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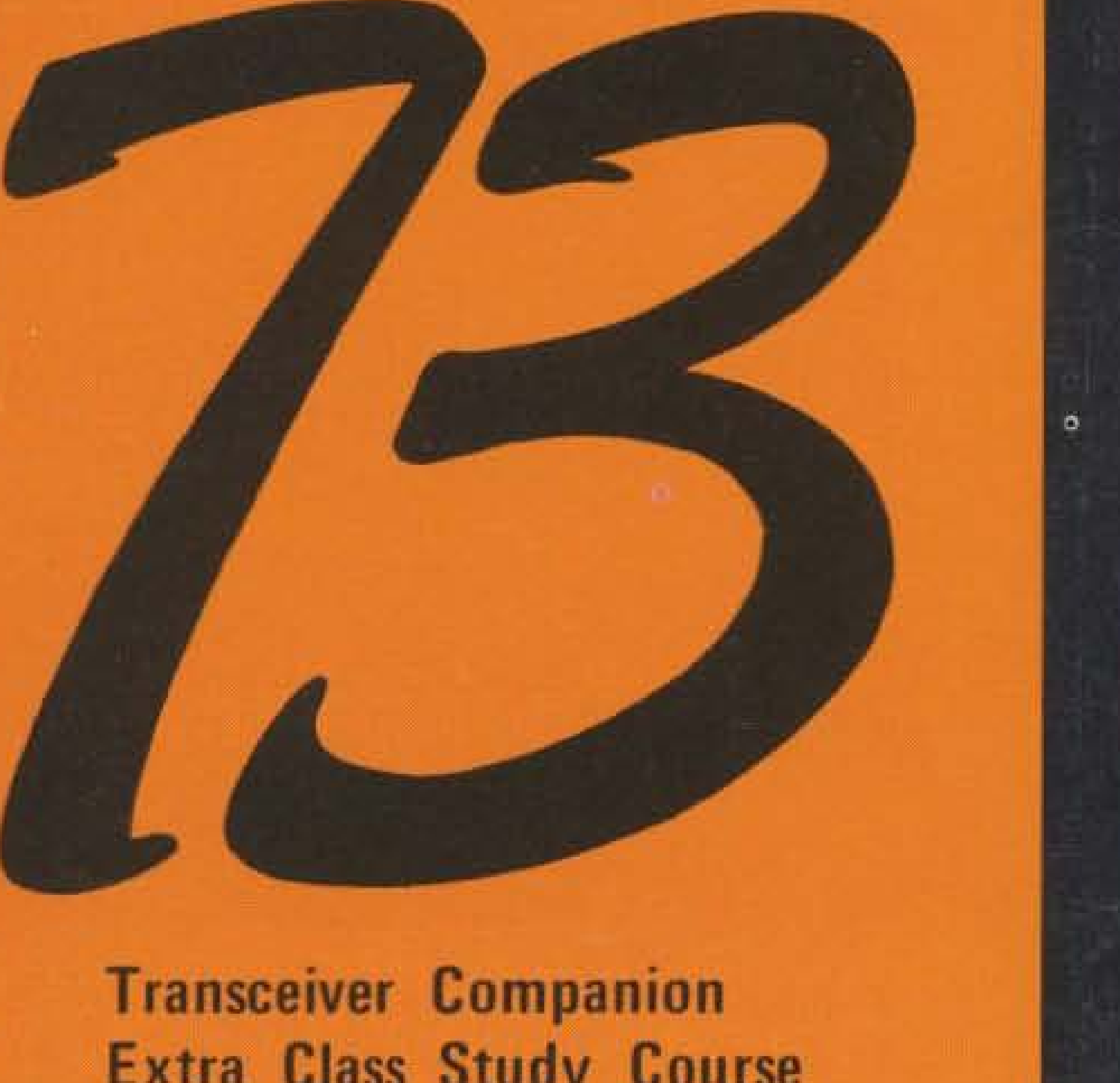


Amateur Slow Scan Color TV Approaches Perfection Slo-o-o-o-wly

Theodore J. Cohen W4UMF
6631 Wakefield Dr. Apt. 708
Alexandria VA 22307

Wade L. Tarr
801 N. Pitt Street Apt. 519
Alexandria VA 22314

Slow Scan Color Transmission

Introduction

In 1861, James C. Maxwell demonstrated the principles of three-color photography. Maxwell analyzed a landscape scene through red, green and blue filters, and from the black and white negatives so produced, made three positive lantern slides. Then, by projecting the black and white lantern slides back through red, green, and blue filters, and superimposing the three pictures, he produced a color picture of the landscape. The principles of tricolor analysis and synthesis first demonstrated by Maxwell are still used today in the field of color photography, color printing, and color television. For example, the first close-up color photographs of the moon's surface were produced by a Surveyor satellite suitably equipped with a black and white television camera and color separation filters. More recently, the color photographs of the earth taken by an Application Technology Satellite (*Scientific American,* 1969) are but another example of color photography by means of color analysis and synthesis.

The application of color analysis and synthesis techniques to amateur television follows as a logical step in the development of this communication mode. In particular, the technique is here applied to the field of slow-scan television, giving the amateur a capability for the long-distance transmission of color information.

