AN-945
APPLICATION NOTE

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System Bandwidth vs. Resolution for Analog Video

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INTRODUCTION

Ensuring the best quality picture is the ultimate goal for video system designers. With the introduction of HDTV, image resolution as well as video signal bandwidth has increased dramatically. Because video systems tend to support multiple resolutions and interfaces, design engineers must carefully examine the system bandwidth requirements to ensure that signals are not distorted.

This application note provides a quick overview of the video-specific terms used to characterize system bandwidth and how they relate to 3 dB bandwidth.

SYSTEM BANDWIDTH DEFINITIONS

Generally, 3 dB bandwidth is a measure of a system's bandwidth. Assuming a low-pass frequency response, 3 dB bandwidth is defined as the frequency at which the output power drops to half of the output power at dc. This translates into a 29.3% drop in the output voltage compared with dc.

For video applications, 3 dB bandwidth has little meaning because it doesn't directly reflect the attenuation of the video signal components. The video literature mentions the term gain flatness, which represents the maximum allowable drop in signal amplitude within the pass band. Tests have revealed that the human eye is unable to distinguish brightness variations of less than 1%, which translates into a 0.1 dB signal drop within the pass band, or put simply, 0.1 dB gain flatness. A more liberal approach allows about 6% signal drop, which translates into 0.5 dB gain flatness.

The following sections describe the relationship between the 0.1 dB and 0.5 dB gain flatness specifications and 3 dB bandwidth. The examples assume a Butterworth frequency response, which is the most common response.

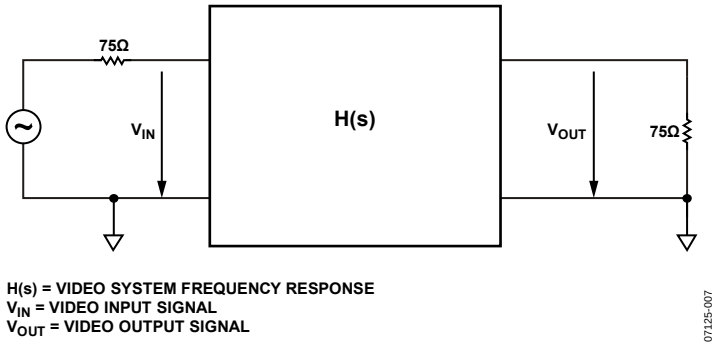

Figure 1. Video System Frequency Response

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LOW-PASS FREQUENCY RESPONSE

The transfer function of a low-pass Butterworth response $|H_{LP}(f)|$, is given by the following formula:

$$|H_{LP}(f)| = \frac{1}{\sqrt{1+\left(\frac{f}{f_C}\right)^{2n}}} \quad (1)$$

where:
f_C is the cutoff frequency.
f is the signal frequency.
n is the order of the system.

Figure 2 illustrates the low-pass Butterworth response with f_C = 1 MHz for n = 1 to 5.

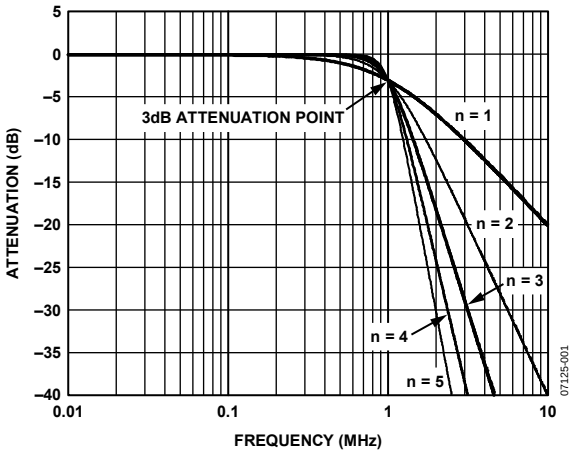

Figure 2. Low-Pass Butterworth Frequency Response

The attenuation of the low-pass filter can be calculated using the following formula:

$$A_{dB} = 10 \times \log\left[1+\left(\frac{f}{f_C}\right)^{2n}\right] \quad (2)$$

By substituting f with the maximum video frequency (f_{MAX}), the ratio between the cutoff frequency, f_C, and the maximum video frequency, f_{MAX}, can be expressed as

$$\frac{f_C}{f_{MAX}} = \frac{1}{\sqrt[2n]{10^{\frac{A_{dB}}{10}}-1}} \quad (3)$$

If A_{dB} is 0.1 dB or 0.5 dB, depending on the two video gain flatness specifications, the ratio between the cutoff frequency and the maximum video frequency for various system orders is listed in Table 1.

