

Direct Digital Output Silver Halide Color Media and the Market Response to this New Capability

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Abstract

Digital writing to silver halide media has been available for several years, in areas such as graphic arts proofing and separations, and commercial applications with digital film recorders. There have been devices available for several years that have allowed direct digital writing to color silver halide paper, although the number of devices has been limited, and the format size has been relatively small. Within the last two to three years a number of devices have become available for direct print writing, which has increased the technical methods for exposing paper, and has increased the allowable exposure size and format.

The introduction of these devices has had a significant impact on the traditional photographic laboratories. There have been changes in the market expectations as the digital images merge with the traditional optical workflow. There is competition for types of output from these digital images. There are several competing technologies for color hard copy, with silver halide being just one of the technologies. All of these technologies are attempting to find the market area where their advantages can be shown. The digital silver halide writers have some unique advantages for certain applications, and allow their participation in this market.

Eastman Kodak Company has been interested in direct digital exposure onto silver halide media for many years. We have participated in, and continue to participate in, the design and manufacture of equipment used to make these exposures. In addition, we have had significant interest in the media used in these types of systems. A team was formed to better understand what aspects of silver halide color paper were important for this application. Ultimately, this team was chartered to produce a silver halide color paper designed specifically for use in these new devices. Our investigation showed areas where performance improvements could be made by designing the material for use with the various writers, and we looked at the available technology to obtain that type of performance. We have created two generations of digital paper, and believe that these papers offer improvements for these applications.

The Market View

The world of the professional photolab has changed greatly in the past 10 years. As digital technology became more affordable, it moved from the highly capitalized graphics pre-press trade shops to commercial labs. Digital equipment specifically for commercial labs soon followed. At a later point, digital equipment entered the portrait lab market. And now, digital photofinishing is on the rise in consumer wholesale and mini-labs.

Many leading commercial labs now report that 40%-50% of their business comes to them already in digital form. And the most frequent request that the customer has for the data is hard copy output. While it seems that customers may be willing to purchase digital capture devices (cameras and scanners) as well as the required image-capable computer system, they look to the lab to have the digital output equipment and media.

In this area of output, the choices seem endless. Today, photolabs of all types can select from a variety of technologies for getting digital image files onto a hard copy, human-readable media. These choices include (in no specific order):

- Inkjet printers, both thermal and piezo
- Dye sublimation thermal printers
- Electrostatic plotters
- Color electrophotograhy printers (laser copiers)
- Digital AgX film recorders
- Digital AgX paper/display media recorders

While this list may seem formidable, the choices grow when you realize that there are options within the options. If we look at digital AgX paper recorders, for example, there are several different writing technologies and printer architectures. From my studies, these can be summarized as follows:

Writing Technologies

CRT, LED, LCD, gas laser, and solid-state laser

Printer Architectures

Flat platen with fixed paper
Internal drum with moving light source
F-theta lens with moving paper

How does the market make sense of all these choices? This is better understood when the needs of both the lab and the end-customer are analyzed. Consider the following list of key attributes:

- Final image size
- Color gamut needed
- Spatial and color resolution desired
- Continuous tone or half tone image structure
- Writing speed
- Media cost
- Text and images required

With some technologies, image size is the determining factor. Both dye-sub thermal and color EP are generally not available in sizes above 11 x 17 or A3. AgX film recorders are limited to sizes less than or equal to 11 x 14 inch, but the digital negative can then be enlarged optically. CRT printer technology tends to limit acceptable prints to 12 x 18 inch or smaller. On the wide end of the spectrum, inkjet printers and their paint jet variants can print materials up to 5 meters wide. Electrostatic printers are generally in the 54-inch range with digital AgX printers designed for 20–50-inch photographic materials.

Another key factor is image structure. For images normally viewed from arm's length, photographic quality is generally needed. In digital terms, we define this as 200-400 pixels per inch spatial resolution with 12-24 bits of color resolution. In small print sizes found in consumer and portrait markets, visibly half-toned images may not be acceptable.

Printer productivity and media costs need to be considered when doing a financial analysis. Inkjet printers have emerged as the output of choice when single images are required. But media/ink costs and productivity become a factor in multiple-print production.

Let us now narrow our discussion to just digital AgX paper recorders. (And in doing so, we are also including AgX display materials as well.) Writing digital data to photographic print materials offers a number of advantages to labs. First, the look and feel of photographic paper is both well known and well accepted by customers. Labs generally have the installed infrastructure, such as processors and laminators, for handling the materials. And the productivity of the digital recorders fits best with the high-volume, multiple-copy workflow that predominates in labs. For labs with an established digital workflow, adding an AgX paper recorder is then a matter of selecting a printer from Durst, Cymbolic Sciences, Kodak, Gretag, Sienna or others, and paying the bill.