Color Principles

In 1801, Thomas Young put forth a hypothesis that human color vision is based on a three-part color analysis, in the eye, of the light received from an object. Young's investigations were extended by Helmholz and others, who showed through mixing experiments that almost all colors could be matched by a mixture of three colors. The three colors used in the matching process are not specified; but then, there are no three unique components that must be used for color matching. It can be shown, however, that red, green, and blue components permit matching the greatest spectral range of colors (without using negative quantities of a component), and for this reason, red, green, and blue are considered as the *primary colors.*

James C. Maxwell, in 1861, demonstrated that the above principles could be used to reproduce a colored scene, and thus laid the foundation for current three-color photography, printing, and television. Maxwell exposed three separate photographic plates to a landscape scene through red, green, and

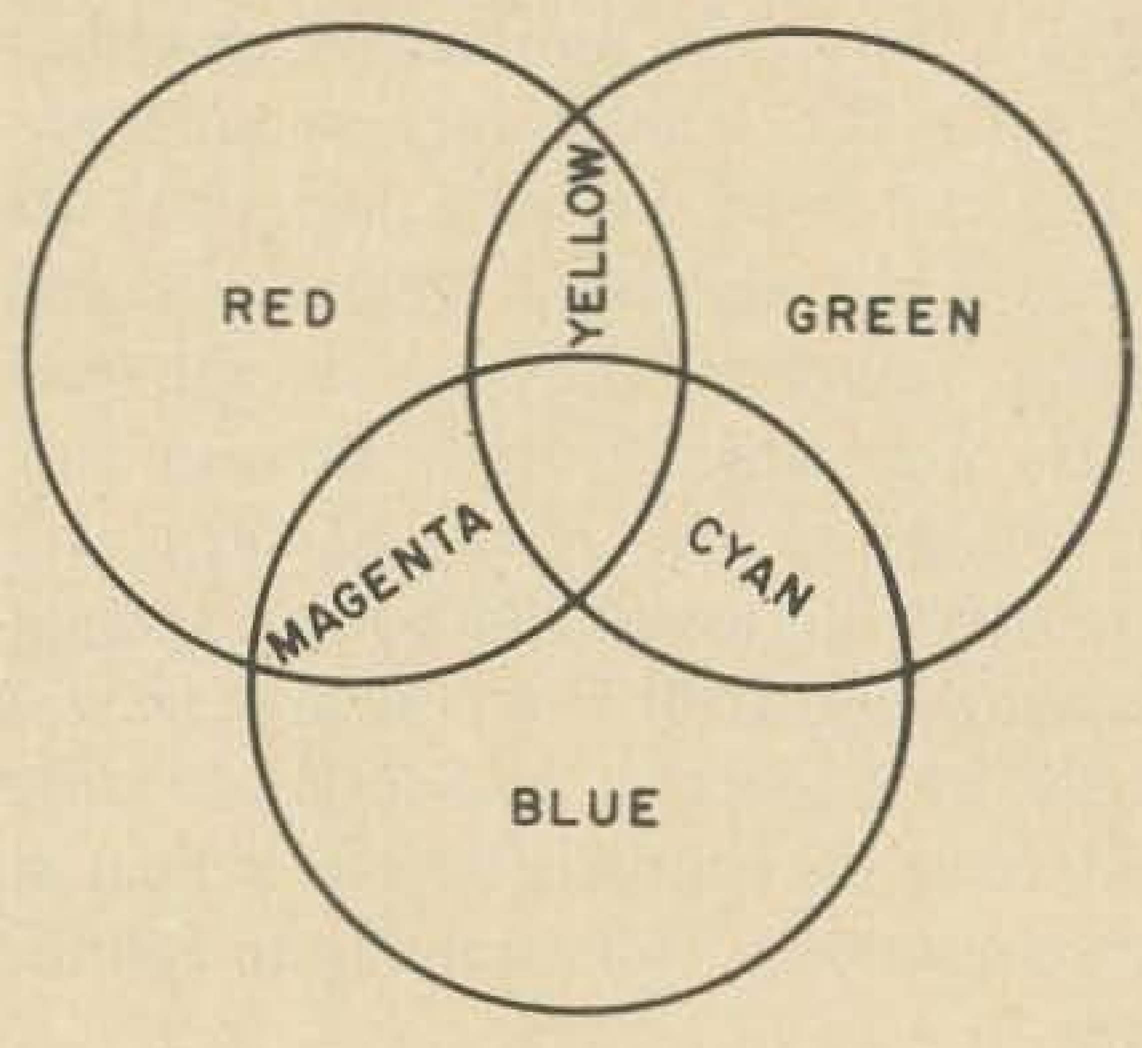


Fig. 1. Color mixture by addition.

blue glass (filters). The photographic emulsion exposed behind the red filter, when developed, showed, in terms of silver densities, the amount of red light reflected from the scene. Areas of the landscape which reflected greater amounts of red light yielded greater densities on the corresponding parts of the black and white negative. Where a lesser amount of red light was reflected, a lesser density was obtained. Similar statements apply to the negatives made with the green and blue filters (substitute "green" and "blue" for the word "red" in the above sentences). Colors formed from two or more colors were recorded on two or more negatives in proportion to the amount of each primary color reflected. Thus, the set of three black and white *separation negatives* recorded the *tricolor analysis* of the scene.

To reproduce the landscape analyzed by tricolor analysis, Maxwell first produced a positive transparency from each of the three separation negatives. These positives were then placed in magic lanterns, and a colored filter corresponding to a given positive's separation filter was placed in front of each lantern. That is, a red filter was placed in front of the lantern containing the positive made from the "red" negative, etc. With the intensities of the lanterns properly adjusted, a reproduction, or synthesis, of the landscape appeared on the screen. Although the reproduction was poor by today's standards, the basic principles of three-color photography had been established.

Maxwell reproduced his image by *additive color synthesis*, wherein three colored light images are added together to obtain a

