S3 s Savage2000 Accelerator:

A New Architecture for Superior PC Video

Abstract

This paper examines mainstream video applications on the personal computer (PC) and develops a set of video features for each application that results in an optimum end user viewing experience. Once application specific feature sets have been developed, implementation details affecting quality and performance will be compared and contrasted thus emphasizing the comprehensive video architecture of the Savage2000™ accelerator.

Introduction

In order to analyze such a broad topic as video on the PC, only mainstream video applications will be considered for the sake of brevity. These applications can be divided into the six major categories listed below. In addition, each category may be representative of additional applications. For example, analog TV tuners typically have configurations similar to video conferencing/video capture systems and are consequently grouped under the Video Conferencing/Video Capture category.

- Software Decode of MPEG-2
    - DVD
    - DTV (SDTV and HDTV)
- Hardware Decode of MPEG-2
    - DVD
    - DTV (SDTV and HDTV)
- Software Time Shifting (PC VCR applications)
- Hardware Time Shifting (PC VCR applications)
- Video Conferencing/Video Capture
    - Analog TV Tuner
    - Streaming Internet Video
- Large Screen Video Display

Each of these application categories has different feature set requirements as well as varying quality and performance requirements. Consequently, Savage2000 uses a modular approach to video processing in order to accommodate the specific needs of each application category.

Savage2000's video processing can be divided into 5 functional blocks:

Video Port - Video Interface Port (VIP) 2.0/Local Peripheral Bus (LPB) The Video Port allows digital YCbCr data (commonly referred to as YUV) to be input from a digitizer (video decoder), hardware MPEG decoder, or some other hardware device via a dedicated hardware interface for display by Savage2000. For maximum flexibility, Savage2000 supports both S3's proprietary LPB video port standard for legacy devices, as well as the newer VESA VIP 2.0 open interface standard for HDTV decoders, DVD decoders, and video digitizers. The VESA VIP 2.0 standard is backward compatible with VIP 1.1. In addition, the Savage2000 video port (LPB or VIP mode) also includes color enhancement (Contrast, Brightness, Hue and Saturation) and mirroring controls for video capture/video conferencing applications.

Some advantages of the VIP 2.0 port include:

- Open non-proprietary standard feature found in S3's Savage2000 Accelerator and future products.
- VIP 2.0 uses a 50-pin dual-row header connector (Connector A) plus a 14 pin connector (Connector B) for power, reset and I^2S digital audio.
- S3's Savage2000 accelerator fully supports VIP 2.0 Levels **I** and **II**. VIP 2.0 Level **I** supports an 8 bit/75MHz video port and targets SDTV (Standard Definition Television/HD0) DTV applications (720p 24fps). VIP 2.0 Level **II** supports a 16 bit/75MHz video port and targets HDTV (High Definition Television/HD1) DTV applications (1080I 60fps).
- VIP 2.0 has comprehensive PnP with System ID and Subsystem ID and also supports power down mode.
- With VIP 2.0, the detection of odd and even fields is very reliable. The VIP video format is based on the ITU-R-656 video standard that defines odd/even field flags in the headers in the video data.
- Through the VIP 2.0 host port, compressed video data can be transferred to a daughter card.
- S3's Savage2000 Accelerator supports a bus mastering DMA channel from system memory to the VIP 2.0 host port FIFO. DMA bus mastering significantly reduces CPU overhead, offers much higher latency tolerance, and provides a much more reliable system environment.
- VIP 2.0 is backward compatible with VIP 1.1.

Overlay The overlay block (Streams Processor, Secondary Stream) allows digital YCbCr data or RGB data in off-screen graphics memory to be displayed in a high-quality window on top of the primary graphics screen. The color depth of the overlay window is independent of the primary graphics screen. For example, it is possible to display 24-bits/pixel equivalent video on top of an 8-bit graphics background. By using the overlay to display video, memory bandwidth and storage capacity are reduced while permitting higher video frame rates since the graphics desktop does not have to be placed in a 24-bit color depth mode to display a 24-bit video window.

In addition, the overlay can also use color keying to define the shape of the video window, allowing for irregularly shaped areas of video to be displayed. When in color keying mode, the overlay window can be thought of as under the graphics desktop as opposed to over it. Using color keying, video can be displayed through any desktop color that is defined as transparent. This area can have any shape or size.

