Bandwidth Versus Video Resolution

This article discusses the key relationship between video resolution and the required bandwidth to accurately process and display that video signal. The equations and table address standard definition, NTSC and PAL, as well as high definition DTV standards. Computer display formats are also covered. Slew rate requirements are also discussed.

Visual resolution in video systems is defined as the smallest detail that can be seen. This detail is related directly to the bandwidth of the signal: The more bandwidth in the signal, the more potential visual resolution. The converse is also true: The more the signal is band-limited, the less detail information will be visible. This article addresses this relationship and provides a straightforward way to determine the bandwidth required to achieve the desired visual resolution.

First, we will clarify a common confusion between *visual resolution* and *format resolution.* Visual resolution relates to the amount of detail that can be seen and is specified in terms of TV lines (abbreviated TVL), whereas format resolution pertains only to the specified format of the signal. For example, an XGA format computer signal has a format resolution of 1024 horizontal pixels and 768 vertical pixels and a maximum visual resolution of 538 TVL. If this signal is band-limited to 20MHz, its visual resolution will drop down to 377 TVL and it will not be possible to view all of the detail that is present in this format. Another example is a standard NTSC video signal. The typical horizontal resolution is about 330 TVL. If this signal, for example, is band-limited to 3MHz instead of the maximum of 4.2MHz, it will have a visual resolution of only 240 TVL. This illustrates the importance of paying close attention to the bandwidth of all devices in the signal path of video signals.

The highest frequency contained in a video signal, and therefore in the signal bandwidth, is a function of the scanning system—meaning, the number of scanning lines, the refresh rate, and so forth. It can be calculated with the following equation:

$$BW_S = 1/2\ [(K \cdot AR \cdot (V_{LT})^2 \cdot F_R) \cdot (K_H / K_V)] \qquad \text{EQ 1}$$

Where:

BW_S = Total signal bandwidth

K = Kell factor

AR = Aspect ratio (the width of the display divided by the height of the display)

V_{LT} = Total number of vertical scan lines
F_R = Frame rate or refresh rate
K_H = Ratio of total horizontal pixels to active pixels
K_V = Ratio of total vertical lines to active lines

The 1/2 factor comes from the highest frequency component in a video signal occurring when alternating black and white vertical lines with a width of one pixel are displayed on the screen. Because it takes two lines to form a complete cycle, the highest frequency is one-half the pixel rate.

The Kell factor represents the effect of reduced visual resolution primarily due to the line-scanning structures. Visual information is lost due to the probability that some of the video information will be displayed during the retrace instead of the active portion of the scan line. Even though it may seem like half the information would be lost because there are equal number of scan and retrace lines, empirically it has been shown that about 30% is lost to this effect, yielding a Kell factor of about 0.7.

The frame rate is the rate at which each complete set of scan lines is displayed. Because a set of scan lines makes a complete picture, this can be thought of as the picture-update rate. Most television signals are in an interlaced format. This is where each picture (or frame) is divided into two fields, each with half of the vertical scan lines. This doesn't affect the calculation as long as the actual frame rate is used in the equation. Just remember that the frame rate is equal to half the field rate.

K_V represents the ratio of the total number of vertical lines divided by the number of active lines. The difference between these is the vertical blanking lines. Similarly, the K_H term is the ratio of the total horizontal pixels to active pixels. If the K_H and K_V values in the above equations are not known, they can be approximated or inferred from the values in the table below.

Visual Resolution

Visual resolution is a measure of the smallest detail that can be seen. TV lines, and therefore resolution, are defined as the number of alternating lines that can be discerned in a width of the screen equal to one picture height. Stated another way, it is the number of visible horizontal pixels divided by the aspect ratio, which is 4:3 for standard TV and 16:9 for digital TV.

The visual resolution can be calculated from the signal bandwidth (BW_S) by using the following equation:

$$TVL = (2\ t_{HA}\ BW_S)/AR \qquad \text{EQ 2}$$

Where:
TVL = Horizontal resolution specified in TV lines
t_{HA} = Active horizontal period
BW_S = Signal bandwidth
AR = Aspect ratio (the width of the display divided by the height of the display)

The active horizontal period is the time it takes to display the active picture portion of one scan line. It is the total time for one scan line minus the retrace time. It can also be expressed as the total horizontal time divided by the K_H factor, defined earlier.

The following table uses the equations defined above and calculates values for several video signals with different formats. This table can be used as a handy quick reference to see the relationship between resolution and bandwidth.

Table: Performance Requirements for Various Video Standards

Standard/Application	Symbol	TV-NTSC	TV-PAL	DTV	DTV	DTV	DTV	VGA	SVGA	XGA	SXGA	UXGA
Horizontal Visual Resolution (TV Lines)	TVL	338	403	336	336	504	756	336	420	538	717	840
Total Horizontal Active Pixels	H_{PA}	451	538	640	704	1280	1920	640	800	1024	1280	1600
Total Vertical Active Lines	V_{LA}	483	576	480	480	720	1080	480	600	768	1024	1200
Total Active Pixels per Frame (k)	P_T	218	310	307	338	922	2074	307	480	786	1311	1920
Aspect Ratio	AR	1.33	1.33	1.33	1.78	1.78	1.78	1.33	1.33	1.33	1.33	1.33
Ratio of Total to Active Horizontal Pixels	K_H	1.19	1.21	1.13	1.22	1.29	1.15	1.25	1.32	1.30	1.34	1.35
Total Horizontal Pixels	H_{PT}	536	650	720	858	1650	2200	800	1056	1328	1720	2160
Ratio of Total to Active Vertical Lines	K_V	1.09	1.09	1.09	1.09	1.04	1.04	1.05	1.04	1.05	1.04	1.04
Total Vertical Scan Lines	V_{LT}	525	625	525	525	750	1125	504	625	806	1067	1242
Scan Method Interlaced (I)/ Progressive (P)	SM	I	I	P	P	P	I	P	P	P	P	P
Frame Rate (Hz)	FR	29.97	25	60	60	60	30	76	76	76	76	76
H Rate (kHz)	HR	15.73	15.6	31.5	31.5	45.0	33.8	38.3	47.5	61.3	81.1	94.4
Pixel Rate (Mp/s)	PR	8.4	10.2	22.7	27.0	74.3	74.3	30.6	50.2	81.3	139.5	203.9
Max Signal BW	**BW_S**	**4.2**	**5.1**	**7.9**	**11.5**	**26.0**	**26.0**	**10.7**	**17.6**	**28.5**	**51.9**	**71.4**
BW(-3B) Nominal for 0.5dB flatness (Mhz)	BW 0.5	18	22	34	49	111	111	46	75	122	223	306

