Smart Printhead Electronics controls Print Quality in Océ's Direct Imaging Process

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Abstract

Direct Imaging (DI) is a unique 7 color print process being developed by Océ and applied for the first time in the Océ CPS700 printer/copier that will be introduced this year [1]. In this process digital information is converted into a (dry) toner image on a DI-drum ('printhead') in a one-step process. In a single pass process 7 color toner images from 7 separate DI image forming units, are collected on a rubber intermediate roller and subsequently fused onto paper using Océ's Color Copy Press technology. In Direct Imaging, 5000 to 7500 conducting tracks on the surface of each DI-drum are controlled by means of a large number of ASIC's that convert a digital image into either 0 or 40V voltage at appropriate times.[2] When a track is powered with 40V, toner locally adheres to the surface.

Recently we discovered a unique feature inherent to the DI Print Process that enables us to use smart driver electronics, implemented in ASIC's specifically designed for Direct Imaging, to control print quality in a very elegant and stable way. The same driver electronics that power the DI-drum tracks, thereby forming a toner image on the surface of a DI-drum, is able to measure directly the amount of toner deposited. This is done by measuring the change in capacitance (or more general impedance) of drum-tracks which shows to be directly related to the amount of toner deposited on each track. Measurements can be done fast enough and with such high sensitivity that toner coverage can be measured directly after or even during printing of each pixel-line if necessary. This holds for toner coverage on a very local scale (on each track, 'pixel-information') or averaged across many tracks. This paper will describe how above mentioned 'tonersensing' measurements are done and how this offers many opportunities for using feedback schemes for stabilizing or improving print quality.

Introduction to Direct Imaging

The printing surface of a DI-drum is 317 mm wide and has a resolution of 400 dpi (600 dpi is being developed). This requires about 5000 drum-tracks. The term 'Direct Imaging' refers to the imaging principle: electronic circuits inside the drum generate a toner image 'directly' in a one-step process (see figure 1). This distinguishes DI from most commonly used electrophotographic printing processes that all use a latent electrostatic image on a photosensitive image carrier whereby a toner image is formed in several successive steps (such as charging, exposure, developing).

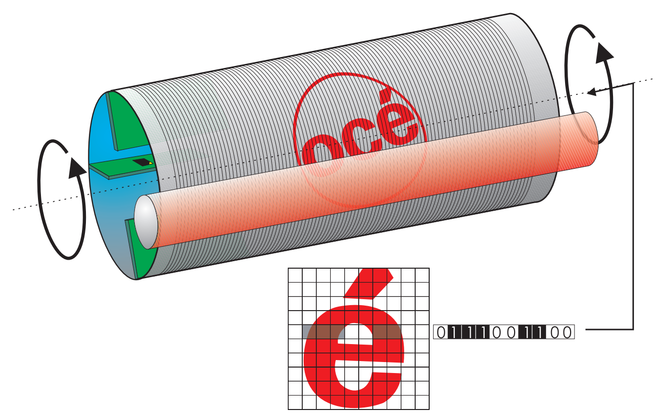

Figure 1. Direct Imaging converts digital information directly into toner-image.

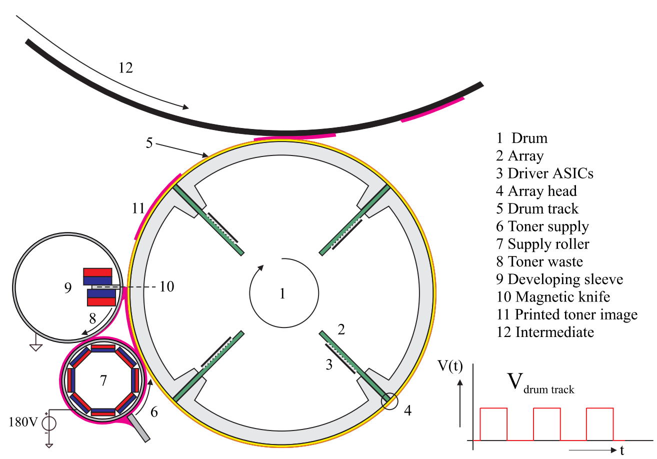

Figure 2. Schematic drawing of Direct Imaging unit

Four sets of control prints (arrays) inside the drum, each having 1280 outputs, supply the tracks with the required voltages.

