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APPLICATION NOTE 4287

Reconstructing Analog Video with the Maxim Video Filter Family

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Abstract: This application note provides an overview of video digitization, and the spectrum and sidebands produced. The article examines the process of converting digital video back into analog video and explains how video reconstruction requires proper filtering techniques. Examples are provided to avoid or minimize moiré effects and picture artifacts.

Introduction

Once analog video is captured and digitized, the big challenge remains: restoring the video image without artifacts or moiré effects so that the best possible viewing experience is delivered. To do this, designers must examine the process of converting digital video back into analog video (i.e., video reconstruction), and the various filtering techniques and implementation examples that can be used to avoid or minimize moiré effects and picture artifacts.

Maxim video filters make digital-to-analog video conversion simple and reliable. The filter family consists of 36 filters (number of devices as of July 2008) and covers standard- (SD) and high-definition (HD) standards. Many devices have multiple channels matched in frequency response, group delay, and gain. The typical channel is not only automatically tested, but is also inexpensive. At low volume (1000k pieces, FOB USA, web price) the cost at the time of this publication is much less than one dollar (USD) per channel.

Why Convert Digital Video to Analog?

Television is literally seeing at a distance. Analog light is captured by a camera and typically the video is digitized for convenient transmission. Eventually our analog human eyes require analog light to view the image (**Figure 1**). The process for turning digital video back into analog video is called reconstruction. Due to quantization and other issues caused by moving from the digital to analog domains, moiré effects and picture artifacts have to be removed through various filtering techniques to deliver top-quality video.

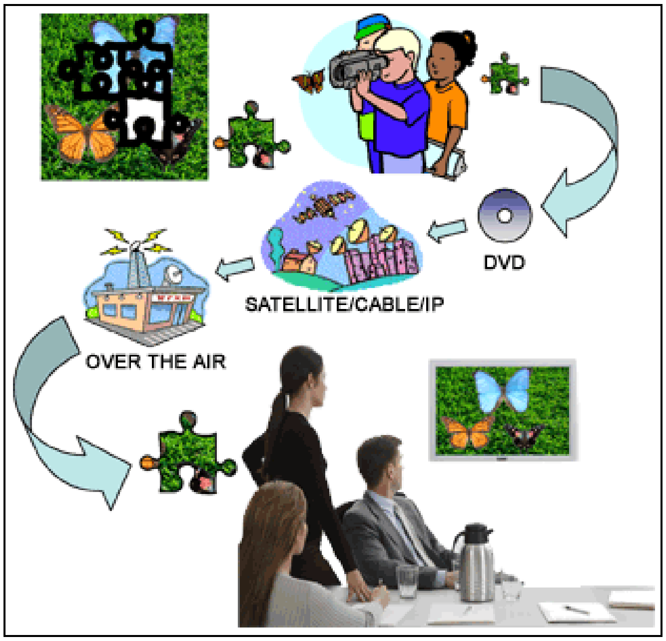

Figure 1. Television starts as analog light, becomes a digital transmission, and returns to analog light for our eyes.

Digital video has many advantages. It can be compressed with predictable quality and, once digitized, it does not degrade with storage and transmission. Transmission includes many ways of delivering the image such as DVD, satellite, cable, and over-the-air systems. To view digital video with our analog human eyes, it must be reconstructed into an analog video signal and into analog light.

Like digital video, a jigsaw puzzle emerges from the box: jumbled, out of order, and with strange spurious shapes or artifacts. The shapes have little coherence with the puzzle's image. By following the basic rules we learned as children, we sort out the corners and edges to start reconstructing the image. In a similar way digital video transmission is comprised of picture pieces which may be transmitted out of order and contain spurious artifacts. However, by following a set of rules we can reassemble (reconstruct) the picture whose quality corresponds to the original analog video input signal.

At the end of the digital reassembly process both video and the jigsaw puzzle need some "analog smoothing." For the jigsaw puzzle, that analog smoothing can be squinting our eyes or moving back far enough so that the lines between puzzle pieces are not objectionable. For digital video, this analog smoothing is accomplished by an analog lowpass filter.

