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YCbCr to RGB Considerations

Introduction

Many video ICs now generate 4:2:2 YCbCr video data. The YCbCr color space was developed as part of ITU-R BT.601 (formerly CCIR 601) during the development of a world-wide digital component video standard.

Some of these video ICs also generate digital RGB video data, using lookup tables to assist with the YCbCr to RGB conversion. By understanding the YCbCr to RGB conversion process, the lookup tables can be eliminated, resulting in a substantial cost savings.

This application note covers some of the considerations for converting the YCbCr data to RGB data without the use of lookup tables. The process basically consists of three steps:

1. 4:2:2 to 4:4:4 YCbCr Conversion
2. 4:4:4 YCbCr to RGB Conversion
3. Linear RGB Generation

Converting 4:2:2 to 4:4:4 YCbCr

Prior to converting YCbCr data to R´G´B´ data, the 4:2:2 YCbCr data must be converted to 4:4:4 YCbCr data. For the YCbCr to RGB conversion process, each Y sample must have a corresponding Cb and Cr sample.

Figure 1 illustrates the positioning of YCbCr samples for the 4:4:4 format. Each sample has a Y, a Cb, and a Cr value. Each sample is typically 8 bits (consumer applications) or 10 bits (professional editing applications) per component.

Figure 2 illustrates the positioning of YCbCr samples for the 4:2:2 format. For every two horizontal Y samples, there is one Cb and Cr sample. Each sample is typically 8 bits (consumer applications) or 10 bits (professional editing applications) per component.

The 4:2:2 to 4:4:4 conversion consists of generating interpolated Cb and Cr data for those Y samples that have no Cb and Cr data. Although complex interpolation filtering is specified in BT.601, most NTSC and PAL video decoder chips (such as the HMP8115) use simple linear interpolation. This is usually acceptable since the bandwidth of the color data is 0.6MHz-1.3MHz, rather than the 3.375MHz bandwidth specified by BT.601.

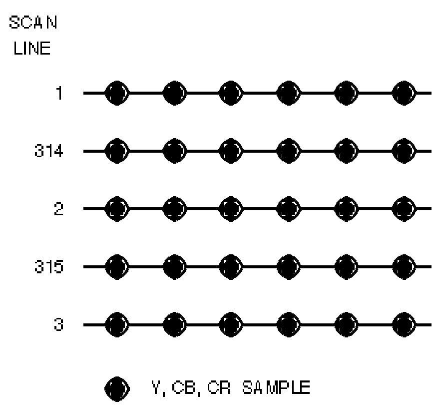

FIGURE 1. 4:4:4 YCbCr SAMPLING STRUCTURE FOR A 625-LINE INTERLACED SYSTEM

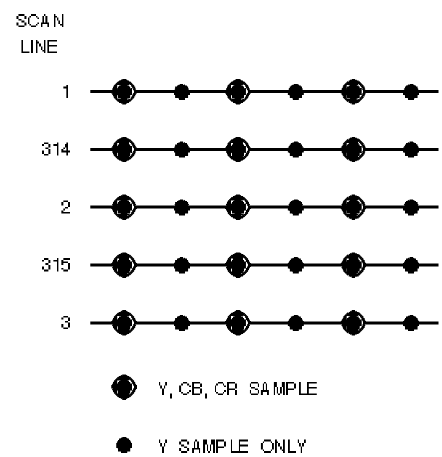

FIGURE 2. 4:2:2 YCbCr SAMPLING STRUCTURE FOR A 625-LINE INTERLACED SYSTEM

R´G´B´ Generation

BT.601 defines Y to have a nominal range of 16-235 (black-white); Cb and Cr are defined to have a nominal range of 16-240, with 128 corresponding to zero. YCbCr is also defined to have been derived from gamma-corrected RGB (R´G´B´) data.

The BT.601 equations are used by many video ICs to convert between digital R´G´B´ data and YCbCr are:

$$Y = (77/256)R' + (150/256)G' + (29/256)B'$$

$$Cb = -(44/256)R' - (87/256)G' + (131/256)B' + 128$$

$$Cr = (131/256)R' - (110/256)G' - (21/256)B' + 128$$

$$R' = Y + 1.371(Cr - 128)$$

$$G' = Y - 0.698(Cr - 128) - 0.336(Cb - 128)$$

$$B' = Y + 1.732(Cb - 128)$$

When performing YCbCr to R´G´B´ conversion using the above equations, note that the resulting R´G´B´ values have a nominal range of 16-235 (black-white). Occasional excursions into the 0-15 and 236-255 values are possible due to Y and CbCr occasionally going outside the 16-235 and 16-240 ranges, respectively, due to video processing, rounding errors, and noise.

However, if the 24-bit R´G´B´ data are to have a range of 0-255 (black-white), as is commonly found in PCs, the following equations (used by the HMP8115) should be used to maintain the correct black and white levels:

$$Y = 0.257R' + 0.504G' + 0.098B' + 16$$

$$Cb = -0.148R' - 0.291G' + 0.439B' + 128$$

$$Cr = 0.439R' - 0.368G' - 0.071B' + 128$$

$$R' = 1.164(Y - 16) + 1.596(Cr - 128)$$

$$G' = 1.164(Y - 16) - 0.813(Cr - 128) - 0.392(Cb - 128)$$

$$B' = 1.164(Y - 16) + 2.017(Cb - 128)$$

For the YCbCr to R´G´B´ equations, the R´G´B´ values must be saturated at the 0 and 255 levels due to occasional excursions outside the nominal YCbCr ranges.

Linear RGB Generation

PCs usually prefer to use the linear RGB data format due to the amount of software already written and the simplified algorithms. Gamma correction for the display monitor may then done real-time in the GUI acceleration chip. Therefore, it may be desirable to remove the gamma information from the R´G´B´ data.

NTSC video is pre-corrected using a gamma of 2.2. Thus, to generate 24-bit linear RGB data:

for $(R', G', B') < 21$

$$R = ((R'/255) / 4.5) * 255$$

$$G = ((G'/255) / 4.5) * 255$$

$$B = ((B'/255) / 4.5) * 255$$

for $(R', G', B') \geq 21$

$$R = 255 * (((R'/255) + 0.099) / 1.099)^{2.2}$$

$$G = 255 * (((G'/255) + 0.099) / 1.099)^{2.2}$$

$$B = 255 * (((B'/255) + 0.099) / 1.099)^{2.2}$$

PAL video specifies a gamma of 2.8, although a value of 2.2 is now commonly used. If the video is pre-corrected using a gamma of 2.8, the following equations may be used to generate 24-bit linear RGB data:

$$R = 255 * (R'/255)^{2.8}$$

$$G = 255 * (G'/255)^{2.8}$$

$$B = 255 * (B'/255)^{2.8}$$

Many modern PAL video decoders, such as the HMP8115, allow the selection of either the 2.2 or 2.8 gamma factor to be used for calculations.

Summary

This Application Note discusses some of the considerations for converting YCbCr video data to digital RGB. To ensure proper black and white levels for the PC environment, the basic BT.601 YCbCr to RGB equations should be slightly modified to generate the full 0-255 RGB range. The generation of linear RGB data should also be optional, and is easily implemented.

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