# Print Quality Test Page

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## Abstract

A print quality (PQ) test page is a diagnostic tool which is designed for accurate and efficient diagnosis of PQ defects. We develop a set of test pages for the user to check the condition of his or her printer without using any other tools. We design test features which clearly reveal the common PQ defects that occur with color laser printers, such as failure of color plane registration, ghosting, and repetitive artifacts. We then incorporate the test features into a set of test pages for a specific printer model. We introduce the concept of imperfections within specification which are PQ defects that fall within the PQ specification of the printer. The PQ test pages should be designed not to reveal such defects to the customer. For the constant tone fields on the test page, we consider the specific case of designing halftone patterns that will not show banding that is within specification. Finally, we describe the design of a set of instruction pages that walk the customer through the process of identifying PQ defects shown on the test pages, that can be remedied by customer-replaceable parts.

## 1. Introduction

An important class of print quality (PQ) defects of laser printers are the artifacts degrading the quality of printed images which are generated by the electrophotographic (EP) process. Some common forms of such PQ defects are randomly scattered dots or smudges, repetitive patterns, and density variation in constant tone areas. For a color laser printer, temporal color inconsistency is also considered to be a PQ defect. The aforementioned defects can be either caused by the non-ideal characteristics of the printer unit or by physical damage to the unit itself. Some defects may disappear after several prints. For example, foreign matter may become attached to a roller and then later be removed in the course of normal printing. As another example, rollers that sit under pressure may develop a flat spot at the point of contact while the printer is idle. After continued use, the flat spot gradually disappears. However, a permanently damaged unit may continue to be a source of defective prints.

If a customer finds a PQ defect on a print, he or she may consult the user manual to identify the cause of the problem. If the customer finds that the problem persists, he or she can call the customer support center to ask for help in diagnosing the problem. For several reasons, it is, however, difficult for agents in the customer support center to identify a defect over the phone. The agent obviously does not have first-hand knowledge of the defective image and there may be discrepancies in the technical lexicons used by the customer and the agent. Remote diagnosis is made all the more difficult because defects may look different depending on the image content. When there are problems in remote diagnosis, the surest way to eliminate confusion and identify the defect is to have the customer send in samples of his or her defective image, or to dispatch a service technician to the customer site. These solutions are costly to both the customer and the printer manufacturer.

PQ defect diagnosis can proceed more efficiently with the aid of a PQ test page, which is based on prior knowledge of the defects for a particular printer, such as the spatial patterns of the defects. Once the customer notices a defect in a print, he or she prints the test page from the defective printer and calls the customer support center. Since the agent is already familiar with the test page, the customer need only describe the symptoms of the defect without explaining what is the image content. In addition, the customer can solve some problems by referring to the user manual or instruction pages, which contain sample defects shown on the test page, and which suggest how to solve the problem causing each defect. Therefore, the PQ test page can increase efficiency in identifying PQ problems and decrease the cost of customer support and service.

It is the purpose of this paper to show how to design a set of PQ test pages for a color laser printer. In addition, we describe an accompanying set of instruction pages, which are a tool for self-diagnosis and remedying the cause of the PQ defects. The rest of the paper is organized as follows. In Section 2, a strategy for design of PQ test pages is presented. The basic features in the PQ test pages that we have developed are then described in Sec. 3. Finally, we talk about how to use the PQ test pages for defect diagnosis in Sec. 4.

## 2. Strategy for Designing Test Pages

Since the PQ test pages are expected to bring benefits to the customer as well as the printer manufacturer, the test page designer should consider the needs of both sides. One key criterion in designing PQ test pages is ease of interpretation. Several problems may arise if the test page is complicated. The customer might call the customer support center without even trying to solve the problem by him or herself. It will also be difficult for the customer support center agent to diagnose the problem over the phone because it will be difficult to explain to the customer how to use the PQ test page. Failure to diagnose the problem remotely may require that a technician be dispatched on-site which will increase the cost of support.

