4:4:4 to 4:2:2 YCbCr Conversion

Converting 4:4:4 YCbCr to 4:2:2 YCbCr (Figure 7.3) is a common function in digital video. 4:2:2 YCbCr is the basis for many digital video interfaces, and requires fewer connections to implement than 4:4:4.

Saturation logic should be included in the Y, Cb, and Cr data paths to limit the 8-bit range to 1–254. The 16 and 128 values shown in Figure 7.3 are used to generate the proper levels during blanking intervals.

Y Filtering

A template for the Y lowpass filter is shown in Figure 7.4 and Table 7.1.

Because there may be many cascaded conversions (up to 10 were envisioned), the filters were designed to adhere to very tight tolerances to avoid a buildup of visual artifacts. Departure from flat amplitude and group delay response due to filtering is amplified through successive stages. For example, if filters exhibiting –1 dB at 1 MHz and –3 dB at 1.3 MHz were employed, the overall response would be –8 dB (at 1 MHz) and –24 dB (at 1.3 MHz) after four conversion stages (assuming two filters per stage).

Although the sharp cut-off results in ringing on Y edges, the visual effect should be minimal provided that group-delay performance is adequate. When cascading multiple filtering operations, the passband flatness and group-delay characteristics are very important. The passband tolerances, coupled with the sharp cut-off, make the template very difficult (some say impossible) to match. As a result, there is usually a temptation to relax passband accuracy, but the best approach is to reduce the rate of cut-off and keep the passband as flat as possible.

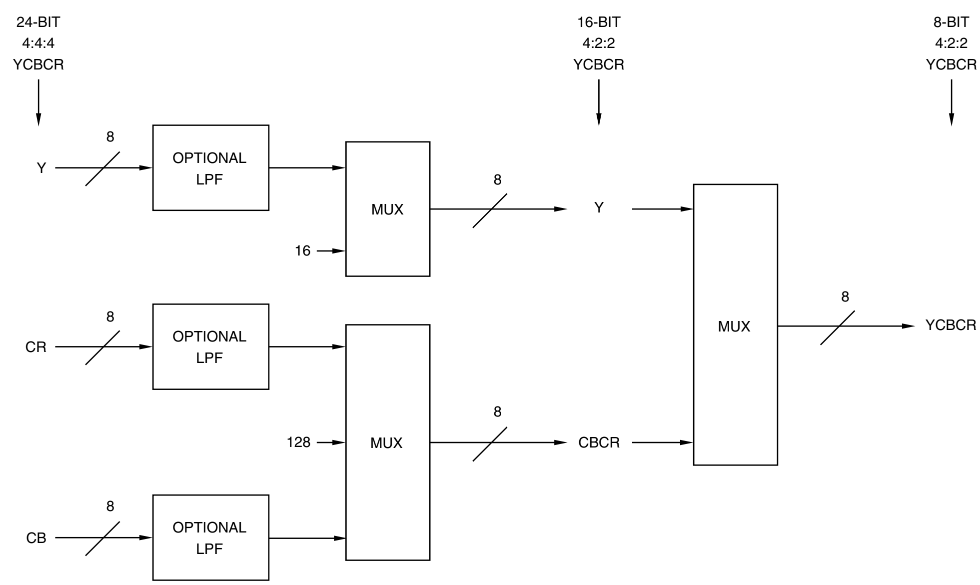

Figure 7.3. 4:4:4 to 4:2:2 YCbCr Conversion.

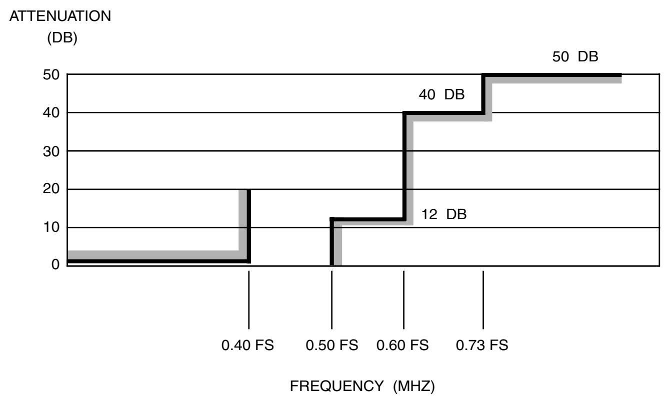

Figure 7.4. Y Filter Template. F_s = Y 1× sample rate.