The overlay block supports resolutions up to 1280x1024 at 85Hz or 1600x1200 at 60Hz with programmable color space coefficients for YCbCr 4:2:2 and YCbCr 4:2:0 video data. YCbCr 4:2:2 data (CCIR-601 and CCIR-656) is typically output by video digitizers, digital cameras, DVD and DTV hardware decoders. YCbCr 4:2:0 data is typically output by software MPEG-2 decoders. The overlay block can adjust the hue, saturation, color, and brightness settings for both types of video data compensating for minor variances in luma and chroma (i.e. CCIR-601 vs. CCIR-656) and ensuring the best possible video display.

Video Engine Unit (VEU) The primary function of the video engine is to read data from either system or video memory and transfer the data to the video memory (frame buffer) after performing one or more of the operations listed below:

- Subpicture blending (for DVD playback)
- Horizontal scaling (up/down – 2/up to 16 taps)
- Vertical scaling (up/down – 2 /up to 16 taps)
- Format conversion
    - RGB888 (32 bit per pixel) to RGB565 (16 bit pixel) – For multimedia file playback
- Color space conversion
    - YCbCr4:2:2 to RGB888 – For display of digitizer data or multimedia file playback
    - YCbCr4:2:2 to RGB565 – For display of digitizer data or multimedia file playback
- Color enhancement (Hue, Saturation, Contrast, and Brightness).
- De-interlacing

Master Engine Unit (MEU) The Master Engine Unit allows bus master transfers of video data from system memory to frame buffer or from frame buffer to system memory. While the CPU normally controls the transfer of information over the PCI/AGP bus, bus master transfers allow the graphics chip to take control of the PCI/AGP bus without requiring the intervention of the CPU. By using bus master transfers, the CPU can be freed to do other work while video data is being transferred back and forth across the bus. The MEU supports three different kinds of bus master operations for video:

- Master Image Transfer (MIT) – Copies blocks of data in any format (RGB, YCbCr, etc) from system memory to the frame buffer or vice versa. The MIT command also copies blocks of data from the frame buffer or system memory to the VIP host port FIFO. In addition, the MIT command performs planar-to-packed format conversions (for YCbCr4:2:0 MPEG-2 data).
- Scaled Image Transfer (SIT) – Transfers an image from system memory to frame buffer or vice versa, optionally stretching, shrinking, or color space converting video data in combination with the VEU. For example, YCbCr422 to RGB16. The SIT command also performs subpicture alpha blending for software DVD and planar-to-packed format conversion.
- Motion Compensation (Macroblock Command) – Reads software DVD IDCT data from system memory and sends it to the Motion Compensation Acceleration Unit for further processing.

MPEG-2 Acceleration Unit (MAU) The MPEG-2 Acceleration Unit is used for hardware accelerated DVD playback. It reads data output by the IDCT stage of a software MPEG-2 decoder and does the motion compensation part of the decode using motion vector and other control data output by the software decoder to create a complete MPEG-2 frame in the frame buffer. Savage2000 features a third generation MPEG-2 acceleration unit.

Depending on the video application, these five blocks can be engaged or disengaged in combination together or separately.

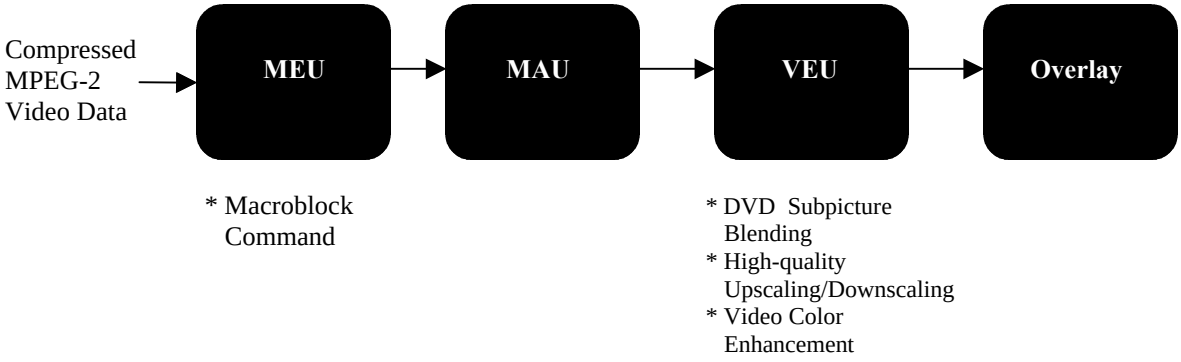
Software DVD

DVD has rapidly become the predominant video application on the personal computer. Due to faster processor speeds, software decode has also gained popularity as the preferred DVD decode method due to its high performance, low cost and ease of installation.

