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Electronic Printing of Color Materials

The designers of light sources, electronics, and color emulsions unite their efforts to solve difficult technical problems

ABSTRACT: *Very shortly after the first LogEtronics Contact Printers, designated CP/10, were delivered to their owners, the inevitable question had to be, "But can I print color on this thing?". These first pioneering efforts were disappointing, but not discouraging. It took almost ten years, incredible as it may seem, to bring together at one conference table the designers of the necessary components for a successful system: (1) the light source; (2) the electronics; (3) the color emulsions. This paper describes the major problem areas of electronic exposure control and electronic unsharp masking, using a light source having an interrupted spectrum.*

LOGETRONICS WAS FOUNDED March 14, 1955, and very shortly thereafter became interested in Color Printing. As you may recall, these first electronic printers utilized intensity modulation circuitry to expose incrementally the negative on a spot-size basis. Further, the spot, which was usually about ¼ inch in diameter, was caused to change its brightness in an inverse fashion under control of signals from a photo multiplier tube (PMT). That is, if the PMT received a strong signal from the cathode ray tube (CRT) through the negative and printing material, it would cause the CRT-beam current to be reduced, and the spot intensity would almost instantaneously be decreased, and vice versa (inverse feed-back).

For many years this phenomenon has been referred to as *dodging*. Somehow I find the word objectionable, and would rather call it *electronic unsharp masking* or *incremental exposure control*, which certainly more accurately describes the system, and is more compatible with the price tag.

A little later there was added to the circuitry a second PMT whose job it was to integrate all of the light passed through a manually selected area in the negative, and to turn off the exposure when it had collected a predetermined amount of light as determined by the exposure index setting. Without this second PMT the system was substantially a variable-intensity constant-time device. The

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second PMT permitted shorter exposure times for thin negatives and, of course, longer times for dense negatives. The CRT beam current was modulated from nearly zero to several hundred microamps. The lower current limit was fixed primarily by the total gain of the inverse feedback loop, and the upper limit was determined by how much energy the phosphor could withstand without over-heating when employing a small, electronically, well-focussed scanning spot, because phorphor burning is a problem of area concentration of the electron beam as a function of time or scan rate.

Compared to TV scan rates, our spot is practically standing still, hence much lower current densities are usually involved. For example, the scanning pattern of your television is repeated 30 times per second over the entire tube faceplate, while our spot moves over a 10×10-inch negative about once per second in our early printers. Depending on the focal length of the lens being used, and the magnification to cover the format, the raster size on the CRT may be only three inches square.

Very early another phenomena was encountered. As the CRT beam current was reduced, the spot size grew smaller; and inversely, as the beam current was increased toward maximum, the spot got larger. We never tagged this effect with a scientific name, but we may have missed a good bet. Actually, we were never really sure whether it was working for or against us, but like all things ignored, they either go away or come back to haunt you.

ALSO, IN THE EARLY days we used the standard television P-4 phosphor which employs a red, green, blue mix having an appearance of white light. As you have already guessed, it was not really *white*, because there was so little red component. But this fact did not deter some of our pioneer users from experimenting with color materials.

The lack of suitable red emission was recognized and steps were taken to provide the missing component. We obtained some experimental CRT's with a mixture of blue, green, and red phosphors. The early efforts were a disappointment because we found that this very necessary red component was very inefficient in terms of the printing material response. If we added more of the red phosphor the result was mottle because of the then large particle size of the red phosphors. I should mention that the europium red phosphor which gives your home television the brilliant red hues is almost worthless in terms of photographic color printing material response, due to its extremely narrow spectral peak.

The blue component was much too efficient, and the green phosphor was somewhere in between. Fundamentally, the problem was to find a more efficient red component, let the green alone, and reduce tht efficiency of the blue phosphor. As CRT phosphor coatings were not our particular cup of tea, the logical solution to this problem was to unload the problem to our cathode ray tube supplier which at the time was, and still is, Thomas Electronics, Inc.

We found a very sympathetic ear in the person of Mr. Peter Seats, President of Thomas Electronics. His approach to the problem was classical. Together we would find the most qualified firm in the free world to conduct a study of the basic phosphors to determine the suitability and availability of some family of phosphors which would meet the specific requirements. In establishing the specific objectives for the phoshor study we decided to save time by arranging a meeting between one of the leading manufacturers of the photosensitized color materials, the CRT manufacturer, and the designers of the electronic circuitry.