Table 1. Low-Pass f_C for 0.5 dB and 0.1 dB Gain Flatness

Gain Flatness	f_C/f_{MAX} Ratio				
	n = 1	n = 2	n = 3	n = 4	n = 5
0.1 dB	6.55	2.56	1.87	1.6	1.46
0.5 dB	2.86	1.69	1.42	1.3	1.23

Figure 3 and Figure 4 illustrate the low-pass frequency responses for 1 MHz 0.5 dB and 0.1 dB gain flatness specifications. In addition, the attenuation axis is intentionally limited to −3 dB to highlight the 3 dB bandwidth as the intersection of each plot with the frequency axis.

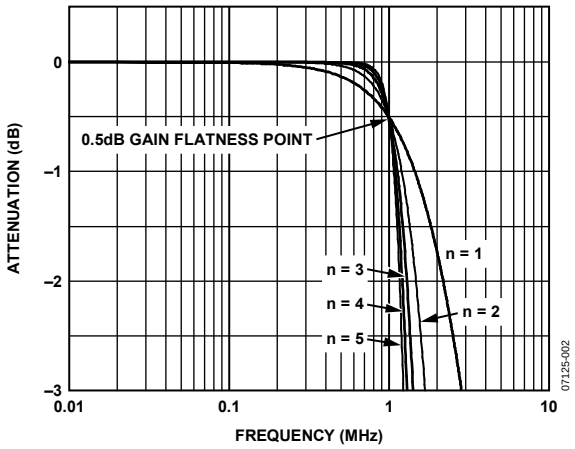

Figure 3.Low-Pass Cutoff Frequencies for Normalized Systems (0.5 dB Flatness)

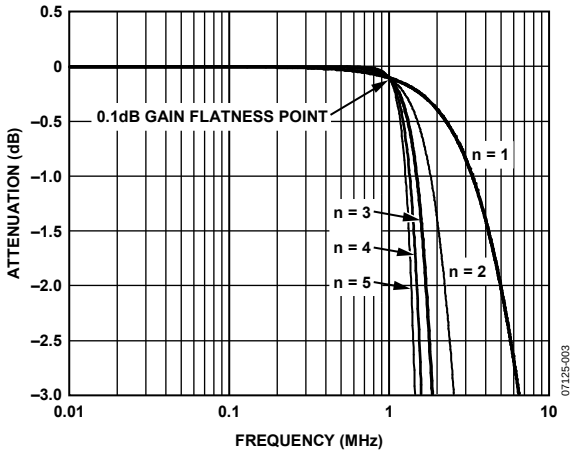

Figure 4. Low-Pass Cutoff Frequencies for Normalized Systems (0.1 dB Flatness)

HIGH-PASS FREQUENCY RESPONSE

When ac coupling is used, the high-pass filter formed by the ac coupling capacitor and the input impedance of the video receiver attenuates low frequency signals. The Butterworth high-pass transfer function, $|H_{HP}(f)|$, is given by the following formula:

$$|H_{HP}(f)| = \frac{1}{\sqrt{1+\left(\frac{f_C}{f}\right)^{2n}}} \quad (4)$$

Figure 5 illustrates the high-pass Butterworth response for a system with f_C = 1 MHz and n = 1 to 5.

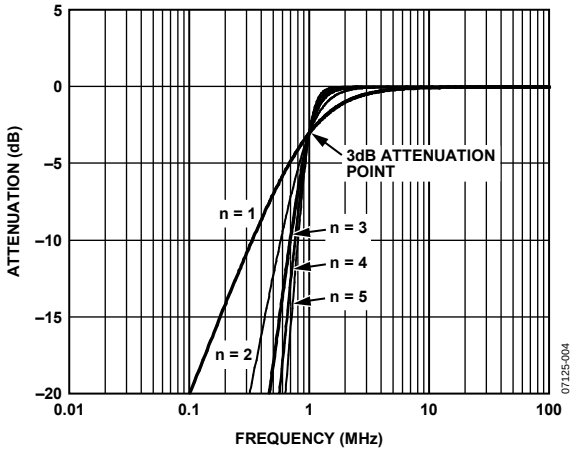

Figure 5. High-Pass Butterworth Frequency Response

The attenuation of the high-pass response is given by

$$A_{dB} = 10 \times \log\left[1+\left(\frac{f_C}{f}\right)^{2n}\right] \quad (5)$$

