matrox Parhelia™
High Fidelity Graphics™

UltraSharp Display Output Technology

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UltraSharp Display Output Technology

High fidelity refers to a superb reproduction that is completely true to the original. This is a term that is well known by the audio industry, which has been seeking to create the perfect signal reproduction for years. To achieve the highest fidelity graphics, Parhelia-512 was designed with tremendous attention to detail paid to every aspect of the graphics pipeline. Parhelia-512's UltraSharp display outputs are designed to enable the best quality output through well-tuned, high-quality electronics for precise and crisp images. Matrox products are renowned for their output quality and this is Matrox's best ever.

Introduction

Advanced visualization using computers is becoming an increasingly important part of the work of many different professionals. The computer may be used for the creation, visualization and/or analysis in the fields of photo editing, publishing, financial modeling, 3D CAD, medical imaging, biotech engineering, architecture and a host of other applications. With display technology advancing at rapid paces, the cost of high-resolution RGB monitors has dropped significantly. Flat panels are increasing in popularity and many companies are aggressively working to push the envelop of higher and higher resolution displays. Multi-headed display setups are becoming more and more popular. With this dramatic increase in the need, use and deployment of high fidelity monitors and flat panels, the importance of having a matched high fidelity graphics accelerator increases accordingly.

Signal output quality is an extremely important attribute of a graphics accelerator. To draw an analogy with the consumer audio marketplace, the graphics accelerator is like the audio amplifier in a stereo system and the RGB monitor is like the speakers. It is well understood that the best speakers in the world can sound bad if they are fed a noisy signal from a substandard audio amplifier. This is the simple concept of "garbage in, garbage out". Similarly, the best RGB monitor will only be able to display images as colorful and sharp as allowed by the quality of the display output signaling of the graphics accelerator. In the audio world, the concept of both power and fidelity is well accepted. Given that our eyes are much higher fidelity sensory organs than our ears, it stands to reason that graphics fidelity is of even more importance to visualization.

Historically, the signal output quality of graphics boards has been poorly tested in typical graphics accelerator round-ups in magazine reviews. This is due to the fact that it is more difficult to set up quantitative, reproducible tests to rate graphics fidelity than it is to test raw performance. Qualitative differences can be easily seen by looking at images generated by different graphics controllers on the same monitor, but qualitative tests are subjective and therefore less used in typical product reviews. Given the demonstrated importance of explaining the relative quality of graphics output to a large market of professionals, this white paper outlines and applies a quantitative set of signal quality tests to a number of graphics accelerators. The study is based on standard recognized methods for quantifying analog video quality. Detailed descriptions of the testing methodology are included to enable the test results to be reproducible by a third party.

This paper will prove that the video quality of Parhelia-512 is superior to that of other competing products. Parhelia-512 has better frequency and transient responses and improved jitter performance on its primary and secondary outputs. Furthermore, its symmetrical outputs have been designed to offer full performance on both displays. Testing results show that competitive solutions take shortcuts, which are significantly worse on their second output, resulting in a poorer overall quality. These products do not have the ability to accurately reproduce the intended signal and exhibit artifacts.

Background

Color in computer graphics is represented through a combination of red, green and blue values that are sent to the computer display to light up each pixel on the screen. The combination of red, green and blue color values, referred to as the RGB color space, can generate a wide range of colors perceptible to the human eye. Within computers, RGB values are stored in a digital format in the frame buffer - a memory space found on graphics cards.

Images are drawn in the graphics card's frame buffer by the GPU. They are then sent to the digital to analog converter (DAC), which converts the digital value in the frame buffer to a voltage level that is sent to the display via the connectors placed on the graphics board. In the case of RGB monitors, the standard is to have the voltage level range from 0 to 700mV— 0mV represents black and 700mV represents the full intensity of the color signal.

As monitors have been consistently increasing in both size and resolution, so have the demands placed on the display circuitry. Many design efforts are required in order to maintain the video output quality at various resolutions and refresh rates. There are various existing metrics that provide a quantitative measure for signal quality. These include frequency response, transient response, and pixel and sync jitter, for example. Some of these metrics have been standardized through the Video Electronics Standards Association (VESA), which published a test procedure for the evaluation of analog display graphics subsystems. The VESA Video Signal Standard specification, referred to as VSIS, was used as the baseline for this analysis to which were added some supplementary tests as described further in this paper.

Test setup

The frequency and transient response measurements were done with a Tektronix TDS-694 3GHz 10Gigasample Digital Realtime Oscilloscope and a high-impedance active probe – Tektronix P6249. These measurements were taken directly at the connector terminated with a 75? resistor.

Hsync jitter measurements were taken with a Tektronix TDS 3054 500Mhz 5Gigasample Digital Phosphor Oscilloscope and a high-impedance probe – Tektronix P6243. Measurements were taken directly at the video connector terminated with a 2.2 K? resistor.

The test system consisted of an Asus P4T motherboard with a 1.4 GHz Pentium4 CPU, 256MB of 400MHz RDRAM and an Enermax EG651P-VE power supply.

The following boards were tested:

?? ATI? Radeon™ 8500 AGP - 64MB DDR
?? PNY Verto GeForce4™ Ti 4400 AGP - 128MB DDR
?? Matrox Parhelia™-512 AGP - 128MB DDR

Frequency Response

The RAMDAC frequency is one of the main metrics that indicate the resolutions a graphics card can display. Most high-end cards currently support 360MHz DACs for their primary output. The frequency of the pixel clock used by the RAMDAC is proportional to the resolution and the refresh rate of the display.

Frequency = horizontal size X vertical size X refresh rate / 0.7

The 0.7 factor is due to the blanking period: the time it takes the cathode ray tube (CRT) raster to return from right to left and from top to bottom.

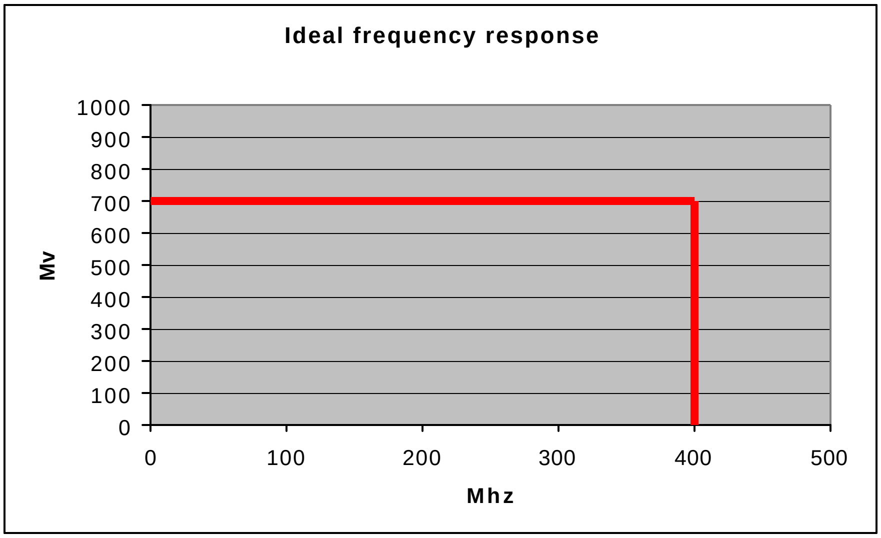
Higher RAMDAC pixel clocks enable larger resolutions at the highest refresh rates. The ability to configure a monitor and graphics card to a higher resolution gives the user more screen real estate for increased productivity. Meanwhile, higher screen refresh rates reduce eyestrain problems commonly associated with low refresh rates and provide more fluid motion on the desktop. Most ergonomic studies recommend PC users to set their monitor refresh rate at a minimum of 85Hz in order to reduce headache symptoms associated with prolonged periods of computer usage.

The frequency response provides a measure of the signal integrity within the range of available pixel clocks. The ideal behavior of a display circuit is to have a consistent output at the various pixel clocks. The real life behavior can be somewhat different, as the test results will show. The variations in the frequency response have a direct impact on the sharpness of the image as well as the color fidelity of the signal.

Output filters

All computer hardware sold in various regions of the world must meet the requirements of a certain number of regulatory agencies. These include the Federal Communications Commission (FCC) and CE marking provided by the European Economic Community. One requirement that is of particular importance to graphics cards is the emission and radiation levels of the hardware product. The product must not emit more than a predetermined intensity level of energy at various frequencies measured at a fixed distance. Products need to be tested in a licensed laboratory in order to certify that they fall within the allowed level of emission prior to being sold to the public. This is a must for all commercial and residential products.

