Avivo and the Video Pipeline

Delivering Video and Display Perfection

Introduction

As video becomes an integral part of the PC experience, it becomes ever more important to deliver a high-fidelity experience to the end user by providing a solution of the highest quality. This entails treating the video data properly from the moment it enters the PC to when it is displayed. This end-to-end process is referred to as the video pipeline.

The growing integration of media into the PC experience is exemplified by growth in deployment of media center PCs (increasingly becoming components of home theaters) and the arrival of High Definition video (from network TV and imminently, on HD disc formats such as Blu-ray and HD-DVD). The explosion in digital photography and digital imaging also brings new importance to vibrant, high-fidelity displays.

Avivo is ATI's next-generation video and display platform that is targeted specifically at delivering the highest quality and performance for this growth in media usage. Avivo has a number of technologies that provide new video experiences, and numerous capabilities representing a quantum leap in quality tailored to the best experience for all display needs. Some of the key capabilities delivered by Avivo are:

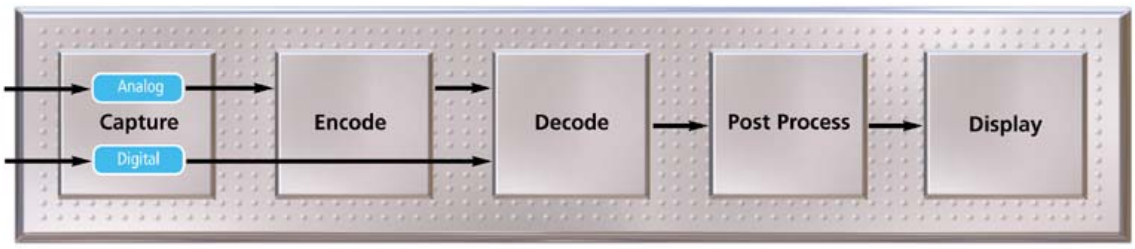
- The Media PC experience: tuner-enabled PCs entering the living room and becoming the premier consumer electronics device for TV and PVR (personal video recorder) functionality
- The Digital TV revolution: Digital, over-the-air broadcasting is taking hold worldwide. The ability to receive and playback these signals will be central to future media PCs
- HD-Disc playback: Next-generation blue-laser optical discs such as Blu-ray and HD-DVD are on the horizon. Avivo enables their use on the PC with advanced decoding capabilities
- Digital Photography and Digital Imaging: with digital imaging becoming an integral part of people's professional and personal lives, it becomes important to deliver a flexible, flawless experience to even the most demanding user

This whitepaper provides an overview of the key technologies that underpin ATI's Avivo video and display platform. It provides an introduction to the video pipeline, and helps the reader understand the ways that ATI delivers the key benefits and capabilities that Avivo espouses.

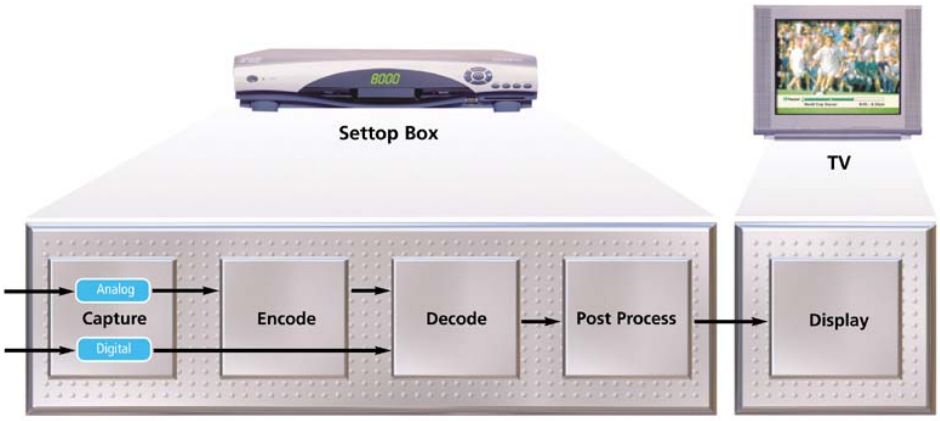
To fully understand how ATI Avivo can deliver these to the end-user, it is helpful to take a look at how ATI technologies work together in what we call the video pipeline.

