Application Report
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Analog Reconstruction Filter for HDTV Using the THS8133, THS8134, THS8135, THS8200

Karl Renner
Digital Audio Video Department

ABSTRACT

The THS8133, THS8134, THS8135, and the THS8200 devices are part of a family of chips for graphics and video applications, which contain triple DACs that operate up to 240 MSPS. For television applications, an analog low-pass filter is required to reconstruct the signal that is input to the monitor. High definition television (HDTV) requires a sampling frequency of 74.25 MHz and has pass-band, transition-band, and stop-band attenuation requirements, which affect the complexity of the filter. A higher sampling rate results in a lower filter complexity.

Introduction

The THS8133, THS8134, THS8135, and THS8200 comprise a family of graphics/video chips that have triple digital-to-analog converters (DACs) that convert digital graphics signals GBR/YPbPr to analog. They insert bilevel or trilevel syncs into the green/luma signal. The trilevel sync is used for horizontal synchronization of high definition (HD) television signals. Table 1 lists the chips and their capabilities. The THS8200 incorporates a 1:2 upsampling and interpolation filter, which results in a simplification of the filter design that is used to reconstruct the analog output signal. The advantages of 2x oversampling are examined for the high definition (HD) television application.

Table 1. Graphics/Video Chips

Part	Bits	MSPS	2x Oversampling
THS8133	10	80	No
THS8134	8	80	No
THS8135	10	240	Yes
THS8200	10	205	Yes

Table 2 lists the different HD standards. The 1080i format corresponds to system 4 in Table 2 and the 720p format corresponds to system 1 in Table 3. Both have a sampling rate of 74.25 MHz and a 30-MHz bandwidth requirement for the luma and RGB output filter.

Table 2. 1080 Progressive and Interlaced Formats (SMPTE 274M)

System	Active Samples Per Line	Active Lines Per Frame	Frame Rate (Hz)	Scan Format	Sampling Frequency (MHz)	Bandwidth (MHz)	
						Luma	Chroma
1	1920	1080	60	Progressive	148.5	60	30
2	1920	1080	60/1.001	Progressive	148.5/1.001	60	30
3	1920	1080	50	Progressive	148.5	60	30
4	**1920**	**1080**	**30**	**2:1 interlace**	**74.25**	**30**	**15**
5	1920	1080	30/1.001	2:1 interlace	74.25/1.001	30	15
6	1920	1080	25	2:1 interlace	74.25	30	15
7	1920	1080	30	Progressive	74.25	30	15
8	1920	1080	30/1.001	Progressive	74.25/1.001	30	15
9	1920	1080	25	Progressive	74.25	30	15
10	1920	1080	24	Progressive	74.25	30	15
11	1920	1080	24/1.001	Progressive	74.25/1.001	30	15

Table 3. 720 Progressive Formats (SMPTE 296M)

System	Active Samples Per Line	Active Lines Per Frame	Frame Rate (Hz)	Scan Format	Sampling Frequency (MHz)	Bandwidth (MHz)	
						Luma	Chroma
1	1280	720	60	Progressive	74.25	30	15
2	1280	720	60/1.001	Progressive	74.25/1.001	30	15

Filter Design

Figure 1 illustrates the frequency spectrum of the digital-to-analog converter output that has a bandwidth (f_{bw}) and operates with a sampling frequency (f_s). The sampling produces aliases that occur at harmonics of f_s. An analog reconstruction filter is required to convert the stair step DAC output into a smooth continuous signal. The complexity or order of the filter is determined by the frequency transition band from pass band to stop band. Each pole in the Butterworth filter contributes 20-dB/decade rolloff to the transition band. The rolloff requirement can be determined by dividing the stop-band attenuation requirement by the number of frequency decades from f_{bw} to $f_s - f_{bw}$.

$$\text{Rolloff} = \text{stop\_band\_attenuation} / \log_{10}((f_s - f_{bw})/f_{bw}) \quad [\text{dB/decade}]$$