DI uses mono-component magnetic dry toner consisting of particles with a diameter of approximately 10 micron which are electrically conductive (through surface conductivity) and can be magnetized due to the presence of very small soft magnetic particles dispersed inside the polyester tonermaterial. Color pigments or dyes are used to get different colored toner.

A DI drum has a SiO_x top-layer of about 1 micron thickness which covers all drum tracks. This makes it possible to use an electric field between toner and drum-tracks to attract toner to the drum surface. In figure 2 the principle of DI is clarified. A rotating toner supply roller containing very strong magnets deposits toner particles onto the drum by means of applying an electrical voltage of approximately 100 to 180V between the toner and the drum-tracks. In this process the toner is inductively charged and about a mono-layer of toner is formed on the drum surface. Further along in the rotational direction of the drum, a developing-roller produces a very strong (order 2T), high-gradient (order 2000 T/m) magnetic field. This so-called 'magnetic-knife' attracts toner along a line set at a 90 degrees position to the rotational direction of the drum and the track pattern. A very thin metal developing-sleeve rotates around this stationary magnetic-knife. When an electrical voltage is generated on any given drum track, an electrical field is produced between toner and said drum track. When there is no electric field (track potentials 0V), the magnetic force combined with mechanical inter-particle interaction forces (together: cleaning force) is greater than the electrical force, resulting in cleaning of all supplied toner. The rough sleeve-surface picks up and moves any excess toner back to the supply-roller for re-use. A track potential of approximately 40V changes the force-balance in favor of the electric force, thus producing a toner image on the drum. The electronic track-drivers in the drum provide each drum track with predetermined voltages at the right time. The number of drum tracks determines the axial print resolution. In the CPS700, this is 400 dpi. The switching frequency of drum- tracks and speed of rotation determine the tangential resolution. This results in a high degree of freedom in choosing a high resolution of, for example, 1600 dpi in tangential direction. In principle the resolution in this direction can be much higher.

The Océ CPS700 has 7 drums, each producing its own color image (i.e. black, blue, red, green, cyan, magenta and yellow). A soft silicone rubber intermediate roller collects all separate color images by adhesive forces between the toner powder and rubber and fuses the full color image on paper in a single pass process. This enables a very short paper path and good color registration. This *Color Copy Press* principle makes the Océ CPS 700 an extremely reliable and productive printer. Using this principle means that any given color on paper is a composition of several mono-layers of color pixels positioned side by side instead of color overlays. The advantages of this process are a high color quality, low and consistent gloss and a wide range of supported media. The 'Image Logic' image processing developed by Océ ensures an optimum and constant print quality.

Tonersensing: Measurement Principle and Results

Océ produces DI-drums in a clean-room. The base is formed by an aluminium cylinder with the four arrays bonded in grooves at an angle of 90 degrees to the track direction. Very small chisels cut the track pattern in a thin coating of epoxy. This produces the characteristic 'turret shape' of the drum tracks (see figure 3).

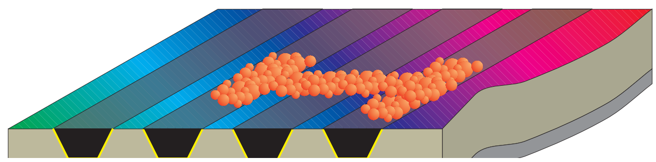

Figure 3: 3-D perspective of drum-tracks with toner particles on drum surface

The ASIC's that power the drum-tracks contain special circuits to enhance the testability of the drum parts, the drum production and the Océ CPS700 machine. These tests include parametric tests among which is a drum-track capacitance measurement.

In figure 4 the measurement principle is explained schematically. During 'normal' driving operation both switches p and n are used to switch the track to either 0 or 40V. One single testline that can be connected via a testswitch ts to every ASIC-output makes it possible to connect each track to an off-chip electronic integrator circuit.

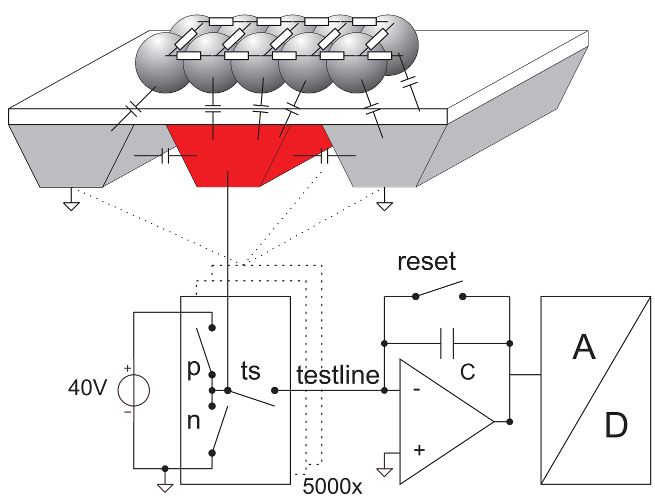

Figure 4. Principle capacitance measurement. Individual toner particles can been seen as a mesh of small capacitances with small contact resistances.

