A Proposed Computer-Controlled Digital HDTV Chroma-key System

By Z. Misawa, K. Nakashima, T. Iwamoto, and S. Shimoda

Picture quality utilizing the soft chroma-key method is influenced by the degradation on the edge area between the foreground image and the background image. A new technique is proposed to subtract chroma-key blue while considering the distribution of chrominance on the edge area. A new high-definition television (HDTV) digital chroma-key system using this method is described.

Chroma key is an image-composition method that was introduced early on and subsequently improved in many ways. In 1978 a soft chroma-key method developed by NHK, among others, was at that time a very innovative approach to NTSC signal composition. Since then, manufacturers have marketed various types of video image composing machines using this method. One example is the Ultimatte Composer, introduced by Ultimatte Corp. in the U.S., a chroma-key system that uses multiple nonadditive mixing (NAM) circuits, instead of the addition/subtraction of RGB signals, for the generation of a key signal. HDTV chroma-key systems have utilized these techniques.

Discussed in this paper is a digital chroma-key system that is based on the soft chroma-key experience but adopts new ideas to realize an advanced image composing technique suitable for HDTV.

Presented at the 1994 SMPTE Advanced Television and Electronic Imaging Conference in Chicago (paper no. 28-4) on February 4, 1994. T. Iwamoto (who read the paper), Z. Misawa, K. Nakashima, and S. Shimoda are with NHK (Japan Broadcasting Corp.) Development Center, Tokyo, Japan 150-01.

Soft Chroma-key Principles

As shown in Fig. 1, the chroma-key effect before the advent of the soft chroma-key method had been generated by the key signal being put through a color-selection circuit and then through a slicing circuit. This method, however, is liable to compose the object in the foreground with the background in a clear-cut contour. It makes it impossible to compose images of translucent materials or those of objects optically dissolving, such as objects out of focus.

Soft Key Signal

The soft chroma-key method has overcome this shortcoming in the following way. Figure 2 shows the circuit diagram of a soft chroma-key system. The chroma-key color selection circuit here chooses a color from the RGB signals of the object in the foreground to become a key signal (hereinafter referred to as the key color, with blue used in most cases). The circuit's output is directly proportional to the key color's saturation. If, for example, a glass is placed in front of the key color of blue, the blue at its periphery has a 100% saturation, while the blue passing through the glass may have a lower degree of saturation in accordance with the glass's transmittance, or it may be partially eliminated by refraction. The signal in proportion to the blue signal ratio is called the soft key signal. Since the background image may be considered to remain unchanged if a glass is actually in place, it is multiplied by the soft key signal to generate a natural background signal. (It should be noted, however, that image distortion by refraction cannot be reproduced.)

Erasing the Key Color

In this process the background image, multiplied by the soft key signal, is mixed with a foreground image. The foreground image, however, contains the key color (blue) and, if this is mixed unchanged with the background image, the key color will also be mixed in. Therefore, a key color erasing circuit eliminates the key color to turn the area into an achromatic color prior to composition.

A generally practiced method to eliminate the key color is to generate a false signal with a complementary color vector to the key color and

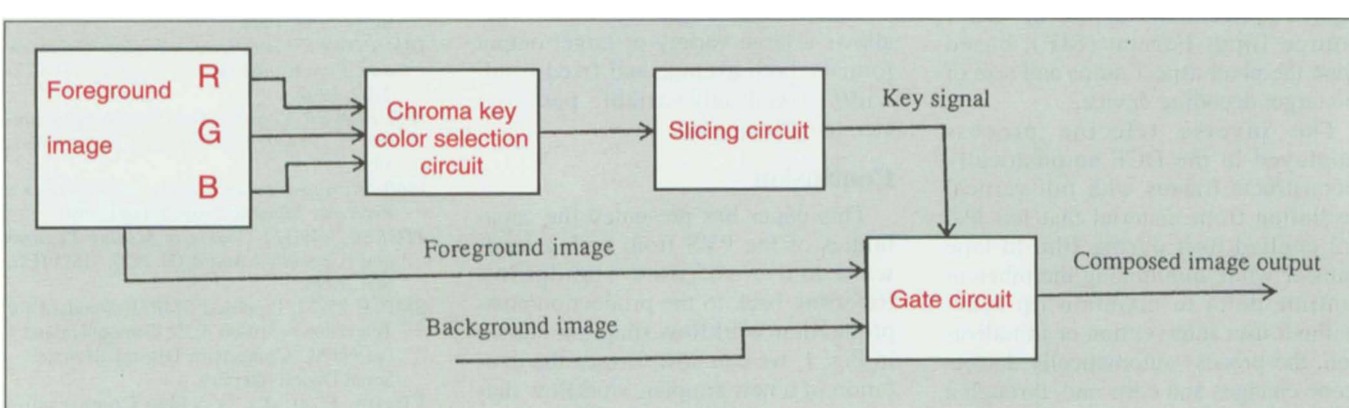

Figure 1. Block diagram of an early chroma-key system.