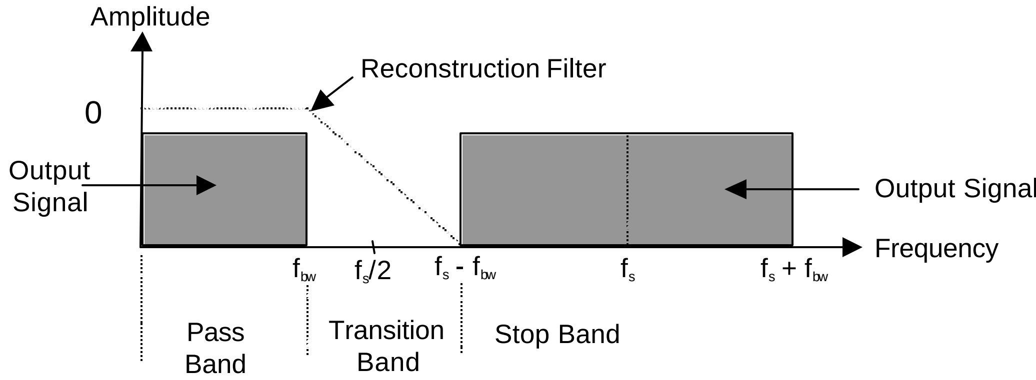

Figure 1. Analog Reconstruction Filter Characteristic

The filter order can be determined by dividing the rolloff requirement by the 20 dB/decade per pole and rounding up to the nearest integer.

Filter order = Truncate (rolloff / 20 dB/decade + 0.99)

Table 4 illustrates the Butterworth filter order required for different signal bandwidths and sampling frequencies where a stop-band attenuation of 40 dB is specified. The worst case is a filter order of 12 for the 1x-sampling rate that reduces to 4 for the 2x-sampling rate. The number of reactive components (capacitors and inductors) in an LC ladder circuit corresponds to the filter order.

Table 4. Butterworth Filter Order Requirements

Bandwidth (MHz)	1x Sampling Frequency (MHz)	Filter Order	2x Sampling Frequency (MHz)	Filter Order
60	148.5	12	297	4
30	148.5	4	297	3
30	74.25	12	148.5	4
15	74.25	4	148.5	3

The Butterworth filter is designed to have a maximally flat amplitude characteristic in the pass band and a monotonically decreasing characteristic in the transition and stop bands. The amplitude decreases to –3 dB at the cutoff frequency. Examination of the filter requirements for the luminance/RGB filter for 1080i standard (recommendation ITU-R BT.1120) shows a pass band ripple tolerance of 0.1 dB. The Butterworth filter fails to meet this requirement, since its characteristic decreases to –3 dB at the cutoff frequency. A better choice is the elliptic (Cauer) filter which has ripple in both the pass band and stop band and a sharper rolloff characteristic due to zeroes in the transfer function. Specification of the pass-band and stop-band frequencies and loss shown in Table 5 results in the elliptic filter orders shown for 1x and 2x sampling frequencies as generated by a filter synthesis software.

Table 5. Elliptic Filter Design Parameters and Order

Parameter	1x	2x
Pass-band frequency (MHz)	30	30
Stop-band frequency (MHz)	44.25	118.5
Pass-band ripple (dB)	0.1	0.1
Stop-band loss (dB)	50	40
Filter order	6	3

Figure 2 and Figure 3 illustrate the attenuation characteristics for the Butterworth and elliptic filters designed for the 1x and 2x sampling frequencies; Figure 4 and Figure 5 illustrate the pass-band characteristic. The filter requirements taken from ITU-R BT.1120 for HDTV are also shown, which include the allowable range for the attenuation characteristic and its frequency limits.

