Stabilized Three-Level Highlight Color Imaging with High Resistance Developer

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A one-pass process with combinations of charged and discharged area developments is used for three-level highlight color imaging. The process yields excellent gradation images between black and color because of perfect color registration. However, there are some special problems of fringe images, blurring, and appearance of white spots in the second color images, etc. Employing a very low resistance developer can overcome these problems. As a consequence, though, this type developer results in developing instability due to charge leakage. A highly stable three-level process without these problems is proposed which employs a higher resistance developer without charge leakage and applies a newly developed edge effect control technology and the first color developing station with dual rotation rollers. This process provides excellent highlight color images.

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Introduction

Copiers and laser printers for printing color logo marks and/or small additional images have been commercially available since the 1980s. Such preliminary printing is called spot color or accent color because it provides additional color images in black and white documents. Since the early 1990s, with the evolution of Print On Demand, more precise highlight color images have been desired, including underlines, color blends, etc., with heavy duty printing for large area coverage such as machine readable forms. A three-level or tri-level process is suitable for such use.

In the three-level process, a charger and an exposure device form the charged, intermediate and discharged electric potential levels on the photoconductor. The charged and discharged areas are developed with black and color toners. Since the black and color areas are formed by the same exposure device, the process has perfect registration between the black and color areas and is essentially a one pass process. This perfect registration provides a precise highlight color image. On the other hand, because the charged electric potential is divided into two parts, each development must have a very small imaging potential, a very small back potential with reference to the intermediate potential, and a very large back potential with reference to the other color imaging potential. This causes several problems unique to the three-level process, which are weak development, fringe images, blurring between adjacent colors in the first color images and appearance of white spots in the second color (usually black) images.

The three-level process originally appeared in the Japanese patent literature in 1973 as “Two-color developing method”.[1] In 1978, it appeared in the US patent literature as “Method for Two-color Development of a Xerographic Charge Pattern”.[2] These two patents were followed by some investigations of the three-level process,[3–6] which included examinations of some of the special problems.

In this study, the process and details of the problems are considered further. Particular attention is given to the relationships between the problems and the process, employing a high resistance developer. Previous reports mentioned the need to employ a soft conductive magnetic brush development.[3,4] However, development instabilities, due to charge leakage and other reasons, should be overcome by employing a lower resistance developer. To allow the use of the high resistance developer process that has more stability, development of technology to control the edge effect to prevent the fringe images, and application of the dual rotation developing station at the first color developing station, to eliminate adjacent color blurring, are carried out. At the same time, these measures result in stronger development and

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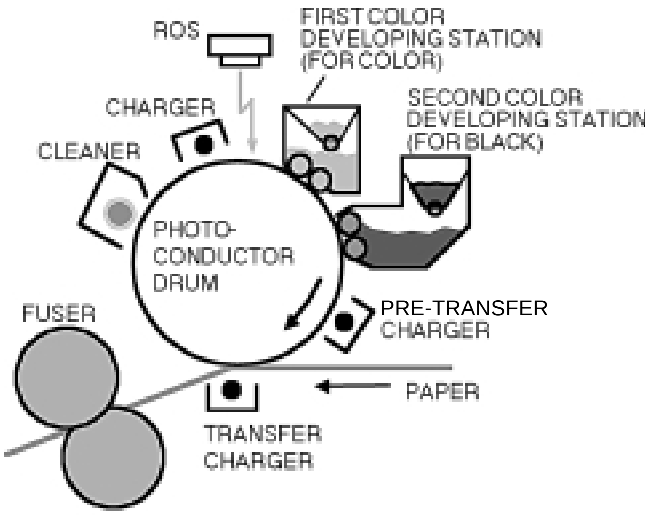

Figure 1. Three-level process.

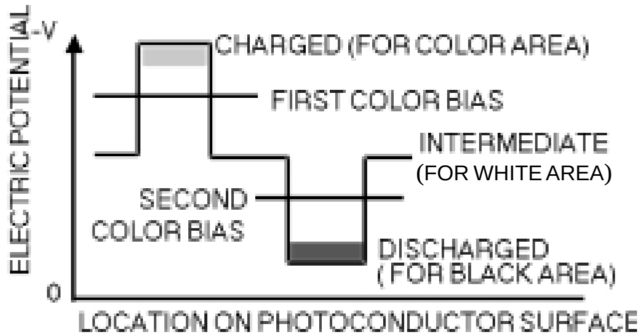

Figure 2. Electric potential distribution.

preventing the white spots. Finally a highly stable process using a high resistance developer, which provides an excellent highlight color image, is proposed.