In order for software DVD solutions to truly rival the quality and performance of dedicated hardware DVD solutions, software DVD solutions require the graphics chip to have a specific set of features optimized for DVD play back. These features include:

Software DVD Specific Feature	***Benefit***
MPEG-2 Motion Compensation	• Enables 24/30 fps playback of DVD content on slower CPUs. • Frees up CPU bandwidth on faster CPUs for more responsive multitasking. • Frees up PCI/AGP bus bandwidth to allow more responsive multitasking.
Universal DVD Decoder Support/ Direct Draw 7 Hardware Video Acceleration (HVA) Interface	• Gives customers more options in selecting a software decoder that meets their performance, quality and cost requirements.
DVD Subpicture Blending	• Similar to consumer set top DVD players, alpha blending mixes subpicture (subtitle) information with the video data using multiple levels of transparency (15) for correct display of DVD menus and other interactive graphics encoded with DVD titles.
High Quality Multi-tap Upscaling and Downscaling	• Enables the video image to be enlarged or reduced without degrading the picture quality.
Video Color Enhancement	• Similar to a television set, video enhancement enables the user to adjust the hue, saturation, color and brightness of the video image to his or her preference.

When using a software DVD application, Savage2000 uses the following video processing blocks:



Savage2000 Motion Compensation The DVD video format is based upon the MPEG-2 video-coding standard. In this standard, motion vectors are used to describe the movement of pixels from one successive frame of video to the next. By storing the movements of blocks of pixels, as opposed to the pixels themselves, MPEG-2 achieves significant compression. From a graphics chip perspective, motion compensation refers to the process of decoding delta information (output of the IDCT stage of the software decoder) and movement information (Motion Vectors) into frames of video. This process is the most CPU intensive part of the DVD decode process since the CPU has to copy a lot of data slowly over the PCI/AGP bus.

In order to reduce CPU overhead and decode DVD-Video on slower systems (Pentium II 266 MHz, etc.), Savage2000 features highly optimized, third generation motion compensation hardware (MAU). The Savage2000 motion compensation block not only lowers CPU utilization, but also reduces the amount of data transferred over the PCI/AGP bus, as compressed data–not decompressed data–is transferred. This allows for more bus bandwidth to be available for other applications.

Unlike competitive solutions on the market, the Savage2000 motion compensation block achieves highly effective CPU utilization by efficiently packing IDCT/Motion vector data. In some solutions currently on the market, IDCT and motion vector data are mixed together in the format output by a particular decoder. Changing the decoder requires the driver to reformat all of this data to match the hardware interface. This means the CPU must reread all of the data output to memory or directly to the accelerator. This reformatting step severely impacts performance as it consumes system memory bandwidth as well as CPU bandwidth that could otherwise be used to decode more frames per second. By keeping the IDCT and motion vector data separate, Savage2000 eliminates any need to reformat. This reduces CPU utilization dramatically, making Savage2000 a better solution on a wider range of platforms.

Savage2000 Subpicture Blending DVD uses a concept called “subpictures” (graphic overlays) to display additional user information such as subtitles, captions, menu highlighting, etc. over video. A DVD disc may contain up to 32 channels of subpicture information, with each subpicture containing up to 16 simultaneous colors and each color having up to 14 levels of transparency, plus opaque. Unlike competing graphics chip solutions, which use color keying (on or off) to display subtitles, Savage2000 uses hardware alpha blending. Hardware alpha blending allows Savage2000 to set a level of transparency for each subpicture pixel as intended by the content producer. With Savage2000’s subpicture blending, subpictures display the same as on dedicated DVD players. Using color keying, they do not.