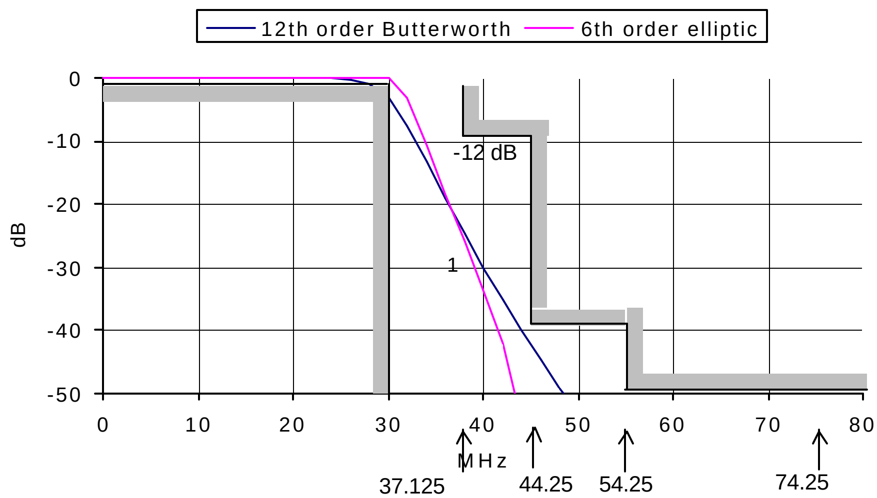

Figure 2. 1x Filter Attenuation Characteristic

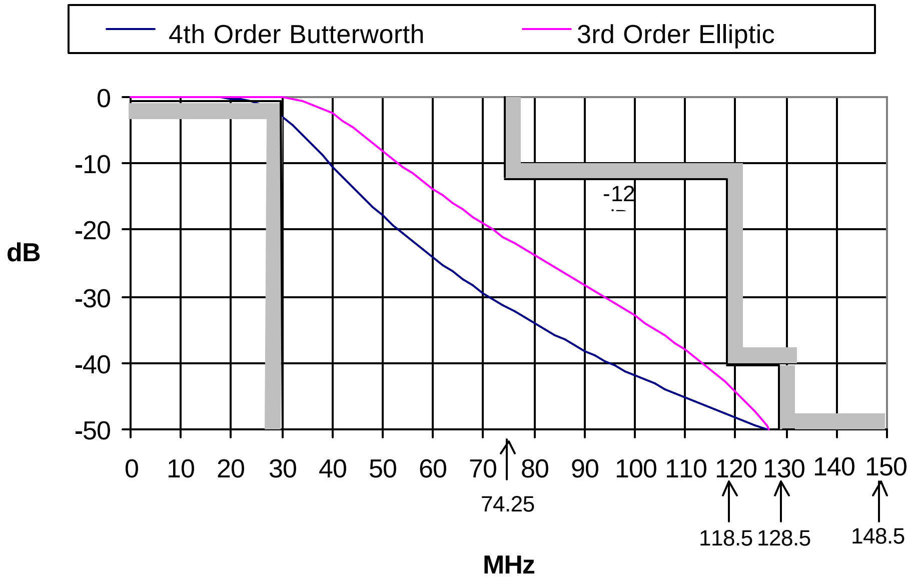

Figure 3. 2x Filter Attenuation Characteristic

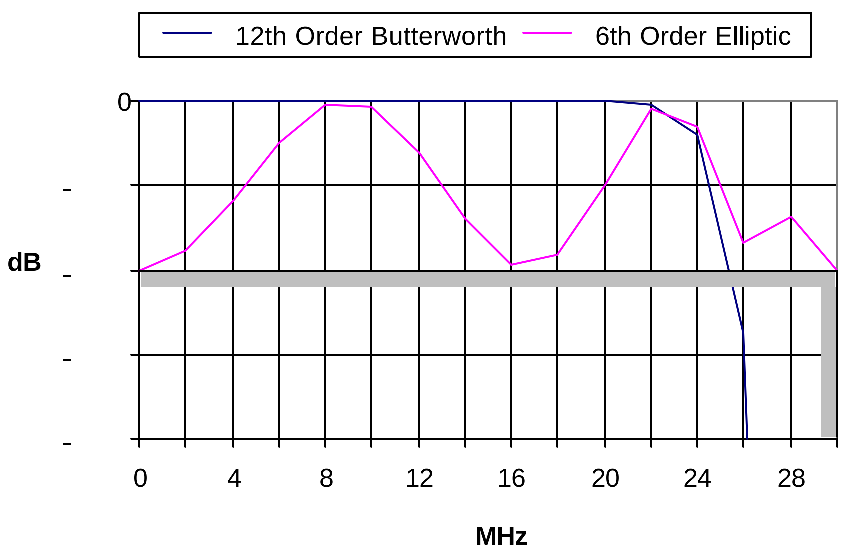

Figure 4. 1x Filter Pass-Band Characteristic

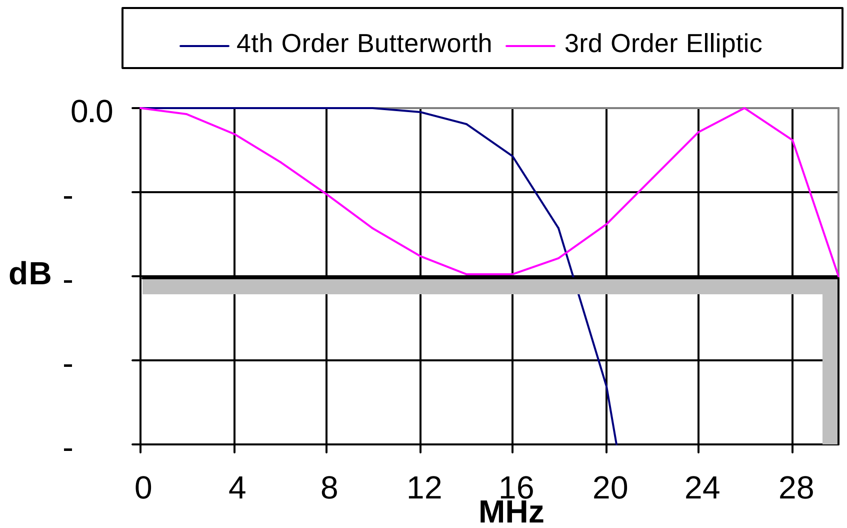

Figure 5. 2x Filter Pass Band Characteristic

The requirement for HDTV is a pass-band group delay tolerance of 1 ns as shown in Figure 6. The group delay of these filters increases during the pass band and peaks near the cutoff frequency as shown in Figure 7 and Figure 8. The group delay beyond the pass band is not specified, since the signal is attenuated. An all-pass filter is normally used to compensate for the group delay variation.