BW(-3B) Nominal for 0.1dB flatness (Mhz)	BW 0.1	41	50	78	113	255	255	105	172	280	510	701
Slew Rate Nominal (V/µs)	SR	53	64	100	144	327	327	135	221	359	653	897

Circuit-Bandwidth and Slew-Rate Requirements

The circuits that process video signals need to have more bandwidth than the actual bandwidth of the processed signal to minimize the degradation of the signal and the resulting loss in picture quality. The amount the circuit bandwidth needs to exceed the highest frequency in the signal is a function of the quality desired. To calculate this, we assume a single-pole response and use the following equation:

$$H(f)(dB) = 20\log(1/(1+(BW_S/BW_{-3dB})^2)^{.5})$$

Rearranging and solving for the -0.1dB and the -0.5dB attenuation points, we get the following:

$$BW_{-3dB\ min} = BW_S\ (-0.1db) \bullet 6.55 \quad \text{EQ 3}$$

$$BW_{-3dB\text{-}min} = BW_S(-0.5db) \bullet 2.86 \quad \text{EQ 4}$$

Where:
BW_{-3dB} = the minimum -3db bandwidth required for the circuit

From equations 3 and 4, if you want to keep the signal attenuation to less than 0.1dB, the circuit needs to have a minimum bandwidth that's about six and a half times' the highest frequency in the signal. If you can tolerate 0.5dB attenuation, it needs to be only about three times. To account for normal variations in the bandwidth of integrated circuits, it is recommended that the results from equations 3 and 4 be multiplied by a factor of 1.5. This will ensure that the attenuation performance is met over worst-case conditions. In equation mode, it is expressed as follows:

$$BW_{-3dB\ nominal} = BW_{-3dB\text{-}min} \bullet 1.5 \quad \text{EQ 5}$$

In addition to bandwidth, the circuits must slew fast enough to faithfully reproduce the video signal. The equation for the minimum slew rate is as follows:

$$SR_{MIN} = 2 \bullet pi \bullet BW_S \bullet Vpeak$$

Substituting and simplifying,

$$SR_{MIN} = BW_S \bullet 6.386 \quad \text{EQ 6}$$

For optimum performance, it is necessary to specify a slew rate larger than that given by equation 6. This is because some distortion can occur as the frequency of the signal approaches the slew-rate limit. This can introduce frequency distortion, which will degrade the picture quality. Multiplying the equation 6 result by a factor of at least two or three will ensure that the distortion is minimized.

In equation form:

$$SR_{nominal} = SR_{MIN} \bullet 2 \quad \text{EQ 7}$$

As an example, let's assume we have a standard NTSC video signal and the following requirements:

$V_{LT} = 525$
TVL = 346
AR = 1.3333
$K_H = 1.17$
$F_R = 29.94$
$K_V = 1.09$

Using equation 1, we calculate a maximum signal bandwidth (BW_S) of about 4.2MHz. This is the highest frequency in the signal. Now let's assume that we need less than 0.1dB attenuation. Using equation 3, we calculate the minimum signal bandwidth necessary to be 27.5MHz. Using equation 5, to account for variations, gives 41.3MHz. This is the circuit -3dB bandwidth required to achieve our desired resolution and maintain the signal quality.

The last calculation we need to make for our example is the minimum slew-rate requirement. Using equations 6 and 7 and plugging in the 4.2MHz value for BW_S, we see that we will need at least a slew rate of 52V/µs and a more desirable value of 80V/µs.

Additional Issues

The analysis above was based on a single-pole response for the circuit. For many operational amplifiers, this is a good model and the equations above will provide useful guideline numbers. Many circuits can exhibit a second-order or higher-order response. Consistent with multi-pole responses, these amplifiers typically exhibit some peaking at or near the cutoff frequency. This will affect the attenuation numbers predicted by the single-pole equations contained in this article. Peaking, in general, has a broadbanding effect—that is, it appears to extend the bandwidth of the response, because the increase in output at the higher frequencies compensates for the normal roll-off of the circuit. The trade-off for increased bandwidth is a more rapid change in phase versus frequency, which can yield degradation in the group delay and the group-delay distortion parameters.

Summary

To achieve the best picture possible from a video source requires comprehending the relationship between circuit bandwidth and picture detail. The circuits must be designed with sufficient performance to maintain this detail all the way to the final display. A designer armed with a thorough understanding of video circuits, as well as resolution and bandwidth, will be able to design circuits to accomplish this goal.

References

Whitaker, Jerry C. *DTV: The Revolution in Electronic Imaging.* McGraw-Hill, 1998

VIDEO DESIGNERS: Join our E-mail-based Discussion Group for Analog Video Designers.

May 2001