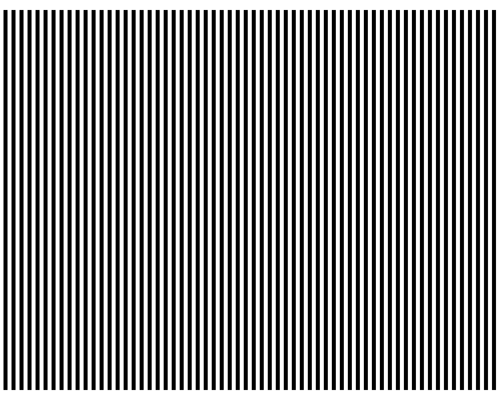
In order to meet these stringent requirements, graphics cards include a low-pass output filter circuit. The goal of this circuit is to let through the signals that fall within the frequency range used by the product and to reject all signals that are above that frequency.



The chart above showcases the ideal theoretical frequency response for a 400MHz video DAC. It allows all of the signals that have a frequency lower then 400MHz to go through to the output connector unchanged and rejects all of the signals above 400MHz. It is important for the frequency response to be flat in the 0-400 MHz range. This allows for consistent color output and a sharp image that utilizes the complete contrast range of the monitor.

Test Methodology

In order to test the frequency response we used a vertical line pattern with alternating black and white pixels. The maximum and minimum steady-state voltage levels were measured on the RGB DACs at various resolutions and refresh rates indicative of the response at various pixel clock frequencies. The measurements were taken at 10 different pixel clock frequencies in order to plot the frequency response curve.



Sample test image for frequency response measurements

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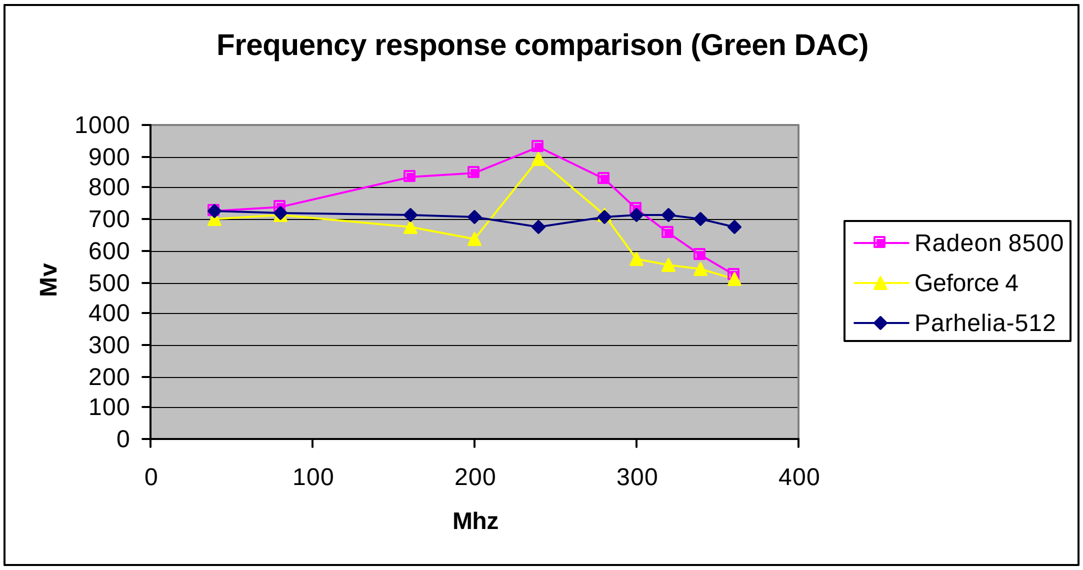
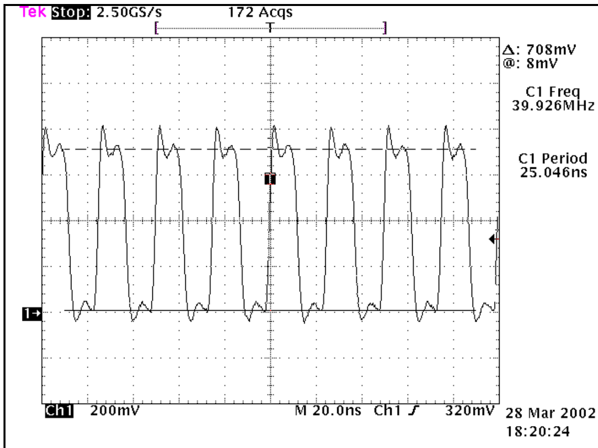
Test Results - Primary output

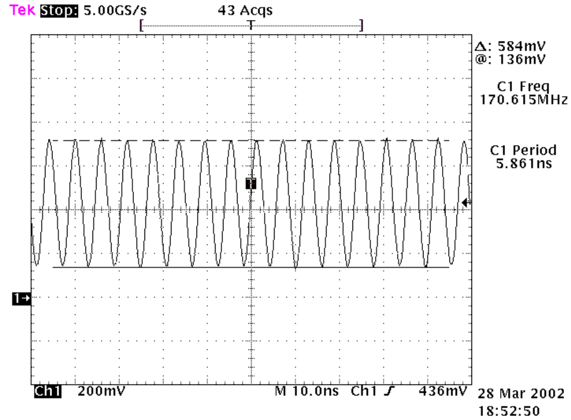
Please note: complete test results are available in appendix A



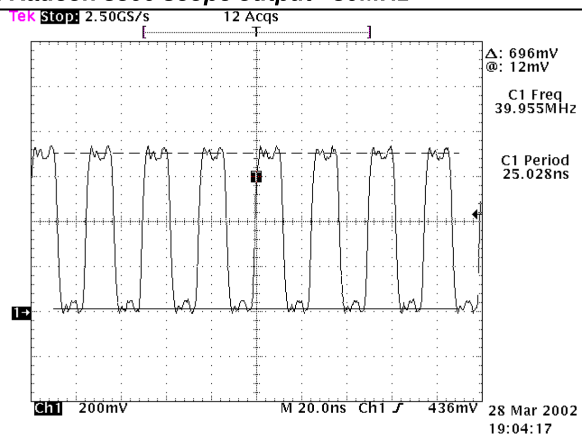
The graph above shows the frequency response of the green component of the primary DAC. Notice that the Parhelia-512 has a flat response throughout the frequency range and is very close to the ideal response. The output of the GeForce4 dips at 200Mhz, peaks at 240Mhz and breaks beyond 280MHz. The response of the Radeon 8500 is quite inconsistent. Frequencies above 80MHz yield an output that is as much as 33% out of range (932mV @ 240MHz). This will result in colors that are saturated and too bright. Its cut-off frequency is in the neighborhood of 320MHz.