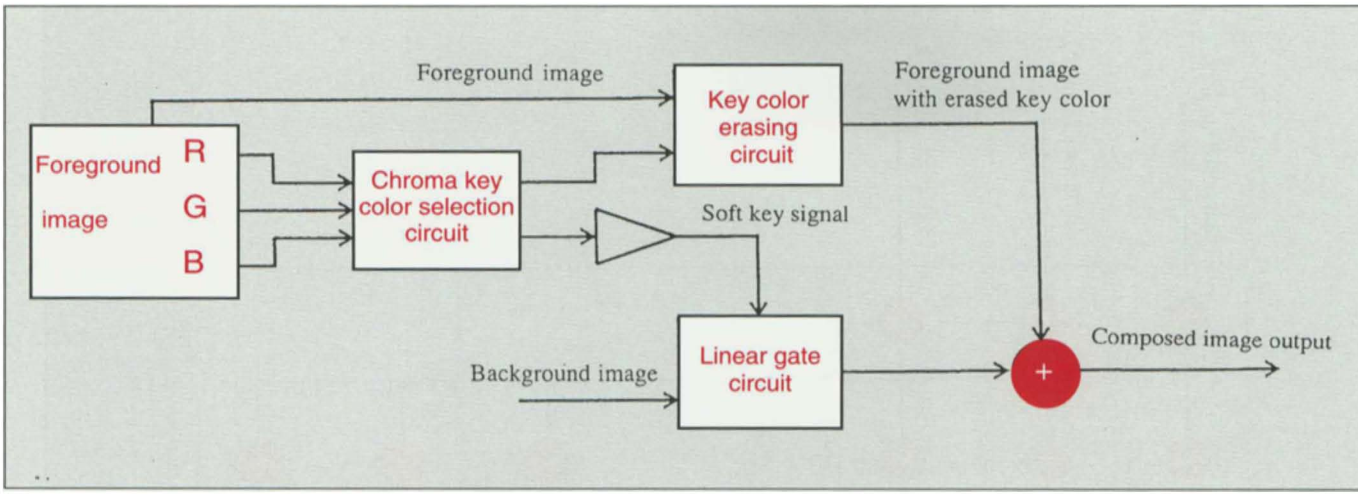

Figure 2. Block diagram of the soft chroma-key system.

compose it with the foreground image. Various other methods have also been contrived. Thus, the soft chroma-key method has facilitated the composition of images of translucent materials (i.e., smoke, etc.), a process that was virtually impossible previously.

Overview of HDTV Digital Chroma-key Method

The computer-controlled digital chroma-key method employs a newly developed key color erasing method to realize more natural composed images. It also uses a RAM-aided lookup table throughout its circuitry to offer greater processing freedom. To simplify the signal-processing work, this digital chroma-key method turns the foreground image into Y, Pb, Pr signals based on the BTA S-002 digital standards of HDTV, instead of into RGB signals. Figure 3 shows a block diagram of an HDTV digital chroma-key system, with each block described as follows.

Memory Circuitry

The memory circuitry has a color data sampling function to specify the necessary color for each part of the operation and a noise-reducing function to improve the key signal's signal-to-noise ratio (SNR).

Color Sampling

For color sampling, a necessary color is chosen at will from frozen data in the memory, using a freely moving cursor, and put in the central processing unit (CPU). The cursor size is variable and data in the cursor is averaged to reduce the effects of noise. This sampling process is used to take in key color data to generate the main key signal and color data to generate auxiliary key signals and those to be specified for color correction.