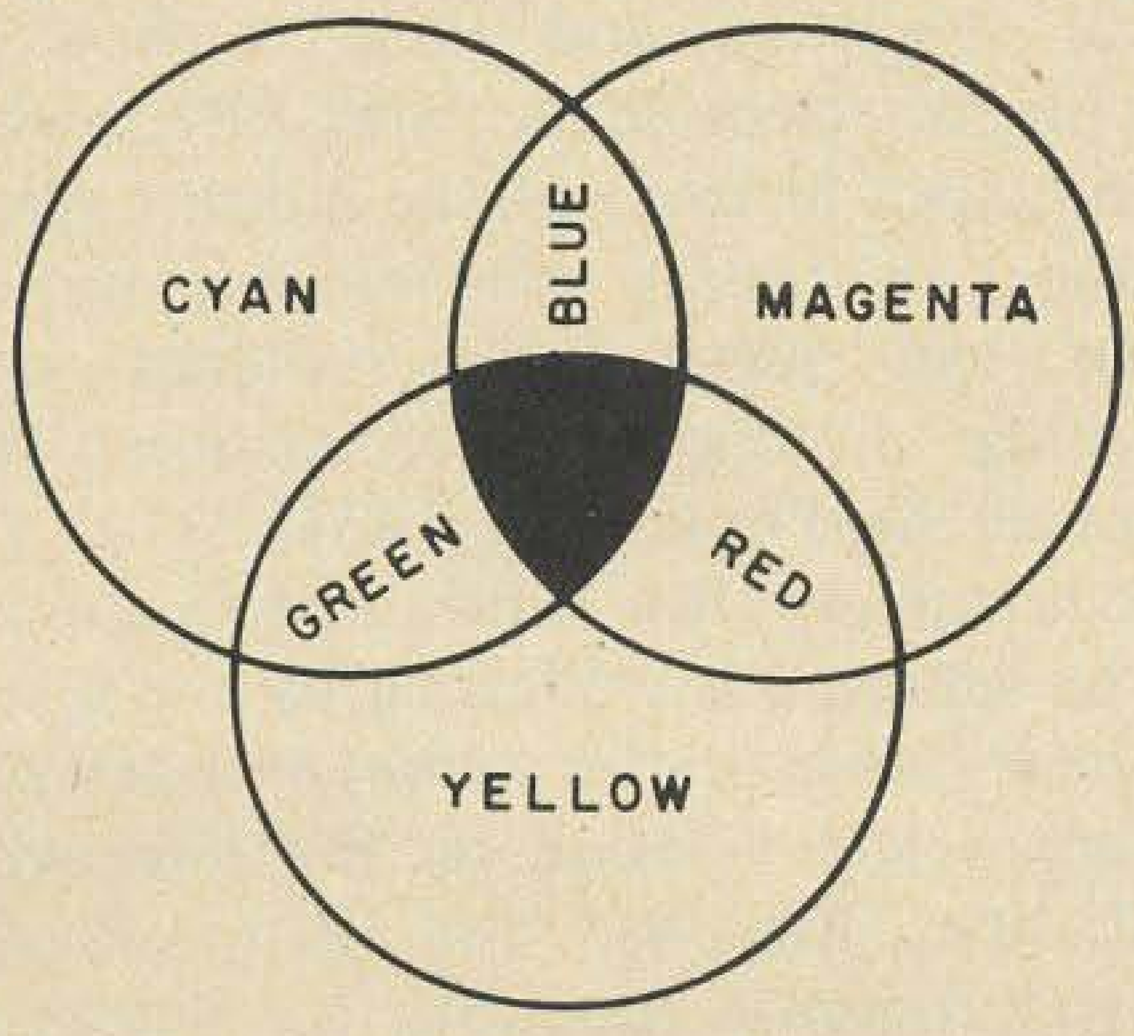


Fig. 2. Color mixture by subtraction.

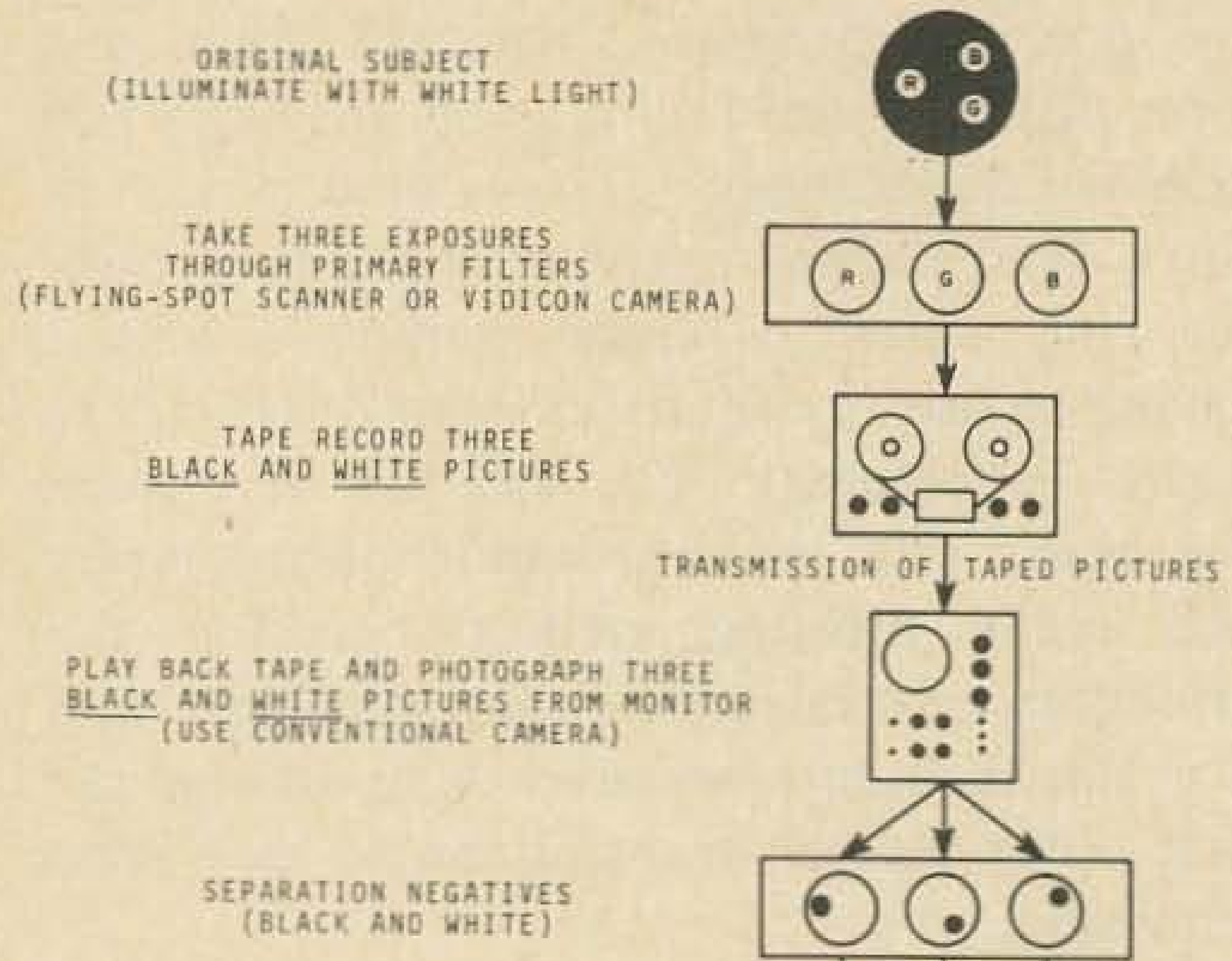
suitable mixture. This process is illustrated in Fig. 1, where white-light sources are projected onto a screen through three primary color filters. Besides the areas where the primary colors are observed, and where all three colors are superimposed (white), three additional colors are observed. These are: cyan, (white light minus red); magenta (white light minus green); and yellow (white light minus blue). This suggests that color mixing may be performed using the colors of cyan, magenta, and yellow; that is, by subtractive mixing.