From the manufacturer's perspective, it is important that the PQ test pages not reveal artifacts that may occur when the printer is functioning within specification, and which would probably not be noticed by the customer in the content that he or she routinely generates with the printer. We refer to artifacts of this type as imperfections within specification. Banding is a good example of such an artifact since it is generally characteristic of laser printers. For a specific printer model, the level of banding is determined by the design of the printer mechanism, and usually cannot be reduced by adjusting the parameters of the device or by replacing parts. Therefore, the designer should plan the test page in such a way that the customer will not discern imperfections within specification, but he or she will be able to clearly recognize the artifacts caused by a defective printer unit.

In the following two subsections, we will discuss a design procedure for a general printer architecture. Then we will briefly describe a specific printer architecture for which we have developed a set of PQ test pages.

### 2.1. General design procedure

In the design procedure, the designer should determine the printer model for which he or she will develop a set of PQ test pages. Then he or she should consider a list of PQ defects that have been observed with the targeted printer model. This data can be based on the results of internal testing of the printer or on the PQ defects reported by customers if the printer has already been introduced in the marketplace. In this paper, the PQ defects that we address are streaks, repetitive marks, ghosting, and failure of color plane registration. Jang and Allebach described the characteristics of these defects in their previous work[1].

Once the list of PQ defects is determined, the designer can start to devise test features for each defect. In this step, he or she should identify the conditions under which a certain defect is clearly visible. At the same time, he or she should carefully control the design parameters so as to not show any artifact caused by an imperfection within specification.

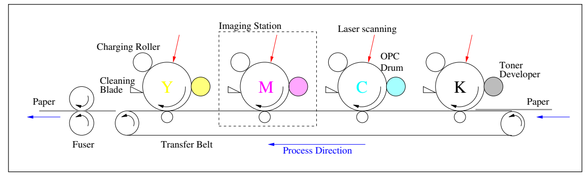



*Figure 1*: *In-line color EP printer. There is a separate imaging station for each of the four color separations. Each imaging station consists of an OPC drum, a charging roller, a laser scanner unit, a toner developer, and a cleaning blade. The paper is transported past each imaging station by the transfer belt. After all four color separations are transferred to the paper, it passes between a heated fuser roller and a pressure roller to fuse the toner to the paper.*

The final step of the design procedure is to incorporate those test features into a set of PQ test pages for the targeted printer model. A compact integration of the test features will minimize the number of test pages that need to be printed. This is an important consideration, since the customer may be reluctant to use his or her consumables to print test pages. In fact, he or she may be resentful of having to do this if he or she views the PQ problem as being the manufacturer's fault.

### 2.2. Test page design for in-line printer model

The two major classes of color EP printer architectures are in-line and multipass. Within each of these classes, there are a number of variations. Although some PQ defects are generally characteristic of the EP process, the specific appearance of these defects may depend on the printer architecture and EP process behavior for each particular printer model. Other PQ defects may be unique to a specific printer model.

In this paper, we will show how to design a set of PQ test pages for the *in-line printer* architecture, which is illustrated in Fig. 1. The in-line printer has four different imaging stations. Each station has an OPC drum, a charging roller, a laser scanner unit, and a toner developer. A transfer-belt transports the paper sheet between these stations. In the final stage of the printing process, a fuser melts toner particles onto the paper to create a permanent image.

In this paper, we assume that the media is Letter-sized (or A4-sized) and that it is fed to the printer long edge first. Thus, the process direction is along the short edge of the media; and the scan direction is along the long edge.

## 3. Test Features in the PQ Test Pages

In this section, we will show how to develop test features to make the defects clearly visible. When we develop the test feature for a given defect, we should consider the condition under which the defect and its cause are clearly identified. The basic features that we have developed are a constant tone background which is divided into sections, ghosting test blocks, rulers, color plane registration (CPR) test blocks, and page identification numbers. Finally, we will show how to incorporate the test features into a set of PQ test pages for a color laser EP printer.

### 3.1. Constant tone background

A PQ test page should be designed to clearly show defects that the manufacturer considers to be out of specification and which the customer can remedy by replacing a consumer-replaceable part, or which should be reported to the customer support center.

With the exception of CPR, PQ defects are generally most visible in areas of the print that consist of a constant tint fill. Thus we will use a constant tone background, on which other test features will be built. If we use four different constant tone images, each of which contains only one of the four primary colors, we can separately check the condition of each imaging station. For example, if white streaks are found in the magenta constant tone image, the magenta imaging station can be suspected to be defective.