Savage2000 Scaling Of all the operations that can be performed by Savage2000’s video engine (VEU), the primary feature is video scaling. Video scaling is an operation where one is interested in either increasing or decreasing the dimensions (width and height) of a given source image. In the following section, we will discuss some of the fundamental

aspects of scaling and compare the technique implemented in Savage2000 with those available in other current generation graphics accelerator chips.

The general idea of downscaling images is to reduce the width and height of a given source image. There are several ways to downscale images and, as always, there are good and bad ways of achieving the target. The performance of any scaling algorithm is evaluated based on the extent to which visual artifacts corrupt the quality of the output. Two of the visual factors that compromise the quality of the output are the amount of aliasing in the destination image and also, the extent to which the image is blurred. Aliasing shows up as jagged patterns in the high frequency regions of an image. Often times, these jagged patterns can be tolerated in still images. However, when they manifest as creeping artifacts in motion video, a poorly implemented downscaling technique might render a visually unacceptable result. One commonly accepted way to determine the quality of a given downscaling technique is to use a test pattern such as the Zone Plate shown in Figure 1 below.

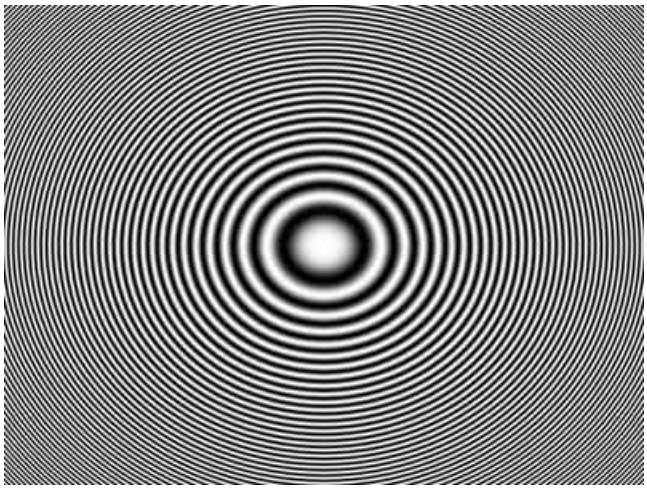


Figure 1.
Original Zone Plate image
(400 x 300 resolution).

Until Savage2000, most graphics chips in the market used either decimation or linear interpolation for downscaling images. Decimation is a primitive downscaling method performed by dropping pixels (in the horizontal direction) or by dropping scanlines (in the vertical direction). Although this approach is easy and straightforward to implement, there are both conceptual and performance problems associated with it. Dropping pixels (or lines) amounts to sub-sampling the input data stream which could result in a severe aliasing problem, especially when the scaling ratio is large (scale factor defined as source dimension/destination dimension). This is because the Nyquist criterion[1] for sampling is violated. Aliasing artifacts can be reduced to an extent by first pre-filtering (using an antialiasing filter), thereby band limiting the frequency components in the source image. Even then, the output may not be acceptable.

Results can be further improved by using interpolation filters. Linear interpolation is often used due it its ease of implementation and, if the cost of implementation is not an issue, interpolation can also be done non-linearly. Although the interpolation filters significantly improve the quality of scaling, they have a fixed number of taps and thereby perform well only over a “range” of scale factors. Savage2000’s approach is to use a downscaling filter where the number of taps varies with the scale factor and the filter coefficients are computed dynamically. Consequently, Savage2000 has superior performance over a wide range of scale factors [1.0, 16.0]. Figure 2.a illustrates the superior image quality generated by Savage2000 when the Zone Plate image shown in Figure 1 is downscaled to a target resolution of 320x180. Figure 2b shows the same Zone Plate image downscaled by using linear interpolation in horizontal and vertical directions. Notice the artifacting (visible as “ringing”) introduced on the Figure 2b image from the poor quality downscaling.

