# GRAPHIC ARTS COLOR FILTERS FOR FLAT PANEL DISPLAYS

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Abstract: Filmless printing, computer-to-plate, and digital transmission have made soft monitor proofing more desirable than ever before. The cathode ray tube (CRT) is being slowly displaced by flat panel displays, such as the active matrix liquid crystal display. The paper will describe an application of printing technology to flat panel color filter manufacture that lowers the cost of the color filter, and promises to give a better match to ink on paper.

## Introduction

The increasing demands of the digital format are creating a greater demand for soft proofing, computer-to-plate, computer-to-press, and remote proofing. The participants in the printing process, such as publishers, trade shops, and printers, are often in widely separated locations. Each requires access to contract quality proofs of the document to be reproduced. The analog proofs are too expensive and just can't get there in time. We need a soft proof at least as good as the popular analog hard copy proofs. We need an electronic Matchprint (TM). If the right soft proofing concept can be defined, there are well over half a million CRTs running Photoshop (TM) at the present time and flat panel display manufacturers are looking for a new market (Lind, 1996a). The CRT monitor has definite disadvantages for soft proofing. The major drawback, in our opinion, is

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the metameric nature of any color match from monitor to ink on paper. A more strict definition that will be seen in this paper relates to the spectral reflectance or radiance curves of two colors. If two colors have the same spectral curve shape, they will match under any light source, and the match is called invariant. The two red spectral radiance curves in Figure 1 are metameric at best.

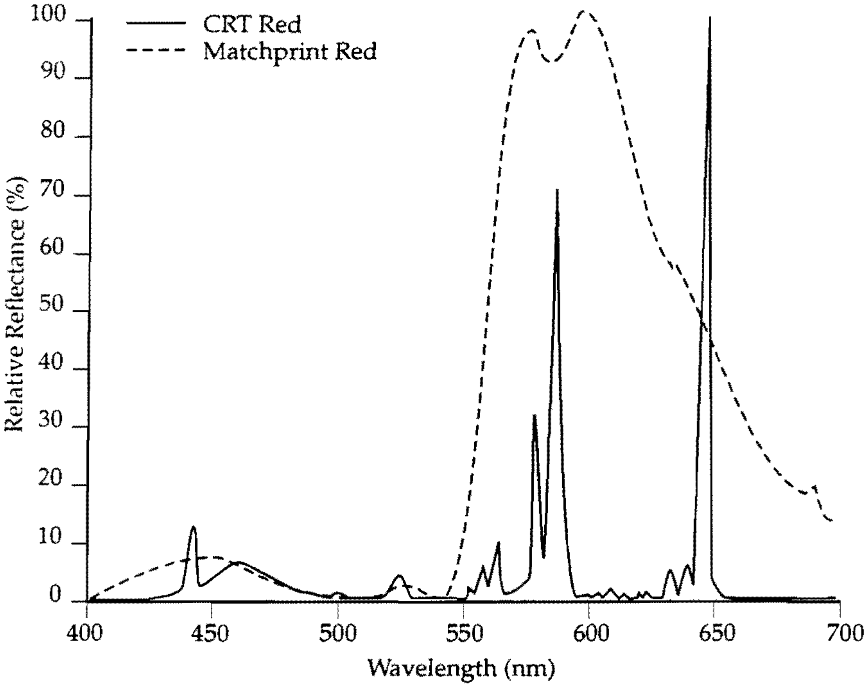


Figure 1. Spectral radiance curves of a CRT phosphor and Matchprint (TM) red.

The smooth curve is a graphic arts proofing material, and the subject of this paper. The sharp spikes are the phosphors of a cathode ray red phosphor. The advantages of the flat panel are perceived to be the following: no scintilation effects, since they are passive and not emissive; color management should be easier; properly manufactured filters have the ability to closely simulate ink and paper brightness; and calibration will be more constant, since each color will not depend on an electron gun voltage. Important advantages that belong to the CRT are its commodity status, familiarity, and relatively low cost.