Although a constant tone image clearly shows PQ defects such as scattered spots or repetitive artifacts, it may also reveal banding artifacts that might not be visible in the content normally printed by the customer. Thus banding is considered to be an artifact caused by imperfection within specification; and it should be concealed in the test page. We found that a line screen halftone is more robust to the banding artifact than a dot screen halftone for a fixed number of dots printed in a halftone cell of a fixed size. This is because the dots forming lines along the paper process direction efficiently mask the dot position error, thereby reducing the severity of banding. For this reason, we use a line screen halftone for the background of the test page.

### 3.2. Ghosting test block

When a drum is not thoroughly cleaned, the residual toner particles are transferred onto the paper, causing a ghosting defect. The heavier the density of the image content, the more residual toner particles remain, showing a darker ghosting image. Since those residual toner particles are transferred after one revolution of the drum, the ghosting image can appear on the same page as the original object that provided the source of toner, if the source object is located near the leading edge of the paper and the circumference of the drum is less than the width of the paper.

Let $\delta$ be the circumference of the drum, $W$ the width of the paper, $w_g$ the width of the test bar, and $m$ the margin on each side of the test page. Then provided $\delta < W - (w_g + 2m)$ the test bar located at the leading edge will be reproduced on the same page by a defective drum as illustrated in Fig. 2.

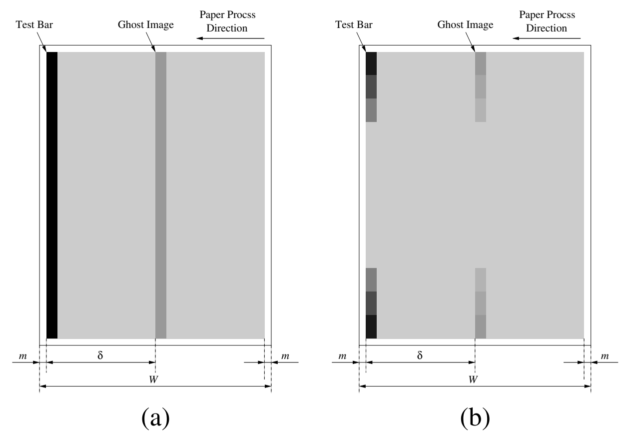



*Figure 2: Features for detecting ghosting: (a) simple test bar, and (b) two test bars of three tint fill blocks with varying densities.*

The source of the ghosting artifact tends to influence the entire surface of the drum, so that the ghosting image for the test bar in Fig. 2(a) would have almost the same tone along the full height of the page. Since the defect of repetitive lines which is caused by the charging roller shows a shape similar to that of the ghosting defect in Fig. 2(a), the customer would have trouble differentiating between the two defects. This problem can be avoided by changing the shape of the ghosting test bar. For example, as shown in Fig. 2(b), the ghosting test bar can be made shorter than the height of the page; and it can be designed with a characteristic structure. Here the three tint fill blocks with varying densities can help to gauge the strength of the ghosting.

### 3.3. Ruler

In some cases, the customer will need distance information or location information to identify the source of defects. For example, the distance between two repetitive marks is the information that identifies the source of the defective printer unit because the interval of the repetitive defect is the same as the circumference of the defective printer unit. Also, we can identify which printer unit causes a ghosting defect by measuring the distance between the ghosting test bar and the faintly reproduced ghost image. Since the location of the ghosting test bar is fixed on the test page, the ghosting caused by a particular printer unit will always occur at the same position. In other words, the customer can identify the source of the defect by examining the position where the ghost image is located on the printed test page. In this case, the customer can identify the source of the ghosting defect with location information only.

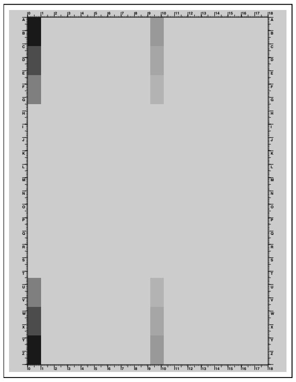
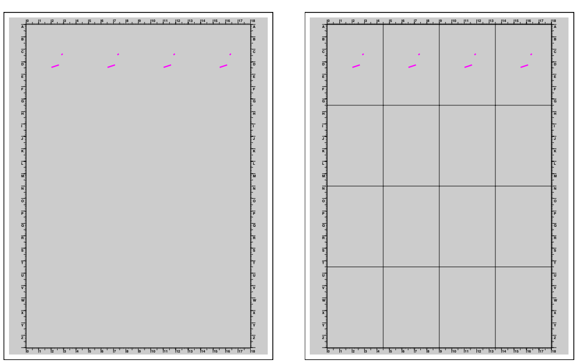