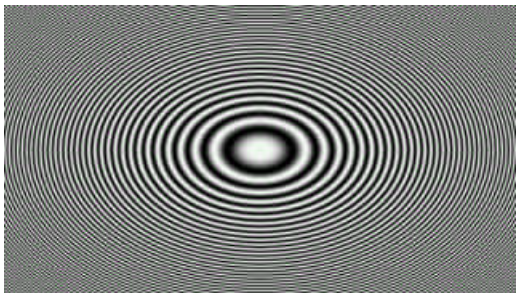


Figure 2A. Zone Plate image (400x300) downscaled to 320x180 using the Savage2000 video engine. Notice the image contains few artifacts (visible as “ringing”).

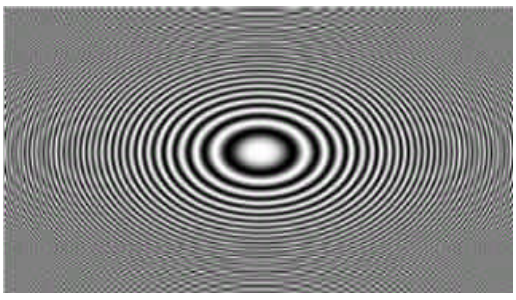


Figure 2B. Zone Plate image (400 x 300) downscaled to 320 x 180 by using linear interpolation in the horizontal and vertical directions. Notice the artifacts (visible as “ringing”) introduced on the Zone Plate image from the linear interpolation algorithm.

[1] The sampling frequency should be greater than twice the maximum frequency component for proper signal reconstruction.

A popular way of upscaling images is via pixel replication or by introducing new pixels as a linear combination of neighboring pixels at regular intervals. While popular, both methods suffer from severe aliasing artifacts. In addition, the latter approach introduces undesirable artifacts especially when scaling motion video. Images tend to remain sharp in parts of the image where the original pixels are retained and blur out in regions where new pixels are introduced. In Savage2000 however, bilinear interpolation (2-taps each in horizontal and vertical directions) is used to perform upscaling while reducing aliasing artifacts.

Software DTV (SDTV and HDTV)

Digital television is quickly gathering momentum as one of most compelling video applications on the personal computer. However, wide variances continue to exist in the capabilities of commercially available PC DTV solutions. One trend has been towards "soft DTV" decode solutions where the MPEG-2 video data is either decoded by the CPU alone or assisted by the graphics chip using a combination of motion compensation and IDCT or just motion compensation alone.

"Soft DTV" solutions are commonly touted as an affordable option for DTV viewing, but – unfortunately – this is not the case upon closer inspection. Due to the intensive processing power required to decode HDTV, software-based DTV decode solutions only support a subset of the 18 possible DTV resolutions. This subset, known as HD0, constitutes the lower resolutions of the DTV standard, which are also referred to as Standard Definition Television (with the exception of the 720p 24fps mode). Since broadcasters are free to transmit different levels of DTV resolution (SDTV and/or HDTV) throughout the broadcast day, this means a "soft DTV" is a partial solution and must be combined with an additional hardware DTV decoder or "hard DTV" solution to receive all 18 DTV resolutions. In addition, a "soft DTV" solution still requires 75% of the electronics of a "hard DTV" solution (Figures 3 and 4).

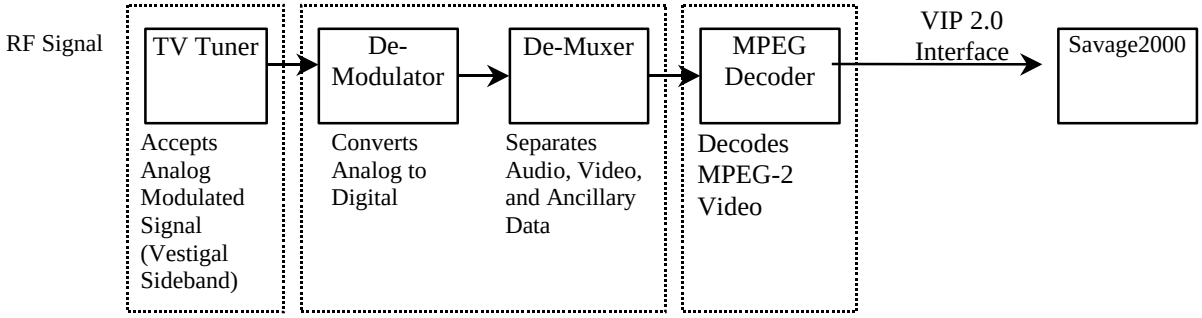


Figure 3. Sample decoder card for full DTV decode (SDTV and HDTV)

