The Avivo™ Display Engine

Delivering Video and Display Excellence

Introduction

As video and digital imaging become integral to the PC experience, it is vital that a high-fidelity experience is delivered to the end user through the highest quality solution. This entails treating the video data properly from the moment it enters the PC to when it is displayed.

Avivo™ is ATI's video and display platform designed specifically to deliver the highest quality and performance for these rapidly growing media usage scenarios. 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 visual applications. Some of the key capabilities delivered by Avivo are:

- Digital Photography and Digital Imaging: with digital imaging becoming an integral part of people's professional and personal lives, it becomes vital to deliver a flexible, flawless experience to even the most demanding user
- The Media PC experience: tuner-enabled PCs are 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 play back these signals will be central to future media PCs; furthermore, the ability to display HDTV content on PC displays that matches DTVs, or that is CE quality, is becoming imperative

The video aspects of Avivo are described in detail in a separate paper; see 'Avivo and The Video Pipeline'. It is recommended that the reader refers to that paper for the larger context of Avivo. The present document covers the capabilities of the Avivo Display Engine (available on ATI's Radeon® X1000 family of GPUs, and latest workstation graphics accelerators FireGL™ V7300 and V7350) in more detail.

Display Devices & Display Processing

A wide variety of display devices and display technologies are in use today; the future holds both refinements to these existing technologies as well as entirely new ones. The various display technology avenues are pursued for various reasons, such as performance, cost, etc., but all result in display devices that have characteristics that can vary widely:

- Gamma response
- Color space (RGB or YUV)
- Resolution and aspect ratio
- Color depth (bits per color)
- Display technology-specific (such as LCD response time)

When sources such as PCs and set top boxes drive these devices, display processing needs to take the above into account, and tailor the outgoing image to the display device. Because of the display-specific processing that takes place here, it is of great use to all visually-oriented applications, including video playback, still-image editing, workstation applications, 3D gaming and more. In all such cases, the processing optimizes the image to the display being used for the best visual appearance.

Today's display processing on PCs

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. 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. Many PCs today fall short of providing such interfaces, as well as key display processing capabilities. For example, most PC motherboards with built-in graphics capabilities do not support an integrated digital interface for connectivity to LCD displays or DTVs. Furthermore, many PC display controllers provide only basic display processing capabilities, such as limited up-scaling abilities; additionally, many do not support any means for downscaling or color space conversion. What's more, various display controllers exclude support for certain display timings or can not support high-resolution displays.

In terms of supporting PC display resolutions, currently most graphics cards can support 2048x1536 over VGA connectors for CRTs, and 1920x1200 over single-link DVI for LCD displays, where single-link DVI goes up to only 165 MHz. For resolutions higher than 1920x1200 on LCD displays, a dual-link DVI interface is required. A dual-link DVI interface is effectively utilizing two single-link DVI interfaces, and hence doubling the bandwidth limit to an effective 330 MHz (however, each link is still operating at 165 MHz). Today, there are several LCD displays that boast very high resolutions, such as 2048x1536, 2560x1600, and 3840x2400; these would require one or more dual-link DVI interfaces. Dual-link DVI interfaces were not supported on consumer graphics cards prior to the introduction of ATI's Radeon X1000 family.

The output over analog interfaces, typically VGA on PCs, is 10-bits per color, or a color space of 1.07 billion colors. This is enabled via 10-bit DACs (Digital to Analog Converters), as found on most ATI graphics cards today; these DACs convert the 8-bit display data to 10-bits at the last stage of the display engine after being processed, e.g. gamma-corrected. In contrast, today, the output over digital interfaces is only 8-bits per color, or a color space of 16.7 million colors. While the majority of LCD displays are 8-bit per color, in the past year, several display vendors have launched LCD displays supporting 10-bits and 16-bits per color, and this trend is expected to amplify going forward. This is due in part to many displays vendors developing panels which offer higher levels of brightness. Higher levels of brightness, or higher dynamic range, necessitates supporting larger color spaces on LCD displays. Today's display controllers do not support digital interfaces with color depths larger than 8-bits, and hence can not support a growing number of high-color depth LCD displays.