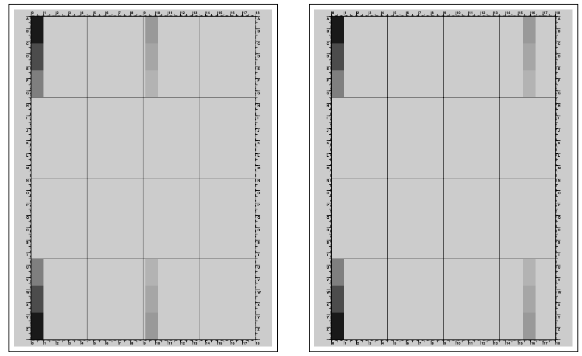
*Figure 3*: *Ghosting defect shown on a test page which has rulers. The horizontal rulers provide the distance information to help identify the source of the ghosting defect.*

If rulers are incorporated into the PQ test page, then customers do not need to use a separate instrument to obtain distance information or location information. We use horizontal and vertical rulers to acquire this information in both directions. We put those rulers on all four sides of the PQ test page as illustrated in Fig. 3. Normally, a ruler consists of evenly spaced tick marks and numbers. However, using numbers for both the horizontal and vertical rulers can be a source of confusion for communication between the customer and the agent in the remote diagnostic process. In order to avoid this potential problem, we use two different sets of characters for the horizontal and vertical rulers; one is a set of numbers, and the other is a set of alphabetical characters. Since it is more convenient to use a numeric ruler for measuring the distance between repetitive artifacts which always occur along the paper process direction (horizontal direction in our design), we use numbers for the horizontal rulers.



(a) (b)

*Figure 4*: *Repetitive marks caused by the magenta charging roller (circumference 45mm). (a)To identify the defect, the interval of the repetitive marks must be measured with the horizontal rulers. (b) Here, the fact that the defective mark appears at the same position in each divided section indicates that the source of the defect is the magenta charging roller.*



(a) (b)

*Figure 5*: *The ghosting defect can be attributed to one of two possible sources by identifying the column in which the ghost occurs. (a) Ghosting defect shown in the third column, and (b) ghosting defect shown in the fourth column.*

### 3.4. Divided sections

A repetitive artifact appears at a particular interval in the process direction. As previously mentioned, we can identify the source of a repetitive defect by measuring the distance between two successive defect marks. If the designer knows which repetitive defect is expected to occur most frequently, the source of the defect can be identified by evenly dividing the test page in the process direction into sections whose width is the same as the interval of the defect. Then the customer just needs to check whether the defect marks occur at the same horizontal position in each section of the test page. Although this information could be obtained by using the rulers at the top and bottom of the page, the sections allow the customer to identify the targeted repetitive defect at a glance without the need to make measurements with rulers. In a similar way, the sections can provide location information that can be used to identify the cause of a PQ defect. For example, if there are two different printer units which cause ghosting defects; and the difference between the circumferences of these two units is greater than the width of one section, then the ghosting images would appear in different columns, as shown in Fig. 5. Here the source of the ghosting defect can be identified by simply referring to the column number without using a ruler to get exact position information.

### 3.5. Test block for color plane registration (CPR)

Levien developed a registration mark by overprinting two screened patches which have slightly different screen frequencies showing a moire pattern [2]. Misregistration in any direction results in a moire pattern that is different from that observed when the screens are properly registered. He also designed marks which use a line-pattern showing misregistration in either the vertical or horizontal direction.

We develop a test feature for color plane registration that uses overlapped line patterns to assess how much a color plane is displaced. Figure 6(a) shows a series of test units identified by numbers ranging from -5 to 5. Each unit contains several horizontal lines, and is divided into two parts. The left half consists of black lines only, and the right half has both black lines and magenta lines. Except for the unit 0, the magenta lines in the right part of each unit are deliberately displaced by $n\Delta$, where $n$ is an integer and $\Delta$ is the increment of displacement.