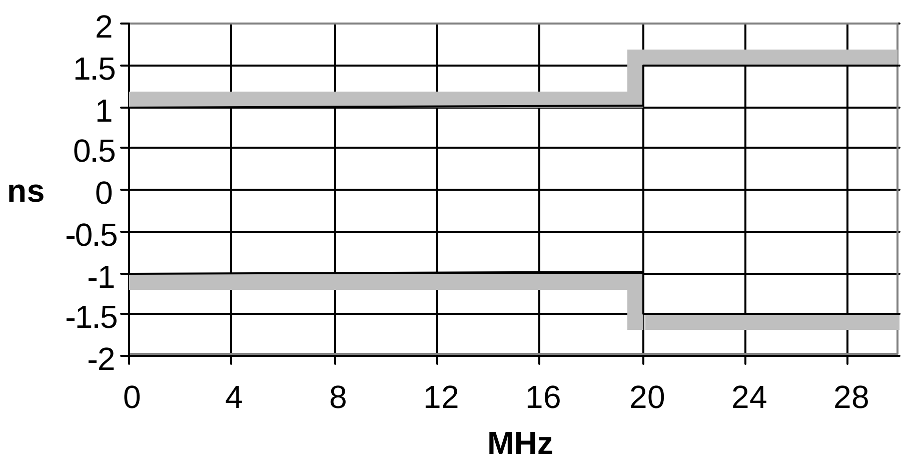

Figure 6. HDTV Pass-Band Group Delay Tolerance

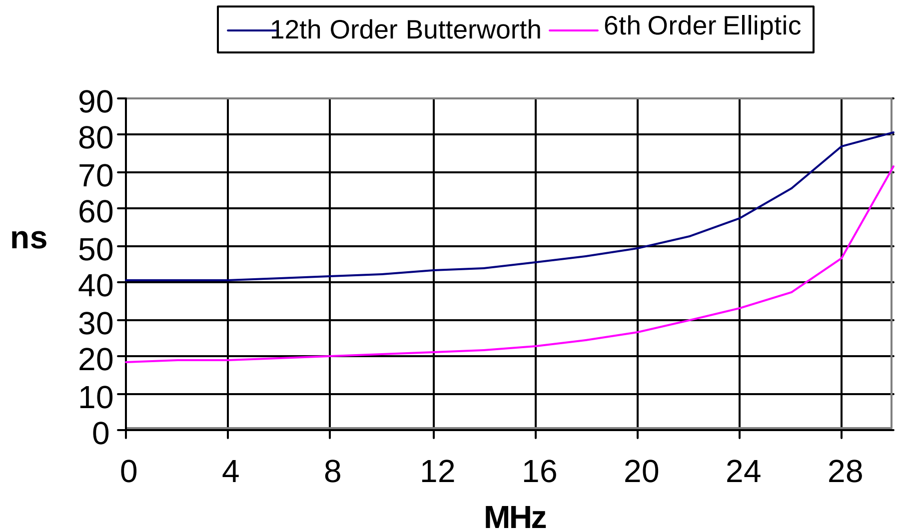

Figure 7. 1x Filter Group Delay

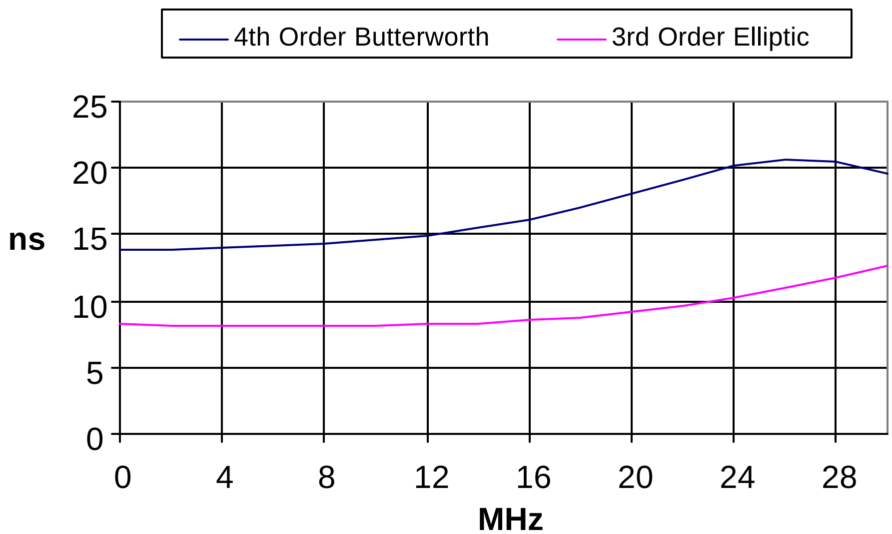

Figure 8. 2x Filter Group Delay

Filter Synthesis

The minimum inductor circuits for the third- (for 2x sampling rate) and sixth- (for 1x sampling rate) order elliptic filters are shown in Figure 9. Component values produced by synthesis software are shown in Table 6. The sixth-order filter requires four more components than the third order.

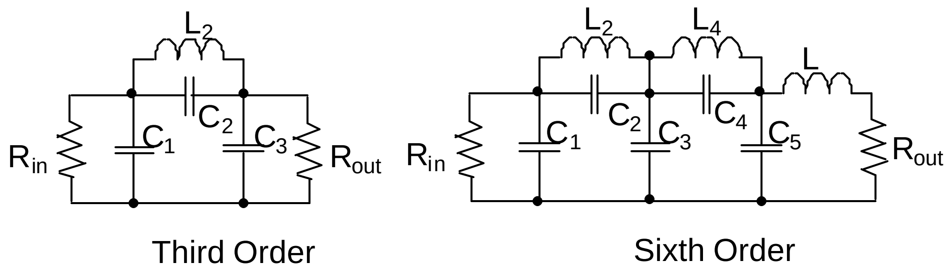

Figure 9. Elliptic Filters

Table 6. Component Values

Component	Third Order	Sixth Order	Component	Third Order	Sixth Order
Rin	75	75	C_1 (pF)	67.47	58.94
Rout	75	75	C_2 (pF)	2.98	15.46
L_2 (?H)	0.417	0.489	C_3 (pF)	67.47	96.95
L_4 (?H)		0.473	C_4 (pF)		27.84
L_5 (?H)		0.408	C_5 (pF)		87.71

Conclusions

Oversampling reduces the design complexity of the analog output reconstruction filter. The THS8135 and THS8200 have the capability to operate at a 2x sampling rate for the HDTV format; the THS8200 has an internal 2x interpolation filter. The best choice for the analog reconstruction filter is the elliptic filter, followed by an all-pass filter designed to compensate for the group delay variations of the elliptic filter.

References

1. *Digital Interfaces for 1125/60/2:1 and 1250/50/2:1 HDTV Studio Signals*, Recommendation ITU-R BT.1120, 1994.
2. *Digital Filter Designer's Handbook*, C. Britton Rorabaugh, McGraw-Hill, Inc., 1993, pages 93-108.
3. *LADDER-A Microcomputer Tool for Passive Filter Design and Simulation*, IEEE Transactions on Education, Vol. 39, No. 4, November 1996.
4. *LADDER filter synthesis software obtained from Rob Koeller*, University of Wyoming, email: koller@uwyo.edu, see http://asuwlink.uwyo.edu/~koller/asee.html.
5. *FILTER synthesis software*, Michael Ellis, downloaded from http://members.tripod.com/michaelgellis/zip/filter.zip.

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