Noise Reduction

The SNR of a foreground image greatly affects the quality of images composed with the chroma-key method. This means that signals with high levels of noise must be processed to reduce the noise prior to obtaining a chroma-key signal. In Fig. 3, the output (P) is represented by the following formula:

$$P = (I - P_{-1})K + P_{-1}$$

where

I: Input signal

K: Multiplier taking a value between 0 and 1

P_{-1}: Frame memory output (1 frame delay)

When K is 1, the input is output unchanged and when it is zero, the picture is frozen. When 0<K<1, a noise-reduction effect is obtained in accordance with multiplier values. As shown in Fig. 4, actual multipliers have a threshold in accordance with interframe difference ($I-P_{-1}$). In areas where this difference is large (moving areas), the output is produced by a "through" mode, so that greater effects may result in small-difference stationary areas. K values, which provide conversion data for multiplication needed for the lookup table, are variable in 16 stages.

Key Generating Circuitry

The key generating circuitry consists of a RAM-assisted lookup table to generate key signals by converting data on the coordinates using Pb/Pr signals as addresses. The CPU performs data conversion at all points on the Pb/Pr coordinates using color data sampled from the memory circuitry. This process enables direct key signal generation using Pb/Pr signals as addresses. A key signal is classified into a main key signal and an auxiliary key signal, which overlap each other in CPU calculations for color elimination.

Main Key Signal

As shown in Fig. 5, the main key signal extends in a sectoral area with its center at the phase axis of a sampled key color point (indicated with x in the figure) on the Pb/Pr coordinates. This is a soft key signal whose level is zero at the origin and equivalent to the absolute value of the vector amount at point x (a, b). An angle, θ, is given as a variable for CPU operations and is adjustable from the control panel.

Auxiliary Key Signal

A defect of the soft chroma-key method is manifested when objects with the same color as the key color are composed. For example, an object with a mixture of a key color (in the current case, blue) and red (e.g., a red translucent glass or an image with the red color out of focus), will appear as magenta (Fig. 6). Since the main key signal is only proportional to the pure key color saturation but not proportional to a mixture with other colors, no key signal for the blue component is obtained. This has an adverse effect on the key color elimination process discussed below and produces an