During a capacitance measurement a specific track is charged to 40V while the neighbouring tracks are grounded. Subsequently switch p is opened and the track is discharged through the integrator by closing switch ts. This makes it possible to measure the ammount of accumulated charge (Qtrack) and thus the capacitance (Ctrack = Qtrack/40V) of the drum-track. In case of a 'clean' drum this capacitance mainly consists of track-to-track capacitances (approximately 30 pF to neighbouring tracks). There is no theoretical formula to calculate the exact capacitance due to fringing effects. We have used a Finite Element Method to determine the value numerically.

Due to the conductivity and diëlectric properties of the toner deposited toner will increase the total capacitance. This increase in capacitance can be easily determined by measuring the capacitance of all tracks without toner first and using this as a baseline which is afterwards subtracted from measurement signals.

Evaluation of Measurements of Several Print-Patterns

To our suprise it turned out that in case of a [..0101..] printed pattern (see figure 5) both tracks with and without toner show a comparable increase of capacitance of around 5 pF.

50% duty cycle				100% duty cycle			
4.6	4.6	4.6	4.6	22.5	22.5	22.5	22.5
..0101..				..0110..			
4.8	5.1	4.7	5.1	4.7	14.3	14.3	4.7
..1001..				..0000..			
4.7	2.2	2.2	4.7	0.0	0.0	0.0	0.0

Figure 5. Relations between a number of printed patterns and measured capacitances. Columns indicate separate tracks with or without toner (dots).

This behaviour is explained by FEM-calculations (figure 6). Both situations show a comparable electric field distribution and increase of capacitance. A track covered with toner shows a large 'track-to-toner' capacitance. However this capacitance is in series with a much smaller 'toner-to-neighbouring-track' capacitance (edge-effect). The latter dominates the measured value in both cases. In the same way measurements on [..1001..] patterns can be explained: the '0 tracks' in this patttern see only one 'edge'.

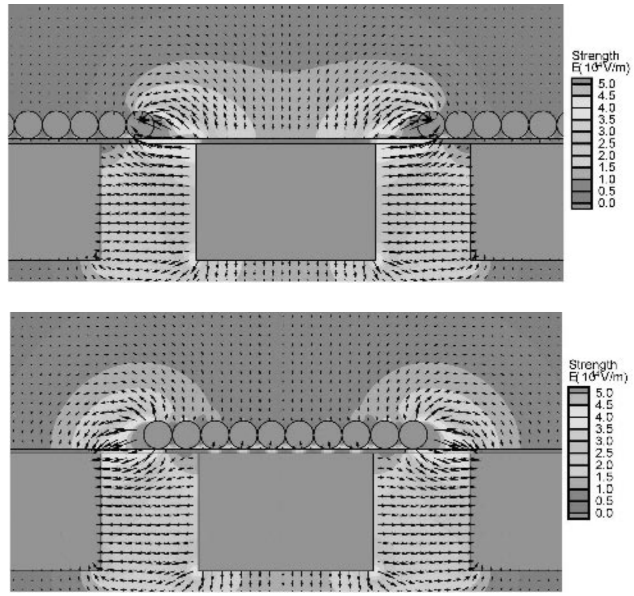

Figure 6. Electric field distributions of [..0101..] patterns. Upper: calculated capacitance of tracks without toner is 3.8 pF. Lower: calculated capacitance of tracks with toner is 4.8 pF.

Bitmaps with more adjacent tracks with toner like a [..0110..] pattern (2 adjacent tracks with toner) show more than proportional higher values for the tracks covered with toner. In these situations conductive horizontal 'toner-bridges' are formed between drum-tracks that behave as a equipotential surface with a large toner-to-track capacitance. In this case the 'edge-capacitance' is no longer in series but parallel to the track-to-toner capacity. This is clarified in figure 7.