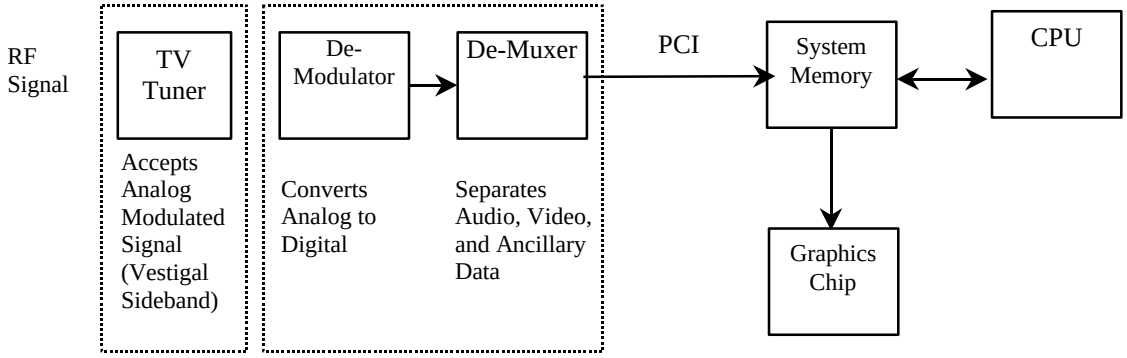


Figure 4. Sample decoder card for partial DTV decode (SDTV only)

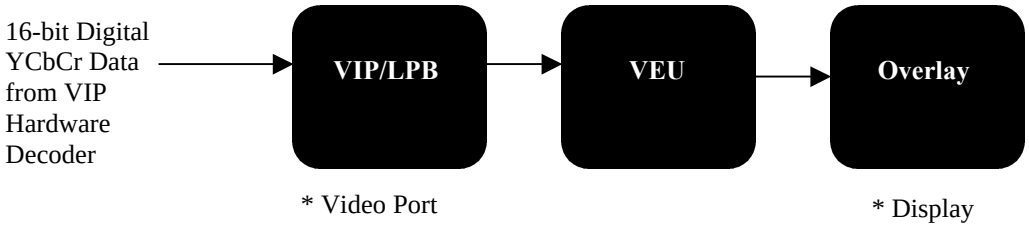
As illustrated in the examples above, both the soft and hard DTV solutions use the same tuner, de-modulator and de-muxer electronics, however the soft DTV solution cannot display HDTV content. To enable software decoding of HDTV content, an Intel Pentium III or AMD Athlon-class processor with a clock speed in the neighborhood of 750MHz would be required. Systems with this clock speed are far from mainstream and are not available for second half of 1999. For these reasons, Savage2000 does not support soft DTV decode and instead concentrates on issues relating to the quality of the DTV display.

Hardware DVD and DTV

For those customers who prefer a dedicated hardware DVD or DTV solution, Savage2000 offers a compelling feature set. These features include:

Hardware DVD/DTV Specific Feature	***Benefit***
Fully Compliant VIP 2.0 Port	• Supports cost-effective industry standard DVD/DTV hardware decoders • Supports multiple DVD/DTV configurations, including daughterboards, combo boards, and PCI add-in-cards
DMA bus master on VIP host port	• Reduces CPU overhead • Provides a much more robust system environment
High-quality Upscaling and Downscaling	• Enables the video image to be enlarged or reduced without degrading the picture quality.
Video Color Enhancement	• Similar to a television set, video enhancement enables the user to adjust the color, saturation, hue and brightness of the video image to his or her preference.
De-interlacing	• For display of interlaced DVD content on progressive scan (non-interlaced) PC monitors.

When using a hardware DVD or DTV application, Savage2000 uses the following video processing blocks:



Savage2000 De-interlacing De-interlacing is the process of displaying video (interlaced) information on a computer monitor (progressive) where fields (top and bottom) coming in at a rate of 60 fields per second have to be converted to frames at 30 frames per second. One cost-effective de-interlacing technique is to weave two adjacent fields together to generate a frame. This solution works well if motion has not occurred between the fields being merged. If there is motion, weaving leads to an annoying artifact known as feathering. A second solution called the Bob method, simply upscales fields by a factor of two in the vertical direction and displays them successively. To reduce a noticeable jitter in the output sequence, the bottom field is shifted down by one scan line. The Bob method works even when there is motion between fields, but suffers from a shimmering artifact due to a loss in picture resolution. For software DVD playback, the method is automatically switched frame by frame depending on which will yield the best quality.