The Video Pipeline – An Overview

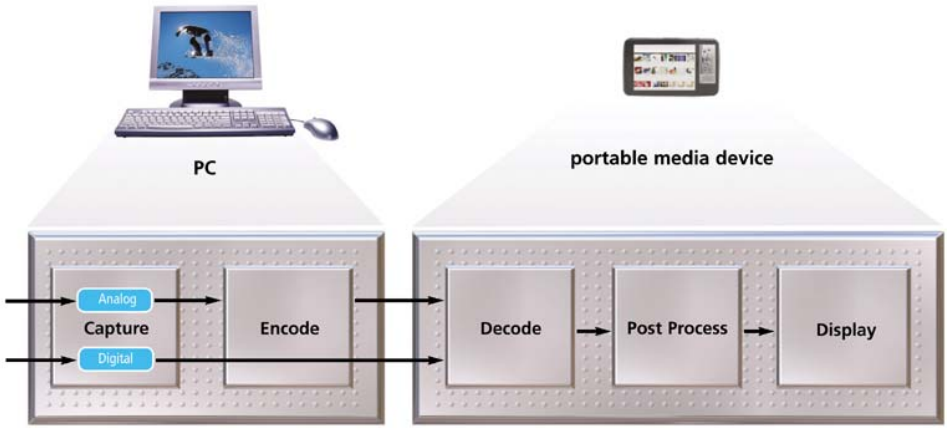
From the time a video signal enters a system to the time the image is displayed on a TV or computer screen, it undergoes several steps of processing and format transformations. This is true whether we are talking about a PC or a consumer electronics (CE) device such as a TV or set-top box. These steps are communally referred to as *the video pipeline*. We will examine each of the key stages of the video pipeline.



First it should be noted that the 'video pipeline' concept is quite general, as the entire video pipeline does not always apply to any given device (PC or CE). For example, a PC that is not equipped with a TV tuner capability will not typically have tuning or encoding capabilities. Some of the possible configurations



Here, a cable set-top box is responsible for all the decoding and processing, while the TV set does any final processing for the display inside the unit (e.g. CRT, LCD, Plasma, etc)



Here, a PC does video capture and the content is then transferred (with transcode, if necessary) to a portable media device, where it is decoded, processed and displayed

Capture

Video capture is the process of acquiring video data in digital format so that it can be stored, processed and displayed by the subsequent parts of the video pipeline.

In the case of analog capture, a video signal is tuned to, demodulated (separated from a carrier signal used for transmission) and then digitized. This is where the signal effectively

enters the digital world, and it is critical that the best digitization process is used to achieve this. Here, analog-to-digital converters (ADCs) perform the necessary digitization.

In the case of digital capture, a digitally-encoded signal is tuned to and demodulated, but no digitization is required, as the demodulated signal is effectively a compressed video stream ready for decoding. The next stage of the pipeline, encoding, is typically not required as the digital signal is already compressed.

A number of key factors are required to ensure the high quality capture of video, and as with the processes themselves, there are differences between analog and digital. Good analog capture is characterized by high quality signal separation (comb filtering), high bit-depth Analog-to-Digital conversion, and adaptability to the incoming signal.

In the case of digital capture, particularly in the case of over-the-air digital broadcasts, compatibility with the local transmission standard and high signal sensitivity are the key capabilities to pursue.

Encoding (compression)

Once the video is captured from an analog source, it needs to be compressed; this entails encoding it into a format such as MPEG-2 or other compression schemes scheme (codec). The compression offers a more practical means of storing the data for archiving or time-shifting applications, commonly used in Personal Video Recorders (PVR).