Flat panel displays, of the liquid crystal type, are the materials and displays of tomorrow. For very large diagonals, plasma displays may have the edge, but these will have line spectra like the cathode ray tube. The flat panel display is ubiquitous, and continuing to increase in diagonal length with every laptop version. This trend in laptops cannot continue indefinitely or they will be too large and heavy. We are suggesting that the next size should be 21 inches in diagonal, and be targeted to the printing industry.

Every color flat panel display has a color filter in front of the liquid crystal light valves. This paper describes a method of creating the color filter that results in a material that is a spectral match for the inks used in the printing process. In Figure 2 we show how the red color filter material of this paper matches the magenta and yellow overprint of the offset printing process. This spectral match is expected by the authors to have a great impact on the process of soft proofing. The matches will no longer be metameric. It is for this reason that the Graphic Arts Technical Foundation (GATF) and R.R. Donnelley and Sons filed for a patent for the process to make it easily available to the graphic arts industry (Lind, 1996b). This paper will outline the anticipated advantages of this approach to soft proofing.

While a working prototype is not available at this time, this communication was considered necessary. The prototypes will be ready soon. This presentation will stimulate interest, demand, and more prototypes for this necessary evolution of digital technology.

The paper will be divided into a short discussion of proofing history, the creation of the color filter, and a discussion of advantages that the concept will have over current flat panel color filters and CRTs for soft proofing. There will be a section devoted to the ideal soft proofing display, from a printing industry perspective, the problems with soft proofing with CRTs, and finally, some caveats and possible roadblocks for the prototype.

## Historical Evolution of Proofing

Our industry struggles every day to work digitally and proof analog, with films. We started with ink and paper proofs. Metamerism was still an issue, since we were trying to match watercolors or dye transparencies. Some say that this is still the best proof, if you can afford the time and money. The concept survives today in many parts of the world, and SWOP (TM) proofing on four color sheetfed presses (SWOP, 1993). There are so many variables, but by beginning with the most simple controls, the color of the ink, great strides were made in controlling the process. There are similarities between the SWOP (TM) high-low color references and the color filters proposed here.

Over the last two decades, offpress proofs have established themselves at the expense of press proofing, at least in some countries. They are cheaper than press proofing for small numbers of copies, more consistent, and some of them are close to matching ink on paper. These are the contract proofs of today. One of the most successful offpress proofs is the basis of the color filter in this paper.

The cathode ray tubes (CRTs) arrived with the Color Electronic Prepress (CEP) workstation. They were used for the quick check, for cloning and retouching before making films. A color match wasn't expected, since the analog proof was still the contract. Then the digital revolution gathered momentum and moved to the desktop. The amateur color separator wanted to use the CRT as a proof. Soon the designers, agencies, and publishers all wanted to use the CRT as a proof, just to get rid of the film, especially with the advent of computer-to-plate. With this development, the film was really supposed to be superfluous. Designers wanted CRTs with larger color gamuts. Printers wanted a CRT that was better for color matching, and more consistent for press side use (invariant instead of metameric). Color management systems try to bridge this gap, but with limited success.