IN MAY OF 1966, LogEtronics arranged for such a meeting which took place in Rochester, New York. I will recall this meeting as a real milestone in the advancement of color printing. At this point, it might be well to remind you that a so called white light produced by three basic color phosphors must be regarded as an interrupted spectrum and therefore cannot be identified on the Kelvin color temperature scale. Most color materials require a light source of between 2,900 and 3,200 degrees Kelvin. Our immediate problem was to match the peak emission characteristics of three basic color phosphors (red, green, and blue) with the peak response characteristics of the three dye-sensitive layers in the color emulsion, but to avoid those phosphors that have sharp spike-shaped peak efficiencies in favor of those having a broader peak to allow for minor shifts in the emulsion spectral sensitivity.

Levy-West of Derby, England, was chosen to conduct a study which would, hopefully, result in the selection of three basic phosphors most likely to succeed. The criteria were: (1) wave length of peak color emission, (2) particle size, (3) decay time, (4) useful life at a given beam current density and, finally, (5) availability in reasonable quantities.

AT ABOUT THE TIME we discovered that the intensity modulated system caused a color shift with variations in beam current in these early white light CRT's, added attention was devoted to our velocity modulation circuitry as a system which would not exhibit some of the undesirable symptoms previously encountered. For instance, where heavy correction filter packs were required to produce a satisfactory color reproduction, I would expect that the signal reaching the first PMT was so weak that very little masking was accomplished, and the second PMT was having a difficult time with the exposure control aspect.

Velocity modulation is basically a constant-intensity variable-time system. It uses only one PMT to control the scan rate as an inverse function of density. It is also in essence a stupid system. The spot doesn't remember where it has been or what it saw, nor does it know that is coming next. It only deals with *now*. The stupidity might well be a blessing in disguise if the man-machine communication link is intelligent. Perhaps its greatest virtue is its ability to operate with positive as well as negative feed-back signals from the PMT, and the ease with which these signals can be clipped or grated to reshape the *D log E* curve. These functions require either a pre-scan of the image content, which must not contribute significantly to the final exposure, or the man-machine intelligence link previously mentioned. In the latter case the operator performs the pre-scan function with a very intelligent but subjective device called the human eyeball.

IF WE EXAMINE the minimum and maximum scan rates of the velocity modulated system, it should be obvious that if the minimum rate is reduced sufficiently, the spot will stand still and burn a hole in a very expensive light source. If the maximum rate is extended sufficiently, the spot may move so rapidly that it will lose its shape or fail to energize the phosphor completely on a spot size basis, perhaps causing the system to begin exhibiting some type of intensity modulation characteristic. The previously mentioned limitations are, of course, determined by the state of the art of present CRT phosphor coatings relative to decay time, brightness, and half-life characteristics. As this art improves, the dynamic range of the system could be extended.

At the moment the minimum scan rate permissible is approximately 10 inches per second with a zero-microamperes signal from the PMT at a beam current of 250 microamperes over a 4-inch square raster on the CRT faceplate. This condition is obtained by means of a *keep alive* current when no signal is being provided by the PMT. It is a protective circuit to prevent damage to the phosphor coating. The maximum scan rate presently is about 7,000 inches per second. (*Note:* The useful maximum scan rate is about 6,000 inches per second at zero negative density which produces a 50 microamp PMT signal. Also, the useful minimum scan rate at 2.0 negative density at a PMT signal of about 5 microamps is approximately 60 inches per second. Therefore, 60 to 6,000 is a useful dynamic range of 100 to 1.) The maximum rate is fixed by the deflection amplifier and CRT yoke design which, in turn, was arranged to be compatible with existing phosphor coatings.

IN PREVIOUS CONVERSATIONS, I have remarked that if the sensitivity of the feed-back loop could be increased to extend considerably the dynamic range of spot brightness or velocity, and the spot size in the image plane could be made infinitely small (approaching the grain size of the emulsion), and the contrast of the light source and lens could be greatly increased, we could theoretically eliminate all of the information detail in the original photograph and produce an informationless reproduction at some absolute density.