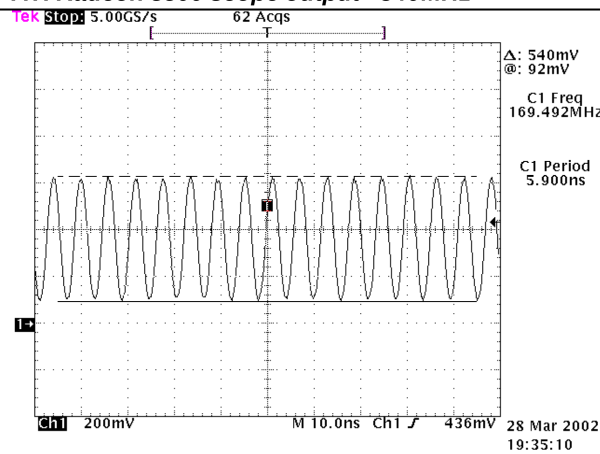
ATI Radeon 8500 scope output - 80MHz



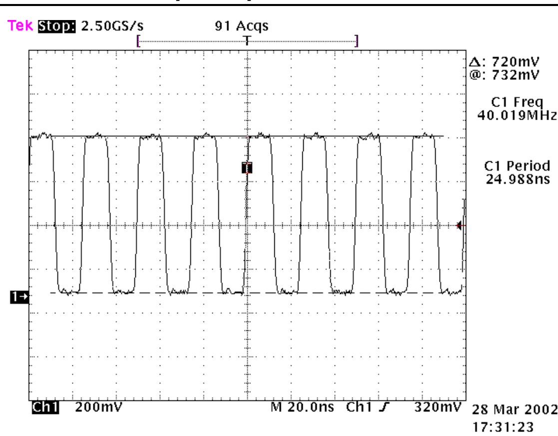
ATI Radeon 8500 scope output - 340MHz



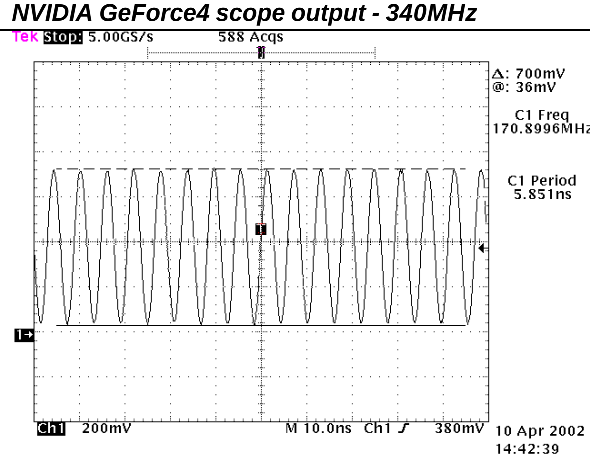
NVIDIA GeForce4 scope output - 80MHz



NVIDIA GeForce4 scope output - 340MHz



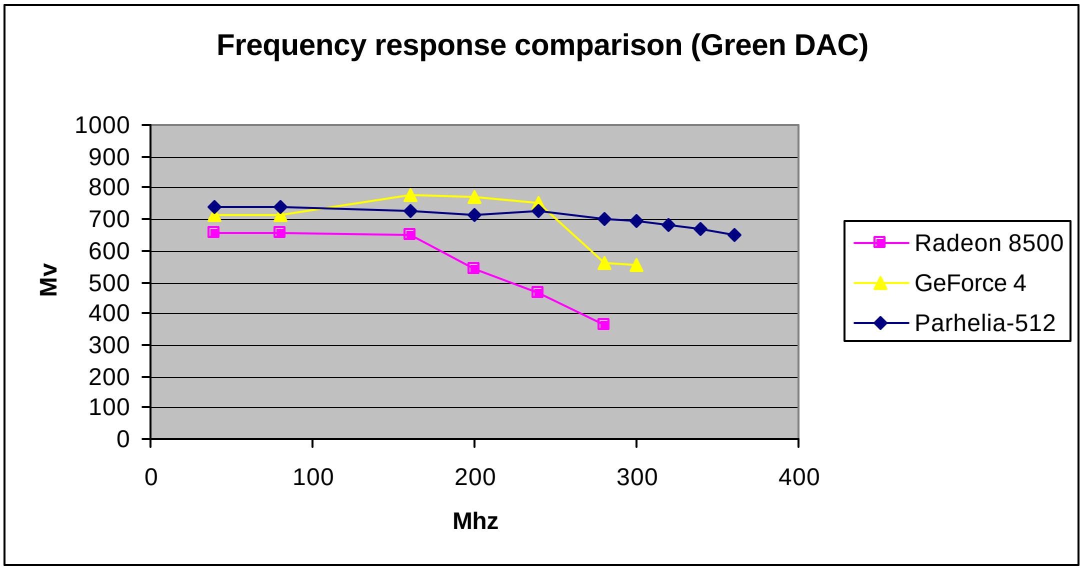
Matrox Parhelia-512 scope output - 80MHz



Matrox Parhelia-512 scope output - 340MHz

The images above show the output of the primary DAC at pixel clocks of 80 and 340MHz. You can observe the noise on the Radeon 8500's and the GeForce4's outputs at 80MHz. At 340MHz, both competitors have a peak-to-peak voltage of 540 to 584mV. Therefore, the output signal will not have the time to complete its swing from white to black and vice versa. Images will lack contrast and sharpness. Parhelia-512's output swing covers the complete 700mV range as per the requirements.

Test Results - Secondary output



The graph above shows the frequency response of the green component of the secondary DAC. You can clearly observe that the second outputs of the Radeon 8500 and the GeForce4 are sub-par versus their primary outputs. The cut-off frequency of the Radeon 8500 is somewhere near 160MHz and the GeForce4's is approximately at 250MHz. As per its primary output, Parhelia-512 has a flat response throughout the frequency range, although it dips a little beyond 330MHz, it is very close to the ideal response.

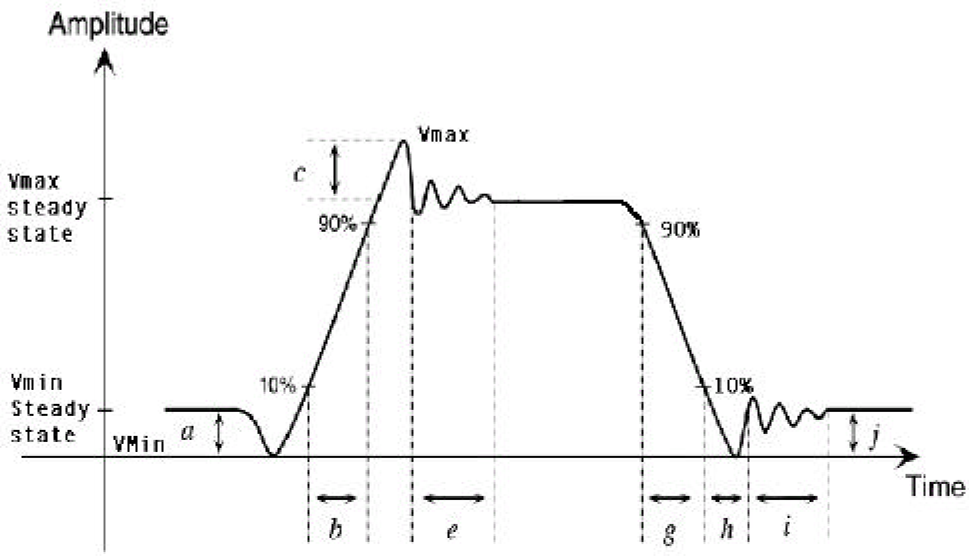
Summary

The frequency response is a measure of the display system's ability to correctly reproduce a digital signal. Values above 750mV will exhibit too much brightness and may distort the color representation. Values below 650mV will not reach a full brightness level and will lack sharpness and contrast.

Matrox Parhelia-512 is the only single-chip display controller that is fully symmetrical. Unlike the other solutions, there have been no compromises in the quality of any of the outputs. The design specifications of Parhelia-512's DACs are carefully studied and are extremely stringent. The board uses 5th-order filters with precise components to enable a flat response with a sharp cut-off at the appropriate frequency. The order of the filter denotes the exponent of the mathematical function representing the filter response. Higher-order filters enable a sharper drop at the cut-off frequency. Conversely, products with lower-order filters are forced to cut off some of the higher frequency data in the visible range in order to meet FCC/CE requirements. Having a flat response curve requires a large amount of testing and tuning in order to obtain the optimal combination of components. Also, variations in the values of the capacitors and inductors contained in the filter greatly affect the actual results. Most competitive products are built with 3rd-order filters using lower quality components.

Transient Response

The transient response reflects the ability of the graphics card to respond rapidly and accurately to the variations in color required for displaying computer images. The VSIS specification indicates various characteristics of the video signal that have an impact on video quality. The graph below, which represents a video signal varying from black to full intensity and back to black, highlights some of these metrics.



VSIS curve: Definition of steady-state voltage levels, rise and fall times, settling time, overshoots and undershoots.

a – Vmin steady-state amplitude before transition
b – Video rise time delta
c – Overshoot amplitude
e – Settling time
g – Fall time
h – Undershoot amplitude
i – Settling time
j – Vmin steady-state amplitude after transition

The rise and fall time should be as short and as balanced as possible. The VESA test procedure states: *"Longer rise and fall times are indicative of limited video bandwidth and may cause a loss of spatial resolution in the displayed image."* The maximum video bandwidth of a graphics card can be expressed as the inverse of the sum of the rise and fall times – [2/(b+g)] as per the VSIS curve.

The overshoot and undershoot, as well as the settling time, should be inexistent or as small as possible. The VESA test procedure states: *"Excessive overshoot or undershoot may cause image artifacts, such as luminance variations or streaking, along the trailing edge of a displayed object or character. Excessive settling time may cause video artifacts such as streaking in the displayed image."* Streaking, also known as ghosting, creates a blur effect on the right side of images with sharp transitions, as shown in the screenshot below:

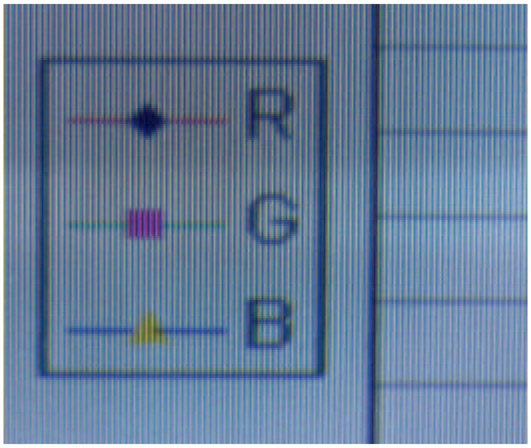
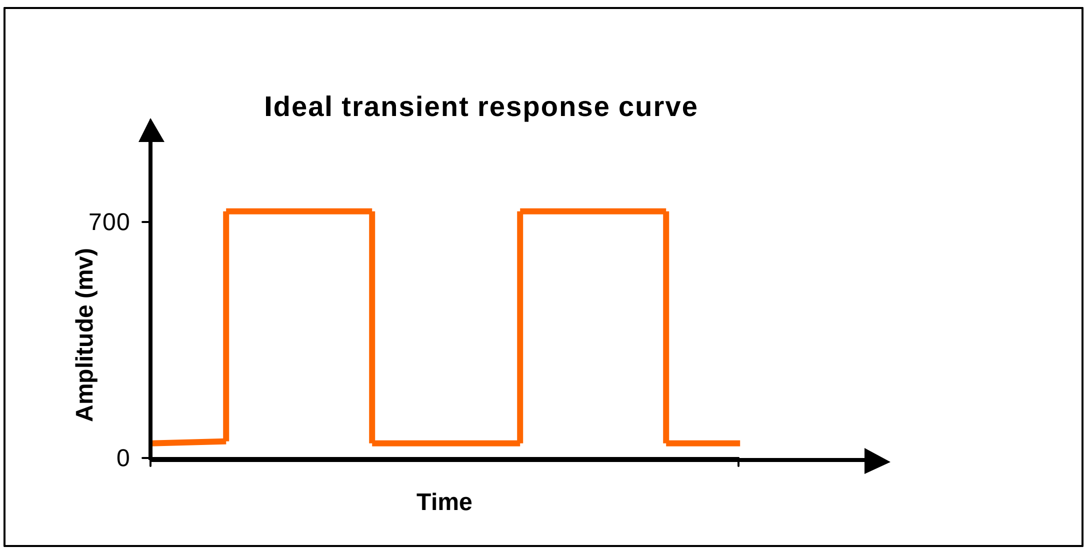


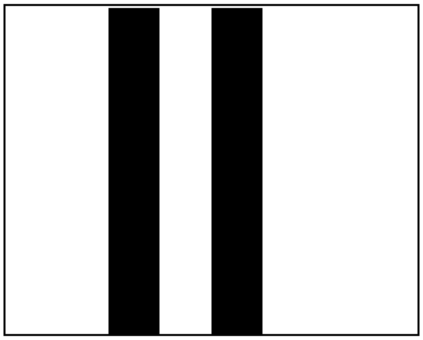
Photo of monitor screen. Ghosting is visible to the right of the vertical lines

The ideal transient response is like the curve below. Note that it is very difficult to achieve a good balance between short rise and fall times and little or no overshoot. There is a significant transfer of energy when the signal goes from its min to max points and vice-versa. You can compare it to pulling an elastic and letting go – the elastic will always contract itself to a smaller size than its natural state.



Test Methodology

In order to test the transient response, we used the pattern specified by the VSIS test specification, which consists of alternating white and black bars of the same width. The various characteristics specified by the VSIS tests were captured on the RGB DACs at 1280 x 1024 @ 85Hz and 2048 x 1536 @ 60Hz.

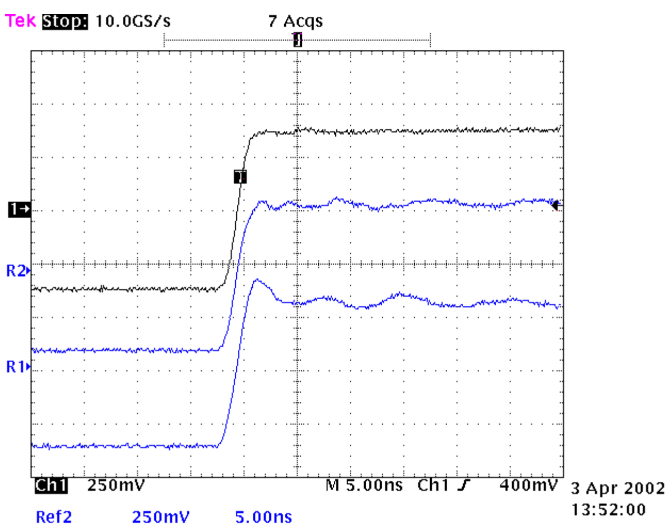


Sample test pattern for transient response

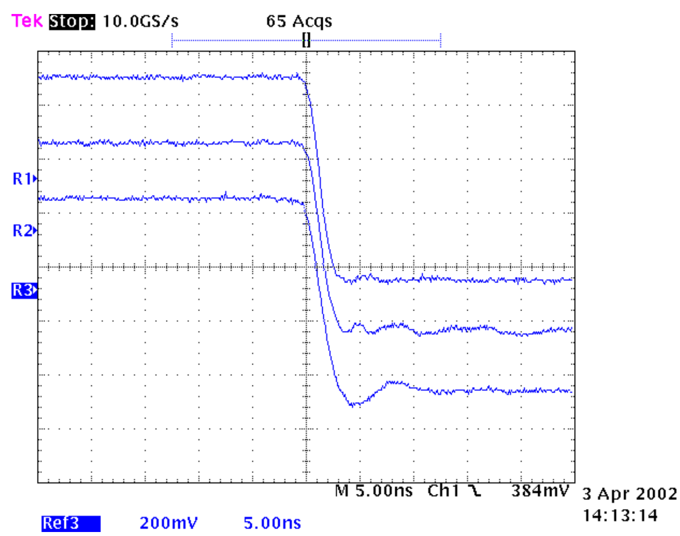
Test results – Primary Output

	Rise time	Overshoot amplitude	Settling time	Fall time	Undershoot amplitude	Settling time	Max video bandwidth
Radeon 8500	1.925ns	136mV	15.3ns	2.466ns	60mV	5.2ns	455MHz
GeForce4	2.4ns	10mV	11.4ns	2.433ns	0mV	20.5ns	414MHz
Parhelia-512	1.986ns	0mV	0ns	2.066ns	0mV	2.44ns	494MHz

Transient response on Primary output at 1280 x 1024 @ 85Hz



Output curve - Rise time
From top to bottom: Parhelia-512, GeForce4, Radeon 8500



Output curve – Fall time
From top to bottom: Parhelia-512, GeForce4, Radeon 8500

The results above point out the significant overshoot and undershoot of the Radeon 8500's video signal. Its signal also shows significant noise at the higher level. Its rise time is the fastest but it comes with its overshoot. Rise and fall times have a 25% difference and the settling time is extremely long.

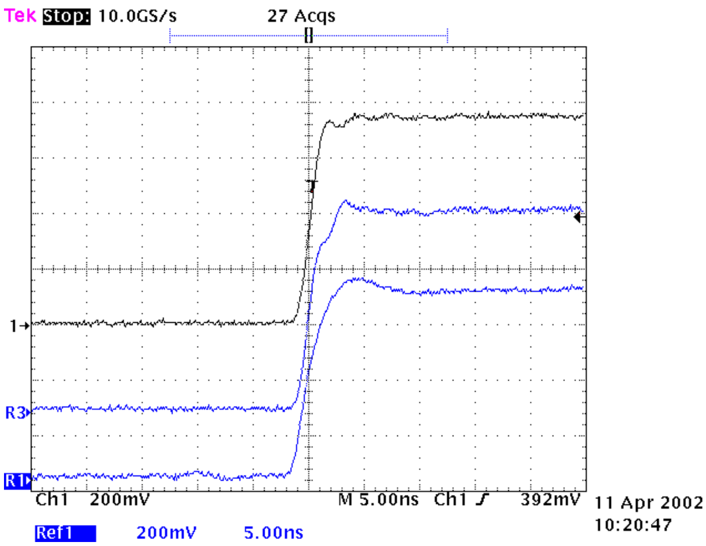
The GeForce4's signal has very little overshoot and undershoot, but has very slow rise and fall times—its maximum video bandwidth is 16% lower than Parhelia-512's. Furthermore, the signal is fairly noisy upon transitions and takes a long time to settle within the 5% tolerance prescribed.

Parhelia-512 has the highest video bandwidth while maintaining the cleanest signal. It is clearly the closest to the ideal curve. Upon rise, the signal settles immediately within the 5% tolerance, and upon fall the signal displays minimal undershoot. Both rise and fall times are fairly symmetrical, their slopes are consistent and the signal is the most stable after transitions.