Background - Digital Exposures

We assume people are generally familiar with traditional and digital imaging. However, we will give a brief background on how the digital writing systems work with silver halide paper, and the unique impact it has on the media.

In general, these digital writers work with a digital file that represents the image to be printed. This file could have a variety of origins. It could have been a piece of film that was digitized by scanning. It could have come from an image that was manipulated or even completely created on a computer. It could have come from a digital camera, that has never used film. This file is a matrix of information about the image to be printed, with the red, green, and blue information and location for every spot or pixel of the image. After the appropriate computation, the controlling computer can then tell the printer just how much red, green, and blue light to use to expose the silver halide media. Most of the printers will expose the image one pixel at a time. The actual exposing will be done with the light source the printer uses, be it lasers, LEDs, CRTs, LCDs, or some other type. The printer makes this pixel by pixel exposure using the red, green, and blue printing information from the computer for each position of the image until the entire image is exposed. Because this media is similar to traditional photographic media, the image is now on the material only as a formation of latent image. Chemical processing is now required, so the media is processed in the traditional fashion. For the media that is being discussed here, Process RA-4 or one of the Process RA-4 derivatives is used.

One important difference between the traditional form of imaging and this digital exposure is the role the media plays, versus that of the software. In traditional photographic imaging, the paper or media has much control over the final image in terms of color reproduction, tone scale, and contrast. In the digital arena the media still plays an important role, but in a somewhat different fashion. Much of the color, contrast, and tone scale control is in the software rather than in the media, allowing computer adjustments for the final image. Therefore, when media is being designed, some of these parameters are not as critical for digital media as for traditional media. However, some of the image characteristics are still controlled by the media. The media controls the maximum density, the minimum density, and the total dye space or dye gamut. So these parameters are still as critical, and in some cases more critical, than for the traditional photography.

Digital Media Development - Technology Investigation

Eastman Kodak Company has been involved with direct digital writing onto silver halide media for several years. In the early 1990s, a technology team was assembled to better understand what performance features of an emulsion system of print media were important for direct digital writing systems. At that time most of the print imaging devices that were commercially available were based on CRT exposing systems. That team also had a laser printer to examine how the media would interact with a laser system. This allowed them to examine some of the differences between the CRT and laser exposing systems, such as spectral energy output, exposure times per pixel, and exposure uniformity. They also had other types of experimental devices, such as the breadboard of the KODAK LED Digital Color Printer, to evaluate other media/exposure interactions.

Testing our traditional paper through this variety of devices, as well as looking at some experimental papers, showed some of the characteristics of the paper that were important for this type of exposure. Some of the important characteristics were:

1) Overall exposure required, or power level, to achieve the appropriate D-max
2) Spectral sensitivity of the media relative to the spectral energy output of the exposing device
3) Media response to the very short exposure times (as seen by a silver grain) that are typical of these digital printers
4) Systems flare and fringing, due to the printer design and emulsion power requirements
5) Inherent contrast of the media when exposed by the digital light source

This analysis gave us some ideas of what requirements were needed when designing a paper for these digital applications.

Test Line Development

Much of the evaluation we had done also suggested that our standard paper test line was not appropriate for developing a digital media. The main difference was in the exposure method. Our typical sensitometer had a significantly longer exposure time than that of a digital writer, and the spectral energy of the light was vastly different. We found that this could give inaccurate test results for testing the sensitometric characteristics of digital media. We designed and built a sensitometer that used a red, green, and blue laser exposure for exposing the material to generate the D-log E curves typical of evaluating silver halide media.

We also found that many of the other performance characteristics of color paper are related to the exposure time. Therefore, many of the other tests we performed had to originate with the new laser sensitometer. For the most part, the remainder of our testing facilities, such as processing and densitometry, could be used for digital media as well as the standard media.

Digital Media Development – Commercialization

A team was formed within Kodak to commercialize a paper for digital exposures. The first step was to benchmark just how our existing professional and consumer KODAK EKTACOLOR Papers performed in the range of devices that were available for measurement. We also looked at the target markets for these devices, and tried to judge the imaging criteria they used for evaluating prints.