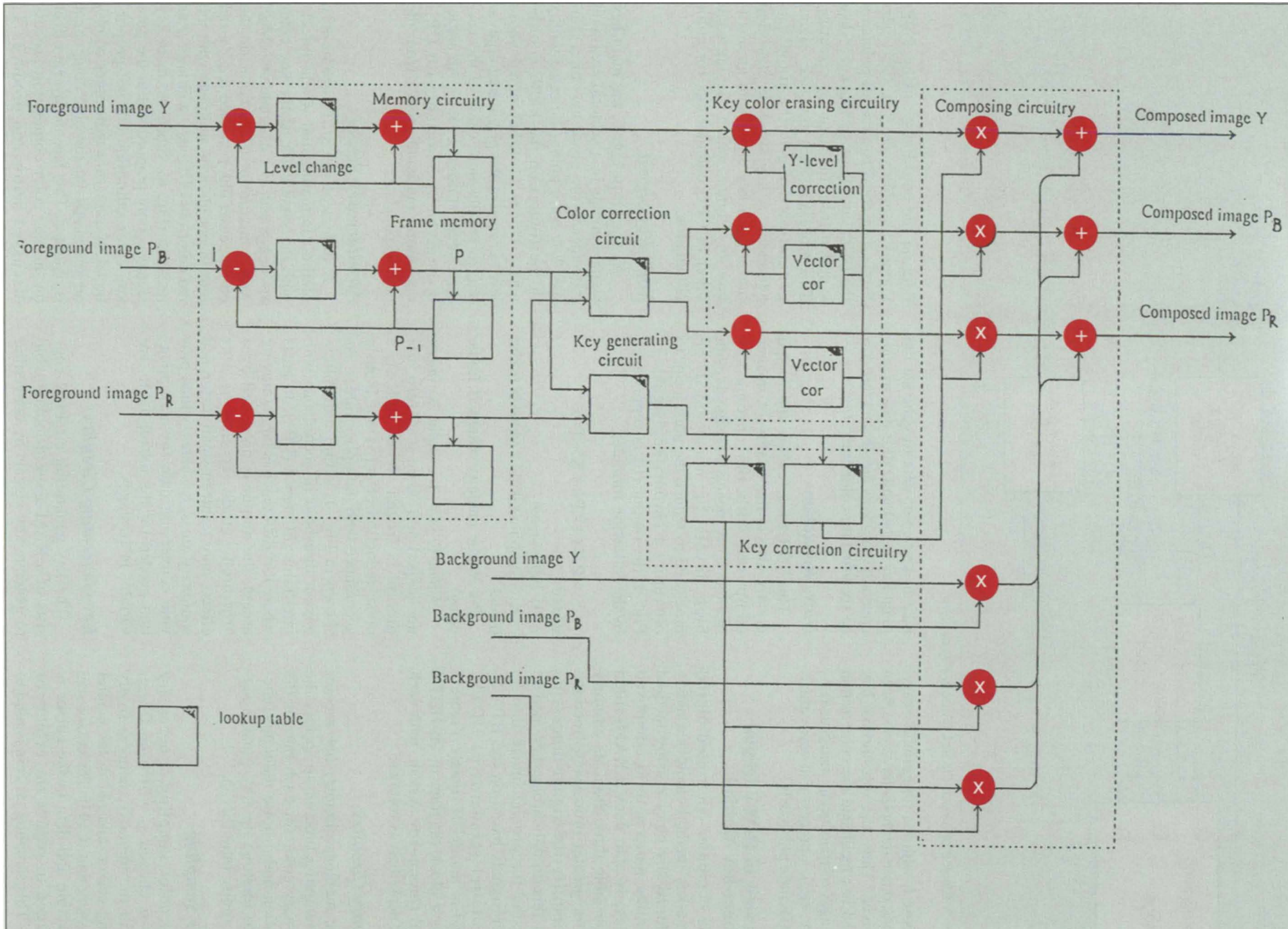

Figure 3. Block diagram of a computer-controlled digital chroma-key system.

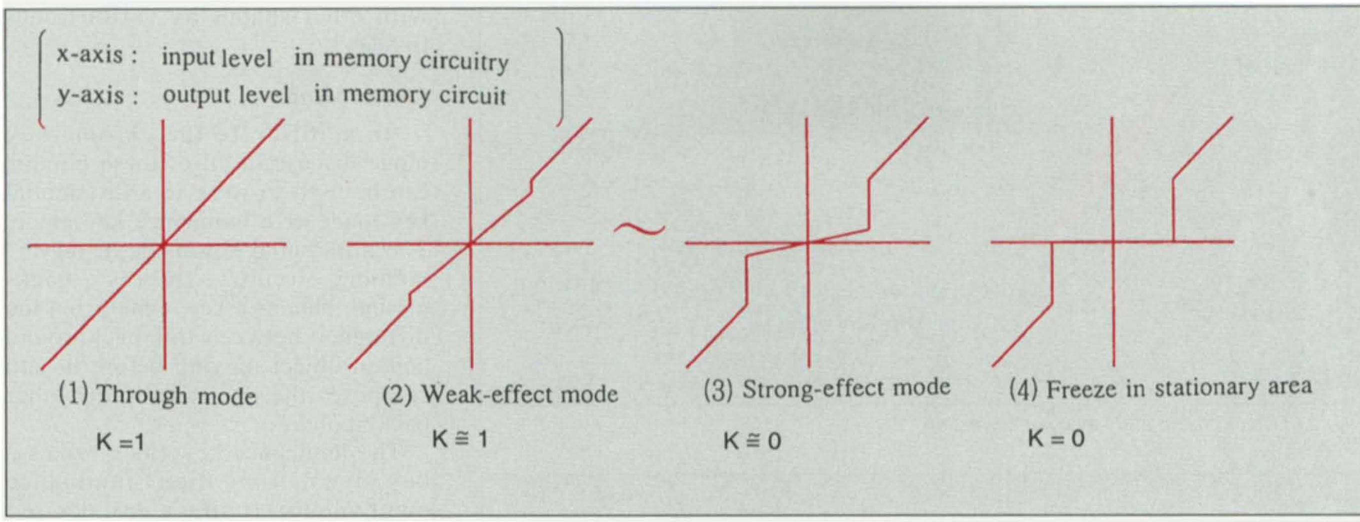

Figure 4. Operation modes for noise reduction.

obstacle to the composition of natural images.

In the auxiliary key signal, color is specified with an auxiliary mode, apart from a key color. As shown in Fig. 7, this enables the acquisition of a sectoral key signal with its origin at the color specified using the auxiliary mode and centered on a straight line to the key color (sample point). This is a soft key signal representing the blue component in a mixture of a key color and another color. The use of this for composition will result in a natural image, including an object in colors mixed with the key color.

After CPU operations, the auxiliary key signal is put through NAM operations, together with the result of main key operations, and both are written in a key-generating RAM as overlapped conversion data.

Key Color Erasing Circuitry

As discussed earlier, one shortcoming of the conventional soft chroma-key method is revealed in the composition of objects with the same color as a key color. In the example presented in Fig. 7, the area where red was mixed with the key color (blue) appeared as magenta. This color should not remain in the composed image. However, since the key color erasing circuit of a soft chroma-key system generates an erasing signal from soft key signals (main key signals in the current system), magenta remains present in composed images (Fig. 5).