PC to TV connectivity

At present, there are several issues that plague PC-to-TV connectivity, such as lack of support of native resolutions and/or timings. Many PCs today do not natively support common DTV resolutions such as 1366x768 and 1920x1080, causing interoperability issues as well as hindering the end-user's capability to run certain applications that are resolution-specific. In addition, some of PC graphics products do not fully support TV timings, leading to a less than optimal image quality on their TVs. DVI TV timings are based on the CEA-861 standard, as defined by CEA (Consumer Electronics Association), while PC-based timings are different and defined by VESA (Video Electronics Standards Association). Many graphics cards are designed for VESA-defined timings, and don't comply with CEA timings.

Another issue related to connectivity is overscan: within a TV context, overscan is the area at the edges of a television tube (or panel or screen) that is covered to hide possible video distortion; this portion of the image is outside of the visible area of the TV screen. This poses

a problem when PCs connect to TVs via analog or digital component video; for example if one is using their TV to display Microsoft Windows™ OS, the 'Start' button and the task bar on the bottom often would be partially or completely hidden below a TV's bezel. The typical workaround for this issue is to reduce the resolution to one that is smaller to enable displaying the full image. This workaround is not favorable since the PC is no longer driving the TV at its native resolution, creating issues in the case of applications that only run at pre-specified resolutions, such as PC games.

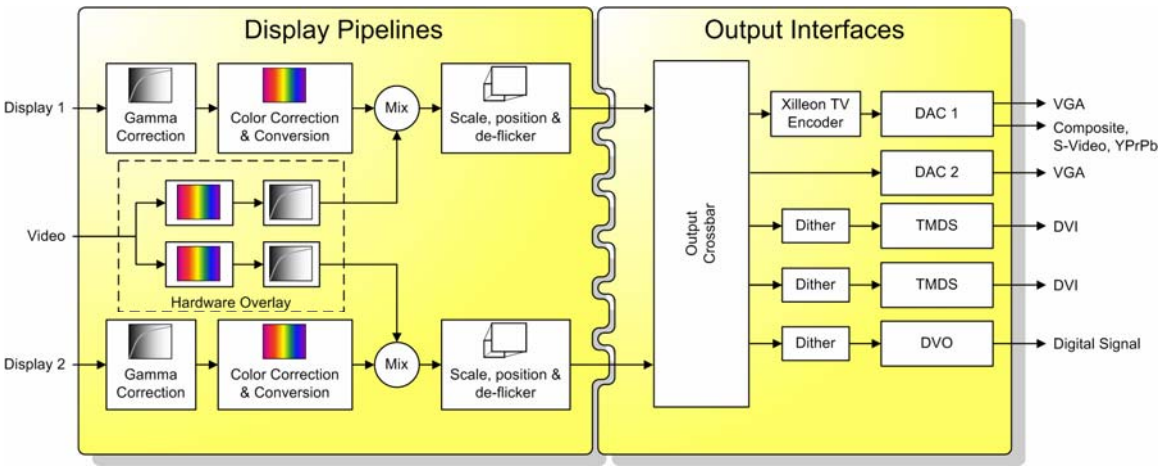
The above issues are part of what Avivo Display Engine aims to resolve, along with offering many more features, as described in the next sections.