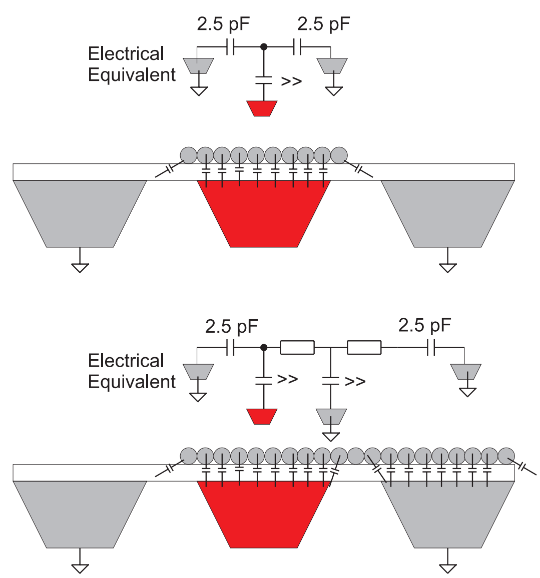

Figure 7. Electrical equivalent circuits of [..0101..] (top) and [..0110..] (bottom) patterns.

In case of a completely covered drum surface the measured tonercapacitance on each track is around 20 pF. Based upon FEM-calculations a much higher value was expected (about 500 pF). Probably this is because a steady state situation is assumed in FEM-calculations while actual measurements take only several microseconds per track. This time may well be insufficient to allow charge distribution between separate toner particles to reach a steady state. This would suggest that increasing the measuring time would yield higher capacitance values. First experiments have already confirmed this assumption.

Applications of Tonersensing

Measurement and Control Of Background Free Level

In figure 8 the relation between applied printing voltage Vp and the amount of toner deposited (toner coverage) is shown.

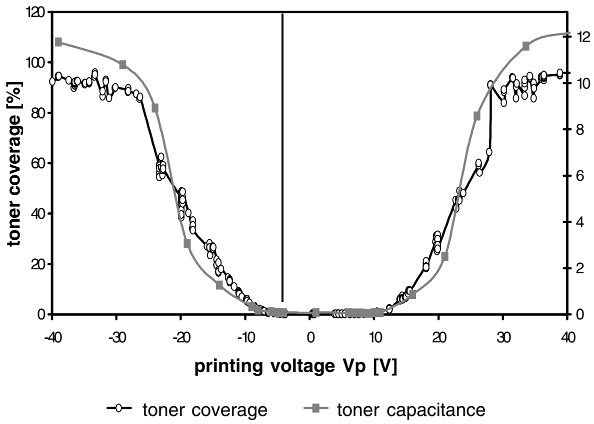

Figure 8. Relation between toner coverage and printing voltage Vp

In figure 9 we have zoomed in on the region with low toner-coverage around Vp=0. As can be seen from this figure toner deposition starts when the potential difference between toner and the surface of a DI-drum exceeds a certain value. We refer to this value as Background Free Voltage Level (BFVL).

Notice that it is possible to define a positive BFVL (BFVL+) as well as a negative BFVL (BFVL-). The 'width' of the background free region is |(BFVL+)| – |(BFVL-)| and is called Background Free Voltage Window (BFVW). Ideally, this BFVW will lie symmetrical around 0 [V].

Due to several possible causes the BFVW can 'shift' (for instance in case of extreme aging or pollution of the toplayer of a DI-drum resulting in possible residual charge build-up). When the shift in BFVW would exceed the BFVL (either on positive or negative side) it will be clear that unwanted toner development occurs (background toner) which is unacceptable. To prevent this from happening there are several technical possibilities (for example ensuring high BFVL, very stable DI-drum toplayer, minimizing pollution). Another approach is to compensate for the shift by applying an offset-voltage to the development roller sleeve. When a shift of for instance +3V would be observed, compensating would simply mean applying an equal offset voltage of +3V for compensation. Both approaches (prevention and compensation) are widely used in different printing technologies to ensure background free printing.