If there is no CPR problem, the magenta lines in unit 0 will be completely covered by the black lines so that the left and right parts of each unit will match. The right part of each other unit shows an increasing hue difference from the left part, as the unit index increases or decreases.

If the magenta plane is vertically shifted relative to the black plane, the left and right parts of the unit 0 will no longer match, indicating there is a CPR problem as shown in Fig. 6(b). In this figure, the magenta plane is vertically shifted by $2\Delta$, so the magenta lines in the right part of unit 2 are covered by the black lines, thereby making the two parts of this unit look the same. Thus, we can tell how much a color plane is shifted by identifying the index of the test unit in which the two parts of the cell match each other most closely. If the test units are symmetrically arranged in increasing or decreasing order as in Fig. 6, the unit corresponding to correct registration of the two color planes is located in the center of the series. This arrangement makes it easy to assess the CPR performance.

If the level of misregistration is not a multiple of $\Delta$, but is $a\Delta$ where $a$ is not an integer, we can infer the actual misregistration by identifying the two adjacent units in which the left and right parts most closely match each other. The unit indices will be $\lfloor a \rfloor$ and $\lceil a \rceil$.

A CPR test block with the same structure as that shown in Fig. 6, except that the lines in each unit are rotated by $90°$, can similarly be used to assess horizontal CPR.

### 3.6. Page identification number

If the PQ test page suite consists of more than one page, a page identification number facilitates communication between the customer and the agent. In choosing the color for these numbers, the designer should consider the case in which one of the primary colors is not developed so that the background for that color is missing. In this case, the page identification number can be easily used to identify which page does not show its background color. This information would be lost however, if the page identification number is printed in the same color as the background.

In order to avoid this problem, we use the secondary color that is complementary to that of the background in each page. This choice, additionally, provides good contrast thereby making these numbers easily noticed.

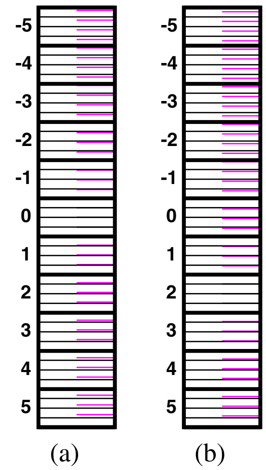



*Figure 6*: *CPR test block designed for testing the vertical registration of the magenta plane relative to the black plane. (a) The left and right parts in unit 0 match each other without any vertical CPR problem. (b)The magenta plane is vertically shifted so that the two parts in unit 0 no longer match. Instead, the left and right parts in unit 2 look the same, thereby indicating there is a CPR problem.*

### 3.7. Integration of test features

The suite of the PQ test pages that we have developed consists of five pages. Each page is designed to test one of the four color separations: K, C, M, and Y. The background of the last two pages is divided into two parts, which are yellow and green. The green background is comprised of yellow and cyan color separations, which is expected to show more clearly density variation in the yellow plane. Figure 7 illustrates the PQ test page for the M separation. The rest of the test pages are shown on the user instruction pages (Fig. 8) as iconic images. In each test page, the ghosting test blocks are located at the leading edge; and the page identification number is positioned between the two ghosting test blocks.

In order to efficiently detect repetitive defects, we set the width of each section to $45mm$, assuming that the repetitive artifact caused by the $45mm$ circumference charging roller is expected to be most frequently reported among the repetitive defects. On each test page, there are 12 sections arranged in a $4 \times 3$ array surrounded by the four rulers. The unit of the rulers is $mm$.

There are two sets of CPR test blocks which are placed at the left and right side of each test page. Each set consists of three blocks: one horizontal CPR test block is located between two vertical CPR test blocks. Since the range of misregistration in the paper process direction is generally larger than that in the scan direction, we use more levels in the horizontal CPR test block. The horizontal and vertical CPR test blocks incorporated in this test page can show misregistration up to $\pm$ 8 pixels at 600 dpi ($\approx \pm 340\mu m$)

and ± 6 pixels at 600 dpi ($\approx \pm 250\mu m$), respectively. The degree of misregistration of a color plane can vary throughout the page. The four vertical and two horizontal CPR test blocks can monitor this variation within each page. For the K separation page, we put CPR test blocks for the cyan and magenta planes on the left and right sides, respectively.

