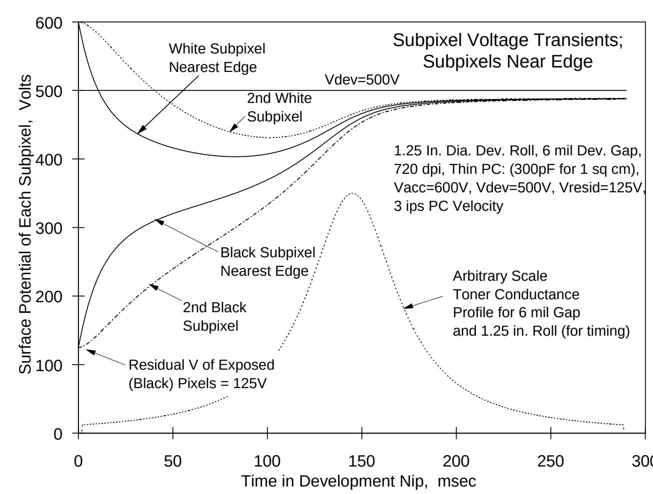

Figure 8. Voltage Transients for Subpixels Near Edge; Large Black Areas Separated by One White Pixel

tween the two large black areas under one particular set of conditions. Notice that the edge white subpixel and the next-nearest-neighbor white subpixel ("2nd white") both drop below the 500V development voltage early in the nip.

Figure 9 shows the current transients for the same case. Notice that the two white subpixels have positive current flowing onto them later in the nip, as a result of their having dropped below the 500V development potential, as they contributed cross talk current to their discharged neighbors earlier in the nip. These positive white subpixel currents are numerically integrated to determine the amount of toner "mistakenly" and irreversibly deposited on them by the development roll.

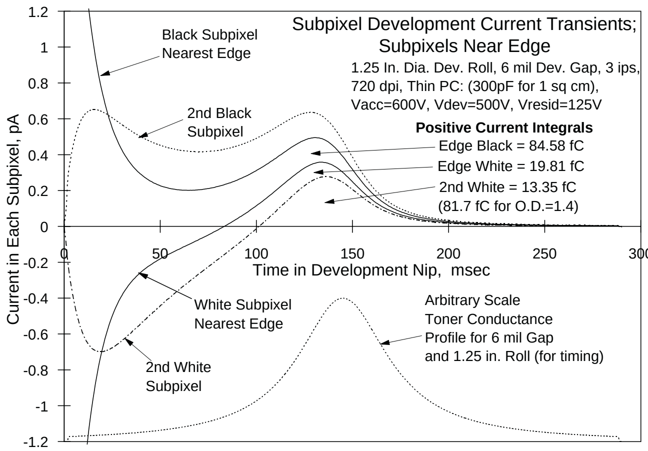

Figure 9, Current Transients for Subpixels Near Edge

More than 150 transients were run, several for each set of process parameters, such as development gap (1 mil to 6 mils), development roll diameter (0.75 in. to 1.25 in.), toner conductivity, pc thickness (150pF to 300pF for 1 square cm of pc, under constant charge constraint) and process speed (3 ips to 6 ips). Toner nip transit time varied from 75ms to 300ms. For each case, the "normal" toner conductivity used was that conductivity which resulted in 95% development completion in the nip time under consideration for black subpixels within large black areas (i.e. in NO cross talk region). Higher-than-necessary conductivity toners (up to 3 times as conductive) were also included (development to completion in much less than the nip time).

Results and Conclusions

In Figure 10, each subpixel positive current integral (proportional to deposited toner mass per subpixel) is plotted as a "profile" across the single white pixel to compare and visually-summarize the results. A small sampling of five particular cases are plotted. The "ideal" profile would have NO toner mass deposited in the white subpixel areas. Notice the "weak edge effect" -- not the "classical" one of course.

As can be seen from Figure 10, smaller diameter developer rolls are superior to larger ones, and smaller roll-to-pc gaps

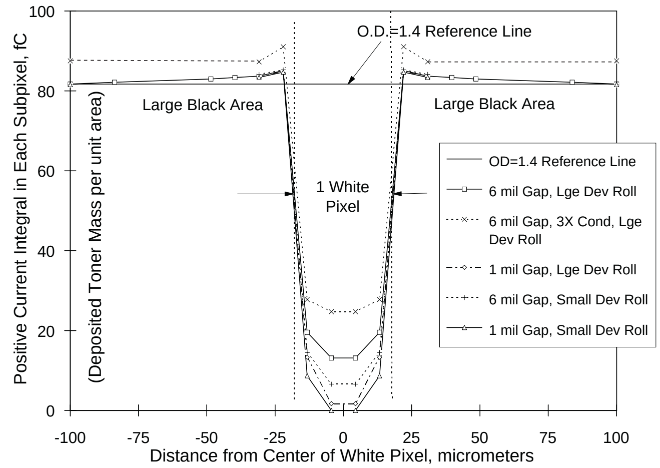

Figure 10. Deposited Toner Profiles Across Single White Pixel

are significantly superior to larger ones. Higher toner conductivities, those that are higher than are necessary for just-complete-development in the available nip time, aggravate the problem. The results are independent of process speed, provided the toner system can deliver the required development currents at high speed without otherwise compromising quality. The results are also independent of the photoreceptor thickness, assuming the usual constraints wherein one holds the initial charge per unit area constant, as well as the deposited toner mass (in large areas) constant. (This is independent of other photoreceptor thickness considerations such as voltage required, transit time of photocarriers, and lateral photocarrier charge diffusion during transit.) Space does not permit further discussion of the intuitive logic of the results

References

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2. Kotz AR, Ender DA, Dynamic Electronic Circuit Model for an Emerging, High Quality Liquid Electrophotographic Process. *Proc. IS&T's NIP14*, pg. 235. (1998)

Biography

Arthur Kotz received his BS in Physics from The University of Minnesota, Minneapolis, and MS and Ph.D. from The University of Wisconsin, Madison. He joined 3M in 1955, has 44 years experience in the area of electrophotography, toner systems and electronic printers, and holds a number of patents in the field. He is a member of APS and IS&T and has authored and presented many papers, both invited and contributed. He recently retired as a Corporate Scientists from 3M, and is now an independent consultant in the areas of electrophotography, liquid and dry, high speed electronic imaging, and physics in general.

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