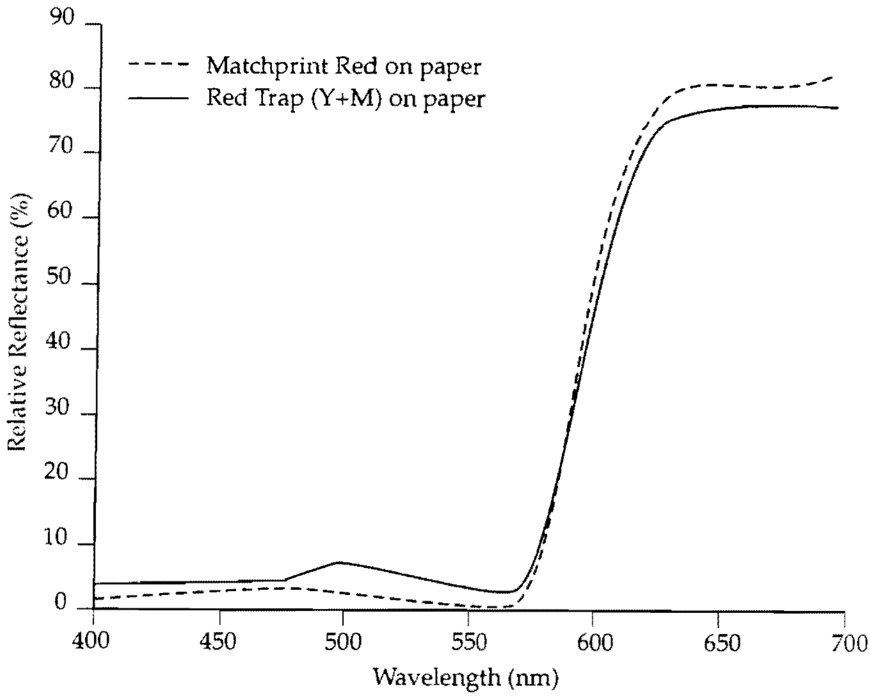


Figure 2. Spectral comparison of red filter material and red ink trap.

This paper proposes that the use of the color filters described here with the same pigments as those used in printing inks will have the same effect as the SWOP (TM) high-low color references on web offset publications. All at once, we will all be using the same color primaries. We will eliminate a big variable in the soft proofing process and further enable the growth of digital prepress.

## The Color Filter

Over the past five years, GATF has worked under Defense Advanced Research Project Agency (DARPA) contract with Active Matrix Associates (AMA) to apply graphic arts techniques to lower the cost of manufacture of flat panel displays and components. T.P. Brody, president of AMA, was awarded a patent for a filter manufacturing process (Brody, 1995). The process involves a familiar lamination process of colored light sensitive films followed by imagewise exposure through pixel RGB film patterns. The process potentially reduces the cost of a color filter from $100US to $10US. The important factors in this development were the temperature resistance of the materials, since they must withstand certain manufacturing temperature excursions, and the color gamut, which had to be at least competitive with existing technologies, such as CRT and other flat panel filter technologies like passive matrix and plasma display. Figure 3 shows the color gamut in the 1931 Chromaticity diagram for the AMA filter material compared to a typical laptop, and two CRT pixel configurations. The laptop color filter could have been produced by one of 26 color filter suppliers throughout the world (Interlingua, 1997). These measurements were made with a PhotoResearch PR 704 spectroradiometer. The spectroradiometer has a lens that can measure a spot 0.002 inches in diameter, and is capable of measuring individual pixels.

The GATF and R.R. Donnelley contribution came at this stage of the development. Not only was the color gamut competitive, as shown in Figure 3, it was also more flexible, as shown in Figure 4, and there was a spectral match of the new filter to ink on paper. The colorants in the laminate are spectrally matched to ink and paper, as shown in Figure 2 and in Figure 5 for blue and green. What was clear was how different these AMA materials were from current flat panel display color filter materials, which emulate the metameric mismatch of the CRT, as shown in Figure 6 for the AMA filter, a laptop, and a CRT.

## Advantages Over Current Flat Panel Displays and CRTs for Soft Proofing

The number one advantage over current display technologies is the spectral match of the AMA filters to offset commercial and publication printing ink and paper. It is a basic fact of color technology that two colors match when their spectral curves overlap or look the same. The new filter will have this feature, as opposed to laptop color filters and self-luminous CRT displays. This