Video Reconstruction Process

An analog video signal delivered by a camera or other capture device is digitized in an analog-to-digital converter (ADC). The ADC "memorizes" the value in an instant of time at each clock edge (**Figure 2**). The arrows at the upper left of Figure 2 show the clock instant that the analog signal data is stored. The analog signal is continuously changing, but the digital representation is sampled periodically. After digital processing and transmission, the digital signal is converted back to analog video by a digital-to-analog converter (DAC). The DAC's output is shown in the upper right portion of Figure 2, with the arrows again representing the clock.

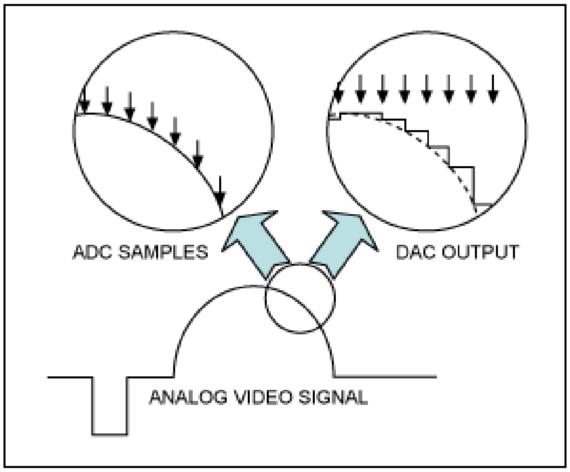

Figure 2. Conversion waveforms from analog to digital and back.

At each clock instant the digital value is converted to an analog voltage. That analog voltage is then held until the next clock edge. The output is a series of stair steps compared to the smooth curve of the original analog signal. This is called a "sample and hold" or "boxcar" reconstruction. An analog lowpass reconstruction filter is necessary to smooth the waveform to approximate the original analog video.

Determining the Correct Reconstruction Filter

When you examine the time domain version of Figure 2, you see that the little stair steps have unwanted high-frequency information but the source of that unwanted information is not obvious. **Figure 3** illustrates the effect of digitizing the signal in the frequency domain. SD, PAL (European), and NTSC (North American) video has a bandwidth of about 5MHz, while the HD ATSC 720p and 1080i (USA) video has a bandwidth of 30MHz. A typical clock frequency for SD is 27MHz; the clock goes up to 74.25MHz or above for HD.

The Nyquist frequency indicated is always one-half the clock frequency. Nyquist is important, as video components and noise above the Nyquist frequency must be removed before the original analog signal was digitized. If information above Nyquist is present, it will be confused with lower frequencies and aliased down to mix with and corrupt the video. Once an alias is created it cannot be removed. Later in this article we will explain why this is important in a home video system.

At the output of the DAC, the video and two image frequency sidebands are present (Figure 3a). The clock is drawn to clarify the figure, although most modern DACs are balanced well enough to suppress the clock frequency. Mathematically these sidebands are the sum and difference frequencies between the video and clock; the sidebands are a normal part of every digital video signal. The upper image sideband has the same characteristic as the video. That is, the low-frequency video signals are found just above the clock and the higher video frequencies extend to the right.