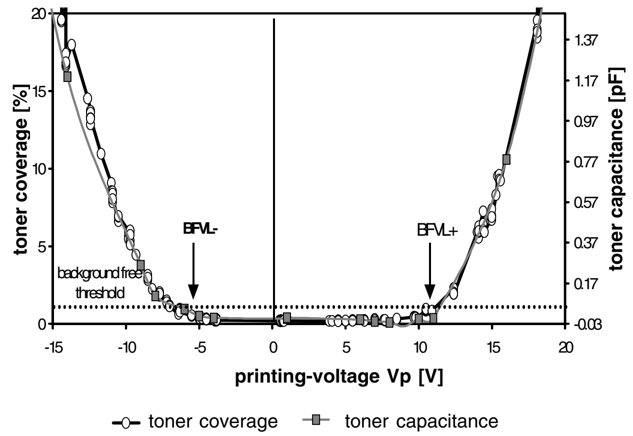

Figure 9. Toner coverage vs printing voltage. Definition of Background Free Voltage Level

With tonersensing it is possible to detect very small amounts of toner. When a voltage sweep is applied to the development roller (for instance Vp from –10 to +10V with 1V steps) we can plot the amount of printed toner as funcion of Vp and evaluate the BFVW and any potential shift in BFVW visually for instance as visualized in figure 9. It is then possible to compensate for any detected shift. With tonersensing it is however also possible to measure the BFVW and shift electronically. In figures 8 and 9 toner-capacitance measurements are shown next to optical measurements. An increase in toner-coverage corresponds to an increase in toner-capacitance. The maximum toner capacitance in these figures is not equal to the before mentioned maximum of 20pF for fully covered tracks because the print-area of the test patterns used in this case was only about 50% of the total drum surface. Advantages of using tonersensing to ensure background free printing when compared with conventional schemes are:

1. Very fast feedback scheme possible
2. No additional functions or sensors required
3. No calibrations through service or by user required
4. Possibility to correct for shifts in BFVW that are not uniform across the printing-width. Any non-uniformity in the shift can be measured because toner-coverage can be measured with axial resolution of the tracks (pixel-wide). For each position on each DI-drum the shifts can be seperately measured and subsequently compensated for by applying the corresponding offset-voltages on the *drum-tracks* instead of on the development-roller.
5. Logging of data gives possibility of remote-diagnostics, prediction of lifetime of supplies and better preventive maintenance.

On Line Continuous 'Grey Scale' Calibration

To achieve good image quality it is necessary for any print process to be able to print good quality halftones. To ensure a consistent image quality for high-demand production environments color halftone blends have to be stable in time.

For almost every print-process the relation between 'input' halftone levels (values between 0-255) and printed toner coverage on paper (0-100%) is non-linear. The exact relation needs to be determined after which 'calibration' is necessary to provide a calibration curve for the image processing. Calibration procedures, either automatically or manually, are commonly used.

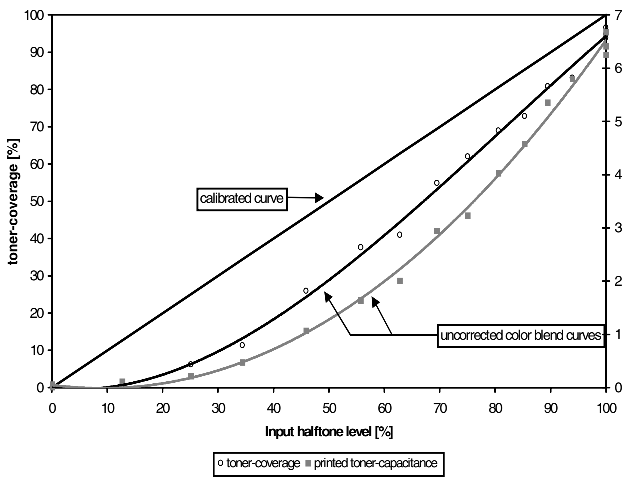

Figure 10. Toner-coverage and toner-capacitance as a function of halftone level

In figure 10 measurements are shown of toner-coverage on the surface of a DI-drum (each measurement has been done on a small printed area). In this figure both optical and toner-sensing results are shown. The curves of both types of measurements look similar but there is no perfect fit. The optical measurement is done by analyzing frames from a CCD camera mounted on a microscope. For toner coverage the accumulated surface of toner particles is measured. In the case of tonersensing it is very unlikely for the measured capacitance to be directly proportional to the accumulated surface of printed toner particles.

To achieve consistent image quality there are in principle two approaches. One is to design a printer to be inherently stable. Another approach is to use more or less frequent calibrations (thus implementing sensors and feedback schemes). During the development of Direct Imaging and design of the Océ CPS700 printer the first approach was always leading which has resulted in a inherently very stable print quality. Calibration is in principle only done once during production of the machine. This gives no user inconvenience resulting from frequent calibrations during use. There is however an ever increasing trend towards higher print resolutions and finer toner particles. It may turn out that in the future these trends tend to compromise the stability of the print process which could lead to a increased need for more frequent calibrations. In this case such calibrations have to be fast and reliable as to prevent productivity loss and user inconvenience. If needed, tonersensing would offer this opportunity. Color-blend curves measured with tonersensing show equal or better results than optical measurements in terms of reproducablity, sensitivity and measurement speed.