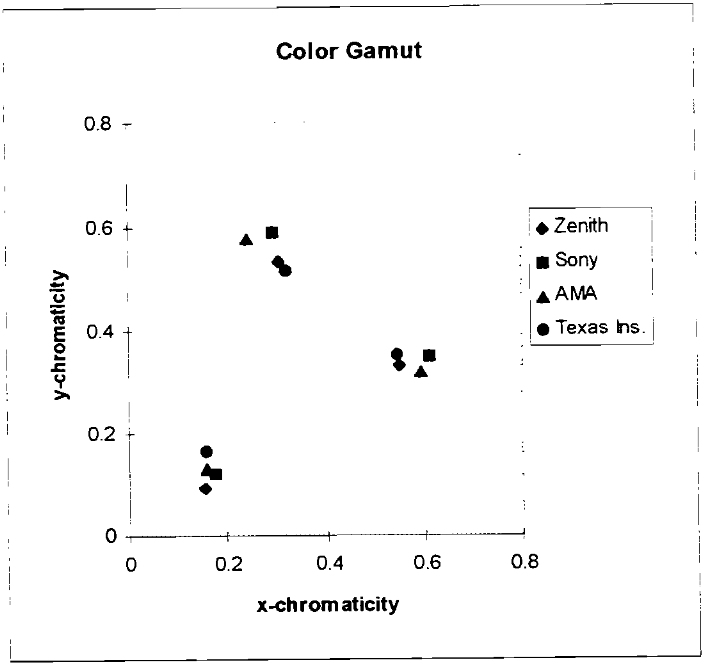


Figure 3. Gamut comparison between proposed filter and three existing technologies. Sony and Zenith are CRTs while Texas Instrument is an active matrix flat panel display.

will eliminate an important variable of color transformations of display to ink on paper. It may make the new flat panel soft proofing monitor a necessary add-on to the console of the printing press of tomorrow.

Aside from the spectral match, there will be gains in consistency of chromaticity across the screen, as shown in Table 1. These measurements were collected by moving the spectroradiometer across the various screens about one inch at a time from left to right, measuring individual red, green, and blue pixels. The AMA filter was backlit with a D5000 transparency viewer, until the prototype is available with a real laptop light source. The Trinitron CRT is stable in luminance, but the chromaticity varies significantly compared to the AMA filter, and even the commercial laptop. The Trinitron CRT is the monitor of choice for

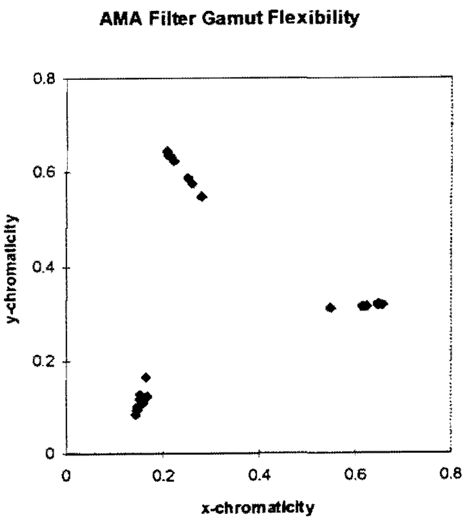


Figure 4. Gamut flexibility of AMA filter material with pigment concentration.

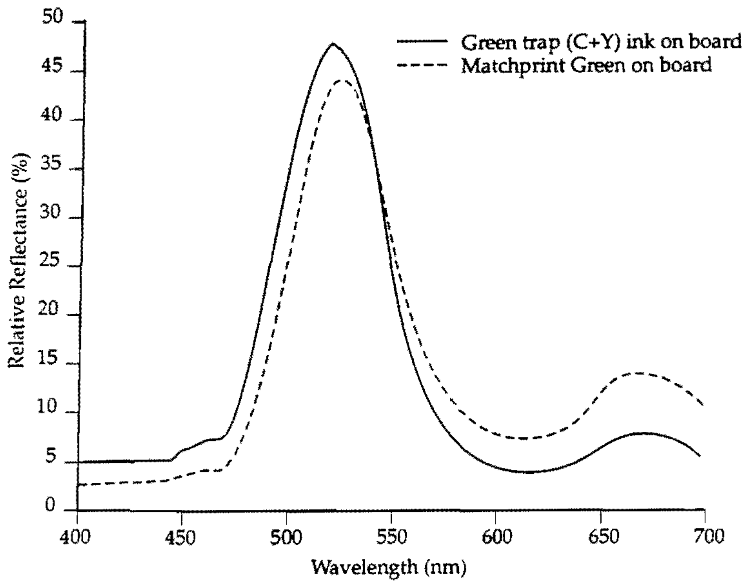


Figure 5a. Comparison of green ink trap and Matchprint green filter material.