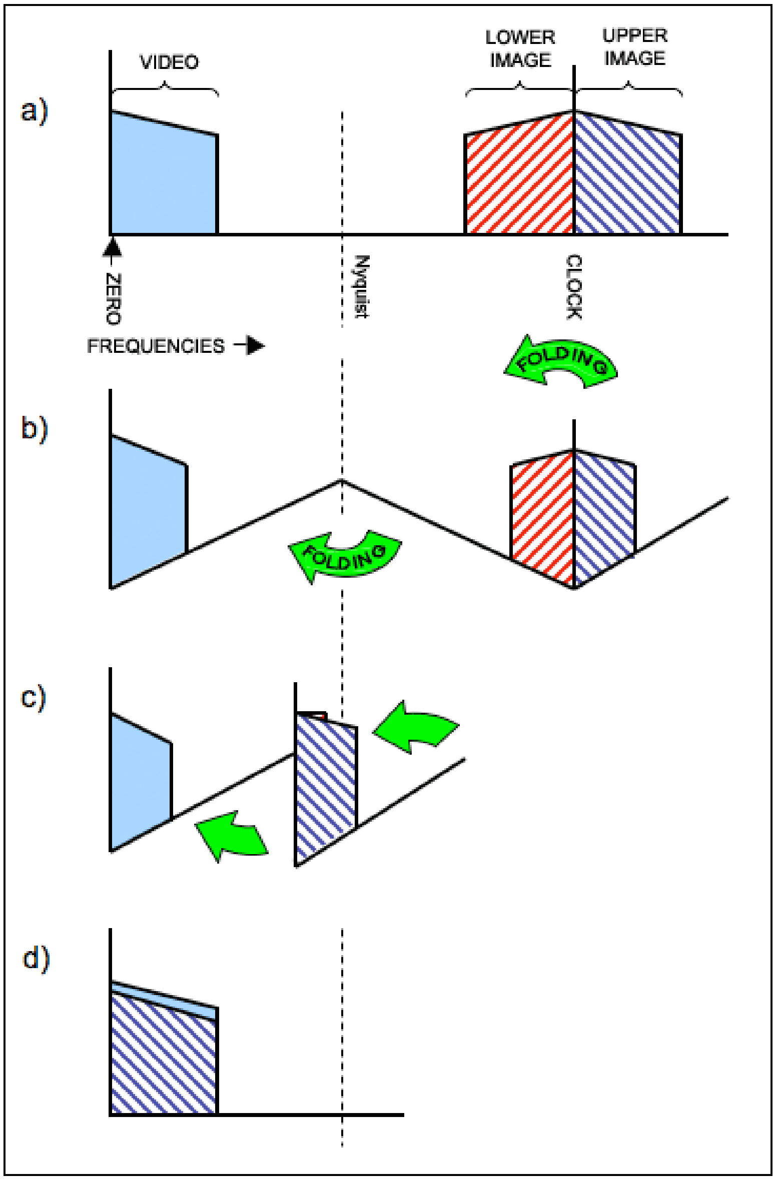

Figure 3. The frequency spectrum folding which shows the sources of interference caused by poor video filtering.

In the case of SD with a 27MHz clock, the top of the upper image is 5MHz plus 27MHz, or 32MHz. The lower image sideband is inverted so that the low-frequency video is just below the clock and the higher video frequencies extend to the left. Therefore, the SD lower image extends to 27MHz minus 5MHz, or 22MHz. It is important to understand where the system's lower image frequency is, so that it can be attenuated and thus its visibility minimized. The critical frequency for HD with a 74.25MHz clock is 74.25MHz minus 30MHz, or 44.25MHz.

To reflect the effect of not attenuating the image frequencies, Figures 3b and 3c show the folding of the spectrum at the Nyquist and clock frequencies. These added image frequencies (Figure 3d) have a random phase compared to the video. **Figure 4** shows the picture errors that we want to avoid. The "edge wiggles" are the high-frequency edge interference that folds back with random and constantly changing phase on top of the video. Moiré is interaction between two frequencies such as the clock and video.