Avivo Display Engine – An Overview

Avivo Display Engine is the last stage in the Avivo pipeline, after video is captured, encoded, decoded, and post-processed. Display is the final step before the data –be it video or a still image- is sent via the actual connection between the source (e.g. the graphics card in a PC system) and the actual display device (a monitor or TV connected to the PC). This step in the pipeline consists of two main portions:

- Processing that is performed by the source in order to best match the rendered image or video to the actual display device being used
- The actual interface used to connect to a specific display

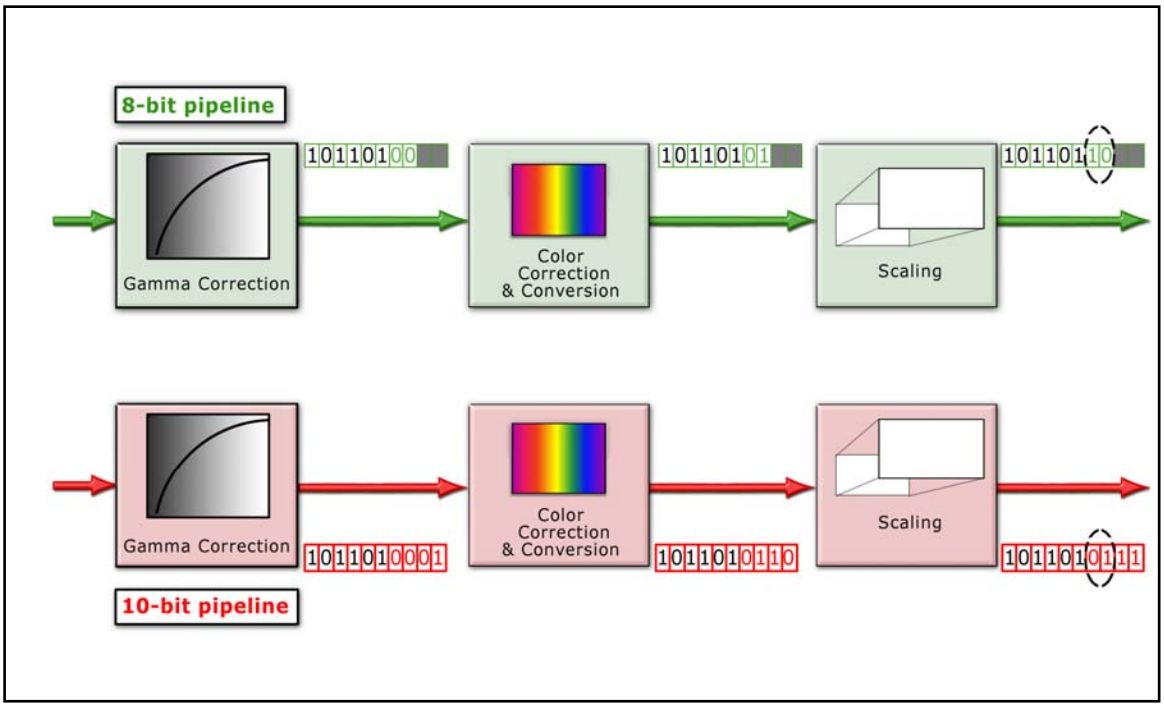
The Avivo Display Engine, found on ATI's Radeon X1000 family of GPUs and FireGL V7300 and V7350, encompasses both abovementioned portions, and they are referred to respectively as the Display Pipelines and the Output Interfaces.