Substituting f with the minimum video frequency (f_{MIN}), the ratio between the cutoff frequency, f_C, and the minimum video frequency, f_{MIN}, can be expressed as

$$\frac{f_C}{f_{MIN}} = \sqrt[2n]{10^{\frac{A_{dB}}{10}}-1} \quad (6)$$

The ratio between the cutoff frequency and the minimum video frequency corresponding to 0.1 dB and 0.5 dB gain flatness respectively is listed in Table 2 for various system orders.

Table 2. High-Pass f_C for 0.5 dB and 0.1 dB flatness

Gain Flatness	f_C/f_{MIN} Ratio				
	n = 1	n = 2	n = 3	n = 4	n = 5
0.1 dB	0.15	0.39	0.53	0.63	0.69
0.5 dB	0.35	0.59	0.7	0.77	0.81

Figure 5 and Figure 6 illustrate the high-pass frequency responses for 1 MHz 0.5 dB and 0.1 dB gain flatness specifications. In addition, the attenuation axis is intentionally limited to −3 dB to highlight the 3 dB bandwidth as the intersection of each plot with the frequency axis.

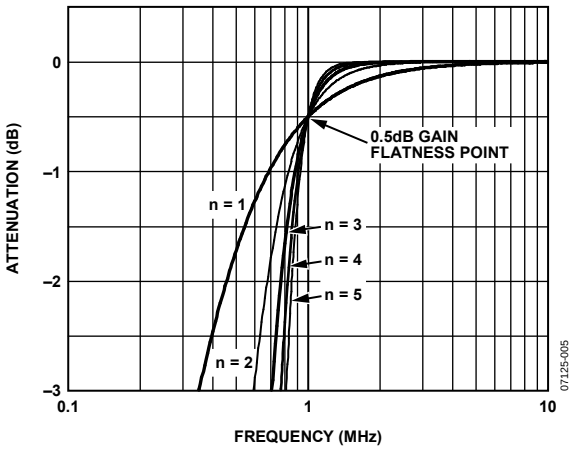

Figure 6. High-Pass Cutoff Frequencies for Normalized Systems (0.5 dB Flatness)

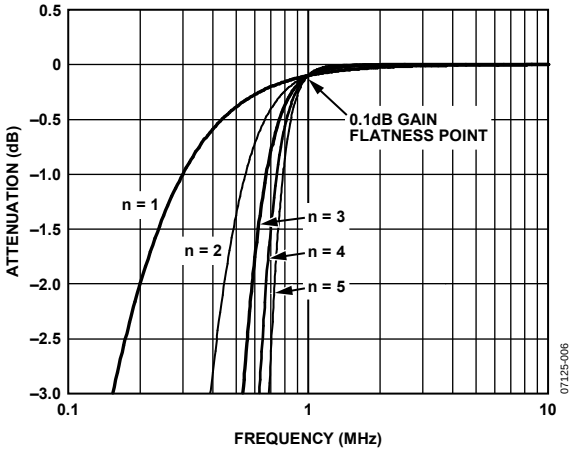

Figure 7. High-pass Cutoff Frequencies for Normalized Systems (0.1 dB Flatness)

CONCLUSION

When designing video systems, the design engineer must carefully analyze the required system bandwidth to ensure optimum performance. Once the gain flatness specification is set, the engineer can derive the required 3 dB bandwidth for the system based on the frequency response type and order of the system.

Table 3 and Table 4 contain the 3 dB bandwidth required (cutoff frequencies) for various video resolutions including TV and PC graphics standards, for both the dc- and ac-coupling options. The Butterworth frequency response is assumed, and n = 1 to 5.