Fig. 2 shows a subtractive mixture of colors produced by projecting a single white light source through an overlapping set of staggered subtractive filters (i. e., cyan, magenta, and yellow filters). Besides the three subtractive colors observed on the screen, we can see areas of red, green, and blue. Where all three subtractive filters overlap, no light (black) is projected. Thus in Maxwell's experiment, let us dye the positive silver image prepared from the red filter separation negative cyan. Similarly let us dye the positives prepared from the green and blue filter-separation negatives magenta and yellow, respectively. If we now place all three dyed transparencies in the same projector, we obtain a color picture (without having to use any filters in front of the white light projector) by *subtractive color synthesis*. Our present color photography and color printing methods employ the principles of subtractive color synthesis, and it is this technique we used to synthesize the first color picture transmitted by slow-scan television.

Method

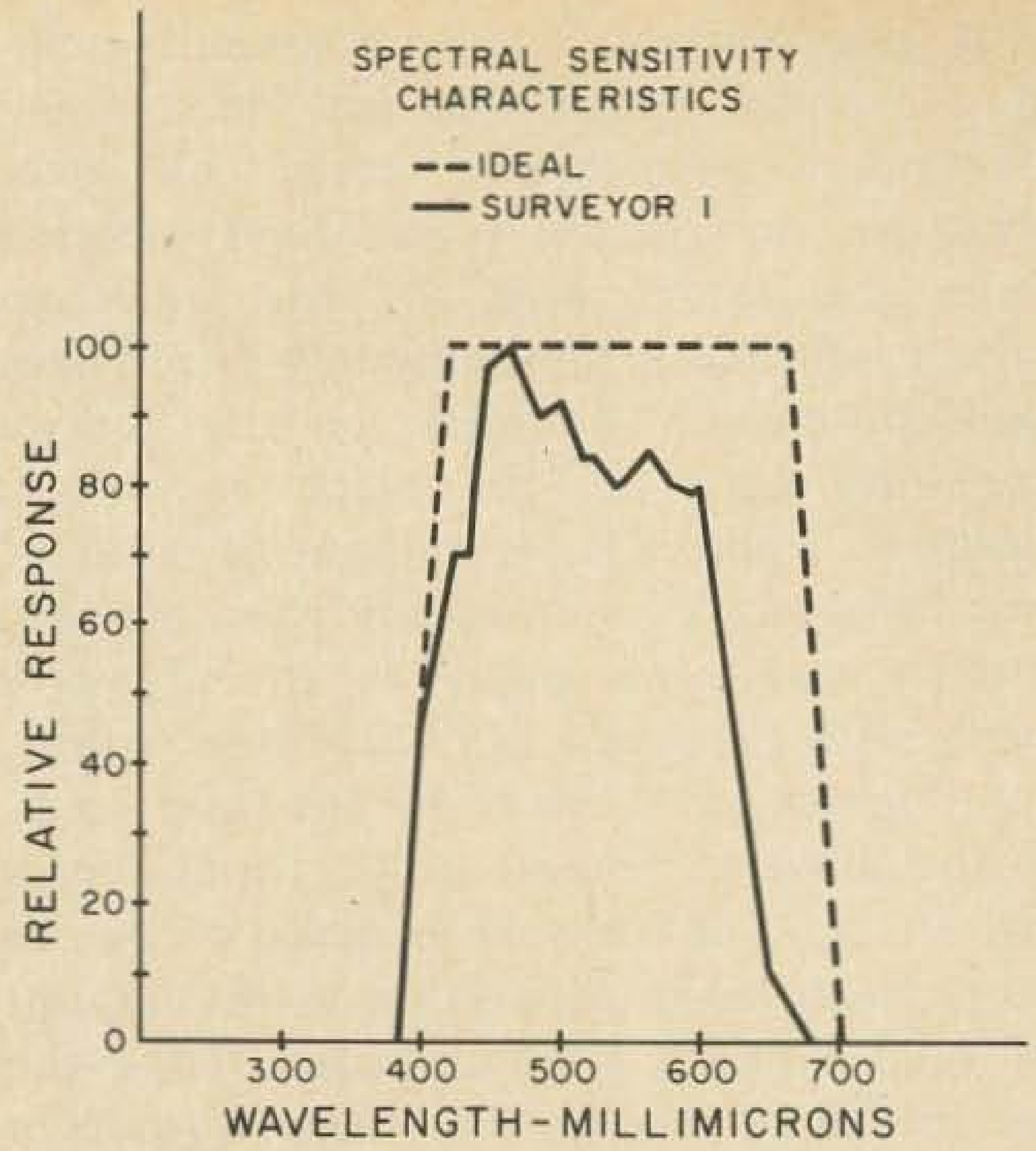
The general method employed to analyze and synthesize the slow-scan color television picture is shown diagrammatically in Fig. 3. The subject here, a black circle containing red (R), green (G), and blue (B) circles, is first illuminated with white light. The subject is then viewed (in sequence) through red, green, and blue filters by an SSTV flying-spot scanner or vidicon camera, and the three black and white pictures obtained – which might be called the separation pictures – are recorded on a conventional audio tape recorder. Once taped, the pictures may be transmitted over the air or on the telephone lines; the tape can also be forwarded through the mail. Whatever the means of transmission, the pictures are eventually played back at the receiving end, whereupon three black and white photographs, corresponding to the three separation pictures, are taken of the monitor's display. Note that no filters are required at the receiving station; the three black and white pictures transmitted already contain the necessary tricolor separation information.