Frequency Range	Typical SDTV Tolerances	Typical HDTV Tolerances
Passband Ripple Tolerance		
0 to $0.40F_s$	±0.01 dB increasing to ±0.05 dB	±0.05 dB
Passband Group Delay Tolerance		
0 to $0.27F_s$	0 increasing to ±1.35 ns	±0.075T
$0.27F_s$ to $0.40F_s$	±1.35 ns increasing to ±2 ns	±0.110T

Table 7.1. Y Filter Ripple and Group Delay Tolerances. F_s = Y 1× sample rate. T = 1 / F_s.

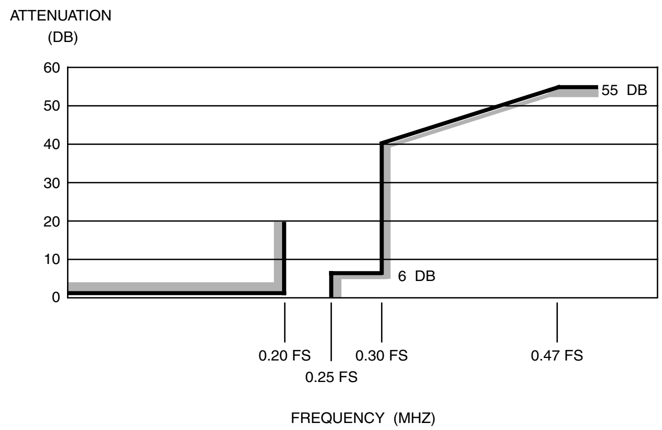

Figure 7.5. Cb and Cr Filter Template for Digital Filter for Sample Rate Conversion from 4:4:4 to 4:2:2. F_S = Y 1× sample rate.

Frequency Range	Typical SDTV Tolerances	Typical HDTV Tolerances
Passband Ripple Tolerance		
0 to $0.20F_S$	0 dB increasing to ±0.05 dB	±0.05 dB
Passband Group Delay Tolerance		
0 to $0.20F_S$	delay distortion is zero by design	

Table 7.2. CbCr Filter Ripple and Group Delay Tolerances. F_S = Y 1× sample rate. T = 1 / F_S.

CbCr Filtering

Cb and Cr are lowpass filtered and decimated. In a standard design, the lowpass and decimation filters may be combined into a single filter, and a single filter may be used for both Cb and Cr by multiplexing.

As with Y filtering, the Cb and Cr lowpass filtering requires a sharp cut-off to prevent repeated conversions from producing a cumulative resolution loss. However, due to the low cut-off frequency, the sharp cut-off produces ringing that is more noticeable than for Y.

A template for the Cb and Cr filters is shown in Figure 7.5 and Table 7.2.

Since aliasing is less noticeable in color difference signals, the attenuation at half the sampling frequency is only 6 dB. There is an advantage in using a skew-symmetric response passing through the –6 dB point at half the sampling frequency—this makes alternate coefficients in the digital filter zero, almost halving the number of taps, and also allows using a single digital filter for both the Cb and Cr signals. Use of a transversal digital filter has the advantage of providing perfect linear phase response, eliminating the need for group-delay correction.

As with the Y filter, the passband flatness and group-delay characteristics are very important, and the best approach again is to reduce the rate of cut-off and keep the passband as flat as possible.

Display Enhancement

Brightness, Contrast, Saturation (Color), and Hue (Tint)

Working in the YCbCr color space simplifies the implementation of brightness, contrast, saturation, and hue controls, as shown in Figure 7.6. Also illustrated are multiplexers to allow the output of black screen, blue screen, and color bars.

The design should ensure that no overflow or underflow wraparound errors occur, effectively saturating results to the 0 and 255 values.

Y Processing

16 is subtracted from the Y data to position the black level at zero. This removes the DC offset so adjusting the contrast does not vary the black level. Since the Y input data may have values below 16, negative Y values should be supported at this point.

The contrast (or *picture* or *white level*) control is implemented by multiplying the YCbCr data by a constant. If Cb and Cr are not adjusted, a color shift will result whenever the contrast is changed. A typical 8-bit contrast adjustment range is 0–1.992×.

The brightness (or *black level*) control is implemented by adding or subtracting from the Y data. Brightness is done after the contrast to avoid introducing a varying DC offset due to adjusting the contrast. A typical 8-bit brightness adjustment range is –128 to +127.

Finally, 16 is added to position the black level at 16.

CbCr Processing

128 is subtracted from Cb and Cr to position the range about zero.

The hue (or *tint*) control is implemented by mixing the Cb and Cr data:

$$Cb' = Cb \cos\theta + Cr \sin\theta$$

$$Cr' = Cr \cos\theta - Cb \sin\theta$$

where θ is the desired hue angle. A typical 8-bit hue adjustment range is –30° to +30°.

The saturation (or *color*) control is implemented by multiplying both Cb and Cr by a constant. A typical 8-bit saturation adjustment