Figure 7 shows a soft key signal generated by specifying the cursor as red with an auxiliary key mode. This auxiliary key signal represents its mixture ratio with other colors, and is overlapped with the main key signal to reduce the achromatic key color through vector correction. As shown in Fig. 8, the magenta produced by mixing is aligned on the straight line linking red and the origin by means of the vector (correction performed) parallel to the key color correction.

In the key color erasing circuit described here, soft key signals (in this instance, an overlap of the main key signal and the auxiliary key signal) are subtracted in accordance with Pb/Pr key color signal levels. In this example, the soft key signal is also subtracted from the key color's Y signal (brightness component) to turn the brightness component of the key color area into black. This circuit also uses a lookup table for changing soft key signal levels.

Composing Circuitry

This circuitry mixes a composed image whose key color has been erased with a background image. The circuitry comprises a level-change circuit to attain the key signal level necessary for composition, a multiplication circuit to "gate" each video signal, and an additional circuit to blend gated images. A lookup table is used for level changes. The key signal is converted into signals needed for respective image gates using conversion values calculated from key color data.

During chroma-key work, the conversion table for foreground images is fixed at 100% to output images with the erased key color unchanged. This is because chroma-key composition virtually replaces the key color area with a background image including dissolved elements, and because the foreground image already incorporates its dissolved elements when the key color is erased. The level change circuit is also used for waveform shaping when in modes other than for chroma-key work.

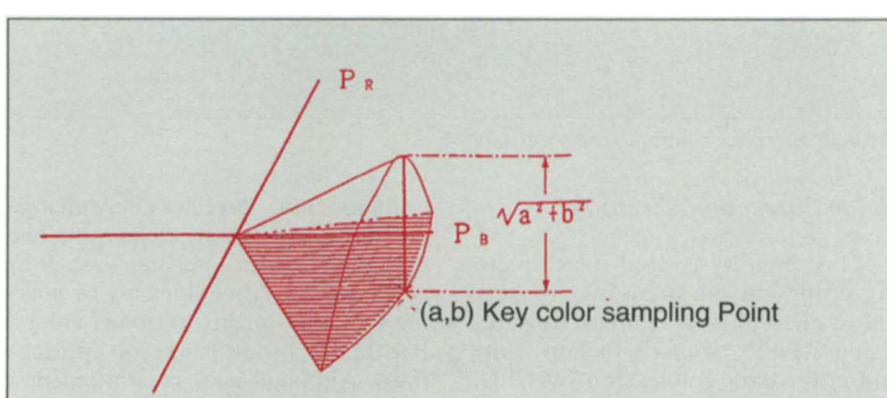

Figure 5. A soft key (main key) concept.

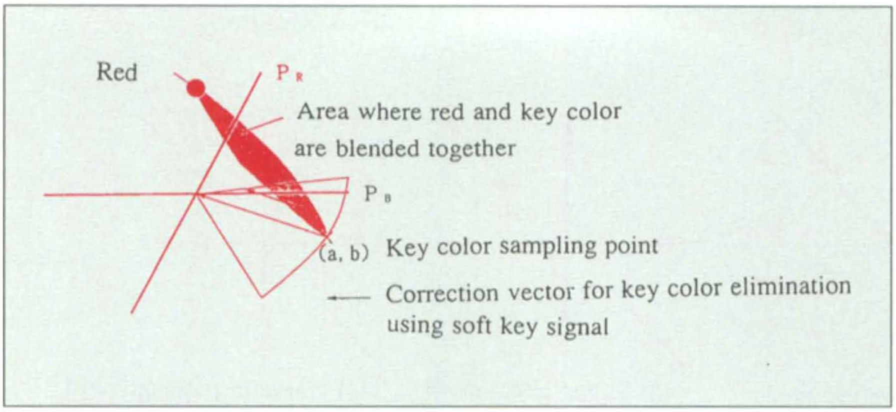

Figure 6. Color mixing and key color correction.