Software Time Shifting

Television time shifting applications, also known as PC-VCR applications, are rapidly emerging on the PC. These applications combine an MPEG-2 encoder, MPEG-2 decoder, hard disk drive storage and network connection to form a highly intelligent VCR. Time shifting applications offer user benefits such as the ability to view programs while they are still being recorded and the ability to self-program among other things. With the availability of Pentium III 500MHz systems with SIMD extensions, a growing number of software vendors are beginning to offer software-based time shifting software packages. By utilizing Savage2000's third generation motion compensation block, these applications are assured of full frame rate playback while freeing up the CPU for the more demanding task of encoding video.

Hardware TimeShifting

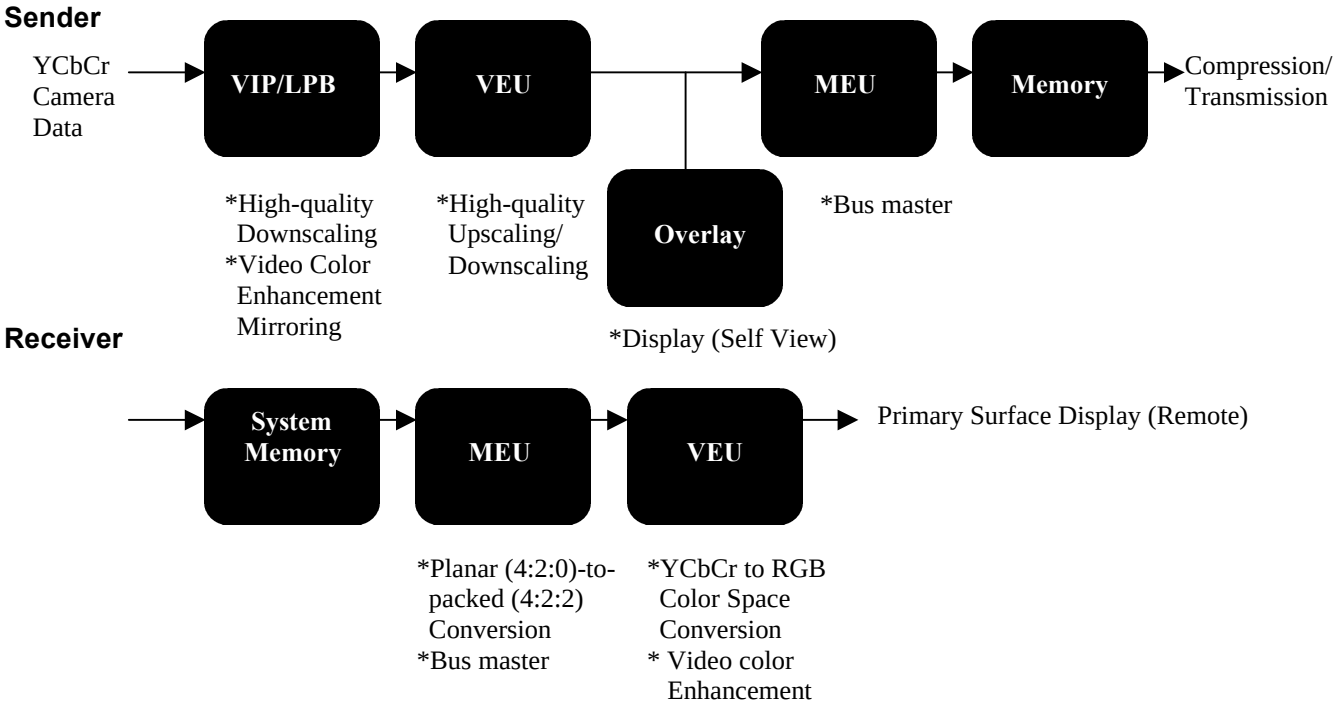
Hardware time shifting applications are similar in functionality to software based systems except for the use of dedicated hardware to encode video. By utilizing dedicated hardware, these systems greatly reduce the minimum requirements of the target system and are operational in a much wider installed base. However, hardware encode products developed for hardware time shifting applications can differ greatly in feature sets. By utilizing Savage2000's third generation motion compensation block, manufacturers of hardware time shifting applications are permitted a wider range of encoder choices including products that do not support simultaneous decode.