The Display Pipelines

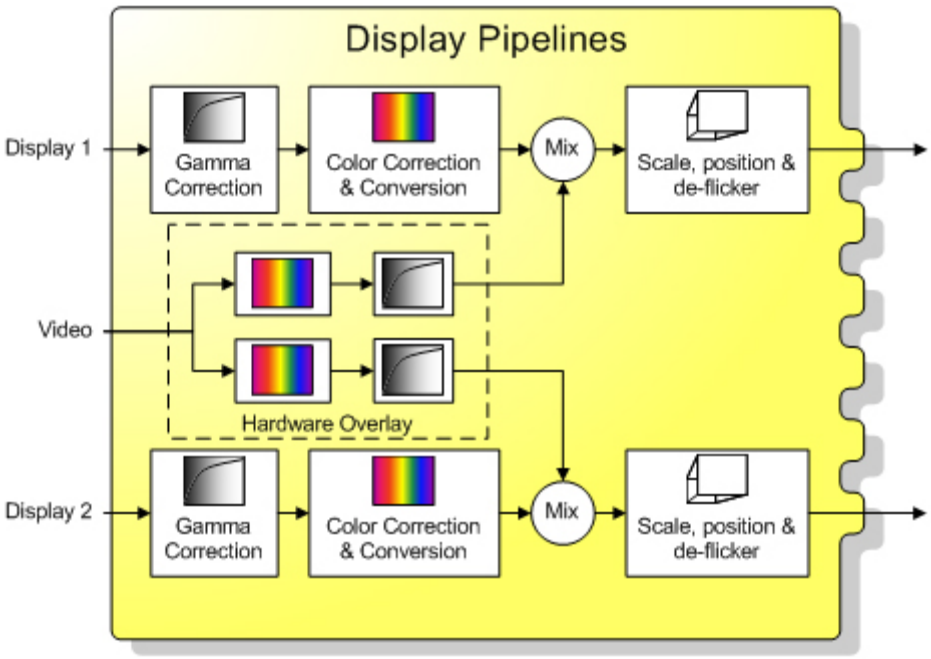
A Display Pipeline encompasses several display processing stages or steps, designed to adjust and fine-tune the display data as per the characteristics of the targeted display device to which the display data will be sent to. Avivo Display Engine supports two symmetric, independent Display Pipelines; each of these Display Pipelines processes data in a standalone manner, without any dependencies on the other pipeline.

Avivo's Display Pipelines operate at a 10-bit per color precision, which is a first for PC display controllers, matching a handful of high-end DTV processors. Conversely, all other PC display controllers operate at only 8-bit color precision. By having all of the units of Avivo's Display Pipelines process data at this higher-depth accuracy, it eliminates processing errors that can be introduced by using 8-bit depth processing. This is highlighted in the diagram below: display data, processed in the 8-bit pipeline, results in inaccurate two lower bits due to rounding errors. While in the 10-bit pipeline, the higher precision, maintained throughout the different display processing stages, provides a high-fidelity, accurate end-result in the lower bits portion of the display data. Furthermore, by virtue of the added precision, the two extra bits of information are utilized in the Output Interfaces portion, later in the display engine.



Each of Avivo's Display Pipelines offers the following stages, as the following diagram shows:

- Gamma correction for primary display data
- Color correction and conversion for primary display data
- Video overlay with its own color correction and conversion unit and gamma correction unit for windowed video data
- Scaling, positioning and de-flicker filtering unit



Each of these stages will be discussed in detail in the following sections:

Incoming display data

Image data that is ready for display comes into the display pipelines in either Display 1 or Display 2, and in certain cases comes in as video for the hardware overlay (this will be discussed separately).

It is important to note that the incoming image data has been prepared by other parts of the graphics processor (in some cases, by the host system/CPU), such as the 3D engine, the 2D drawing engine, or video source, and has been written to local video memory. The display engine is thus simply reading from local video memory. In this way, the display engine is able to affect all output from the graphics processor.

Display data formats

The incoming image data for the display is in whatever format requested by the current running application or the operating system. The Avivo Display Engine supports an unprecedented array of formats and color spaces. The most common color spaces are RGB (for OS desktops and most applications) and YUV (for full-screen video). The Avivo Display Engine accepts the subsequent data formats:

- 8-bit palletized RGB, YUV or monochrome
- 16-bit aRGB in 1-5-5-5, 1-5-6-5, 4-4-4-4 bit format, or alpha-index 8-8 format, or 16-bit monochrome
- 32-bit aRGB or aYUV in 8-8-8-8, 2-10-10-10
- 64-bit aRGB in 16-16-16-16 using integer, fixed point or floating point number formats

Display Pipeline Stages

Gamma correction

Avivo Display Engine supports two gamma correction modes:

The first mode is a standard Look-Up Table (LUT) made up of 256 entries, typically for pixel depths of 8-bits per color component or lower. In this mode, the input pixel color for each color component is used as an address to the LUT memory to "look up" and map the input color to a corresponding 10-bit output color for each color component.