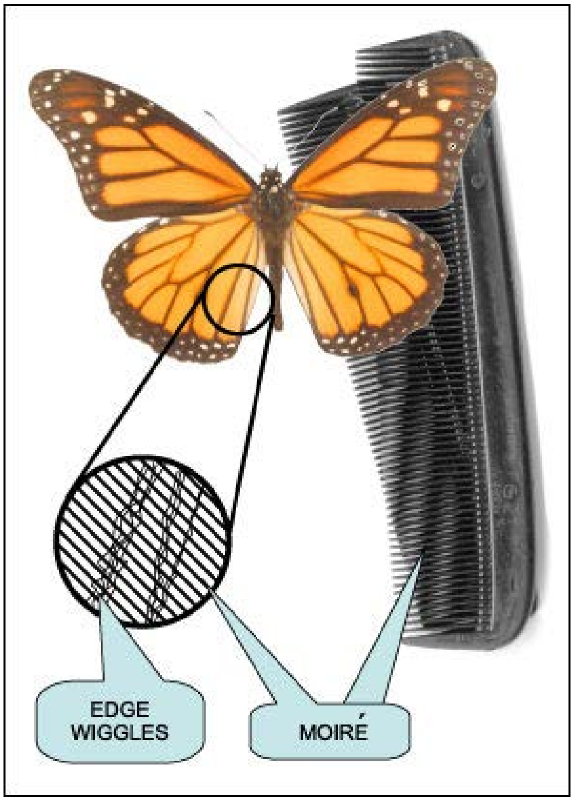

Figure 4. Picture interference resulting from poor video filtering.

Examples of Reconstruction Filter Application

Figure 5 demonstrates the results of a proper reconstruction filter. Some literary license has been taken to make the frequency folding easy to understand. Normally the frequency domain is plotted with both frequency and amplitude having logarithmic scales. The reconstruction filter would then be a smooth curve. However to illustrate the sideband position of the folding, the frequency and amplitude are plotted on linear scales. To show the attenuation of the lowpass filter on the same scale, the filter curve has been bent to show that there is little attenuation of the wanted video and greater attenuation of the image frequencies. Again, Figures 5b and 5c show the folding effect. Note that the image frequencies in Figure 5d are greatly reduced as compared to Figure 3d.