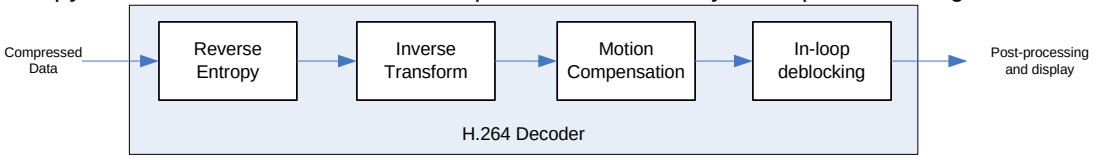
When the video has been captured from a digital source, there is sometimes a need to decode the video from its existing codec and then encode it into another codec; this is referred to as transcoding. Transcoding is usually employed when there is need to bring the video to another device or format. Examples include: a PC on a home network, a portable media device, PDA or even video-capable cell phone.

The compression scheme is standardized, in that the resulting stream of data (bit stream) is output in a specific, fully defined format; however, the actual compression -or encoding- algorithm is not standardized, and thus have potential to be implemented in different ways. These algorithms can be proprietary in nature, and they are typically very processing-intensive operations.

A good compression implementation is one that has high efficiency in terms of resource utilization (CPU, VPU or other hardware) and in terms of the compressed output (low bandwidth requirement for high quality video).

Decoding (decompression)

The decoding stage transforms the compressed video signals back into moving images to enable video playback. This stage involves no proprietary steps, since for each specific codec, the phases are pre-determined; for example, in the case of H.264, it's as follows: reverse entropy, inverse transform, motion compensation and finally in-loop de-blocking.



Simplified illustration of the H.264 decode process

Because decode is an explicitly defined process, 'good decode' can be measured only in terms of how resource-efficient it is. On the PC, this really translates into low CPU utilization (% CPU), which in turn delivers key benefits:

- Lower power consumption, very important for mobile applications
- A less powerful CPU is required in the system, which enables bringing high quality video to lower-cost systems
- More CPU power available for multi-tasking with other applications (such as simultaneous software video encode for PVR)

Post-processing

The post-processing stage is a critical step required to ensure accurate reproduction of the original video signal, and to improve the quality of the video. In cases where the video is interlaced and the display device is not (e.g. interlaced TV signals displayed on a PC display) or vice-versa (e.g. progressive film content output to an interlaced TV), then post-processing techniques become critical to the process of bringing the video frame to the user.

Examples of post-processing steps are de-interlacing, frame-rate conversions, scaling, and color correction.

Comparison of simple (left) vs. advanced de-interlacing (right)

In sharp contrast to the decoding step of the video pipeline, post-processing does not have a definite 'recipe' that must be followed; differing implementations are free to process video in different ways. Equally, however, there is no benchmark by which implementations can be measured for accuracy, quality or efficiency.

'Good' post processing is really defined by the subjective quality of the final image to the viewer's eye, but there clearly better ways of delivering key some key processing steps such as de-interlacing and 3:2 pulldown, amongst others.

Display

Display refers to the actual connection that exists between the source (e.g. the VPU in a PC system) and the actual display device (a monitor or TV connected to the PC). This connection

consists of two portions: the actual interface used to connect to a specific display, and any additional processing (over and above any video processing that may already have been done) that is performed by the source in order to best match the processed image or video to the actual display device being used.

Different display devices have different characteristics that can vary widely:

- Gamma response
- Color space (RGB or YP_rP_b)
- Color response and white point
- Resolution and aspect ratio
- Color depth (bits per color)

Ideally, display processing needs to take the above into account and tailor the outgoing image to the display device. To date, display controllers in PC GPUs only perform a limited subset of the manipulations necessary (e.g. low-precision gamma correction, hard-coded color space conversion, limited or no scaling)

In addition to this final processing, high quality connections need to be in place to ensure the fidelity of the displayed video or image to the original content. Typical PCs have analog and digital connectors:

- Analog: Component (D-connector), S-Video, Composite, VGA
- Digital: DVI, HDMI, LVDS (notebook internal interface)

A PC display controller that is unable to preserve and tailor the video signal jeopardizes any of the decoding and post-processing work that it may have done. The display is the last gatekeeper to a good video experience.