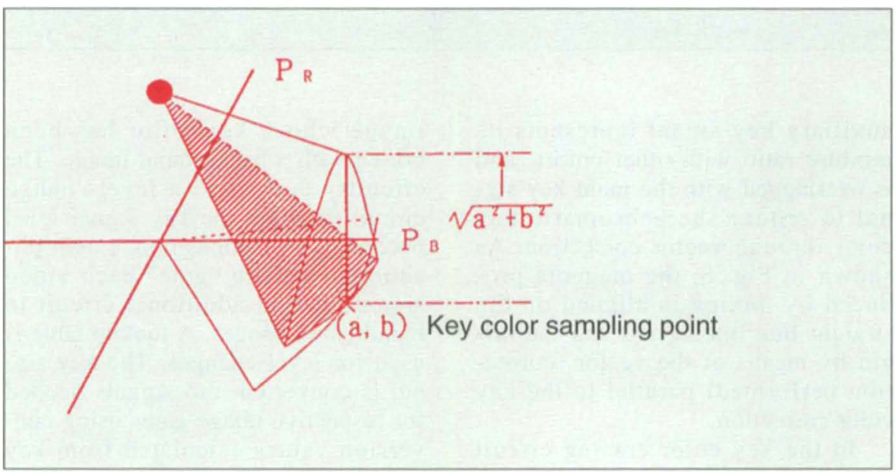

Figure 7. An auxiliary key concept.

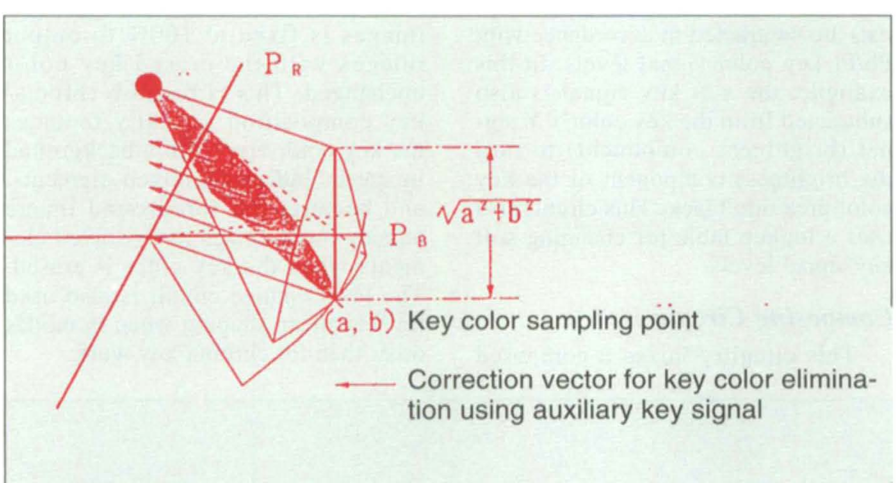

Figure 8. Key color correction using auxiliary key.

Color Correction Circuitry

This circuitry is used for correcting colors in the areas where key color elimination is insufficient. Using a Pb/Pr two-axis lookup table and color data conversion by CPU operations, the circuitry can correct colors in any given area. Although ordinary color correctors may change the entire color of an image, this one is capable of partial changes, such as adjusting the skin color only or making fine adjustments to flower colors. It offers a broad range of applications. Although hues are shifted in a sectoral area in the current example, colors can also be corrected in areas with other shapes by various contrivances.

Other Modes

In addition to the chroma-key mode discussed, all of these circuits can be used to work in a differential key mode or a luminance key mode. The differential key mode, using the memory circuitry, freezes a background, obtains a key signal from the difference between this background and an object moving before it, and composes the object with any other background.

The luminance key mode makes a key signal from sliced luminance components. It slices any desired level using a level change table of the said composing circuitry.

The system described also includes masking circuitry, which is used for key masking in the chroma-key and other modes.

Conclusion

Ever since the introduction of the soft chroma-key method, both digital and analog chroma-key composers have been developed. The analog Ultimatte system mentioned earlier is one such example. On the other hand, recent developments in digital image processing technology have enabled sophisticated image editing processes using multiple composed images. This trend, however, is accompanied by the problem of image-quality deterioration due to repeated dubbing.

The Ultimatte system was also frequently used at NHK for HDTV composition work. Since the completion in April 1993 of an HDTV digital editing room, which eliminates concerns about image deterioration, production personnel at NHK have envisaged a computer-controlled digital chroma-key system that also can handle objects having the same color as the key color. Although various composing methods other than chroma-key have been introduced, this system is the most popular among broadcasters.

The chroma-key system proposed by the authors will eliminate the myriad defects of conventional systems. It will not only ensure adequate high picture quality for HDTV programs but will also prepare the way for possible further improvements to the system, which is designed to utilize multiple lookup tables.