I sincerely hope that I have not given you the idea that the situation regarding Log-Etronics Color Printing instrumentation is pessimistic. I would rather give you the unmistakable impression that if we thoroughly understand the problem, and are fully cognizant of past and present deficiencies, the chances for success are greatly enhanced. Perhaps, even more important to you is that we are doing something about it. Let me just quickly outline for you some of our current probrams directly related to the problems at hand.

★ As a result of the Levy-West phosphor study, we are at the moment testing a group of multi-phosphor CRT's produced by Thomas Electronics. We are evaluating these tubes with the new Kodak Negative Color system and, later in the program, with other direct reversal color emulsions. We hope to establish what modifications are required to achieve optimum performance for each material. It is very doubtful that a single solution will be optimum for all color materials. It is much more likely that specific phosphor mixes will be required for each different type of emulsion to eliminate undesirable compromise.

★ We are constantly improving and refining the velocity modulated circuitry specifically for color printing. We would be delighted to show and demonstrate a prototype device to you in our new and expanded facilities in Springfield, Virginia. It is a Company policy not to exhibit prototype devices at shows and conventions such as ASP-ACSM. We believe that it is important to you to know that this work is going on in depth, and we would welcome your comments and evaluations of the device. When we believe that is has been finalized put into production, and can accurately quote delivery dates and prices, we will exhibit a really new color printer which will be a substantial contribution to your efforts and a credit to our Company.

★ We are currently working with the major film manufacturers to stay abreast of the state of the art in this most important segment of the total problem.

★ We are attempting to improve and enlarge our communications/intelligence pipeline with our customers to understand better their problems on a current and immediate basis.

★ We are at the moment developing techniques and instrumentation to establish a better and more advanced man-machine link as the most likely area for significant improvement. There are two widely and diverse schools of thought on this subject. One group would have us remove all of the controls from the front panel except for the *Go* button so that the operator would find it difficult or impossible to louse up the intended functions of the equipment. This approach is based on the premise that most operators are stupid. The other school of thought is, I believe, by far the most promising, and this approach to it provide all of the necessary controls and adjustments on the front panel to enable a properly instructed operator to produce the type of results required by the ultimate user.

I would like to interject at this point that we have elected to do these things—to conduct these programs with our own funds as proprietary, in-house developments. Occasionally, additional money will not buy time. In such circumstances, our advancement in technology must wait for, or be correlated with, other technologies.

★ Finally, we are adding our voices and support to overcome the next obvious obstacle and objectionable feature of color aerial photography for cartography and photo intelligence applications. The obstacle is at the moment impeding the total acceptance it rightfully deserves. A new electronic contact printing system capable of correctly exposing suitable photographic color duplicating materials at rates up to 50 square inches per second, and incorporating automatic exposure control, programmed exposure correction, unsharp masking and dynamic color correction.

In order to achieve these objectives, this design would be predicated on the use of multi-color stripe-phosphor version of the 10-inch line-scan fiber-optics CRT which we are now developing for rapid black and white printing applications. This type of light source is, at the present stage of the art, best suited to close-up contact printing of single frames or long webs of photography, not exceeding 9.5 inches in width. Implicit in the concept is the need for smooth, linear relative mechanical motion between the light source and the photographic materials in order to obtain two-axis scanning of the exposure area with a single-axis line-type light source. This method of operation has already been demonstrated in both modes with encouraging results. The phosphor technique possesses the following advantages, among others, in color printing:

- An exposure light level 10 to 40 times greater than that which is obtainable from even a fast conventional projection optical system, leading to potential trade-offs between exposure time, scanning spot size and phosphor fatigue.
- Spectral purity and stability, even with intensity modulation of the electron beam, as three different and discrete phosphors-rather than a single compound-phosphor screen are used.
- Enhanced scanning-spot contrast resulting from the absence of faceplate halation ring effects, with leads to improved exposure control, dodging and color correction performance.
- Ability to vary dynamically the color of the light source within the visible spectrum by all-electronic means, either by use of a single electron gun and sequential scanning, or by the use of a three-gun simultaneous scanning system capable of producing an equivalent exposure level in less than one-third of the single-gun time.

In closing, let me say that the third dimension for serial photography was achieved many years ago with the introduction and acceptance of stereo-plotting instrumentation augmented by on line computorized triangulation. I would say that today in spite of the pioneering efforts of a relatively few individuals, we are still standing, or standing still, on the threshold of acceptance of the forth dimension—*Color*.