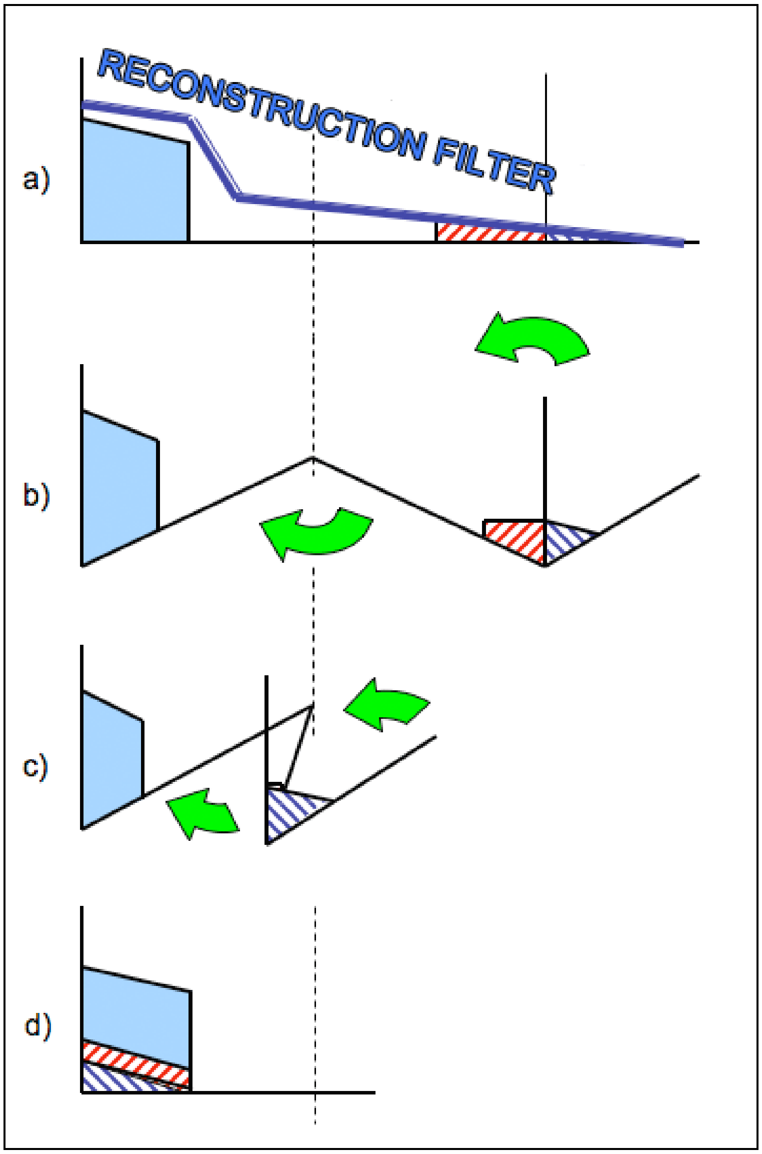

Figure 5. Proper reconstruction filtering reduces the visibility of the folded interference by smoothing the video waveform.

Consumer products are very cost sensitive, but thankfully there are far fewer analog and digital conversions. A typical home has one DAC and one ADC for example in a set-top box feeding an LCD TV set (**Figure 6**). In this case having an attenuation of 20dB (to less than 10 percent of the signal) is acceptable. A set-top box and an LCD TV typically have at least 12dB lower image attenuation in each unit. Two filters with 12dB attenuation add to create 24dB of rejection. This provides a comfortable manufacturing tolerance over the needed 20dB of attenuation.

The block diagram of Figure 6 details a set-top box or DVD player on the left side. The system on a chip (SOC) contains the DACs, whose outputs are routed to lowpass filters such as the MAX7443 which reconstructs the video. The filter ICs also contain 75Ω coaxial cable drivers to deliver the signals through the cables in the center of the diagram. The right side of Figure 6 receives the signals which are anti-alias filtered before going into the TV set's ADCs in the SOC. The Maxim filter drivers here protect the LCD TV from spurious signals which cause interference and aliases.