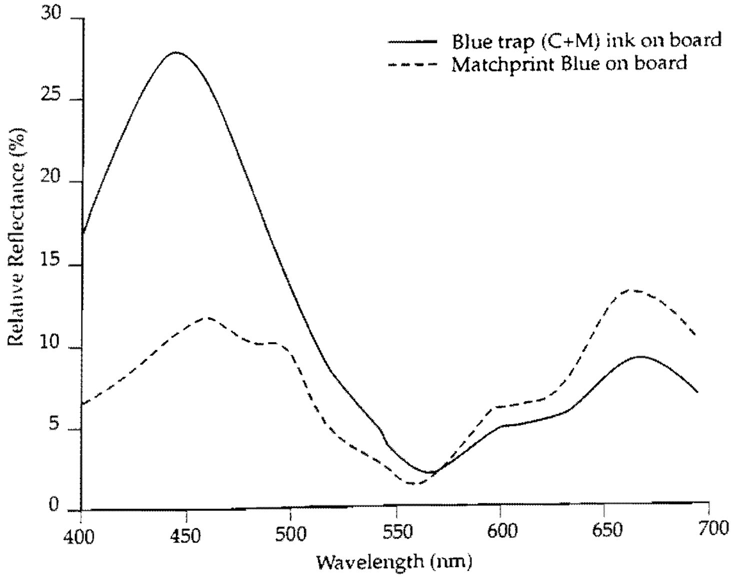


Figure 5b. Comparison of the blue ink trap with the Matchprint blue color filter

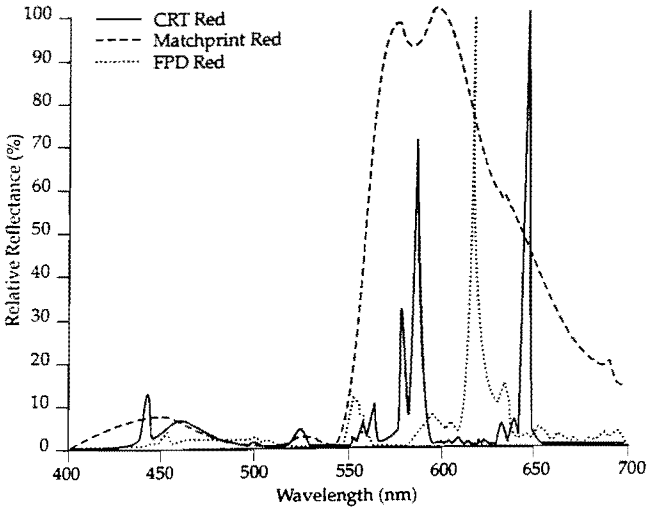


Figure 6. Spectral comparison of a CRT, a laptop computer screen, and the AMA Matchprint red filter