Three-Level Process

Figure 1 shows a schematic of the three-level process. After a photoconductor drum surface is uniformly charged, one laser beam partly erases the charge to the intermediate and discharged potentials. Thus, three electric potential areas, which are for the color, white and black images, are formed. The distribution on the photoconductor is schematically shown in Fig. 2. Figures 1 and 2 show that the color toner development is done at the first color developing station and the black toner development is done at the second. At the first color developing station, positively charged color toner imaging is carried out with the charged area development. Next, the discharged area development for negatively charged black toner in the second color developing station is performed. Even if the discharged area development for the negatively charged color toner is used for the first color developing station, the three-level process can be built up.[4] The black and color toner images, which have opposite polarities, are developed on the photoconductor surface at this point. Next, a pre-transfer charger makes the toner polarities uniform to allow an electrostatic transfer process. Then, the toner transfer to paper is carried out. Finally, the black and color images, held on the paper, are carried to a fuser and fixed.

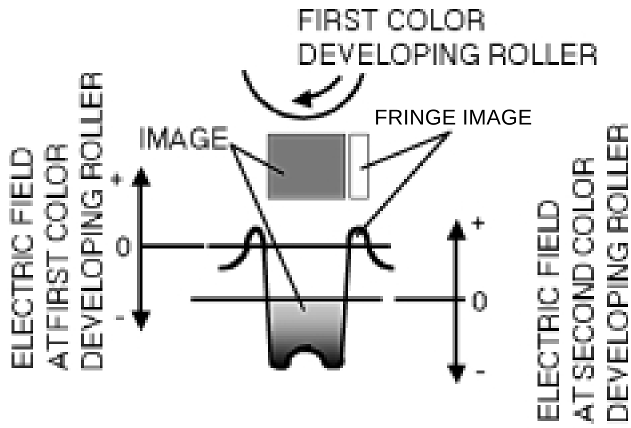

Figure 3. Electric field and fringe image.

Because the applied electric potential is divided into two parts, each color development must have a very small imaging potential and a very small back potential with reference to the intermediate potential, and a very large back potential with reference to the other color imaging potential. The very small imaging potential causes a problem of weak development performance, namely a difficulty in getting sufficient image densities. This potential distribution causes several unique problems, which are fringe images, white spots in the second color (normally black) images and blur between adjacent colors in the first color image.

Fringe Images

Figure 3 shows a schematic of the fringe image and its electric field distribution.[4] The fringe image is a ghost image caused by the opposite color toner which appears at an image edge. The fringe image occurs in the lower portion of an image and in the narrow gap between parallel lines or intersecting lines for the developing roller rotation. These are locations on the photoconductor drum where the edge effect is noticeably stronger. However, even if the edge effect is sufficiently strong, there are some portions where the fringe image is swept out by a magnetic brush on the developing roller and it disappears. The fringe image occurs where drag forces in the opposite direction to the developing roller rotation is generated by the surface electric field. This prevents the toners from being swept out, as if a dam exists.

Use of higher resistance developer promotes occurrence of the fringe image because the electric field at the edge is increased. Additionally, occurrence is promoted by getting the bias voltage of the opposite color closer to the intermediate potential.

White Spots

Figure 4 shows a schematic of white spots. Under conditions that the difference between the first color bias voltage and the discharged area potential is too large and the developer resistance is too small, spotty discharges occur from the magnetic brush to the discharged area on the photoconductor where the magnetic brushes touch the photoconductor surface during the first development. The spotty marks in the discharged area appear as white spots in the second color image. There is less possibility for these to appear in the first color image. When the second color magnetic brushes touch the photoconductor surface, the effective difference between the second color bias voltage and the charged area

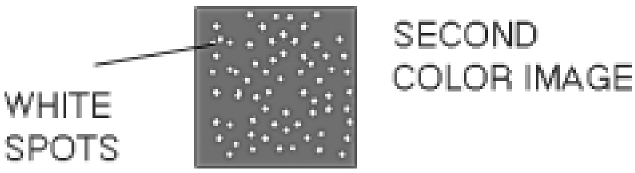

Figure 4. schematic of white spots.