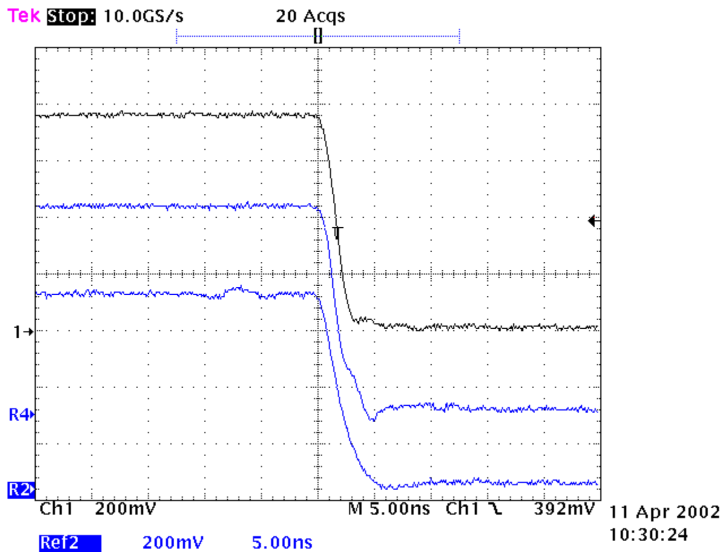
Test results – Secondary Output

	Rise time	Overshoot amplitude	Settling time	Fall time	Undershoot amplitude	Settling time	Max video bandwidth
Radeon 8500	2.970ns	44mV	5.4ns	3.290ns	24mV	0ns	319MHz
GeForce4	3.033ns	40mV	9.0ns	2.900ns	48mV	0.7ns	337MHz
Parhelia-512	1.967ns	0mV	1.8ns	2.104ns	0mV	0ns	491MHz

Transient response on Secondary output at1280 x 1024 @ 85Hz



Output curve - Rise time
From top to bottom: Parhelia-512, GeForce4, Radeon 8500



Output curve – Fall time
From top to bottom: Parhelia-512, GeForce4, Radeon 8500

These results indicate that Parhelia-512 has maintained the highest video bandwidth while the second head of the other solutions is significantly worse than the first one. One thing to note is the bend on the rise and fall curves at about 75% of the transition for the Radeon and, particularly, the GeForce4.

Summary

Both looking at the signal output and reviewing the individual characteristics outlined in the VSIS specifications clearly suggest that the Parhelia-512's transient response is superior to that of the Radeon 8500 and the GeForce4. It has the highest video bandwidth while maintaining an impressive signal quality. This will result in a sharper image that has full spatial resolution with minimal streaking and no luminance variations.

Hsync and pixel jitter

All display circuits base their timing on a signal called the 'pixel clock'. This clock serves to synchronize all of the counters (horizontal and vertical) and each pixel output. The pixel clock is variable in order to cover the various resolutions that the graphics card can support. Current state-of-the-art technology uses clock synthesizer circuits in order to generate a very wide range of output clocks. These clock generation circuits are not perfect; they have various levels of imprecision as they struggle to maintain an exact period for every clock signal. The variation in the period of a clock signal is referred to as the 'clock jitter'.

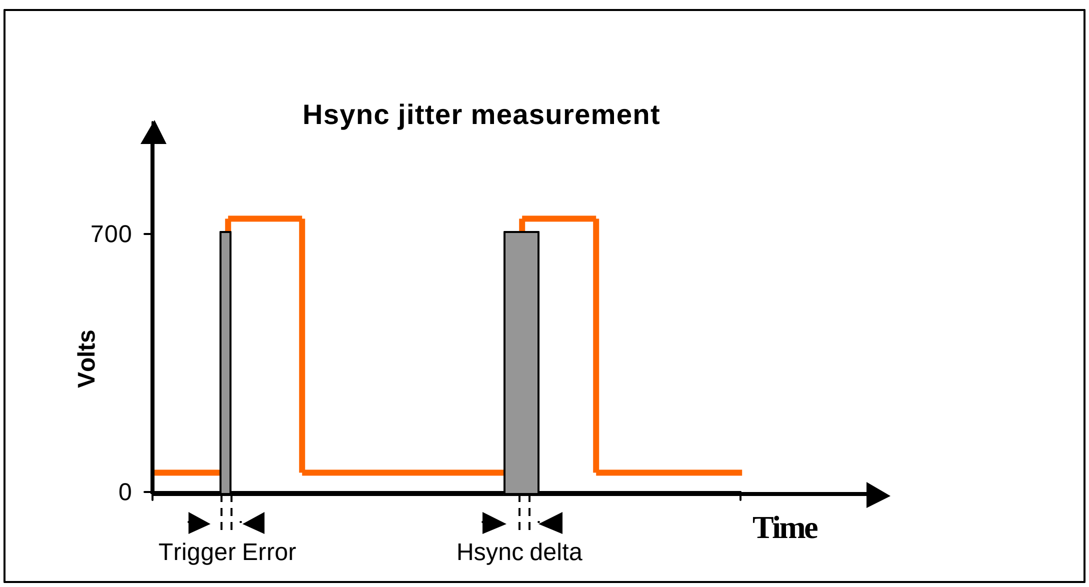
The pixel clock jitter is reflected in the horizontal synchronization signal (HSYNC), which is a multiple of the pixel clock. The VSIS specification describes the artifact caused by jitter as: *"Jitter in the sync signal may cause spatial instability (jitter) in the displayed image."* As described in the VESA document, pixel jitter can create a shimmering effect on the monitor where pixels seem to move horizontally. When the jitter is excessive it will be easily noticed on vertical lines that will appear wavy.

The effect of pixel clock jitter can be much worse on analog flat panels. These panels will sample the analog data that is sent by the video card at the pixel clock frequency. Jitter on the graphics card may cause the analog wave to be interpreted a bit differently on different passes. For instance, the position of a single pixel might be displayed in one LCD cell one moment, and in an adjacent cell the next. This effect is clearly noticeable and is extremely annoying. The worst-case scenario is when the LCD cannot synchronize itself to the signal output of the graphics card and is not able to display anything at that resolution.

Test Methodology

In order to test the jitter we used the methodology described in the VESA VSIS specification. The oscilloscope captured the rising edge of two consecutive sync signals – measuring the period between the two signals. The data was captured and accumulated over a period of one minute to view the overall delta. The final jitter number was calculated with the following formula:

Effective Jitter = (Hsync delta – Trigger Error) / 2



Test results
Note that complete test results for Hsync jitter are included in appendix B

Hsync Jitter – Primary Output

Pixel Clock Frequency		40MHz	160MHz	240MHz	320MHz
Radeon 8500	Effective Jitter (ns)	1.03nS	1.09nS	0.95nS	1.06nS
	Fraction of a pixel (%)	4.2%	17.3%	22.6%	33.5%
GeForce4	Effective Jitter (ns)	360pS	380pS	400pS	450pS
	Fraction of a pixel (%)	1.4%	6.1%	9.6%	14.1%
Parhelia-512	Effective Jitter (ns)	160pS	120pS	90pS	110pS
	Fraction of a pixel (%)	0.6%	2.0%	2.1%	3.5%

Hsync Jitter – Secondary Output

Pixel Clock Frequency		40MHz	160MHz	240MHz	320MHz
Radeon 8500	Effective Jitter (ns)	700pS	750pS	1.17nS	
	Fraction of a pixel (%)	2.8%	12.1%	27.9%	
GeForce4	Effective Jitter (ns)	490pS	270pS	220pS	260pS
	Fraction of a pixel (%)	2.0%	4.4%	5.3%	6.9%
Parhelia-512	Effective Jitter (ns)	120pS	70pS	40pS	90pS
	Fraction of a pixel (%)	0.6%	2.0%	2.1%	3.5%

The results highlight that the Parhelia-512 has the lowest jitter and, therefore, the most stable display output. The jitter of the Radeon 8500 goes up to 33% of the pixel clock. This shows that a pixel can, at any given time, be displayed up to one third of a pixel off its specified position.

The effect of pixel clock and Hsync jitter was tested on a Viewsonic VP230MB LCD monitor. That flat panel monitor has a native resolution of 1600x1200 and is equipped with digital and analog inputs. The analog input was tested with all the cards at standard resolutions [1024x768, 1152x882, 1280x1024 and 1600x1200]. Parhelia-512 provided a stable and crisp image at all resolutions. The Radeon 8500 could not display 1280x1024 or 1600x1200. The monitor was unable to synchronize itself to the RGB signal provided by the Radeon board tested due to excessive jitter. The Geforce4 exhibited significant noise at all the resolutions tested and the display could not synchronize at 1600x1200, again due to pixel jitter.

Board Design: Attention to detail

One of the reasons for the superior quality of the results of the Parhelia-512 is the particular attention paid to the board design. The Parhelia-512 GPU is mounted on an 8-layer printed circuit board (PCB). This allows for contiguous ground and power planes providing better power distribution, signal return paths and reduced AC coupling noise. The 8 layers also enable better routing of the analog sections with each analog signal receiving enough clearance to avoid crosstalk and interference with other signals. The boards are routed by hand in order to achieve the optimal signal quality. All boards go through a rigorous validation procedure to ensure reliability throughout the life of the product. Every single component used on Matrox boards passes through a series of qualification steps to certify the overall quality of the product. When necessary, more precise components are selected to obtain better and consistent quality on all products.