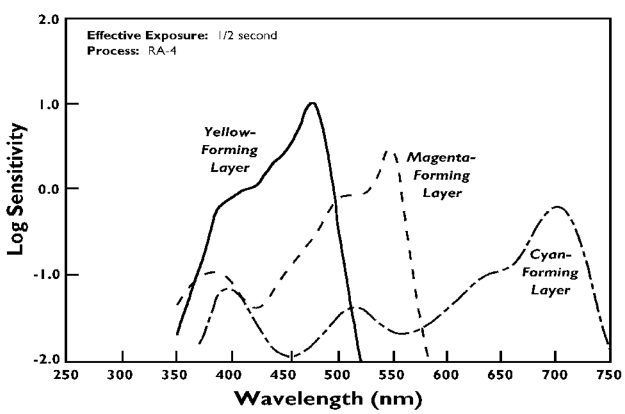

Figure 1. Spectral sensitivity curves.

One item that became apparent was that one feature we had built into the professional papers became a disadvantage for digital exposures. We had incorporated a unique sensitization into our red-sensitive layer to enhance the detail in images with highly saturated reds. While this was an advantage for traditional exposures, it had an undesirable effect with some digital exposures. Figure 1 represents the spectral sensitivity plot of our professional papers. There is a green sensitivity in the red-sensitive layer that peaks a little above 500 nanometers.

In some digital exposing devices there was an exaggerated effect with the non-standard sensitization, which caused reds and magentas to become objectionably dark. We decided that our digital paper should not have this form of sensitization.

Another characteristic that we reviewed was the D-log E curve of our products when exposed by the short exposure times of a laser sensitometer. Figure 2 is a curve of KODAK EKTACOLOR ULTRA Paper when exposed through our standard sensitometer.

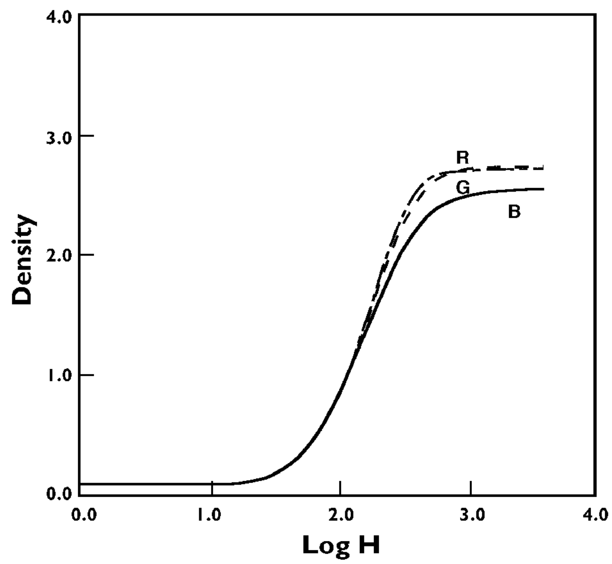

Figure 2. KODAK EKTACOLOR ULTRA II Paper with standard sensitometer.

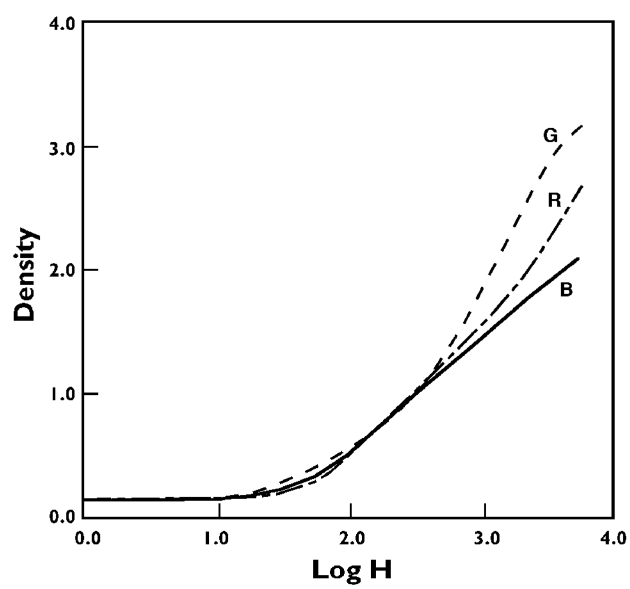

Figure 3. KODAK EKTACOLOR ULTRA II Paper with laser sensitometer.

This is a paper that is targeted for the professional commercial marketplace, where high contrast and high color saturation is desired. The emulsions were optimized for the relatively long exposures that are typical of this market. Figure 3 is a curve of ULTRA Paper when exposed by our laser sensitometer.

You can see that this product is low in contrast, and requires a significant amount of energy to get to D-max. In addition, the D-max of the final output is significantly lower than that achieved with the standard sensitometer. There is a fairly long range in exposure going from D-min to D-max. There are several reasons why we wanted to improve the performance of our paper when exposed in this fashion.