Because of the display-specific processing that takes place here, it is of great use to all visually-oriented applications, including still-image editing, workstation applications and gaming. In all such cases, the processing optimizes the image to the display being used for the best visual appearance.

In order to both preserve the quality of the video from the video pipeline, and to deliver all-round image quality for all applications, the display portion of a modern GPU needs to:

- Flexibly and completely support display specific characteristics with high bit depth processing
- Offer wide range of high-quality outputs in analog and digital going up to the highest resolutions available on displays.

Delivering Avivo

Equipped with an understanding of the video pipeline, it becomes possible to examine how Avivo is delivering new media capabilities along with key quality benefits to the end-user.

Avivo is a set of technologies that, when used together, delivers the best video and display experience. This is achieved by having the entire video pipeline implemented in ATI's Avivo-enabled products.

Each of Avivo's benefits is underpinned by features and capabilities implemented in ATI products; these capabilities can be found throughout the pipeline. In the following section we will explore some of the technologies that Avivo brings to the video pipeline to ultimately deliver an integrated, high-fidelity experience for the end user. Note that only key, new technologies are discussed in detail here.

Avivo Capture

Products featuring Avivo Capture capabilities include the ATI TV Wonder Elite and other Theater 550 Pro based TV capture products; ATI's Theater T3xx and Nxtwave products are digital demodulators that are targeted at the Digital TV market but also serve in ATI's PC products such as the HDTV Wonder and also deliver Avivo Capture capabilities.

Analog Quality Ensemble

This refers to a set of technologies that have been implemented in ATI's Avivo analog capture products to ensure the very best in quality and performance. These include Automatic Gain Control, 12-bit analog-to-digital conversion, and 3D comb filtering and noise reduction.

Automatic gain control

ATI TV/Video capture products since Theater 550 Pro have the ability to examine the incoming video and to dynamically boost the signal (i.e. change the gain) in order to ensure that the signal going into the rest of the pipeline is as rich in brightness and color contrast as possible. The dynamic ability to boost the signal only as much as necessary (and not over-saturate it otherwise) is the key to vibrant quality brought on here.

Avivo Automatic Gain Control (left) ensures that the image always has the right brightness balance and avoids the 'washout' seen on competing tuner products.

12-bit analog to digital converters (ADCs)

The process of converting an analog signal to digital is critical to ensuring that high-quality data is fed to the rest of the video pipeline. Anything in the analog signal that is not properly converted is then permanently lost, jeopardizing the work of the rest of the video pipeline. ATI's 12-bit ADCs sample the analog signal right into the fine-grained detail of the signal to ensure that the best possible data is made available for use further down the pipeline

Avivo 12-bit Analog-to-Digital conversion (left) vs. low quality 9 or 10 bit ADC

3D comb filtering

Comb filtering is a pre-processing step used to separate the color and brightness signals on incoming video when these are input together (as in over-the-air TV and composite video). Simple comb filtering separates these signals from within a single image (thus called 2D comb). ATI's advanced comb filtering is 3D: it uses the two dimensions of the image plus the third dimension of time to best separate the signals.

Avivo 3D Comb filtering (left) vs. typical 2D comb filtering (right – note color bleeding on brown buildings)

Hardware noise reduction

'Noise' in video manifests itself in the form of additional graininess or 'snow' in the video image. This noise has two key detrimental effects: it is visually distracting, and it makes video harder to compress, leading to larger files sizes and bit-rates. ATI's Avivo capture/encoder technology has the capability to remove this noise, and in so doing, makes the image 'cleaner' which improves the compressibility of the video.

Digital Capture – Multipath cancellation

ATI's Avivo-enabled digital capture devices are designed to accept terrestrial (free over the air) digital TV signals in even the most challenging areas, thanks to multipath cancellation. This technique ensures that signal echoes and distortions caused by the environment (such as hills in a rural setting, or buildings in a more urban one) are eliminated prior to the demodulation process. This capability ensures that ATI's digital demodulators are the reference when it comes to capturing digital signals from the air.