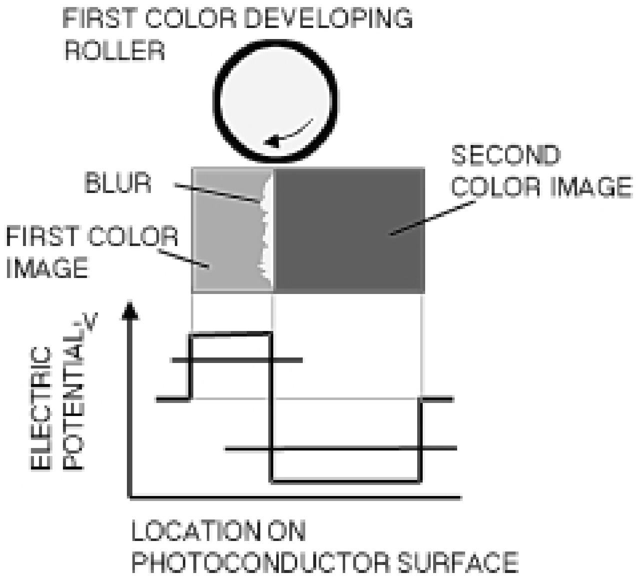

Figure 5. Color blur at adjacent area.

potential is not large because of by the existence of the first color toner image.

Color Blur at Adjacent Areas

Figure 5 shows a schematic of the blur and the potential distribution. The blur occurs in the first color image between adjacent colors. It occurs in the lower portion of a first color image for the first color developing roller rotation, next to the second color image. Initially, the first color magnetic brush scrubs and passes through the untoned second color developing area. The electric potential changes suddenly, to the charged area potential, in the adjacent area. The change from the discharged to the charged potential is significant. Development current direction is changed quickly. If the resistance of the magnetic brush is high, the change involves some response delay involving transient phenomena. During transient response, developing performance is weakened which results in the blur.

Process Formation

Method Using Low Resistance Developer and Low Charged Area Potential

Figure 6 shows the fringe image at an edge of the second color image and the white spots' appearance thresholds, as functions of kinetic specific resistance of the first color developer. The vertical axis is a ranking from no fringe images or no white spots, Rank 0, to the worst, Rank 4. The appearances of white spots and fringe images have a tradeoff relationship; as the fringe images get worse, the number of white spots decreases with increasing kinetic specific resistance. Both occurrence

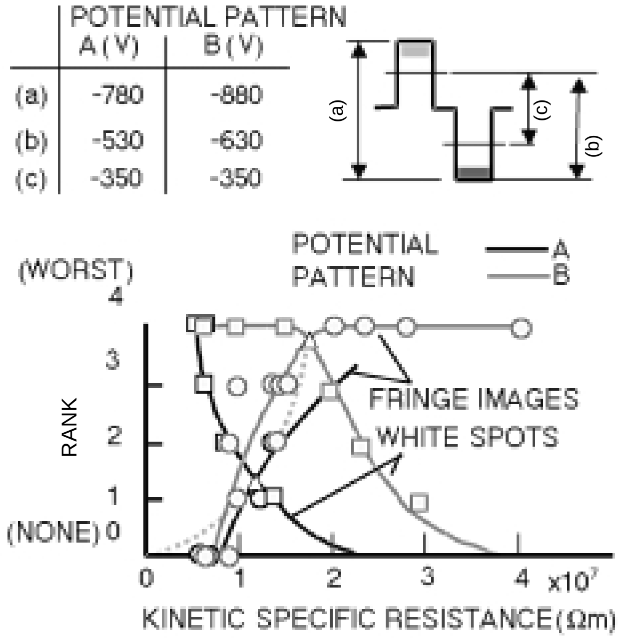

Figure 6. Characteristics of white spots and fringe image.

of fringe images and white spots are fewer in pattern A than in pattern B. For the fringe images, the electric field, which is a cause of the fringe image, is smaller in pattern A because the charged area potential, (a), is lower. As a reason for appearance of the white spots, the potential difference between the first color bias voltage and the discharged area potential, (b), is smaller in pattern A. The smaller (b) is caused by the lower charged area potential, (a), in pattern A. The tradeoff points of fringe images and white spots curves, which are shown by the triangles drop from patterns B to A along the gray dotted line. This means that prevention of both fringe images and white spots can be done at lower charged potential and lower effective resistance. Roughly speaking, the charged area potential and the kinetic specific resistance without occurrence of fringe images and white spots are expected to be lower than |–650 V| and 10^6 Ωm in Fig. 6. Such a low resistance developer has high developing performance and sufficient image density can be obtained. This low resistance developer also ensures quick response performance and no blurring between adjacent colors. On the other hand, such a low resistance developer has the problem of charge leakage, which results in process instability.