Once the monitor's output has been photographed using a conventional camera (time exposures are taken of the three separation pictues), the film is developed. This yields a set of separation negatives from which are prepared three positive prints. Halftone negatives are now made from the three positives, and these negatives processed using the Color-Key printing technique. If the three processed Color-Key films are now superimposed on a white background, the resulting color image is a reproduction of the originally televised color subject.



*COLOR-KEY IS A 3M CO. PROOFING SYSTEM

Fig. 3. Color reproduction by means of color analysis and synthesis. This was the method used by W4UMF and Mr. Tarr to reproduce the first color picture transmitted by amateur SSTV.



MODIFIED AFTER: SURVEYOR I: PRELIMINARY RESULTS, SURVEYOR SCIENTIFIC AND EVALUATION AND ANALYSIS TEAM, SCIENCE, VOL. 152, 24 JUNE 1966.

Fig. 4. The ideal total-system response for color analysis work. This response is shaped, using single-color filters, to produce a response which matches the standard color-matching functions. The total-system response for the camera aboard Surveyor 1 is shown for comparison.

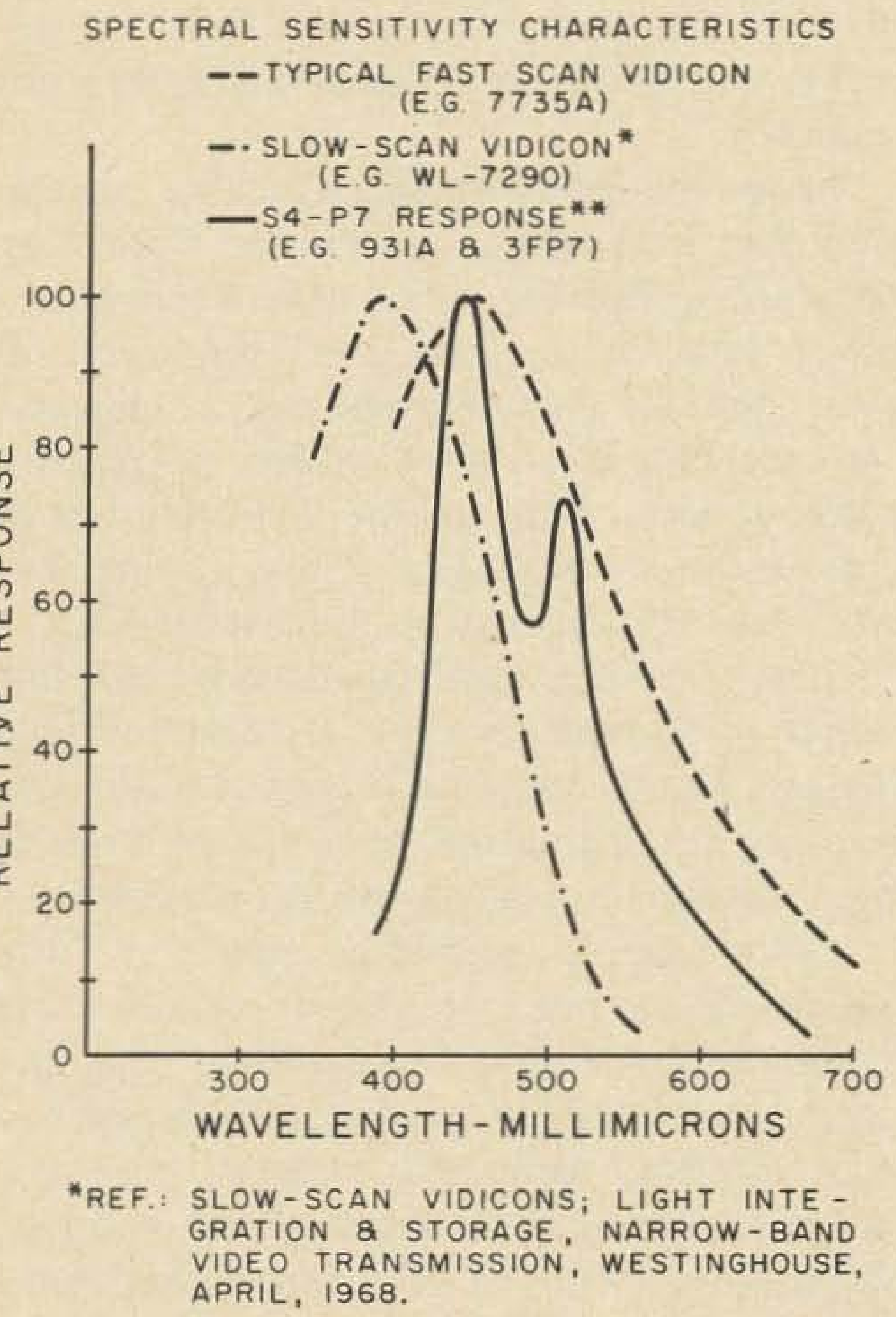
Having outlined the basic principles of color analysis and synthesis, and the application of these principles to the transmission of color pictues by slow-scan television, let us now turn in detail to the techniques employed.

Color Analysis

Ideally, one would wish that the response of his television system be similar to that shown by the dashed line in Fig. 4. The response is seen to be flat over the entire visible spectrum, and thus, it should be possible to select single-color filters which, when placed in front of the imaging system, produce an overall camera-filter response which can match the standard color-matching functions (Commission Internationale de l'Eclairage, 1931). That total system response functions close to the ideal can be achieved is evidenced by the spectral response curve of the Surveyor 1 television cameras (clear position on the filter wheel, solid line, Fig. 4). Overall camera-filter spectral response functions for Surveyor 1 can be found in the report of the Surveyor

Scientific Evaluation and Analysis Team (1966), and for Surveyor 3 in Shoemaker, et al. (1968).