The second one is the piece-wise linear gamma correction mode, where rather than a table, a curve is represented internally by crossing a set of control points. This mode is designed for pixel depths of 10 and 16-bits per pixel per color component. Each of the three color components (red, green, and blue) of incoming display data may be mapped to different segments of the gamma curve. This offers the flexibility to gamma-correct each color component independently.

Since the rest of the display engine operates at 10-bits per color component, the gamma corrected data, i.e. the output of the gamma correction unit, is always 10-bits regardless of which of the two gamma-correction modes above is used.

Color correction and conversion

The Avivo Display Engine features color correction units that implement a 4 by 3 (12 element total) matrix that is multiplied with every outgoing pixel. Each of the 12 elements is independently programmable allowing for a total flexibility in linear operations performed for color adjustments:

- Contrast
- Brightness
- Saturation
- Hue
- Chromaticity correction
- Color temperature

The identical unit offers color space conversion, which is utilized to convert pixels in YUV color space to RGB format, to enable alpha blending in the same color space. Moreover, this unit is also used to convert pixels from RGB color space to YUV, as needed by the output interface (such as component out to TVs). It's noteworthy that both the SD and HD versions of the YUV color space are supported.

The true programmability of the Avivo Display Engine is showcased here as well: Because matrix multiplication is commutative, multiple corrections and/or conversions can be combined to apply color space conversion operations and color adjustments, with the result of these multiplications being the final preferred color-corrected data in the desired color space.

By combining all of these steps into one operation step, maximum precision of the result is obtained. If each color correction step and color space conversion step were done as separate sequential steps, the repeated quantization of results between steps would introduce additional error. Similar to the performance of a 10-bit processing pipeline, Avivo's color correction and conversion unit provides the highest fidelity image possible on PCs today, while offering a plethora of programmable options.

Video overlays

Video overlays are used to display data in a windowed fashion, as typically performed when playing back a video using a media player for example. Since the video data is coming from a different signal, it's often in a different format, such as a different color space, and hence requires its own processing, independent of the rest of the displayed desktop data.

When a user has two displays in clone mode, today's display controllers can not display the video window on both displays. However, with Avivo Display Engine's dual video overlays, the video window can appear on either or both display heads when in clone mode.

While the overlay has a single video source, each of the displays showing the video supports a standalone color correction and conversion unit, and a standalone gamma correction unit. The video data is processed as follows: First, video data could come in various data formats; Avivo's video overlays take YUV or RGB data in an assortment of formats. The data is initially processed by the color correction and conversion unit, which offers the same programmability as the graphics data's color conversion unit, described above. In this unit, the color space conversion is typically from YCbCr to RGB to enable alpha blending of video pixels in RGB format. Since the unit processes in high bit depth, output is simultaneously converted to 10-bit when the color space transformation is applied. Subsequent to the color conversion and correction, the video overlay data undergoes gamma correction using a similar unit as the unit used for primary display data, described earlier. Finally, the video overlay pixels are mixed with the graphics pixels into a single combined stream of pixel data. Avivo Display Engine supports several methods for combining these two pixel data streams.

Scaling

Each of Avivo's Display Pipelines has their own independent image output scaler. The purpose of these scalers is to convert the displayed image to the dimensions required by the monitor. This is particularly important for discrete-element displays such as LCD displays which have a 'native' resolution at which they work best. This fit-to-display processing can be done by centering, replication, or scaling. These scalers can also utilize these modes in combination in some cases.

The image output scalers support up to 6 vertical filter taps and up to 10 horizontal filter taps. These scalers are high-precision polyphase scalers that are highly programmable; they are suitable for upscaling by practically any ratio, or for downscaling by up to 4:1. Moreover, the scalers flexibly offer vertical scaling independent from horizontal scaling, and vice versa.

It's noteworthy that Avivo's downscaling capability is supported on all available interfaces, which is a first on GPUs. This feature is ideal when in cloned mode and the secondary display device, for example a projector, is lower in resolution , than the primary one, such as a notebook; in such a scenario, other display controllers force the higher resolution notebook panel to be displayed at the projector's lower resolution. With Avivo's downscaling, the notebook can run at its native, high resolution, while the image is downscaled to the projector's lower resolution.