Method Using High Resistance Developer and High Charged Area Potential

To get a stable process, a higher resistance developer is needed. The charge leakage problem is negligible at developer resistance above 10^7 Ωm. To compensate for the low developing performance in the high resistance developer and to obtain sufficient image density, a wider developing potential, which means the difference between potentials (a) and (c), should be obtained. The high charged area potential setting, namely pattern A or B, makes it possible.

With high resistance developer and the high charged area potential, the white spots can be avoided. For example, with the difference between the first color bias voltage and the discharged area potential, |–530 V|, as shown in the potential pattern A, when the devel-

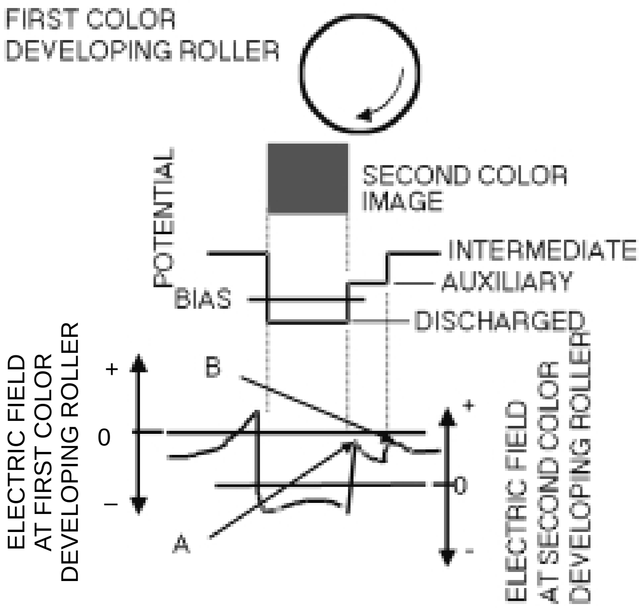

Figure 7. Edge effect control to prevent fringe images.

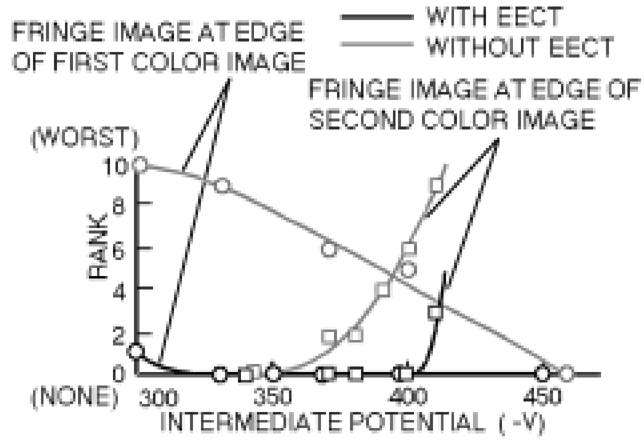

Figure 8. Performance of edge effect control.

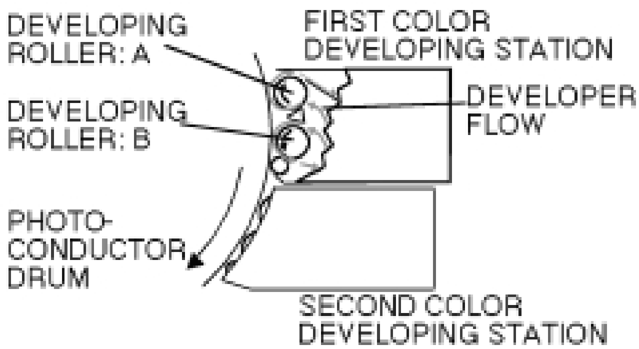

Figure 9. First color developing station.

oper resistance is above $2.3 \times 10^7\ \Omega m$, no white spots occur. However, for these conditions, the fringe images appear and it is hard to avoid the blur between adjacent colors. Some special countermeasures can solve these two unique problems.

Countermeasures for the Problems

Countermeasures for fringe images and blur between adjacent colors, when using high resistance developer and the high charged area potential, are proposed.