As television cameras with "ideal" spectral response curves (like those of the Surveyor cameras) are necessarily expensive, we should not be surprised that the imaging systems employed by amateurs use tubes with response curves far from the ideal. **Fig. 5** shows the response curves for three classes of imaging systems used in amateur slow-scan television work. Flying-spot scanners (e. g., see Hutton, 1967) typically use 931A photomultiplier tubes (S4 response) together with a P4 or P7 CRT raster source. Slow-scan vidicon cameras, on the other hand, generally employ image tubes like the Westinghouse WL-7290. Only recently, Taggart (1968) and Hutton (1969) have demonstrated the use of conventional fast-



*REF.: SLOW-SCAN VIDICONS; LIGHT INTEGRATION & STORAGE, NARROW-BAND VIDEO TRANSMISSION, WESTINGHOUSE, APRIL, 1968.

**REF.: AVERAGE RESPONSE; S4 SENSITIVITY (2870° K TUNGSTEN SOURCE) TIMES AVERAGE P7 SPECTRAL-EMISSION CHARACTERISTIC, RCA HB-3 TUBE MANUAL.

Fig. 5. Three classes of image-tube response used in amateur SSTV systems. The response of a conventional vidicon is preferred for color analysis work, followed by the response for an S4-P7 flying-spot scanning system.

scan vidicons (e. g., 6326, 7038, 7735A, etc.) in the slow-scan mode. Thus, we essentially have three classes of image-tube response to choose between. Of these, the conventional vidicon's response is superior, followed by the spectral response of the S4-P7 flying-spot scanning system. The slow-scan vidicon, however, peaks in the violet, and experiments at W4UMF have shown that its extremely low output in the red (visible wavelengths greater than 610 millimicrons) eliminates it as a possible image pick-up device for direct color separation work.

Robert Tschannen's (W9LUO) dual-931A flying-spot scanner was used for the color analysis phase. This scanner, similar to that described by Hutton (1967), employs a 15 hz horizontal frequency and an 8-second frame period (120 lines). The total-system spectrum response function was shaped for color separation by inserting red (Wratten No. 25) and blue (Wratten No. 47) filters in front of the photomultiplier tubes. No filters were used in producing the green separation picture. While the green separation picture therefore contained, in reality, blue-green information, this color bias was compensated for in the production of the Color-Key print.

The subject chosen for the initial color separation tests is shown on the cover, bottom left. Anyone who has ever tuned a color TV set or viewed a color slide can attest to the fact that the faithful reproduction of skin tones is essential to good color imaging. Thus, it was felt that a subject such as that chosen would provide a good test of the techniques to be employed.

To correct for the non-uniform spectral response of the system, the following procedure was used in preparing each of the separation pictures. With a given set of color filters in place (or no filters, in the case of the green picture), a white card was substituted for the subject picture, and the phototube outputs set to a predetermined level. This level, which was the same for all three white-card separation pictures, was sufficiently high to produce a white picture on the slow-scan monitor. Following equalization of phototube outputs, the subject picture was placed in the scanner, and 8 separation-picture frames were recorded on magnetic tape. Every effort was made to replace the subject picture in the same position following each equalization adjustment; an attempt was also made to maintain a common size for the scanning raster. The necessity of alternately changing picture and card for primary output adjustment could account for some of the misregistration seen in the synthesized picture. It is to be noted that slight defocusing did occur on the red separation picture. This is a result of having to drive the raster source CRT quite hard before obtaining the desired output equivalence.

The recorded pictures were mailed to W4UMF for color processing. The question of whether these pictures should have been transmitted by SSB on 20 meters, via the phone lines, or by tape through the mail is purely academic; tests conducted during the past two years have proven all three transmission modes capable of yielding high-quality SSTV pictures.

Color Synthesis

To produce the required separation negatives, the taped separation pictures were played back through a 3" monitor, and photographed on black and white 35mm film. The camera used was a Bell and Howell-Canon single-lens reflex with a 35mm f/1.8 lens. A close-up lens was also attached. The camera was tripod mounted, and a remote shutter trigger employed to minimize changes in the camera's position. While small lateral and vertical changes in the camera's position can be corrected for in printing the Color-Key picture, changes in the distance between the camera and monitor will produce variations in picture magnification. Such variations in image size are difficult to compensate for, and can result in significant color fringing.

Use of 35mm film necessarily required that the separation negatives be enlarged prior to printing. This suggested that fine-grain film be employed. The film chosen was Kodak Panatomic-X.

The Panatomic-X film has an ASA rating of 32. Because of this rating, and the low light level of the CRT flying spot, it was necessary to experiment with aperture settings. Aperture settings of 1.8, 2.8, 4 and 5.6 were used in obtaining the 3-picture sets.* All pictures taken were 8-second (one frame) time exposures. The black background of the original subject was used as a guide for proper adjustment of the monitor. That is, the brightness for each picture was set such that the CRT beam was just extinguished in the black portion of each frame.

The exposed film was processed in accordance with the film manufacturer's specifications. This not only assured us of obtaining proper silver densities in the negatives, but should also permit duplication of the results obtained to within narrow limits.