Adaptive de-flicker filtering

Avivo's scaling units support adaptive de-flickering filtering to reduce flicker on interlaced displays, such as CRT-based TVs. Unlike other standard de-flicker features, the Avivo Display Engine is content aware. When the adaptive de-flickering feature is enabled, it examines each frame's content; long horizontal lines, which tend to flicker more, are detected, and special filtering is applied to eliminate flicker.

Output Interfaces

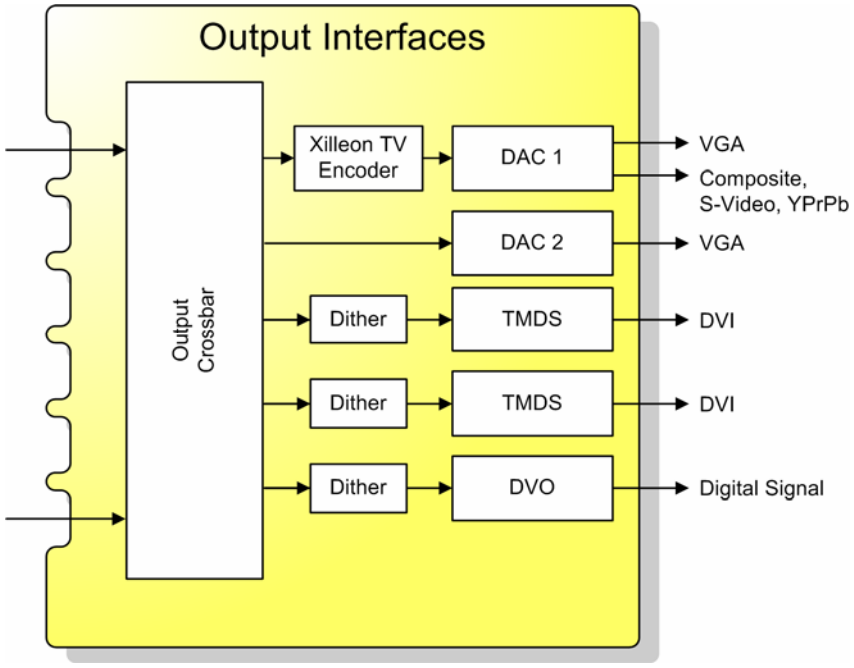
In addition to superlative quality on the display pipelines, the Avivo Display Engine features unique output-interface capabilities to enable the ultimate connectivity to any PC monitor, TV, or projector.

A distinctive advantage of the Avivo Display Engine is the ability to synchronize to a display's timing independently of the resolution being output. This unique feature is enabled by having a separate clock domain per output, offering the most flexible hot-plug experience.

The Avivo Display Engine supports a complete spectrum of analog and digital interfaces available on the market today:

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

Below we highlight some of the exceptional capabilities offered by Avivo's Output Interfaces:



Analog

Xilleon™ TV encoder

While 'Consumer Electronics quality' is a term often used in the PC industry, no company in the graphics space can make the claim of having a CE division from which to draw technology and expertise but ATI. Xilleon™ is the name of ATI's digital TV solution that is used as the brains (and majority of the video pipeline) in DTV's. The Avivo-enabled Radeon X1000 family has the very same TV encoder as Xilleon, with its true CE processing and ultra-high sampling rate for the absolute best in TV output quality over Composite, S-video and component NTSC, PAL and SECAM.

One area where Avivo's CE quality shines is in offering the best picture detail: Some TV encoders have comb filters which unfortunately add discoloration along horizontal edges and hence blurs picture details; on the other hand, Avivo's integrated TV encoder offers comb filtering for composite outputs, which provides finer picture detail as well as reduces discoloration in the fine picture detail. Furthermore, many TV encoders -available on the market today- support 8-bit scaling. Avivo's TV encoder supports 10-bit scaling, with multi-tap filtering, providing higher image quality and purer color.