VideoConferencing (includes Video Capture)

Video conferencing has maintained its appeal as a communications tool with the advent of communication standards that enable interoperability, the declining prices of cameras and application solutions, the deployment of high-performance PCs and the emergence of the Internet as a communications platform. Multiple components are required in the processing of video/audio/data streams over communication lines. For multimedia accelerators, the value-added features are centralized to the pre- and post-processing of video data:

Video Conferencing Specific Feature	*Benefit*
High-quality Downscaling	• QCIF (176X144) resolution is the default capture size for most video codecs due to the challenge of transmitting video data over limited bandwidth. High-quality downsizing enables a high-compression ratio while maintaining good video image quality.
VIP 2.0 Video Port	• Supports industry standard digitizer devices (Brooktree, Phillips, Samsung, etc.) • Provides a much more reliable system environment – odd/even field detection is very reliable
Planar-to-Packed Format Conversion	• Alleviates the application from converting the video format in software, freeing valuable CPU cycles.
Bus-mastering	• Increases video capture performance, which improves the rate for real-time video transmission. Also allows the CPU to compress and decompress data in parallel with data transfers to maximize frame rates.
Mirroring	• Enables the user to flip images for self-view.
Multiple Video Windows	• Enables high-quality video images for multi-point video conferencing applications
Video Color Enhancement	• Enables the user to adjust the color, saturation, hue and brightness of the video image to his or her preference.

When using a video conferencing application, Savage2000 uses the following video processing blocks:



Savage2000 Multi-Window Display Multi-point video conferencing requires more than two video windows to be displayed. Savage2000's VEU allows an arbitrary number of multiple video windows to be displayed at any given time using the same high-quality scaling algorithm for each window. In addition, the VEU performs a hardware based YCbCr to RGB conversion for each window offloading the CPU and freeing valuable CPU resources for other tasks. The hue, saturation, color, and brightness for each video can be adjusted using the VEU color enhancement. The number of available video windows is dependent on the size of each window, the resolution of the Windows desktop, and the size of the frame buffer.

L a r g e S c r e e n V i d e o D i s p l a y

Large screen video displays enable the personal computer to be used as a presentation device for large audiences or as a game console for multiple players. This functionality is enabled by NTSC/PAL encoders, which convert VGA computer signals to NTSC or PAL video signals. Until Savage2000, however, NTSC/PAL encoders had less than ideal configurations. Either the NTSC/PAL encoder had to be embedded internally within the graphics chip driving up the chip cost, or an expensive external NTSC/PAL encoder with an analog interface had to be used. Savage2000 solves the NTSC/PAL encoder problem by utilizing a high-speed digital interface for lossless data connections to high-quality, low-cost NTSC/PAL encoders. By utilizing a digital connection, Savage2000 avoids the analog conversion, which results in data loss and reduces the encoder cost by eliminating the need for an analog front end.

Conclusion

As highlighted by the following table, S3's Savage2000 is a comprehensive video architecture which delivers a new level of features, functionality and performance for the widest range of PC video applications.

	S3 Savage2000	Nvidia TNT2 Ultra	3Dfx Voodoo3 3500	ATI Rage 128	Matrox G400
MPEG-2 Motion Compensation	✓	✓	No	✓	✓
Universal Codec Support (HVA)	✓	✓	No	✓	✓
Hardware Subpicture Blending	✓	✓	No	No	✓
Dynamic High quality Multi-tap Upscaling and Downscaling	✓	No	No	No	No
Fully Compliant VIP 2.0 Video Port	✓	No	No	No	No
VIP Host Port Bus Mastering	✓	No	No	✓	✓
Multiple Hardware Video Windows	✓	No	No	✓	✓
NTSC/PAL Digital Out Port	✓	✓	No	✓	✓