Table 3. 3 dB Bandwidth for DC-Coupled Systems (Low-Pass Response)

Standard	Aspect Ratio	Refresh Rate (Hz)	f_{MAX} (MHz)	Low-Pass Cutoff Frequency (f_C) in MHz									
				0.1 dB Gain Flatness					0.5 dB Gain Flatness				
				n = 1	n = 2	n = 3	n = 4	n = 5	n = 1	n = 2	n = 3	n = 4	n = 5
480i	4:3	30	6.76	44.28	17.31	12.64	10.82	9.87	19.33	11.42	9.60	8.79	8.31
	16:9	30	9.01	59.02	23.07	16.85	14.42	13.15	25.77	15.23	12.79	11.71	11.08
480p	4:3	60	13.51	88.49	34.59	25.26	21.62	19.72	38.64	22.83	19.18	17.56	16.62
576i	4:3	25	6.75	44.21	17.28	12.62	10.80	9.86	19.31	11.41	9.59	8.78	8.30
	16:8	25	9.00	58.95	23.04	16.83	14.40	13.14	25.74	15.21	12.78	11.70	11.07
576p	4:3	50	13.50	88.43	34.56	25.25	21.60	19.71	38.61	22.82	19.17	17.55	16.61
720p	16:9	60	37.13	243.20	95.05	69.43	59.41	54.21	106.19	62.75	52.72	48.27	45.67
1080i	16:9	30	37.13	243.20	95.05	69.43	59.41	54.21	106.19	62.75	52.72	48.27	45.67
	16:8	25	37.13	243.20	95.05	69.43	59.41	54.21	106.19	62.75	52.72	48.27	45.67
1080p	16:8	60	74.25	486.34	190.08	138.85	118.80	108.41	212.36	125.48	105.44	96.53	91.33
	16:9	50	74.25	486.34	190.08	138.85	118.80	108.41	212.36	125.48	105.44	96.53	91.33
VGA	4:3	60	12.60	82.53	32.26	23.56	20.16	18.40	36.04	21.29	17.89	16.38	15.50
	4:3	72	15.58	102.05	39.88	29.13	24.93	22.75	44.56	26.33	22.12	20.25	19.16
	4:3	75	15.75	103.16	40.32	29.45	25.20	23.00	45.05	26.62	22.37	20.48	19.37
	4:3	85	18.00	117.90	46.08	33.66	28.80	26.28	51.48	30.42	25.56	23.40	22.14
SVGA	4:3	56	17.92	117.38	45.88	33.51	28.67	26.16	51.25	30.28	25.45	23.30	22.04
	4:3	60	19.90	130.35	50.94	37.21	31.84	29.05	56.91	33.63	28.26	25.87	24.48
	4:3	72	24.94	163.36	63.85	46.64	39.90	36.41	71.33	42.15	35.41	32.42	30.68
	4:3	75	24.75	162.11	63.36	46.28	39.60	36.14	70.79	41.83	35.15	32.18	30.44
	4:3	85	28.10	184.06	71.94	52.55	44.96	41.03	80.37	47.49	39.90	36.53	34.56
XGA	4:3	60	32.50	212.88	83.20	60.78	52.00	47.45	92.95	54.93	46.15	42.25	39.98
	4:3	70	37.46	245.36	95.90	70.05	59.94	54.69	107.14	63.31	53.19	48.70	46.08
	4:3	75	39.36	257.81	100.76	73.60	62.98	57.47	112.57	66.52	55.89	51.17	48.41
	4:3	85	47.25	309.49	120.96	88.36	75.60	68.99	135.14	79.85	67.10	61.43	58.12
SXGA	5:4	60	53.98	353.57	138.19	100.94	86.37	78.81	154.38	91.23	76.65	70.17	66.40
	5:4	75	67.48	441.99	172.75	126.19	107.97	98.52	192.99	114.04	95.82	87.72	83.00
	5:4	85	78.73	515.68	201.55	147.23	125.97	114.95	225.17	133.05	111.80	102.35	96.84
UXGA	4:3	60	81.00	530.55	207.36	151.47	129.60	118.26	231.66	136.89	115.02	105.30	99.63
	4:3	65	87.75	574.76	224.64	164.09	140.40	128.12	250.97	148.30	124.61	114.08	107.93
	4:3	70	94.50	618.98	241.92	176.72	151.20	137.97	270.27	159.71	134.19	122.85	116.24
	4:3	75	101.25	663.19	259.20	189.34	162.00	147.83	289.58	171.11	143.78	131.63	124.54
	4:3	85	114.75	751.61	293.76	214.58	183.60	167.54	328.19	193.93	162.95	149.18	141.14

Table 4. 3 dB Bandwidth for AC-Coupled Systems (High-Pass Response)