Digital to Analog Converters (DACs)

The Avivo Display Engine brings forward two independent 10-bit DACs, which draw on the 10-bits data provided by the Display Pipelines, and output it natively. Moreover, these DACS offer superior performance through faster sampling rates for higher color fidelity, as well as lower jitter for a more stable image. These DACs can support resolutions up to 2048x1536.

SCART

SCART (Syndicat des Constructeurs d'Appareils Radiorécepteurs et Téléviseurs) is an analog interface which is commonly available on European TVs and other consumer electronics devices. SCART is supported on select Avivo-enabled products sold in Europe.

Digital

Dual, dual-link DVI connectivity

Digitally connected displays are becoming prevalent, and their resolution is increasing apace. Today, single-link DVI is the most common digital interface; however, as resolutions continue to increase, and importantly, cost of higher resolution panels decrease, dual-link DVI is a key mechanism allowing the high-resolution connectivity to take place. Dual-link DVI has twice the bandwidth of single-link DVI for a maximum of 330 MHz (i.e. two times single-link DVI's maximum of 165 MHz).

Radeon X1000 family products have a built-in capability to drive dual-link DVI interfaces, allowing end-users the ability to support high-resolution displays, such as 2560x1600 and higher. Furthermore, ATI's Radeon X1800 GPU and FireGL V7300 and V7350 have a built-in capability to support two dual-link DVI interfaces, an industry first.

Higher-resolution displays, such as 2048x1536 and 2560x1600, are not widespread at present; however, by offering dual-link DVI support now, Avivo allows end-users the ability to upgrade to such displays in the future as they become more prevalent and affordable.

10-bit and 16-bit DVI output

The main benefit of higher color depth is borne by the fact that higher depth means more data per color component or larger color space. For example 10-bits per color offers 64 times more colors than 8-bits (1.07 billion colors), while 16-bits per color lets you experience over 16 million times more colors than 8-bits, for a total of over 280 trillion colors. Therefore, while most LCD panels today are using either 6-bits or 8-bits per color, a migration to 10-bit and higher LCD panels has begun. Presently, there are several generally-available PC displays capable of 10-bits and 16-bits per color, and more such high-end displays are expected to be offered from display vendors going forwards, as they will be able to count on having display sources to drive their higher color depth displays, since the Avivo Display Engine supports both 10-bits and 16-bits per color outputs over dual-link DVI interfaces. Moreover, many DTVs are starting to offer built-in 10-bit support, which along with Avivo's 10-bit high-fidelity digital output would enable an end-to-end 10-bit pipeline from PC source to DTV, providing the best possible image fidelity possible.

Supported modes on 10-bit DVI output

When dual-link DVI is used to support high resolutions, both the primary and secondary links are 8-bits in color depth, and the bandwidth is doubled by the use of the secondary link. However, in the case of 10-bit color support, the secondary link is used to carry the extra 2-bits of color depth of the total 10-bits; in other words, the primary link carries 8-bits of color, and the secondary carries the remaining 2-bits. This limits the bandwidth of the 10-bit dual-

link DVI mode to only a maximum of 165 MHz (same as a regular single-link DVI), vs. a maximum of 330 MHz in the case of dual-link DVI supporting higher resolutions.

To discern which modes can be supported on 10-bit DVI output, one needs to recognize that the total bandwidth available over the interface is the multiplication of resolution, color depth, and refresh rate. By balancing these factors (e.g. increasing one and reducing one or both of the others) different capabilities can be exposed. The following illustrates examples of when 10-bit DVI output is possible depending on the resolution and refresh rate blend (all examples assume reduced blanking):

1. 1920x1200 at 60 Hz: 154 MHz < 165 MHz and hence possible
2. 2048x1536 at 60 Hz: 209.25 MHz > 165 MHz and hence not possible
3. 2048x1536 at 47 Hz: 162.75 MHz < 165 MHz and hence possible

Dithering Units

The Avivo Display Engine's 10-bit processing operates in a space of 1.07 billion possible colors; however, given that most LCD panels are 8-bits or 6-bits, the output of the 10-bits display pipeline needs to be reduced to a lower bit depth to match that of the LCD display. Instead of doing away with of the extra bits of color precision, the Avivo Display Engine leverages a technique, referred to as dithering, which gives the human eye the perception that missing colors are available. This is achieved by modifying the image in a pattern that would mix the available colors to create the perception of more colors; this pattern can be arranged spatially, temporally or a combination of both.