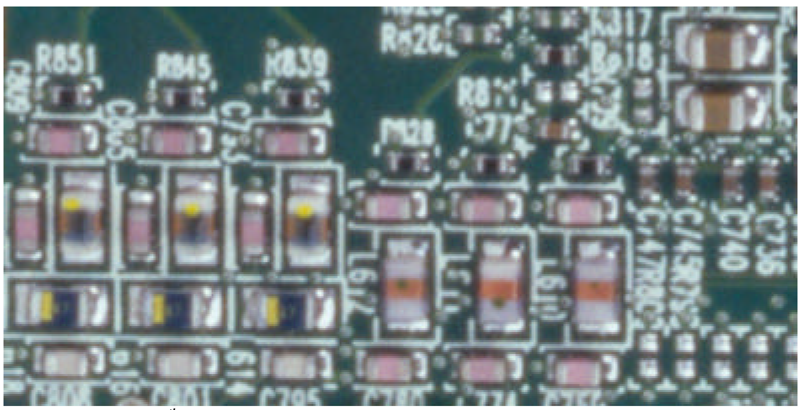


Photo of the 5^{th} order filter used on the Parhelia-512 PCB. This precisely tuned filter is one of the factors enabling the outstanding frequency response of the product

All of these measures come at a price, either through more expensive materials or through extensive testing and design. Most other vendors cut corners in their products in order to reduce overall costs, which is reflected in their output quality as highlighted in this document.

Throughout its twenty-five years of existence, Matrox has developed significant expertise in video signal quality and board design within its professional graphics, video and imaging divisions. This know-how is skillfully utilized to achieve the optimal quality products.

Conclusion

This paper calls attention to the importance of visual quality while providing a quantitative matrix enabling the comparison of various products. The results of the study indicate that the Matrox Parhelia-512 provides a superior signal reproduction that yields the best quality output over the NVIDIA GeForce4 and the ATI Radeon 8500 boards. All of the metrics and test methods are described in the document. Anyone interested in visual quality is encouraged to reproduce these tests in their laboratories using the methodology described in this paper and in the VESA VSIS specification.

The results indicate Parhelia-512 has the most precise frequency response on both outputs that is constant over the complete frequency range. This enables accurate color reproduction that will benefit from the full contrast range available through the monitor. Parhelia-512 also offers the best transient response and the highest video bandwidth to produce sharp outputs that showcase the full spatial resolutions of the monitor without any streaking or ghosting. Finally, Parhelia-512 has the lowest clock and sync jitter to provide the most stable image available on the market.

To achieve the highest fidelity graphics, Parhelia-512 was designed with tremendous attention to detail paid to every aspect of the graphics pipeline. Parhelia-512's UltraSharp display outputs are designed to enable the best quality output through well-tuned, high-quality electronics for precise and crisp images.

Appendix 1 - Complete results for Frequency Response tests

DAC #1

ATI Radeon 8500

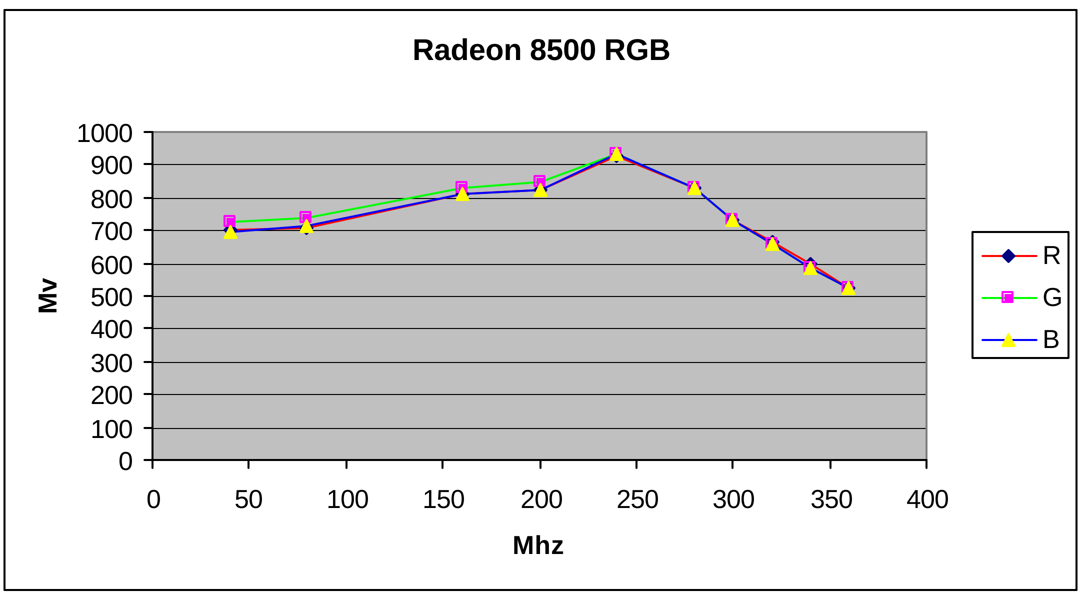
Frequency	**40Mhz**	**80Mhz**	**160Mhz**	**200Mhz**	**240Mhz**	**280Mhz**	**300Mhz**	**320Mhz**	**340Mhz**	**360Mhz**
Red	700	708	812	824	928	828	732	664	596	524
Green	724	736	832	848	932	828	732	656	584	524
Blue	696	716	812	824	932	828	732	656	584	524

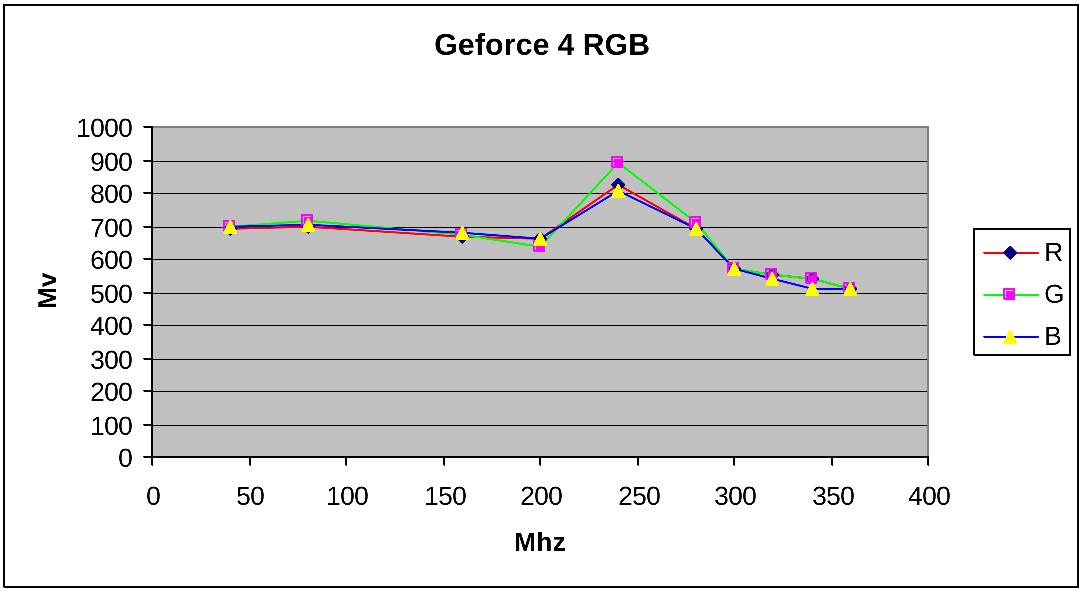
NVIDIA GeForce4

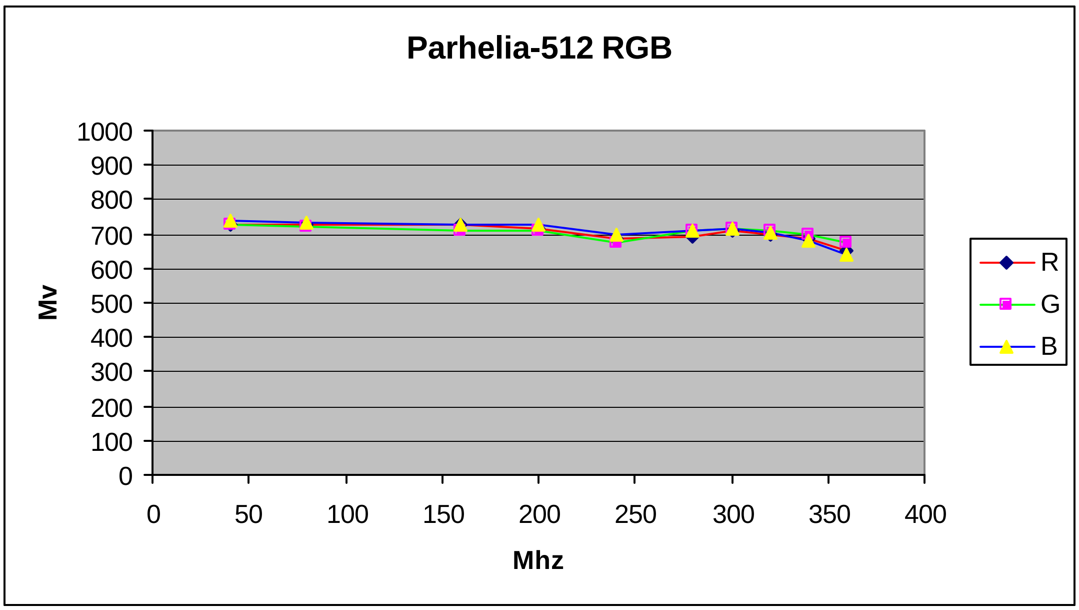
Frequency	**40Mhz**	**80Mhz**	**160Mhz**	**200Mhz**	**240Mhz**	**280Mhz**	**300Mhz**	**320Mhz**	**340Mhz**	**360Mhz**
Red	692	696	668	660	824	692	572	552	540	512
Green	700	716	672	636	892	712	572	552	540	512
Blue	696	704	676	660	804	688	572	540	512	512