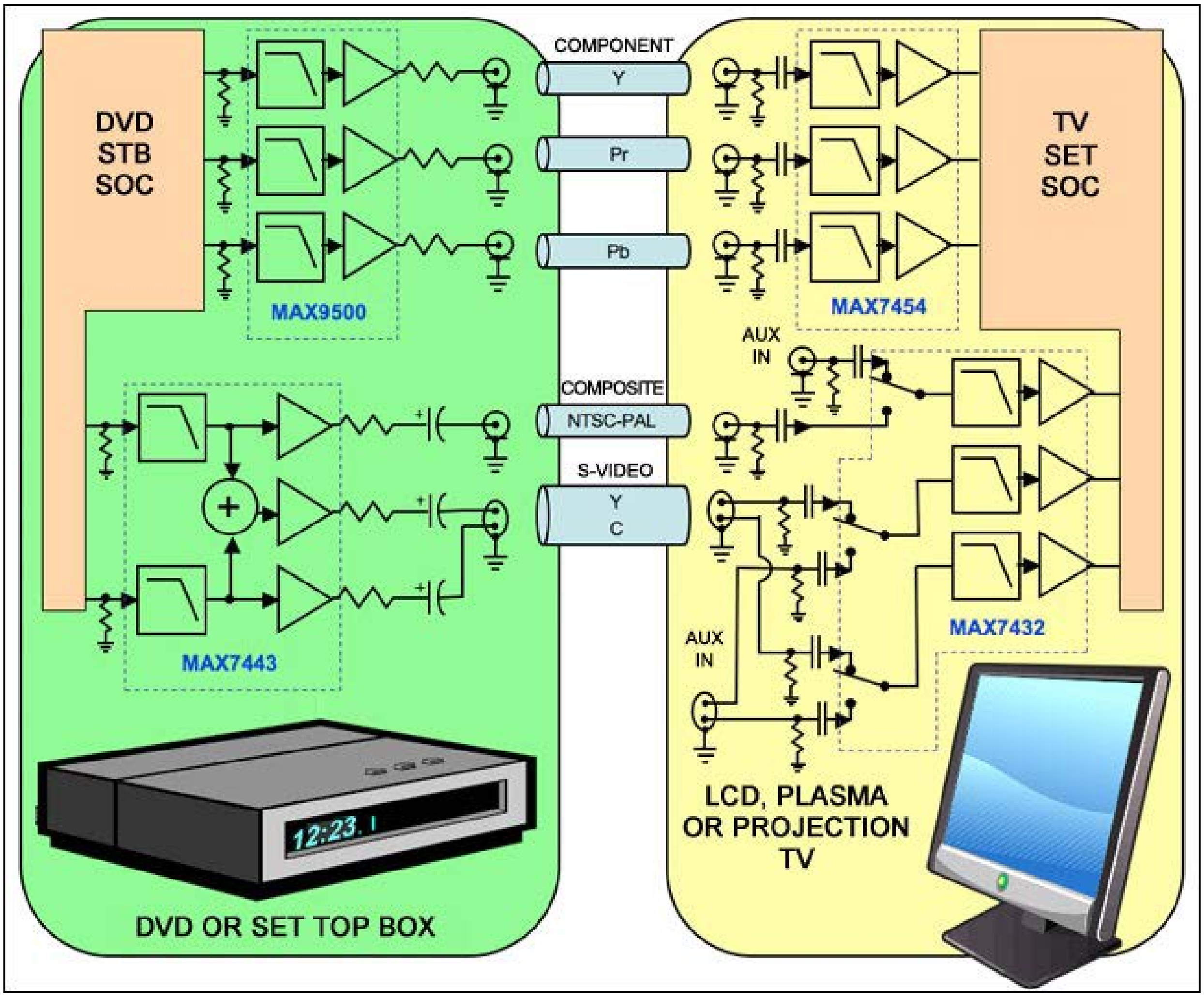

Figure 6. Block diagram of a consumer's home television system shows the proper video reconstruction and anti-alias filters.

The best picture quality demands that Nyquist is respected in the consumer's home video system. Manufacturers of consumer equipment can fall victim to the "last piece added syndrome" in a home. This occurs when a consumer has an operating multiunit system and includes a new piece of equipment. If the picture degrades, the consumer assumes that it is always the fault of the "just added piece." However, this might not always be true.

For example, assume that the consumer replaces a DVD player with a new unit. The existing LCD TV has a poor input filter (with 2dB attenuation). The old DVD player had a very good output filter (with 18dB attenuation), but the new DVD only has a poor or nonexistent filter (with 6dB or less attenuation).

Remember that Nyquist is important because video components and noise above the Nyquist frequency must be removed before an LCD TV redigitizes the DVD analog signal. If information above Nyquist is present, it will be confused with lower frequencies and aliased down to mix with, and corrupt, the video.

Therefore, the old DVD and LCD TV set had 20dB attenuation and the new combination has 8dB attenuation. As a result, the consumer returns the new DVD player even though the LCD TV is more responsible for the mysterious errors.

What can a manufacturer of set-top boxes, DVD players, and TV sets do to protect themselves from the "last piece added syndrome?" There are two principal steps to take.

1. Provide filters that function as designed. Some manufacturers use filters made of discrete inductors and capacitors on their PC boards. There is a potential problem with this: these discrete filters are subject to manufacturing mistakes. The wrong part value can be stuffed on the board. During mass production one might want a 270pF capacitor but pick up the reel marked "270" which is really 27pF. The resulting filter would pass unwanted high frequencies, thus creating picture artifacts in the next piece of equipment. To be cost sensitive, furthermore, the final production test does not test every parameter and typically filter bandwidth is not tested.

2. Use filters that provide more than the bare minimum 10dB attenuation. The additional attenuation will protect the manufacturer from consumer returns and keep the customers happy.