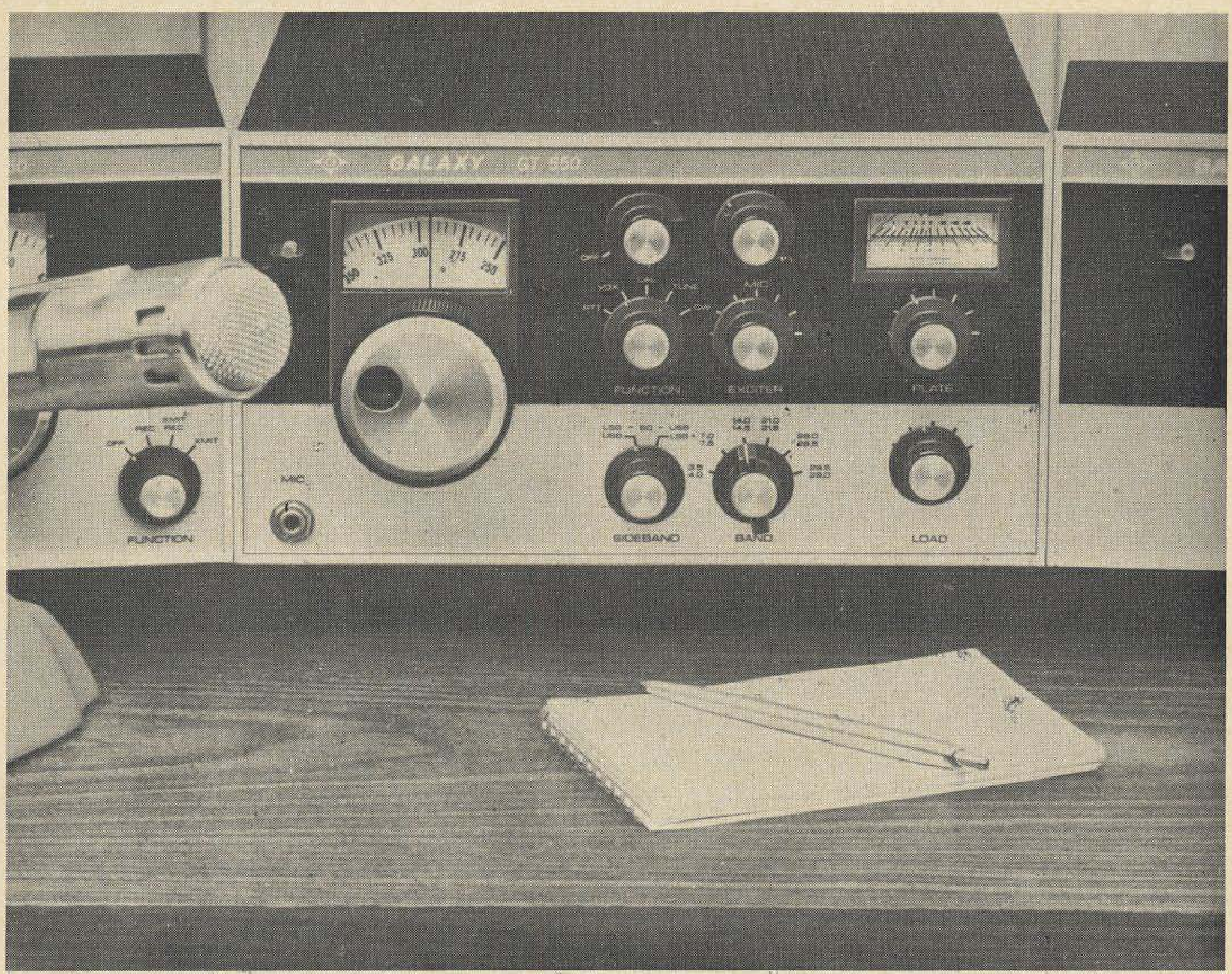
The 35mm separation negatives photographed from the monitor were quite contrasty. This was due in large part to the lack of tonal gradation in the pictures displayed on the monitor. As the P7 cathode-ray tube is capable of reproducing only 4 or 5 shades of gray, some tonal adjustments had to be made in the synthesis process. These adjustments will be discussed in detail later in this section.

From the 3-picture sets available, separation negatives were chosen for Color-Key processing. The choice of negatives was not too critical, as one can exert some control over picture characteristics (i. e. density, contrast, etc.) in a separable subtractive color process such as the dye transfer or Color-Key process. The white flaring was introduced in the analysis process (glare).

The Color-Key method for color printing was used to synthesize the tricolor-analyzed picture. For a complete survey of Color-Key printing the interested reader is referred to the literature on color printing processes.

Color-Key is primarily used by lithographers to produce proofs of separated negatives for multicolor printing. The process can be used by anyone with access to a high intensity lamp. In addition, materials are available in most areas of the country, which is not true of other processing mate-

*The monitor at W4UMF employs a 3RP7A CRT, with an accelerating voltage of 1600 volts. Most monitors use 3FP7A, or 5ABP7 CRT's, which generally employ accelerating voltages closer to 3100 volts. If tubes of the latter type are employed, and Panatomic-X film is used, it is suggested that stops between 2.8 and 8 be tried. If a film such as Plus-X is used with a high accelerating voltage CRT (~3100 volts), f/stops between 8 and 11 should produce good 8-second time exposures.



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rials investigated (e. g., dye tranfer materials). Color-Key is easily handled in subdued light and has a one-step developer which is applied with a cotton swab.

Because of its lack of tonal range, Color-Key must be exposed using a halftone or screened negative.

The Color-Key process uses three sheets of film, each dyed one of three colors: cyan, magenta, and yellow. The halftone negative for the complement of each Color-Key dye is exposed and developed separately. The resulting Color-Key positives are then aligned, one on top of the other. Viewing through the composite film *should* produce a color reproduction of the original color scene. We use the word "should" because of the problems encountered.

It was mentioned earlier that the negatives photographed from the monitor were of high contrast. As such, the glossy photographs were also without tone gradation, and thus, the halftone negatives had relatively little tone variation. The reason for this follows. Let us examine the synthesis process in detail. Consider that black and white picture on the monitor which had been analyzed through the red filter. The picture had white areas on the screen where the skin tone was on the original. As the skin tone (large percentage of yellow-red) would pass through a red filter, the face should have appeared light gray. The green area of the dress, composed of cyan and yellow, was not entirely passed by the red filter, and should have appeared dark gray on the screen. This area however, was displayed as black. This shift to higher contrast is a product of the monitor's CRT limited dynamic range. Thus, it was not possible to accurately reproduce the tones of the original picture. Similar statements apply to the green and blue separation pictures as observed on the monitor. As such, we were required to use some color correction to reproduce the tone values between white and black.