Matrox Parhelia-512

Frequency	**40Mhz**	**80Mhz**	**160Mhz**	**200Mhz**	**240Mhz**	**280Mhz**	**300Mhz**	**320Mhz**	**340Mhz**	**360Mhz**
Red	724	724	724	716	684	692	712	700	684	652
Green	724	720	712	708	676	708	716	712	700	672
Blue	736	732	724	724	700	708	716	704	680	640




Geforce 4 RGB
1000
900
800
700
600
500
400
300
200
100
0
Mv
0
50
100
150
200
250
300
350
400
Mhz
R
G
B


Parhelia-512 RGB
1000
900
800
700
600
500
400
300
200
100
0
Mv
0
50
100
150
200
250
300
350
400
Mhz
R
G
B

DAC #2

ATI Radeon 8500

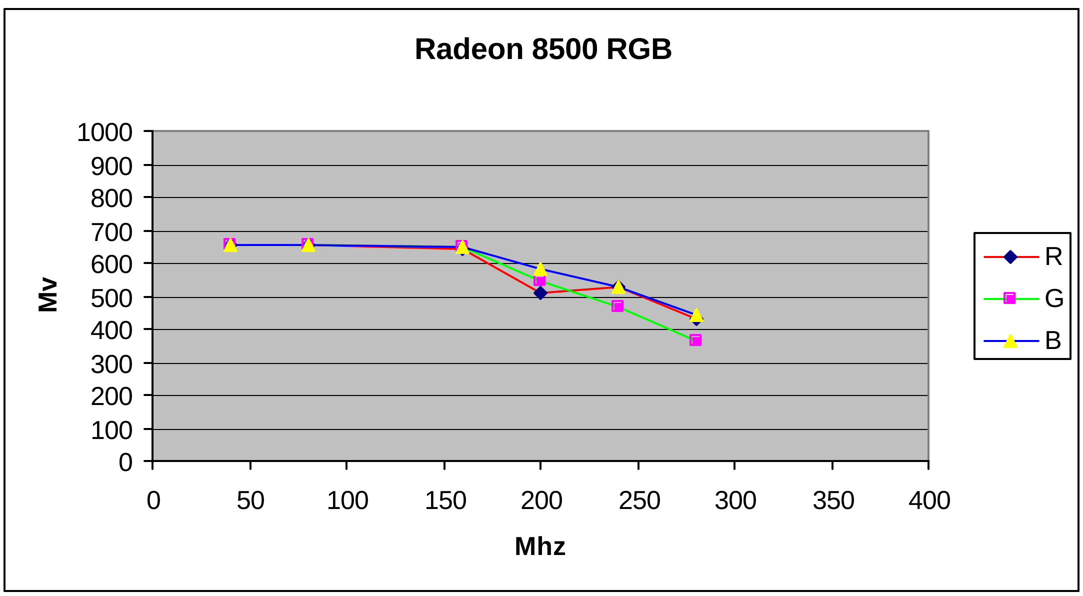
Frequency	40Mhz	80Mhz	160Mhz	200Mhz	240Mhz	280Mhz	300Mhz	320Mhz	340Mhz	360Mhz
Red	656	656	644	512	528	428				
Green	656	656	648	544	468	364				
Blue	656	656	648	580	528	440				

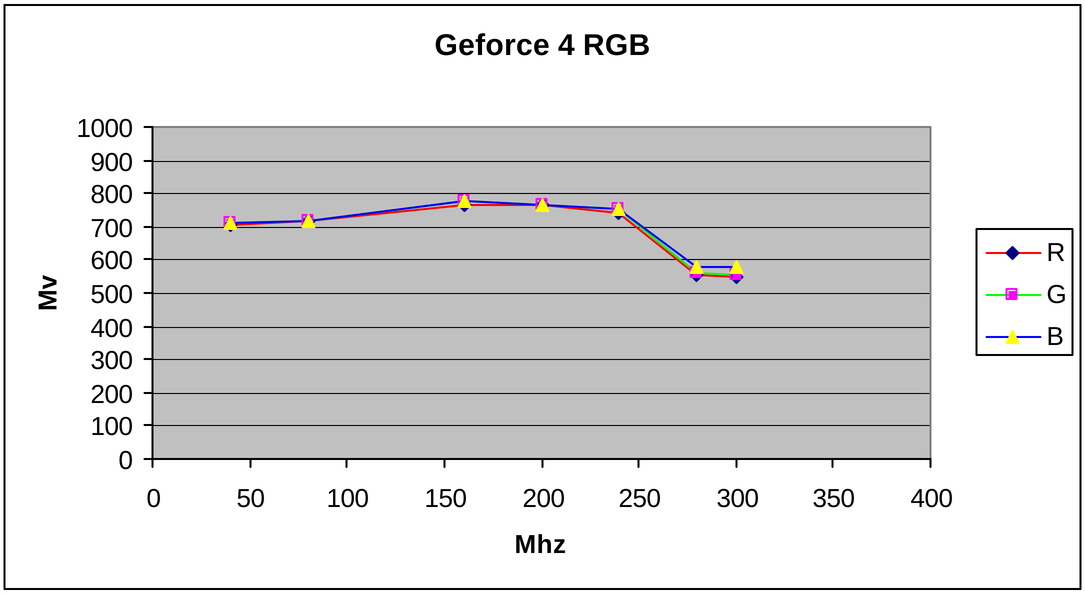
NVIDIA GeForce4

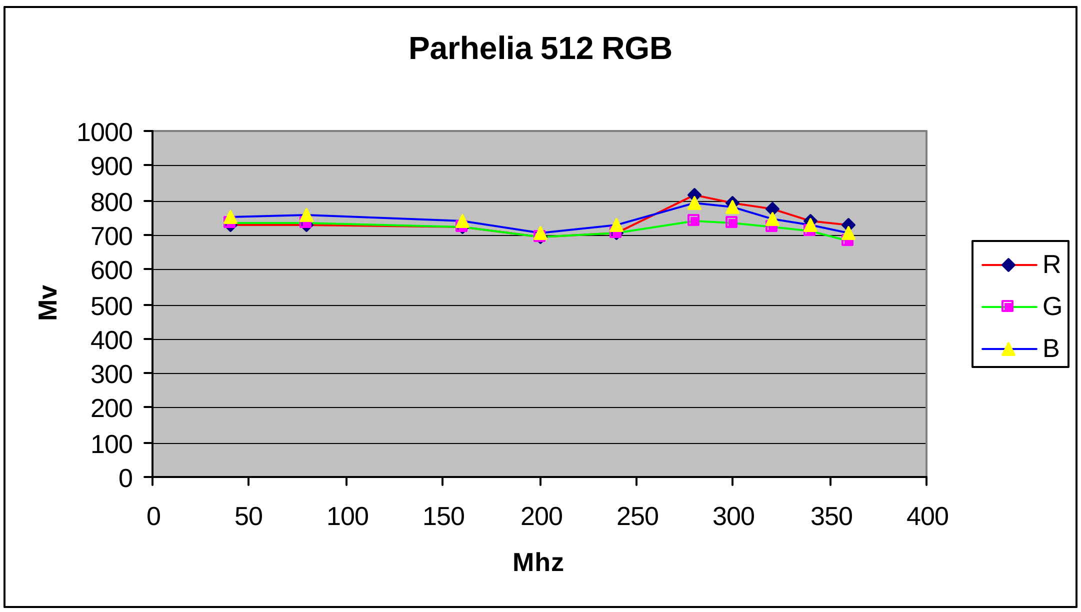
Frequency	40Mhz	80Mhz	160Mhz	200Mhz	240Mhz	280Mhz	300Mhz	320Mhz	340Mhz	360Mhz
Red	704	716	768	768	740	556	548			
Green	712	716	780	768	752	558	556			
Blue	708	716	780	768	752	576	580			