Conclusion

The Maxim family of filters solves both of the above "last piece added syndrome." Maxim's integrated filters are 100% bandwidth tested by the Company's automatic test equipment (ATE) before the filters are mounted to the PC board by the manufacturer of the end equipment. Maxim's filters also provide more than the typical industry attenuation. For example, the MAX7443 for SDTV provides more than 30dB image and more than 40dB, 27MHz clock attenuation. The MAX9500 for HDTV provides more than 38dB image and, additionally, more than 38dB, 74.25MHz clock attenuation.

A similar article was published on December 7, 2007 on *Video/Imaging DesignLine* by TechInsights, (formerly CMP), a division of United Business Media LLC.

Related Parts		
MAX11500	Three-Channel, High-Definition Video Filter	Free Samples
MAX11501	Three-Channel, Standard-Definition Video Filters	
MAX11502	Three-Channel, Standard-Definition Video Filters	Free Samples
MAX11504	Four-Channel, Standard-Definition Video Filters	Free Samples
MAX11505	Four-Channel, Standard-Definition Video Filters	Free Samples
MAX11506	Low-Cost, 6-Channel SD Plus HD/SD Selectable Video Filters and Buffers	Free Samples
MAX11507	Low-Cost, 6-Channel SD Plus HD/SD Selectable Video Filters and Buffers	Free Samples
MAX4079	Complete Audio/Video Backend Solution	Free Samples
MAX7428	Standard Definition Video Reconstruction Filters and Buffers	Free Samples
MAX7430	Standard Definition Video Reconstruction Filters and Buffers	Free Samples
MAX7432	Standard Definition Video Reconstruction Filters and Buffers	Free Samples
MAX7441	6-Channel Integrated Video Reconstruction Filters	
MAX7442	6-Channel Integrated Video Reconstruction Filters	
MAX7443	Triple-Channel Video Reconstruction Filter and Buffer for Composite and Y/C Outputs	
MAX7453	Triple-Channel Video Reconstruction Filter and Buffer for	Free Samples

	Composite and Y/C Outputs	
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MAX7463	Single-Channel Video Reconstruction Filters and Buffers	Free Samples
MAX9500	Triple-Channel HDTV Filters	Free Samples
MAX9501	Triple-Channel HDTV Filters	Free Samples
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MAX9503	DirectDrive® Video Amplifier with Reconstruction Filter	Free Samples
MAX9505	DirectDrive Video Amplifier with Reconstruction Filter and Analog Switch	Free Samples
MAX9508	Video Filter Amplifier with SmartSleep and Bidirectional Video Support	Free Samples
MAX9509	1.8V, Ultra-Low Power, DirectDrive Video Filter Amplifiers	Free Samples
MAX9512	Video Filter Amplifier with SmartSleep and Y-C Mixer Circuit	Free Samples
MAX9513	CVBS Video Filter Amplifier with SmartSleep and Bidirectional Video Support	Free Samples
MAX9516	1.8V, Ultra-Low-Power, DirectDrive Video Filter Amplifier with Load Detect	Free Samples
MAX9517	Standard-Definition Video Filter Amplifiers with Dual SPST Switches	
MAX9524	Standard-Definition Video Filter Amplifiers with Dual SPST Switches	Free Samples
MAX9583	Dual, Triple, and Quad Standard-Definition Video Filter Amplifiers with DC-Coupled Input Buffers	Free Samples
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MAX9585	Dual, Triple, and Quad Standard-Definition Video Filter Amplifiers with DC-Coupled Input Buffers	Free Samples
MAX9586	Single, Dual, Triple, and Quad Standard-Definition Video Filter Amplifiers with AC-Coupled Input Buffers	Free Samples
MAX9587	Single, Dual, Triple, and Quad Standard-Definition Video Filter Amplifiers with AC-Coupled Input Buffers	Free Samples
MAX9588	Single, Dual, Triple, and Quad Standard-Definition Video Filter Amplifiers with AC-Coupled Input Buffers	Free Samples
MAX9589	Single, Dual, Triple, and Quad Standard-Definition Video Filter Amplifiers with AC-Coupled Input Buffers	Free Samples

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