After all the Color-Key positives were made, it was determined that more magenta and yellow was needed to reproduce a realistic skin tone. Adding these colors would also make needed corrections in other areas of the picture to correct for the blue-green bias in the original SSTV separation pictures. Color-Key sheets containing dot patterns of 50% color value at 85 lines per inch were added. This corrected the color to within reasonable limits over the entire picture. No attempt was made to correct particular areas of the print; all areas were treated uniformly.

Results

The processed color print is shown on the cover, at the right. In judging the quality of the reproduction, we should be aware of the inherent resolution limitation (120 lines) of the slow-scan system, and the limited dynamic range of the monitor's CRT. To the extent that the Color-Key print approximates the color of the subject, however, we class the quality of the synthesized color print "fair."

Comments and Conclusions

In the case of the picture processed above, the original color photograph was available to be used as a guide in the synthesizing process. To eliminate the need for viewing the original color photograph during color synthesis, it is suggested that a small color-bar set be included in pictures to be analyzed. Upon synthesis, accurate reproduction of the color bars will insure proper color balance in the subject.

We have demonstrated the feasibility of transmitting color pictures by slow-scan television, using the method of color analysis and synthesis. In particular, picture reconstruction was performed using a separable subtractive color process – the Color-Key process. Though the color analysis phase of the test and the production of the separation negatives may seem heuristic in character to the critical experimentalist, the procedures described nevertheless do work. We would hope that more experimentation will be done using the Color-Key process as this process can produce excellent results given separation negatives of good tonal gradation.

That prints made using the Color-Key process are considerably more expensive than conventional color prints, and that an experienced amateur photographer is more apt to obtain the desired results when using this process, would seem to limit the application and use of the color transmission method described. However, given today's technology in quick-processing films (e. g., Polaroid Polacolor), and a continued experimental effort on the part of the amateur-photographer, it is expected that technically and economically more appealing synthesis techniques will be developed shortly for the color transmission by slow-scan television.

. . . W4UMF & Tarr

Acknowledgement

The assistance of Mr. Robert Tschannen, W9LUO, in preparing the separation SSTV pictures, is gratefully acknowledged. The authors further thank Mr. Tschannen for many stimulating discussions on color separation, and for his critical reading of the manuscript. The authors also thank Mr. Charles Cowden, K6BL/4, and Capt. David Veazey, W4ABY, for providing 20 meter liaison communications between W9LUO and the authors.

Mention of trade or brand names is solely for identification and does not imply endorsement of products mentioned, nor does it imply nonendorsement of unnamed products.

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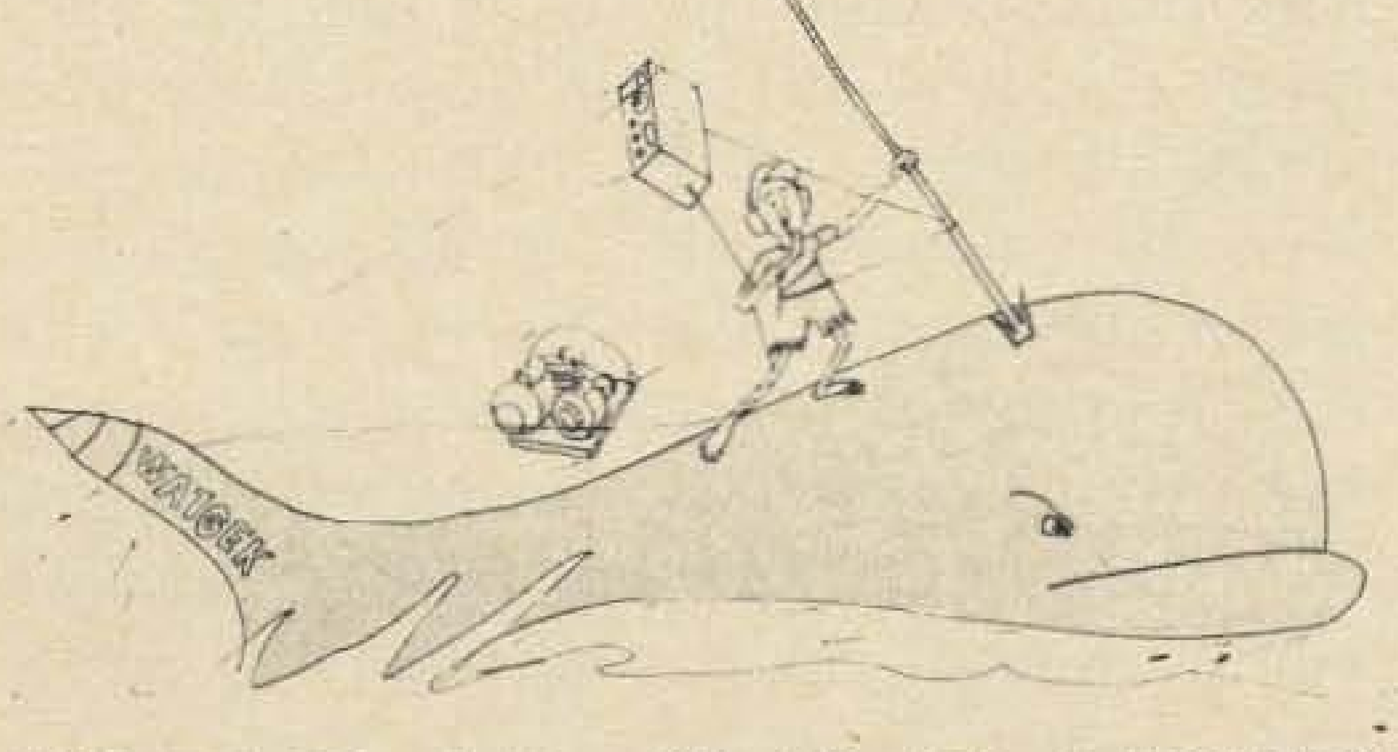

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