Abstract
We have developed an HDTV that adopts semiconductor lasers involving three primary colors, red, green and blue for the light source. The adoption of a laser light source helped us realize a HDTV with a dramatically wide color gamut, namely 190% the color gamut of ITR-U BT.709. In addition, we have also developed an LSI that can deal with an extended color space xvYCC, which is a new international standard, and mounted the LSI in the HDTV. The display of colorful and natural video pictures has been achieved through the effective use of the wide color gamut involved in the laser light source supported by a video signal processing circuit that complies with the xvYCC standard and Natural Color Matrix, a color management technique.

1. Introduction
Seven years have passed since the International Electrotechnical Commission (IEC) announced that sRGB would be the color space standard for multimedia in 1999 [1]. However, a number of colors exist that cannot be expressed by sRGB because sRGB was defined on the basis of the performance of the CRT monitors of those days. Today we can use a much more advanced definition of an extended color space, which enables us to express colors not covered by sRGB. One extended color spaces is sYCC, which is an extended color space that can deal with still pictures, and is widely adopted in digital still cameras [2]. In this situation, we started working on the development of a wide color gamut monitor some years ago, and have developed a wide-color gamut three-primary color LED-backlit LCD monitor that adopts LED as the light source for backlighting and a wide-color gamut six-primary color LED-backlit LCD monitor. For these wide-color gamut LCD monitors, a color gamut was designed for soft the proofing of desktop publishing [3, 4].

On the other hand, a study of an extended color space for moving pictures was organized by the IEC, and xvYCC was published as an international standard (IEC 61966-2-4) in January 2006 [5].

In this paper we report the development of a 52-inch HDTV that adopts semiconductor lasers with three primary colors as the light source which works in the xvYCC standard extended color space for moving pictures. Although a laser light source can drastically expand the color gamut, it may offer unnatural images such as only deep colors over the whole frame if proper color management is not carried out. Hence, we used Natural Color Matrix (NCM), which is our proprietary color management technique, made to be parallel to the xvYCC standard, and succeeded in displaying colorful and natural moving pictures.

2. Extended color space for moving pictures: xvYCC
The xvYCC standard is an extended color space for moving pictures that is downward compatible with ITR-U BT.709 [6] which underlies the HDTV specifications. The BT.709 converts the gamut from the RGB color space to a YCC color space (Y', Cb', Cr') using Equation (1). Since the scope of R', G' and B' covered by BT.709 is between the values of 0 and 1.0, only the inside space of the cube shown in Figure 1 is defined even in the YCC space of BT.709.

\[
\begin{bmatrix}
Y' \\
Cb' \\
Cr'
\end{bmatrix} = \begin{bmatrix}
0.2126 & 0.7152 & 0.0722 \\
-0.1146 & -0.3854 & 0.5000 \\
0.5000 & -0.4542 & -0.0458
\end{bmatrix} \begin{bmatrix}
R' \\
G' \\
B'
\end{bmatrix}
\]  

(1)

On the other hand, the xvYCC standard is defined so that RGB signal with negative values and values of 1.0 or greater can be used. Figure 2 shows the extended region of xvYCC on the Y'-Cr' plane of the YCC color space shown in Figure 1. As seen in the diagrams, the use of a value of 1.0 or higher for RGB signals expresses bright, brilliant colors while the use of negative RGB signal values expresses dark, deep colors.

In xvYCC, definition is established as indicated by Equations (2) and (3) for gamma characteristics for those extended regions and n-bit quantization. In a case of 8-bit quantization, this is extended so that users can use 1 to 16 and 240 to 254 of Cb' and Cr', which were not available in BT.709. As it is evident from these equations, it is completely downward compatible with BT.709 in the range of RGB signals of 0 to 1.0.

![Color space for ITR-U BT.709](image)

Figure 1

Color space for ITR-U BT.709
A laser HDTV has been developed on the basis of 52-inch projection television (PTV). Table 1 lists the specifications of our developed laser HDTV. The actual values of measured wavelength issued by the laser of three primary colors used for the light source are around 635 nm, 532 nm and 465 nm, and the optical power is 6 W for each color. With this laser light source, we could achieve the luminance of 500 cd/m² and a 190% color gamut in the area ratio compared to BT.709 on the 52-inch screen.

Figure 3 shows a comparison of the currently developed laser HDTV, the three-primary color LED-backlit LCD monitor developed in 2003 and the color gamut defined by BT.709. Each of the primary color points of the laser HDTV is in contact with the spectral locus of the CIE xy chromaticity diagram, and it has a wider color gamut than the three primary colors, LED backlit LCD monitor.

### Table 1 Specifications of laser HDTV

<table>
<thead>
<tr>
<th>Specifications</th>
<th>Color Point</th>
<th>x</th>
<th>y</th>
</tr>
</thead>
<tbody>
<tr>
<td>Screen size</td>
<td>R</td>
<td>0.713</td>
<td>0.287</td>
</tr>
<tr>
<td>Brightness</td>
<td>G</td>
<td>0.175</td>
<td>0.793</td>
</tr>
<tr>
<td>Color gamut</td>
<td>B</td>
<td>0.135</td>
<td>0.042</td>
</tr>
<tr>
<td>(vs BT.709)</td>
<td></td>
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</tbody>
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### 3.2 Structure of laser HDTV

Figure 4 shows the structure of our new laser HDTV. In order to make the most of its wide color gamut, we have also developed an LSI that complies with the xvYCC standard. The signal processing circuit of this LSI is structured so that the negative and 1.0 or higher RGB signals involved in the video signals that correspond to the xvYCC standard will not be clipped. The combination of this new LSI, the light source timing control circuit and the micro device (MD) drive circuit which drives the light source enable the display of video pictures that correspond to xvYCC.