Line-Width Measurement and Control

Although it is possible to measure line-width on a DI drum optically this is also possible with tonersensing. Figure 11 shows printed lines photographed on the surface of a DI-drum.

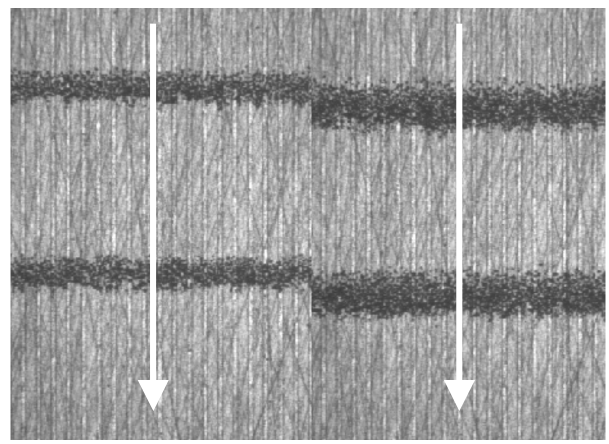

Figure 11. Printed lines on drum surface. Arrows indicate scan-lines for optical linewidth measurements.

Measured line-profiles and linewidths (full-width-half-maximum) are shown in figure 12. Line-widths can vary due to several causes. For this paper we have deliberately varied printing process parameters excessively to give extreme variations.

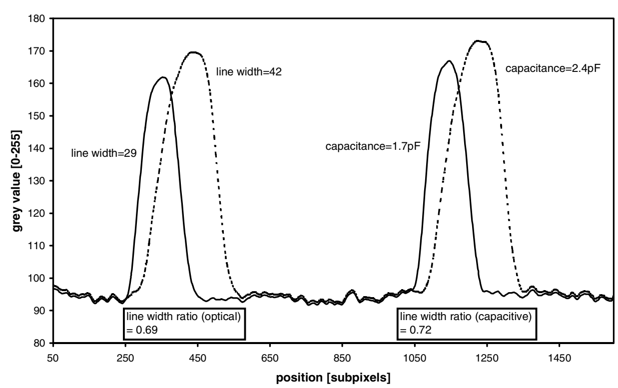

Figure 12. Measured line-profiles and linewidths of printed tonerlines on drum (from figure 10)

The linewidth of the narrow lines in figure 11 is 29/42=0.69 times smaller than the linewidth of the broader lines. The measured capacitance of a printed pattern with narrow lines is 1.69pF while broad lines show a value of 2.36pF. This gives a ratio of 0.72 which is comparable to the result from optical measurements. As stated earlier these measurements can be done extremely fast giving the opportunity to control linewidth by using a feedback scheme.

Future Developments

Increasing Sensitivity

Until now charge and thus capacitance is measured by means of an off-chip electronic integrator circuit. This makes the measurement susceptible to EMC. Especially 50 Hz interference is seen. Current noise level is arround 19 fF or 18 pixels in case of a single pixel toner line printed on a single drum track (5.1 pF). Averaging more measurements gives better results. Much higher accuracy is expected employing an on chip integrator and more accurate capacitance measurements. Noise levels of 50 aF have been reported.3 This would make it possible to measure individual tonerdots with subpixel-size.

Continuous Measurements and Print Quality Control

Measurements of toner-deposition during printing of individual pixels are possible in theory. Using this information in a feedback scheme where one could continuously correct for variations in for example pixel quality would lead to unprecedented possibilities for controlling print quality and stability ('each pixel the same').

References

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Biography

Marcel Slot received his M.Sc. degree in Applied Physics from Twente University of Technology in the Netherlands in 1990. For his M.Sc. work on 'Measuring Bloodflow through Optical Fibers using Self-Mixing Laser Doppler Principle' he received a national award for best M.Sc. thesis in the field of opto-electronics.

Since 1990 he has worked at Océ-Technologies in Research and Development. Most of his work was related to development of the Direct Imaging technology, although in several different functions and projects and with varying fields of interest (a.o. magnetics, particle-dynamics, excimer-laser micro machining, thin-film coatings). At the present time he is working with a project team on further developments of the Direct Imaging technology.