This is a similar principal to that used in plasma displays. Plasma pixel elements really only have two states: on and off. The plasma display controller simulates at least 8-bits (and sometimes 10 or more bits) of color precision by rapidly switching in time the state of each pixel to create the desired perceived intensity. The dithering in the Avivo Display Engine allows a similar effect on other display technologies such as LCD that natively support only 6 or 8-bits of color variation. The effect is a near 10-bit color result.

Dithering is commonly available on notebooks today to provide near 8-bit result on 6-bit LCD panels. In contrast, Avivo-enabled GPUs are the first to make available virtual 10-bit color effect to lower color depth LCD panels.

DTV timings and resolutions support

The Avivo Display Engine is designed to fully support DTV connectivity; this includes native support for all TV DVI timings (as per CEA-861 standard), as well as all DTV resolutions, such as 1366x768, 1280x720 and 1920x1080.

HDMI

HDMI, or High Definition Multimedia Interface, is becoming a prevalent digital interface on CE products such as DTVs, given its integrated audio functionality and small, user-friendly connector. Select ATI Avivo-enabled products support HDMI, enabling end-users to seamlessly participate in a rich media experience via a single cable.

LVDS

ATI's Mobility™ Radeon® X1000 family supports single and dual channel LVDS (Low Voltage Differential Signaling) interfaces for connectivity to notebook LCD panels. Today, most notebook LCD panels are 6-bits. In addition to supporting these, Avivo extends its support to include 8-bit notebook LCD panels, which are becoming more prevalent.

DVO

DVO, or Digital Video Out, enables other connectivity options not supported internally by ATI's Avivo-enabled products.

Summary

Image quality is based fundamentally on display processing. ATI's Avivo Display Engine, delivers the best image and display quality possible today on PCs, and matches the capabilities of high-end TVs, as established through a myriad of unparalleled features:

- Avivo Display Engine is the only PC display controller that supports end-to-end 10-bit display processing; all others offer only 8-bit processing. This GPU-first capability offers highest fidelity possible to LCD displays and CRTs alike
- While majority of GPUs only support one single-link DVI, or at most one dual-link DVI, Avivo-enabled GPUs are the first in the industry to support dual integrated dual-link DVI outputs, for connections to two high-resolution LCD displays simultaneously
- Another first on GPUs is the advanced scaling units' capabilities of downscaling over DVI and VGA. This feature is ideal for clone mode where one display device has a lower resolution than the other; downscaling enables the higher resolution device to run at its native resolution still, instead of lowering its resolution to match the other display
- Avivo Display Engine uses Xilleon's CE-proven TV encoder with its 10-bit scaling and multi-tap filtering for a higher image quality and purer color
- The advanced dithering units support another GPU first: 10-bit to 8-bit dithering, supplying near 10-bit color result to lower color depth LCD displays
- With the emergence of high-color depth LCD displays, Avivo can supply these displays with native 10-bit or 16-bit DVI outputs. Currently, no mainstream PC display controller offers this
- Cloned video overlays: An industry first with Avivo, to enable simultaneous windowed video playback on two displays in clone mode
- Content-adaptive de-flickering filtering to reduce flicker on interlaced displays
- Native support for all DTV timings and resolutions
- Gamma correction units with support for up to 16-bit float point and integer formats – an industry first

Avivo is clearly a well-timed revolution in PC video and display performance and capabilities, leaving ATI ready 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.