We use a unique label for each CPR test unit to eliminate a potential source of confusion. The label consists of three parts. We use X and Y to indicate whether the test unit belongs to a block on the left or right. The second part (a, b, or c) points out whether the block is an upper, middle, or lower test block. The last part is the unit index number which indicates the level of misregistration.

## 4. PQ Defect Diagnosis by Utilizing PQ Test Pages

In this section, we describe how to utilize in the PQ defect diagnostic process, the test pages we have developed. We consider two cases of defect diagnosis: one is a remote diagnosis, and the other is the customer's self-diagnosis.

In the case of remote PQ defect diagnosis, the customer calls the customer support center when he or she observes any PQ problem in his or her print. The agent in the support center will ask the customer to print the PQ test pages and to describe any noticeable symptoms of the defect. Since the agent can be assumed to already know the symptoms of various types of PQ defects when printed on the PQ test pages, he or she can ask the customer very specific questions regarding the symptoms of the defect. For example, he or she can ask the customer to examine if there are dark shadow marks at the particular positions where ghost test blocks would appear. If the PQ defect cannot be successfully diagnosed remotely, the agent can ask the customer to send the printed test pages to the support center for direct evaluation by the agent. Once the agent identifies the PQ defect and its possible causes, he or she can remotely help the customer resolve the problem or send a service technician on-site. Ideally, the test pages should be stored in the printer firmware, and printable from the front panel control menu.

An alternative mode for taking advantage of the PQ test pages is to provide the customer with a set of instructions on the use of the PQ test pages to diagnose the most common defects that can be remedied by replacing customer-replaceable parts. These PQ instruction pages may be stored in printer firmware, and thus be printable from the front panel control menu, included in the user manual for the printer, or accessible at the manufacturer's web-site. In any case, the instruction pages need to be simple, clear, and straightforward to use, or the customer will just call the customer support center, rather than attempting to self-diagnose the cause of his or her PQ problem. The instructions need to accomplish three tasks: (1) familiarize the customer with the features of the PQ test pages and their use, (2) provide information about how the PQ defects of interest will appear on the PQ test pages, and (3) suggest a possible remedy for the PQ problem, once the defect is identified.

Figure 8 shows the first of a set of PQ instruction pages that we designed for a particular printer. These pages exemplify the three tasks just mentioned. At the top left side of the page, there is a general description of the diagnostic procedure. To the right of this description, there is an image of the test page defining all the features and terms used in the instructions that follow. Note that the CPR test blocks are not mentioned, since for this particular printer, identification and correction of CPR problems is not something that the customer is expected to do on his or her own. The remainder of the page is divided into three sections, each devoted to a different PQ defect. Each section shows images of all four PQ test pages, as they would appear in a typical occurrence of the defect. The defects are simulated on the PQ test pages using techniques described in Ref. 1. In each section, labels and dimensioning are used where appropriate to help identify the PQ defect. Below these images, the remedy for the PQ defect is briefly described. Where appropriate, the customer is directed elsewhere for more detailed information.

## 5. Conclusion

In this paper, we introduced strategies and a procedure for designing a set of PQ test pages. We showed how to develop test features for the PQ defects, which are common in color laser printers. We also showed how to incorporate the developed test features into a set of PQ test pages. Finally, we proposed user instruction pages which are designed to enable the customer to diagnose PQ problems by him or herself. Although this work is focused on a specific printer model, the design approach is quite general and could be applied to other printer models, as well.

## References

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## Acknowledgment

We would like to thank the Hewlett-Packard Company for supporting this research. We would also like to express our sincere gratitude to Tony Barrett, Rich Payne, Dave Kendall, and Mark Wibbels for their valuable suggestions and feedback throughout the course of this project. Mark Wibbels deserves special credit for suggesting the approach presented here for assessing CPR.

## Biography

Woonyoung Jang received his BS and MS in electrical engineering from Korea University, South Korea in 1994 and 1996, respectively. He is now pursuing his PhD in the school of electrical and computer engineering at Purdue University. His fields of interest are print quality analysis, image enhancement for digital photography, and color science.