| **RED PIXELS** | | x-value | y-value | luminance, ftLamberts | | |
|---|---|---|---|---|---|---|
| Laptop | mean | 0.5449 | 0.3524 | 42.9 | | |
| | std.dev. | 0.0031 | 0.0039 | 2 | | |
| CRT-PC | mean | 0.597 | 0.3517 | 64.5 | | |
| | std.dev. | 0.0158 | 0.013 | 16.4 | | |
| CRT-Mac | mean | 0.5685 | 0.3397 | 22.9 | | |
| | std.dev. | 0.0256 | 0.0215 | 2.8 | | |
| AMA/GATF/RRD | mean | 0.5953 | 0.3188 | 80.1 | | |
| | std.dev. | 0.002 | 0.0021 | 1.9 | | |
| | | | | | | |
| **GREEN PIXELS** | | x-value | y-value | luminance, ftLamberts | | |
| Laptop | mean | 0.3209 | 0.5144 | 82.4 | | |
| | std.dev. | 0.0034 | 0.0021 | 2.8 | | |
| CRT-PC | mean | 0.3031 | 0.5921 | 226.1 | | |
| | std.dev. | 0.007 | 0.0103 | 63.4 | | |
| CRT-Mac | mean | 0.3147 | 0.5558 | 42.6 | | |
| | std.dev. | 0.0222 | 0.0273 | 7.9 | | |
| AMA/GATF/RRD | mean | 0.2459 | 0.5773 | 143.5 | | |
| | std.dev. | 0.0025 | 0.0034 | 5.5 | | |
| | | | | | | |
| **BLUE PIXELS** | | x-value | y-value | luminance, ftLamberts | | |
| Laptop | mean | 0.1589 | 0.1653 | 20.8 | | |
| | std.dev. | 0.001 | 0.0092 | 1.4 | | |
| CRT-PC | mean | 0.1506 | 0.0766 | 40 | | |
| | std.dev. | 0.0028 | 0.005 | 6.7 | | |
| CRT-Mac | mean | 0.2028 | 0.1792 | 9 | | |
| | std.dev. | 0.0253 | 0.0378 | 1.9 | | |
| AMA/GATF/RRD | mean | 0.1542 | 0.13 | 22 | | |
| | std.dev. | 0.0068 | 0.0038 | 0.8 | | |

Table 1. Variability of chromaticity across the screen for four display types.

the soft proofing of today. The SONY/Trinitron tube is particularly inconsistent across the width of the screen despite calibration just before these measurements were made. The radiance curves show that this is probably due to cross-talk between the pixel rows, such as where red emissions are mixed where blue and green are supposed to be alone. This phenomenon is more pronounced as one moves away from the center of the screen. This was not observed in the AMA filter, the laptop screen, or the mosaic CRT (CRT-PC).

## Soft Proofing Display Requirements from the Printing Industry Perspective

Table 2 is a wish list provided by a large printer (Fling, 1997). A soft proofing display with these features would be the ideal prototype. There isn't much difference from this list and the draft ISO TC-130 Graphic Technology document (Fisch, 1994). It should be noted that the ISO draft contains no reference to any possible use of a flat panel display as a soft proofing device. It is devoted to phosphors, and is typical of the paradigm shift that is represented by this proposed method of soft proofing.

| | |
|---|---|
| Diagonal Dimensions | 16.1 inch |
| Screen Dimensions (mm) | 318.7 x 255.5 (minimum useful size) |
| Number of Pixels | 1280 x 1024 (100dpi- ultimately would like 150 dpi) |
| RGB Arrangement | Stripes (every pixel should contain a R,G, & B element) |
| Pixel Pitch (mm2) | 0.25 x 0.25 |
| Number of Color Pixels | 3072 x 768 |
| Number of Colors | 8 bits per pixel |
| Screen Brightness (cd/m2) | 150 |
| maximum | 200 |
| Contrast | 1 to 150 |
| Viewing Angle (degrees) | Up/Down 70/70<br>Left/Right 70/70 |
| Response Time (msec) | 60 |
| Backlight | Cold Cathode |
| Method | Edge light |
| Symmetrical Controller | Digital RGB signal (8-bits/pixel) |
| Interface | 8 bit each color |
| Consistency pixel to pixel | 5% (digital interface/ any display combination) |

Also should have Look-up Table for each pixel to calibrate

Table 2. Some ideal features of a soft proofing device from a printer's view.