After passing through the optical fiber, the laser beam of the three primary colors is introduced into the light pipe, and then it is brought to the MD via a lenses and mirrors. The light is modulated by MD and passes through the projection lens and displays video pictures on the screen. A conventional PTV uses a color wheel to achieve field sequential color, but direct control of the illumination timing of three-primary color laser beam eliminates the color wheel. Further, the layout of the light source is very versatile due to the flexibility of optical fibers, which can also contribute to the thinner construction of the display unit.

Figure 5 is a photograph of a HDTV image displayed on the laser HDTV which we have developed. Its colors, such as the red of the dress, the cyan and emerald green of the sea and the green of the tree leaves are vividly displayed, satisfactorily offering impactive video pictures.

The use of laser light source enables the reproduction of a dramatically wide color gamut. However, displaying the input video signals simply on a laser HDTV screen will result in an unnatural video picture in which all colors are deep. Certain video pictures composed of flamboyant colors may be agreeable to viewers, but subtle colors will cause some problems. Therefore, we used NCM, our proprietary color management technique, which corresponds to the xvYCC standard, to control the colors, and succeeded in displaying colorful and agreeable video pictures.
3.3  \textit{xvYCC}-compatible signal processing

Figure 6 shows the structure of the LSI corresponding to the currently developed \textit{xvYCC} standard. The \textit{YCC} signals, or the input signals, are converted into RGB signals, having negative and 1.0 or higher values by the matrix computation of Equation (1) in the color space conversion circuit. After the color space conversion, the image signal process processes images so that their values are not clipped. The \textit{NCM} performs color management to avoid unnatural colors, and it also maps RGB signals having negative and 1.0 or higher values to RGB signals with positive values.

Figure 7 is a block diagram of the \textit{NCM} corresponding to the \textit{xvYCC} standard. The RGB signals with negative values are separated into chromatic color signals and achromatic color signals, where the chromatic color signals are then separated into data of six hue regions, red, green, blue, cyan, magenta and yellow and data of six inter-hue regions positioned between these hues, and then color control is executed in each region. As shown in Figure 6, the negative values of RGB indicate the complementary color to each color, and therefore, it is possible to carry out color separation properly and to control colors by \textit{NCM}. In addition to color separation, this \textit{NCM} also detects pixel properties and maps RGB signals by controlling the matrix computation.

4. Result of measurement

4.1 Measurement of color patches

In order to check the color reproduction of video signals that correspond to the \textit{xvYCC} standard, 12 color patches were created and their chromaticity was measured. The color patches were of six colors, red, green, blue, cyan, magenta and yellow positioned inside the color gamut of BT.709 and the six colors were also positioned outside of the color gamut of BT.709. Minolta’s CS-1000 was used for measurement. Figures 8 and 9 show the measurement results of color patches, where \textit{R1}, \textit{G1}, \textit{B1}, \textit{C1}, \textit{M1} and \textit{Y1} indicate the six colors inside the BT.709 color gamut and \textit{R2}, \textit{G2}, \textit{B2}, \textit{C2}, \textit{M2} and \textit{Y2} indicate the six colors outside the BT.709 color gamut. Since the newly developed LSI can switch between compliance with, and non-compliance with, the \textit{xvYCC} standard, each color patch was measured in the relevant conditions. Figure 8 shows the result of measurement of color patches in the case of compliance with the \textit{xvYCC} standard, and Figure 9 shows the result of measurement of color patches in the case of non-compliance with \textit{xvYCC}. Figure 8 reveals that \textit{R1}, \textit{G1}, \textit{B1}, \textit{C1}, \textit{M1} and \textit{Y1} are plotted inside the triangle of BT.709 color gamut and \textit{R2}, \textit{G2}, \textit{B2}, \textit{C2}, \textit{M2} and \textit{Y2} are plotted outside the triangle. Further, in Figure 9, the six colors inside the triangle are plotted in almost the same position as in Figure 8, while the six colors outside the BT.709 color gamut are clipped to the triangle of BT.709.

Due to the adoption of a laser light source and a signal processing circuit that corresponds to the \textit{xvYCC} standard, as mentioned above, it was confirmed possible to display the colors outside the color gamut of BT.709 when signals complying with the \textit{xvYCC} standard are supplied.
4.2 Measurement of natural pictures

Besides the above color patches, video signals were created according to the xvYCC standard using the image data of subjects photographed outside the BT.709 color gamut, and then their chromaticity was measured. Figure 10 shows the images used for measurement, the measurement points and the results of measurement. The diagram indicates that image “a” is plotted a little outside the triangle of BT.709 color gamut, and the other images are plotted in the region near to the edge of the triangle gamut provided by our laser HDTV.

Figure 10 Measurement of natural pictures

5. Conclusion

Through the adoption of a laser light source, we have developed a 52-inch HDTV with a wide color gamut, as large as 190% that of ITR-U BT.709. The use of a laser light source enables the reproduction of a dramatically wide color gamut, but can produce unnatural video pictures with all deep colors. We succeeded in displaying colorful and natural video pictures by correctly controlling colors by means of NCM. We have also developed a signal processing circuit, at the same time, that is compatible with the extended color space called xvYCC, which is a newly defined international standard. The signal processing circuit compatible with the extended color space xvYCC standard and the color management functions of NCM enabled the reproduction of the vivid colors of the xvYCC standard.

In the near future, after sufficient dissemination of moving pictures that correspond to the extended color space xvYCC, we will have more opportunities to enjoy video pictures having more impact.

7. References