Matrox Parhelia-512

Frequency	40Mhz	80Mhz	160Mhz	200Mhz	240Mhz	280Mhz	300Mhz	320Mhz	340Mhz	360Mhz
Red	732	740	728	716	752	676	672	668	660	640
Green	736	740	728	716	724	700	696	680	668	652
Blue	748	752	750	724	772	700	680	672	660	632







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Appendix 2 – Complete Pixel Jitter results

Effective Jitter = (Measured Hsync delta – Trigger Error) / 2

DAC 1

ATI Radeon 8500

Nominal frequency	40MHz	160MHz	240MHz	320MHz
PCLK Period Measured	24.8nS	6.3nS	4.2nS	3.16nS
Trigger Error	260pS	300pS	320pS	320pS
Measured Hsync Delta	2.32nS	2.48nS	2.22nS	2.44nS
Effective Jitter	1.03nS	1.09nS	0.95nS	1.06nS
Fraction of a pixel (%)	4.15%	17.30%	22.62%	33.54%

Nvidia GeForce4

Nominal frequency	40MHz	160MHz	240MHz	320MHz
PCLK Period Measured	24.91nS	6.25nS	4.16nS	3.19nS
Trigger Error	280pS	300pS	320 pS	320 pS
Measured Hsync Delta	1.00nS	1.06nS	1.12nS	1.22nS
Effective Jitter	360pS	380pS	400pS	450pS
Fraction of a pixel (%)	1.45%	6.08%	9.62%	14.11%

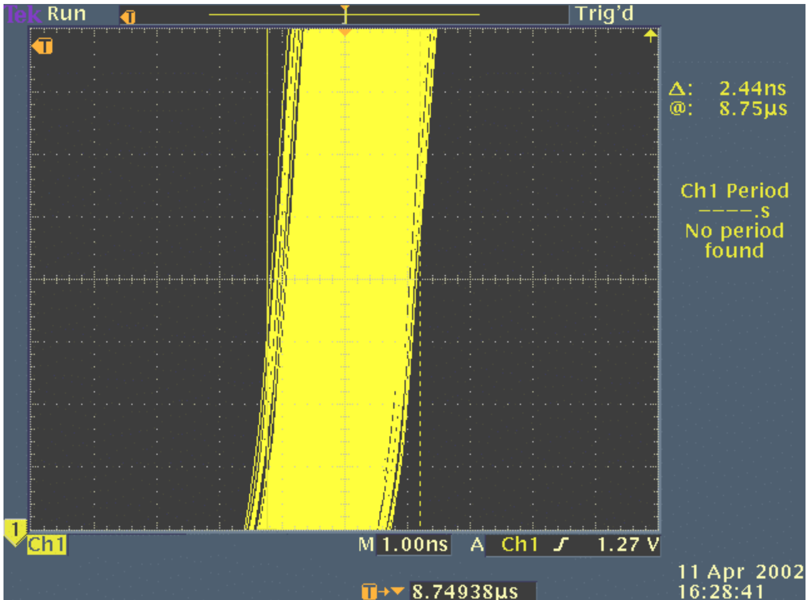
Matrox Parhelia-512

Nominal frequency	40MHz	160MHz	240MHz	320MHz
PCLK Period Measured	25nS	6.15nS	4.2nS	3.16nS
Trigger Error	260pS	300pS	320pS	320pS
Measured Hsync Delta	600pS	540pS	500pS	540pS
Effective Jitter	160pS	120pS	90pS	110pS
Fraction of a pixel (%)	0.64%	1.95%	2.14%	3.48%

DAC2

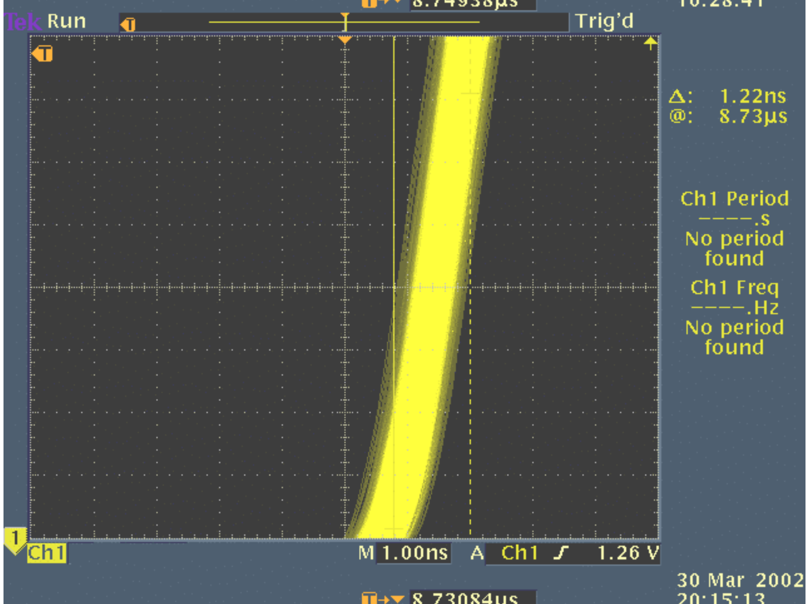
ATI Radeon 8500				
Nominal frequency	**40MHz**	**160MHz**	**240MHz**	**320MHz**
PCLK Period Measured	24.8ns	6.2ns	4.2ns	
Trigger Error	260pS	300pS	320pS	
Measured Hsync Delta	1.66nS	1.80nS	2.66nS	
Effective Jitter	700pS	750pS	1.17nS	
Fraction of a pixel (%)	2.82%	12.10%	27.86%	
Nvidia GeForce4				
Nominal frequency	**40MHz**	**160MHz**	**240MHz**	**320MHz**
PCLK Period Measured	25ns	6.1ns	4.12ns	3.75ns
Trigger Error	280pS	300pS	320 pS	320 pS
Measured Hsync Delta	1.24nS	840pS	760pS	840pS
Effective Jitter	490pS	270pS	220pS	260pS
Fraction of a pixel (%)	1.96%	4.43%	5.34%	6.93%
Matrox Parhelia-512				
Nominal frequency	**40MHz**	**160MHz**	**240MHz**	**320MHz**
PCLK Period Measured	24.7nS	6.25nS	4.12nS	3.16nS
Trigger Error	280pS	300pS	320 pS	320 pS
Measured Hsync Delta	500pS	440pS	400pS	500pS
Effective Jitter	120pS	70pS	40pS	90pS
Fraction of a pixel (%)	0.6%	2.0%	2.1%	3.5%

The following snapshots were taken at a 320MHz Pixel clock:



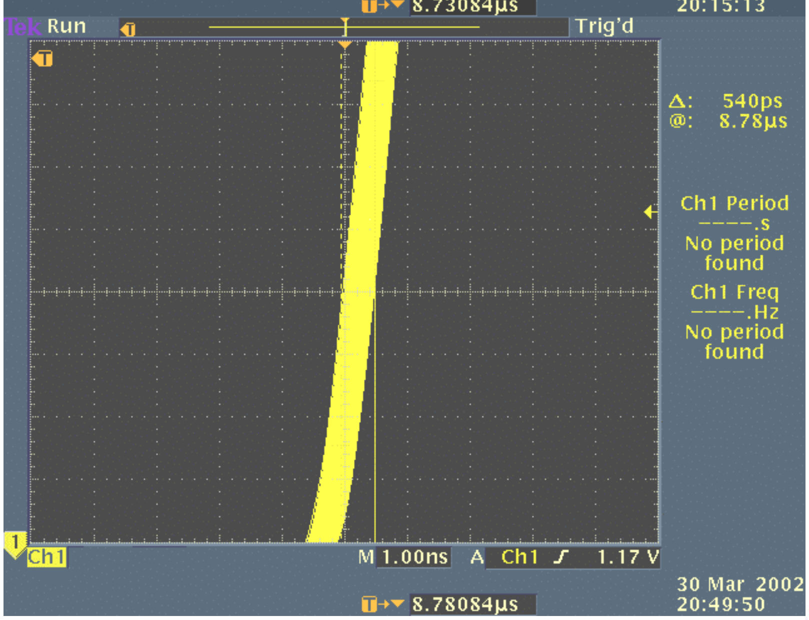
ATI Radeon 8500

The overall Hsync delta of 2.44ns is specified on the top right.



NVIDIA GeForce4

The overall Hsync delta of 1.22ns is specified on the top right.



Matrox Parhelia-512

The overall Hsync delta of 540ps is specified on the top right.

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