Avivo Encode

Avivo-enabled products offer encoding capabilities at two levels. Analog capture products such as those based on the Theater 550 product have integrated compression hardware while all Avivo playback products (ATI's discrete graphics products and integrated graphics chipsets) offer hardware-assisted compression and transcoding, to facilitate media interchange.

Hardware MPEG2 compression

ATI's Tuner-Encoder products bring full hardware MPEG-2 compression to the PC. Full, dedicated video encoding is essential for applications that require low CPU utilization, for the reasons discussed earlier. ATI's encoder products reduce CPU utilization to as low as 3-4% while encoding live TV signals at unmatched quality levels.

Hardware-assisted video compression and transcode

In addition to the dedicated compression (encode) capabilities of Avivo-enabled TV tuners and demodulators, Avivo-enabled VPUs and accompanying software work together to permit transcoding of video signals. Transcoding is the process of re-encoding video in a format (or simply at a bit rate) different from its original. Transcoding capability is becoming extremely important at a time when there is an explosion of video-capable devices (PDAs, cell phones, portable game consoles, etc) that have widely-varying capabilities in terms of the formats they support and the amount of storage they have (which will determine the bit-rate that needs to be used).

Avivo Decode

Hardware assisted video decode for reliable playback

ATI's highly flexible VPUs have dedicated blocks for portions of video decode and also have flexibility to permit support for optimizations and different video codecs. This enables ATI to provide smooth, glitch-free video decode with the lowest CPU utilization and the most forward compatibility.

ATI's Avivo products have comprehensive decode support for MPEG-2, WMV9, and H.264.

H.264 is going to be a codec of great importance over the coming years, as it will be used for next-generation HD optical discs, such as HD-DVD and Blu-ray (see ATI's whitepaper: Introduction to H.264). In May 2005, ATI demonstrated the first ever PC-based hardware acceleration for H.264 decode; this is a testament to the video expertise and flexibility upon which Avivo is built on.

Avivo Post-Processing

Vector Adaptive de-interlacing

Interlacing is a technique that has been in existence since the very beginning of video transmission. A key issue is that most displays today (including virtually every PC display) is actually a progressive scan device. This entails needing to convert interlaced video to progressive scan through a processing step called de-interlacing. While there is no single set way of performing this task, it is difficult (and computationally expensive) to do it well, with poor deinterlacing often showing jagged lines as an artifact.

With Avivo, ATI introduces a highly advanced de-interlacing scheme – vector adaptive - that excels even at the hardest of de-interlacing cases (such as low-angle diagonal lines). In this algorithm, Avivo-enabled hardware selects the best data to build a progressive frame from either the raw field data (when motion is detected to be low) or from a video data that is interpolated along several vectors. This ensures that the reconstructed (progressive) image maintains the greatest amount of data, delivering the best image possible.

Advanced scaling engines

Video and image scaling are critical elements to delivering a crisp final image; video in particular is often not at the resolution of the device it is going to be displayed on, so scaling it (up or down) while preserving detail and reducing aliasing is critical. ATI's Avivo offers both pre- and post- scaling engines.

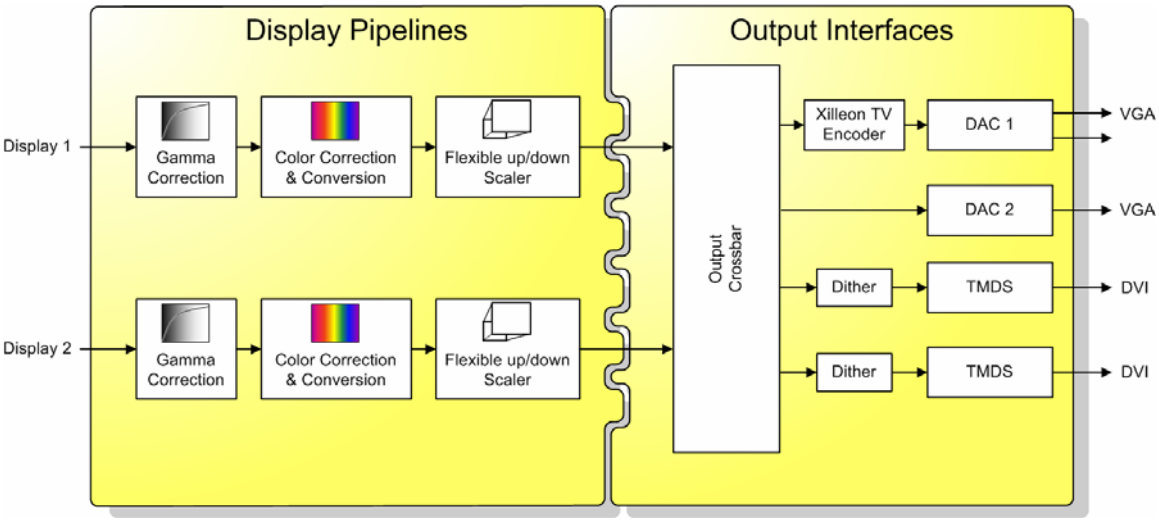
The pre-scaling engine allows video to be scaled from the source resolution to the resolution being requested by an application (the window of a media player, for example).