## Problems with Soft Proofing Today

The biggest problem with soft proofing today is the perception that a metameric match is good enough. This is only because that is all that most users believe is or can be available. One hears from the trenches that it is not good enough. In the pages of this Journal, we hear that 2-3 CIELAB deltaE is remarkably close when comparing a soft proof and a hard proof (Pobboravsky, 1988). The printers of today, faced with the prospect of no analog back-up proof, don't agree. The potential liability associated with a reprint of a document with even reasonably important color is too great to risk using a CRT representation as a contract. With a spectrally matched soft proof, that amount of color difference might be acceptable, but not a metameric match.

There is a lot of discussion about the size of the color gamut of the CRT and whether it overlaps the gamut of the various printing processes. Do some printing colors fall outside the gamut of the CRT, and therefore, cannot be reproduced? The CRT can reproduce 16 million colors, but somehow, some of the 4,000 printing colors are not among the 16 million. This phenomenon may be the result of using the wrong set of primary colors. When the primaries are spectrally matched to ink and paper as hypothesized here, this problem will no longer exist. The new filter and soft proofing monitor does not claim to reproduce 16 million colors, but the color that it does reproduce will contain the colors of the offset printing system, or any other system so targeted.

One label printer claims that the soft proof is not accurate enough. The CRT cannot show the traps, and the display isn't sharp enough (Stager, 1996). The same printer quickly volunteered to be a beta site.

## Caveats and Opportunities for the Prototype

Despite the intuitive simplicity of the new soft proofing display concept, there are a few areas that are not totally understood, especially without a prototype. Do we really know why the CRT doesn't work? Is there a hole in color space where all the mismatches occur? Can we understand how this color proofing device will simulate the offset printing process, when we do not have full understanding of the offset printing process? This will not eliminate all the variables of the printing process that are difficult to control, but it will ensure that all parties can agree with confidence on the desired end product. We have removed one variable from the soft proofing process. Metamerism may be the reason that current soft proofing approaches haven't worked, or it may be a phenomenon or phenomena that we don't yet understand. What we do know is that there are a few analog hardcopy proofs out there that work pretty well, and that allow a match situation on press. This liquid crystal display soft proof will emulate the hardcopy analog proofs. It can be described as an electronic "Matchprint" (TM).

Finally, when the prototype is in front of us, how will we characterize the results? How will we convince ourselves that the prototype matches the output of the press? We can look at it, and react to different color rendering challenges and conclude that it is better or worse than the metameric CRT. We can call in a panel of experts and average their opinions. We can try to correlate the measurements of a spectroradiometer and a spectrodensitometer. We will do all of the above. We can even ask a press operator if it makes the job easier. Before we can do any of this, one has to build the prototype. We expect such a device will be available in the near future.

## Conclusions

We spoke of anticipated advantages because prototypes are being constructed as this is written. This whole paper is a hypothesis. Next year, or sooner, you will hear about the success or shortcomings of this idea. We are hopeful that this technology of spectrally matched soft proofing will benefit all segments of the printing and publishing industry. This development is not the end of color management, we only hope that it will make it easier.

We have presented a new approach to soft proofing, by marrying the analog offpress proof to the liquid crystal display. This will be a paradigm shift, both evolutionary and revolutionary. Maybe it's a little ahead of its time in terms of economics. If it works, if it is as simple as it sounds, time and money will be saved in the process and utilization of this technology.

With our printing and publishing member base, GATF will explore this application and give the information to this industry. GATF and R. R. Donnelley have applied for patents so that this is freely available to those who can benefit from it. By working with the liquid crystal display manufacturers, we will be able to keep the focus on the needs of the printing industry.

## Acknowledgements

The authors point out that without T. Peter Brody, we would know nothing about flat panel displays and their connection to the graphic arts. If not for him, maybe no one would know anything about the active matrix concept. We also thank Richard Adams and Phillip Hutton for their help in computing and software navigation. Finally, we thank the Defense Advanced Research Project Agency for the funding that allowed Active Matrix Associates and GATF to work on this project.

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