				Low-Pass Cutoff Frequency (f_C) in MHz									
				0.1 dB Gain Flatness					0.5 dB Gain Flatness				
Standard	Aspect Ratio	Refresh Rate (Hz)	f_{MIN} (Hz)	n = 1	n = 2	n = 3	n = 4	n = 5	n = 1	n = 2	n = 3	n = 4	n = 5
480i	4:3	30	30	4.50	11.70	15.90	18.90	20.70	10.50	17.70	21.00	23.10	24.30
	16:9	30	30	4.50	11.70	15.90	18.90	20.70	10.50	17.70	21.00	23.10	24.30
480p	4:3	60	60	9.00	23.40	31.80	37.80	41.40	21.00	35.40	42.00	46.20	48.60
576i	4:3	25	25	3.75	9.75	13.25	15.75	17.25	8.75	14.75	17.50	19.25	20.25
	16:8	25	25	3.75	9.75	13.25	15.75	17.25	8.75	14.75	17.50	19.25	20.25
576p	4:3	50	50	7.50	19.50	26.50	31.50	34.50	17.50	29.50	35.00	38.50	40.50
720p	16:9	60	60	9.00	23.40	31.80	37.80	41.40	21.00	35.40	42.00	46.20	48.60
1080i	16:9	30	30	4.50	11.70	15.90	18.90	20.70	10.50	17.70	21.00	23.10	24.30
	16:8	25	25	3.75	9.75	13.25	15.75	17.25	8.75	14.75	17.50	19.25	20.25
1080p	16:8	60	60	9.00	23.40	31.80	37.80	41.40	21.00	35.40	42.00	46.20	48.60
	16:9	50	50	7.50	19.50	26.50	31.50	34.50	17.50	29.50	35.00	38.50	40.50
VGA	4:3	60	60	9.00	23.40	31.80	37.80	41.40	21.00	35.40	42.00	46.20	48.60
	4:3	72	72	10.80	28.08	38.16	45.36	49.68	25.20	42.48	50.40	55.44	58.32
	4:3	75	75	11.25	29.25	39.75	47.25	51.75	26.25	44.25	52.50	57.75	60.75
	4:3	85	85	12.75	33.15	45.05	53.55	58.65	29.75	50.15	59.50	65.45	68.85
SVGA	4:3	56	56	8.40	21.84	29.68	35.28	38.64	19.60	33.04	39.20	43.12	45.36
	4:3	60	60	9.00	23.40	31.80	37.80	41.40	21.00	35.40	42.00	46.20	48.60
	4:3	72	72	10.80	28.08	38.16	45.36	49.68	25.20	42.48	50.40	55.44	58.32
	4:3	75	75	11.25	29.25	39.75	47.25	51.75	26.25	44.25	52.50	57.75	60.75
	4:3	85	85	12.75	33.15	45.05	53.55	58.65	29.75	50.15	59.50	65.45	68.85
XGA	4:3	60	60	9.00	23.40	31.80	37.80	41.40	21.00	35.40	42.00	46.20	48.60
	4:3	70	70	10.50	27.30	37.10	44.10	48.30	24.50	41.30	49.00	53.90	56.70
	4:3	75	75	11.25	29.25	39.75	47.25	51.75	26.25	44.25	52.50	57.75	60.75
	4:3	85	85	12.75	33.15	45.05	53.55	58.65	29.75	50.15	59.50	65.45	68.85
SXGA	5:4	60	60	9.00	23.40	31.80	37.80	41.40	21.00	35.40	42.00	46.20	48.60
	5:4	75	75	11.25	29.25	39.75	47.25	51.75	26.25	44.25	52.50	57.75	60.75
	5:4	85	85	12.75	33.15	45.05	53.55	58.65	29.75	50.15	59.50	65.45	68.85
UXGA	4:3	60	60	9.00	23.40	31.80	37.80	41.40	21.00	35.40	42.00	46.20	48.60
	4:3	65	65	9.75	25.35	34.45	40.95	44.85	22.75	38.35	45.50	50.05	52.65
	4:3	70	70	10.50	27.30	37.10	44.10	48.30	24.50	41.30	49.00	53.90	56.70
	4:3	75	75	11.25	29.25	39.75	47.25	51.75	26.25	44.25	52.50	57.75	60.75
	4:3	85	85	12.75	33.15	45.05	53.55	58.65	29.75	50.15	59.50	65.45	68.85

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