Our investigation showed that there are different areas where paper performance is important in this type of application, largely because of the different exposing method. The traditional definition of photographic speed is less important when using the digital printers. Instead, the amount of energy required to achieve D-max or near D-max is important. If the total energy required is greater than that which the exposing device can deliver, the appropriate D-max cannot be achieved.

Another important parameter is the range of exposure required to get from just above D-min of the material to the effective D-max position. If that range is much greater than 1.2 log E, the energy requirement is too great for the particular media. This means that a significant amount of light is required to achieve D-max, and that this light scatters within the media causing a flare or fringing. This fringing causes unintended exposure in areas surrounding areas of high exposure. This shows as blurring of the image, or fuzziness of text, particularly dark text on a light background or light text on a dark background. As we began specifying the needs for a digital media, we set a limit on exposure range for the paper.

Just as we did not want the exposure difference between D-min and D-max to be too long, if the difference is too short problems can occur as well. If the difference is too short, the effective contrast is too high. Because all of the writing instruments have some level of imprecision in the writing scans, there is some amount of writing non-uniformity. If the contrast of the media is too high, it can aggravate the appearance of these non-uniformities. This can show as lines or bands in the writing scan direction. Another potential concern with media that is too high in contrast is that the image files might not have enough code values in critical areas to show smooth density gradients. This can show as density jumps or image contouring. A lower contrast paper would assist the device in achieving smooth gradients in density.

As we began to design the media, we wanted enough contrast to minimize the amount of image flare or fringing, but did not want contrast so high that the digital artifacts were aggravated. We also found that this characteristic was device dependent. Some devices had more flare than others, and some had more writing precision than others. The optimum point between image fringing and digital artifacts could change as we went from device to device. We had to choose a position that would work as well as possible through as many devices as possible. Another option would have been to have a media optimized for each printer, but that would not be practical from a manufacturing efficiency viewpoint.

KODAK PROFESSIONAL Digital Paper, Type 2933

As mentioned earlier, a team was formed with the intent of creating a paper for commercialization that would be designed specifically for optimized use in as many of the digital silver halide writers as possible. We visited customers to discuss what their needs and expectations were for output from these digital devices. We tried to understand what this output would be used for, and what the final customer needs would be. We examined the technology we had available to us, and measured how it performed in as many devices as we could evaluate. Out of this mix of technology, we tried to select the pieces that would complement the performance requirements for these emerging applications. We also tried to keep the paper as close to traditional silver halide paper as possible, to improve manufacturing efficiencies.

Our first digital paper, KODAK PROFESSIONAL Digital Paper, Type 2933 contained technology selected for the best performance in these digital writers. The emulsions were selected for their performance at exposure times typical of these writers. The spectral sensitivity was selected to avoid the undesired effect mentioned earlier. The image dyes and other components were selected out of our professional product line to maintain some commonality with the professional products. We selected the emulsion coverage based on the performance we wanted in terms of contrast, D-max, and sharpness. Our initial testing suggested that this paper would offer good performance in terms of sharpness, fringing, D-max, D-min, and color reproduction. Figure 4 shows a curve of the product, when exposed by our laser sensitometer. The performance is much improved over our other papers for this application.

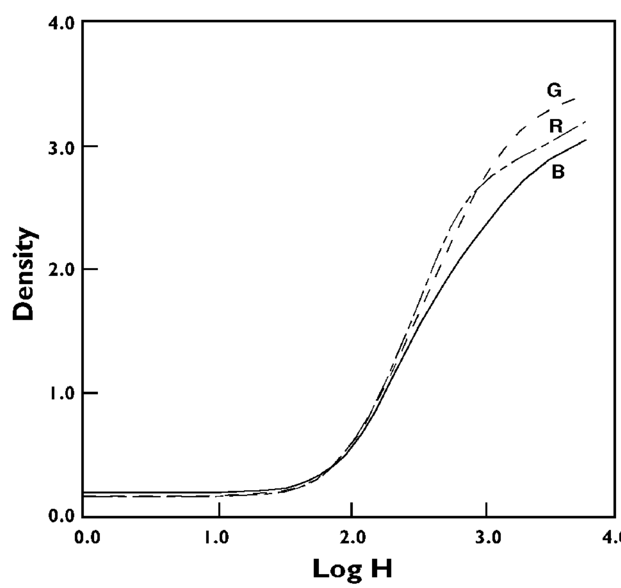

Figure 4. KODAK PROFESSIONAL Digital Paper, Type 2933 with laser sensitometer.