Edge Effect Control Technology

To prevent the fringe images, edge effect control technology (EECT) is considered, since the cause of the fringe images is the edge effect. The fringe images appear in a specific area, the lower portion of an image and in the narrow gap between the parallel lines or intersecting lines for developing roller rotation. Avoiding dramatic potential changes on the photoconductor can weaken the edge effect. In EECT, an auxiliary exposure level is supplied to the area where the fringe image is expected to appear on the photoconductor surface. The exposed portion is selected by pattern matching for an image signal. Figure 7 shows the electric potential and electric field distributions when an auxiliary exposure level is applied to the second color image.

The EECT is also effective for the first color image. The auxiliary exposure level should be set so its potential is between the intermediate potential and the bias voltage to avoid a ghost image. For more accurate optimization, the peak of the edge effect caused by the difference between the discharged and auxiliary potentials, shown as A in Fig. 7, should be at the same levels with another peak caused by the difference between the auxiliary and intermediate potentials, shown as B. It is experimentally confirmed that multi auxiliary exposure levels between the bias and intermediate potentials provide more effective prevention of the fringe images.

Figure 8 shows experimental results for the effect of EECT. The fringe image appearance levels are shown with the intermediate potential. The vertical axis is a rating from no fringe images, Rank 0, to the worst, Rank 10. Multi auxiliary exposure levels are applied. High resistance developers above $10^7\ \Omega m$ for first and second colors are employed and white spots do not appear. In the experiment, the charged potential is changed while keeping the power of each exposure level constant. Thus, the intermediate potential and the auxiliary potentials are changed with the charged potential. When the absolute value of the intermediate potential is increased, the edge effect caused by the difference between the discharged and the intermediate potentials is enhanced. In addition, since the intermediate potential becomes closer to the first color bias voltage, fringe image at the edges of the second color image is apt to occur. Likewise, the absolute value of the intermediate potential is decreased, the fringe image at the edges of the first color image is apt to occur since the intermediate potential becomes closer to the second color bias voltage. Without EECT, fringe image occurs at all intermediate potentials. On the other hand, a wide range of intermediate potentials without occurrence of fringe images can be obtained with the use of EECT.

The First Color Developing Station with Dual Rotation Rollers

A schematic of the developing station is shown in Fig. 9. The first color developing station with developer feeding from the gap between two rollers moving the opposite directions is employed to eliminate the blur. Since the blur is a directional phenomena, which occurs on the low side of the first color for the first color developing roller rotation, the dual rotation developing roller is an effective countermeasure. Prevention of the blur ensures excellent black and color blended images, making the most of the perfect color registration.

As a second advantage of the first color developing station with the dual rotation rollers, dual bias voltage setting can be made. A lower bias voltage is set for roller A than roller B (Fig. 9). Even if the fringe image and background toner is developed at roller A, due to the low bias voltage setting, roller B sweeps them out and they vanish. Finally, the lower developing roller bias voltage setting for roller A provides high developing performance for the first color developing station.

The EECT to prevent fringe images and the dual rotation rollers at the first color developing station to eliminate the blur make use of high resistance developer possible. Thus, stabilized three-level highlight color imaging is obtained.

Conclusions

The problems of fringe images, white spots and blur between adjacent colors, and the process for three-level highlight color imaging were examined. Technology was developed for the edge effect control to prevent fringe images. A dual rotation roller at the first color developing station was applied to eliminate the blur. A high charged potential setting and high resistance developer could be used without appearance of white spots. Thus, stabilized three-level highlight color imaging was obtained.

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References

1. K. Tanno, Two-Color Developing Method, Japanese Pat. Laid-open Publication No. 37,148 (1973).
2. R. W. Gundlach, Method for Two-Color Development of a Xerographic Charge Pattern, US Pat. 4,078,929 (1978).
3. W. E. Haas, D. G. Parker and H. M. Stark, Highlight Color Printing: The Start of a New Machine, *J. Imaging. Sci. Technol.* **36,** 366 (1992).
4. D. G. Parker, J. E. May, H. M. Stark and W. M. Allen, Development of Trilevel Xerographic Images, *Proc. SPIE* **1670,** 72 (1992).
5. N. B. Goodman, Imaging Characteristics of the Tri-Level Highlight Color Xerographic Process, *Proc. SPIE* **1670,** 82 (1992).
6. I. Chen, Mathematical Simulations of Electrophotographic Images in Tri-Level Highlight Color Process, *Proc. IS&T's 8th Int'l. Congress on Adv. Non-Impact Printing Technologies*, IS&T, Springfield, VA 1992, p. 50.