The post-scaling engines are so-called fit-to-display scalers, and are part of the Avivo Display Engine, described next.

Avivo Display

Dual 10-bit end-to-end display processing

The Avivo Display Engine comprises two symmetrical display pipelines. These pipelines ensure that the output image (video or other) is best matched to the display device on which the image is being shown.



Overview diagram of the Avivo Display Engine architecture

Operating at an industry-first 10 bits per color fidelity (30 bits total), these pipelines perform (in sequence):

- High-precision gamma correction. The gamma correction unit is capable of taking input of the typical 8 bits per color, all the way up to 16 bits per color in floating point format
- Color correction. A full color correction transformation is applied to every single pixel as it is output. This allows for both color space conversion (RGB to YPrPb or vice-versa) and for color correction (adjusting white point etc)
- Flexible scaling. Highly flexible scaling allows the source resolution to be scaled either up or down to match the display being driven. High-quality filtering allows for up to 10x6 taps to be used (10 horizontal samples on each of 6 lines contribute to each final pixel).
- Dithering. Because all of the processing is performed in 10 bits, the output of the display pipeline needs to be reduced to either 8 bit per color (typical desktop display) or 6 bits (typical notebook LCD). The dithering units combine both spatial and temporal dithering to deliver full 10 bit quality on almost any display.

All the above display-specific processing ensures that the image is tailored to the display. What is more, with two identical pipelines, the ability to drive two displays with the same features (tailored to two different displays, if applicable) becomes possible.

Ultimate Connectivity

In addition to superlative quality on the display pipelines, the Avivo Display Engine features unique connectivity capabilities to enable any PC usage that can be envisaged:

- True consumer electronics-grade TV output, via the consumer-proven Xilleon TV encoder (Xilleon is the name of ATI's Digital Television line of products)
- VGA DACs use the 10 bits of data provided by the pipeline and output it directly, making any existing CRT a 10-bit device.
- HDMI support for connecting to a digital TV, which combines both the video image and audio into a single connection
- HDCP capability to enable the viewing of protected content on HDCP Ready graphics card and motherboards.
- Two dual-link DVI capability for support of high-resolution displays (over 1920x1200 resolutions on LCD displays)
- Unique ability to support high-bit-depth displays (10 or 16 bits per color)

Summary

By exploring what the video pipeline is, and how Avivo's technologies fit into and enable it, a clear picture emerges: ATI understands video and display and continues to build on 20 years of expertise to deliver the best visual experience to the end-user.

Avivo is clearly a well-timed revolution in PC video and display performance and capabilities, guaranteeing ATI's readiness to spearhead a true PC-CE convergence. With the ability to flexibly drive any display, deliver crisp, rich images and smooth video, Avivo is set to become the obvious choice for consumers and discerning enthusiasts alike.

ATI's Avivo feature-set is intended to be more than a snapshot of features in time however; a living roadmap of technologies that will evolve over time. All of ATI's future PC-based products will deliver Avivo technology and each will bring improvements to the Avivo video and display platform for the PC.