We began a trade trial of this paper, with customers that had purchased these digital writers. This trial was somewhat unique in that the devices for exposing the paper were being developed while the paper was being developed. We had to maintain contact with the customers and with the equipment manufacturers, because changes in the equipment could have a dramatic effect on the performance of the paper. In addition, new types of equipment were becoming available, and we wanted to ensure that there was compatibility with this new equipment. In general, we believe that the trial was successful, and we made this paper available for general sale.

During the trade trial and initial sales of the product, we also found areas where we wanted to improve the performance of our digital paper. We found that the layer with the lowest contrast would be the first layer to fringe or flare. This would cause a color to the flare, which is more noticeable than if it was neutral. We felt that we should increase the contrast of the material slightly, and make each of the layers more similar. This would have the effect of reducing image fringing, and would reduce any off color to the fringing. It would also improve D-max capabilities as well.

A second area of performance we examined was the color reproduction capability. We found that these digital writers are capable of using more of the dye capabilities of the paper than in the traditional photographic world. When exposing a paper in an optical system using a white-light printer and a negative, some of the dye capability, or gamut, of the paper is lost. These digital writers tend to be able to use much more of the existing color gamut of the material, so they put a greater requirement on the paper. In addition, it appeared that the early market for these devices was very color conscious and wanted as much color gamut in the paper as possible, to enable them to meet their customer requirements and produce as many colors as possible. In fact, most of these devices have a calibration target provided with the machine that calls for the pure colors to be produced. Therefore, many of the customers now evaluate materials using these single signal colors, whether these colors would ever be in a scene or not.

A third product improvement we wanted was increased product speed. This would enable a reduction of power in the writers. Depending on the characteristics of the writer, this could allow less exposure to get a productivity improvement, or to get less image flare.

Based on customer feedback on the performance improvements that were desired, we began development of a second generation of paper designed for these digital printers.

KODAK PROFESSIONAL Digital Paper, Type 2976

Since the first digital paper had been developed, more emulsion and dye technology became available for us to use in a digital product. We examined the curve shape of KODAK PROFESSIONAL Digital Paper, Type 2933, and looked at its performance in these printers. We selected new emulsions and balanced their coverage to create a contrast in each layer to give improved fringing and D-max performance. Figure 5 shows the characteristic curve of this new paper.

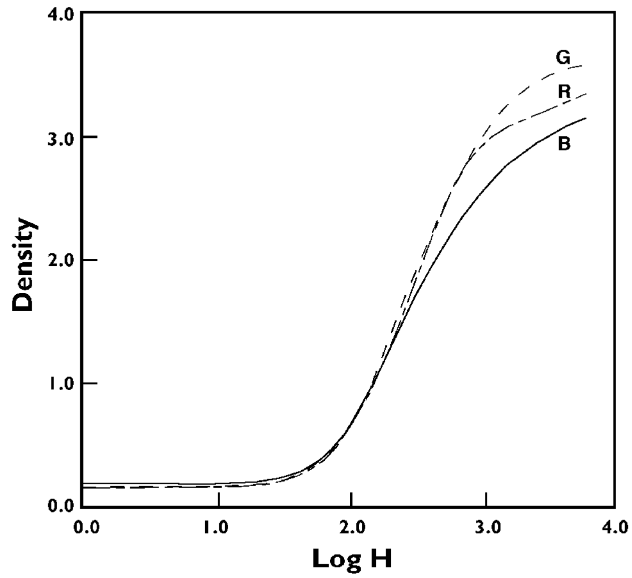

Figure 5. KODAK PROFESSIONAL Digital Paper, Type 2976 with laser sensitometer.

We also selected a new image dye, to increase the color gamut available and to improve the color reproduction of some critical colors. We examined the performance of this product, and found that there was increased chemical interaction between the layers, which could negatively impact color reproduction. This led us to look at alternate layer structures to reduce the unwanted interaction between the layers. Ultimately, we incorporated a structure change that further helped our color position. We ran a trade trial of this new paper, and in 1997 we introduced it as our second generation of digital paper, KODAK PROFESSIONAL Digital Paper, Type 2976.

Conclusion

We believe that direct digital writing to silver halide print materials is an area of growth, and will increase the usage of silver halide materials for several years. It offers the benefits of being able to blend the advantages of digital with the advantages of the traditional photographic world. The product offerings in equipment and media are changing rapidly as new products and applications are found. This means we need to stay in constant communication with the companies participating in this business, to ensure that new equipment developments and new media developments remain compatible. We believe that this area will allow our customers to offer new products and services that were not previously available, which will further enhance their business. We do not think this area will replace traditional photography, but instead will complement it with additional capabilities and applications.

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