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The compatibility of consumer plasma displays with time-sequential stereoscopic 3D visualization

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ABSTRACT

Plasma display panels (PDP) are now a commonly used display technology for both commercial information display purposes and consumer television applications. Despite the widespread deployment of these displays, it was not commonly known whether these displays could be used successfully for time-sequential stereoscopic 3D visualization (i.e. using LCS 3D glasses). We therefore conducted a study to test a wide range of PDPs for stereoscopic compatibility. This paper reports on the testing of 14 consumer plasma displays. Each display was tested to establish whether the display synchronized with the incoming video signal, whether there was electronic crosstalk between alternate fields or frames, the maximum frequency at which the display would work, the time delay between the incoming video signal and the displayed images, whether the display de-interlaced interlaced video sources in a 3D compatible way, and the amount of phosphor decay exhibited by the display. The overall results show that plasma displays are not ideal for use with time-sequential stereo. While roughly half of the plasma displays tested do support the time-sequential 3D technique, all of the tested displays had a maximum display frequency of 60Hz and most had long phosphor persistence which produces a lot of stereoscopic crosstalk.

Keywords: stereoscopic, 3D, plasma displays, PDP, time-sequential.

1. INTRODUCTION

Plasma display panels (PDP) are now a commonly used display technology for both commercial information display purposes and consumer television applications. Despite the widespread deployment of these displays, prior to this study it was not commonly known whether plasma displays could be used successfully for time-sequential stereoscopic 3D visualization (i.e. using LCS (Liquid Crystal Shutter) 3D glasses).

There is an increasing awareness and demand for large stereoscopic displays, and it would be ideal if existing plasma displays could be used for this purpose.

We therefore undertook a research project to sample a wide range of consumer-grade plasma displays to determine their level of time-sequential 3D compatibility. The results of the project would provide an improved understanding of the level of 3D compatibility of consumer-grade plasma displays for those wishing to employ large direct-view stereoscopic displays, and also hopefully raise awareness of the potential stereoscopic capability of these displays in the hope that manufacturers would implement time-sequential stereoscopic display compatibility in future models as a standard feature (and list it in their specifications).

Previous work conducted at Curtin has included studies of the 3D compatibility[1] of CRT monitors[2], LCD monitors[3], and DLP projectors[4]. This study is a natural progression of those previous studies.

1.1 Operation of a Plasma Display Panel

A plasma display consists of a two-dimensional array of millions of tiny cells, called sub-pixels. Each sub-pixel contains a mixture of noble gases and is lined with a phosphorescent material. Three sub-pixels driven together (a red sub-pixel, a green sub-pixel, and a blue sub-pixel) form a full color pixel. Figure 1a shows the structure of a typical AC plasma display sub-pixel. When a voltage is applied across a particular sub-pixel, plasma is created which emits ultraviolet light. The ultraviolet light is absorbed by the phosphor within the cell, which in turn emits light of a particular color.

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Unlike CRTs or LCDs, all the sub-pixels in a plasma display can be driven to output light at the same time. Figure 1b and 1c show the time-domain drive scheme of a plasma display panel. In these graphs, the horizontal axis is time and the vertical axis is the vertical position on screen (the pixel row number counting from the top down). In this example, during each field-period the plasma display can be energized up to 8 times – each of these 8 periods is called a sub-field. Figure 1c shows the structure of one sub-field (SF), comprising a reset period, the addressing period (each sub-pixel in the entire display is individually addressed for triggering or not-triggering), and the sustain period (the entire panel is energized, and those sub-pixels that have been triggered, will output light). It can be seen from Figure 1b that the sustain period is different for each of the sub-fields, in a binary pattern – i.e. SF1 has a sustain period of 1 'unit' (0.01ms), SF2 has a sustain period of 2 'units', SF3=4, SF4=8, … , SF8=128 'units' (1.28ms). In general terms, a sub-pixel triggered during sub-field 8 (SF8) will have double the brightness of a sub-pixel triggered during sub-field 7 (SF7). For each sub-pixel, different grey-levels are achieved by triggering the sub-pixel only in selected sub-fields. For example, in general terms, a black sub-pixel would be achieved by not triggering the sub-pixel during any of the sub-fields, a full-bright sub-pixel would be achieved by triggering the sub-pixel during all of the sub-fields, and a half-brightness sub-pixel would be achieved by only triggering the sub-pixel during sub-field 8 (SF8).

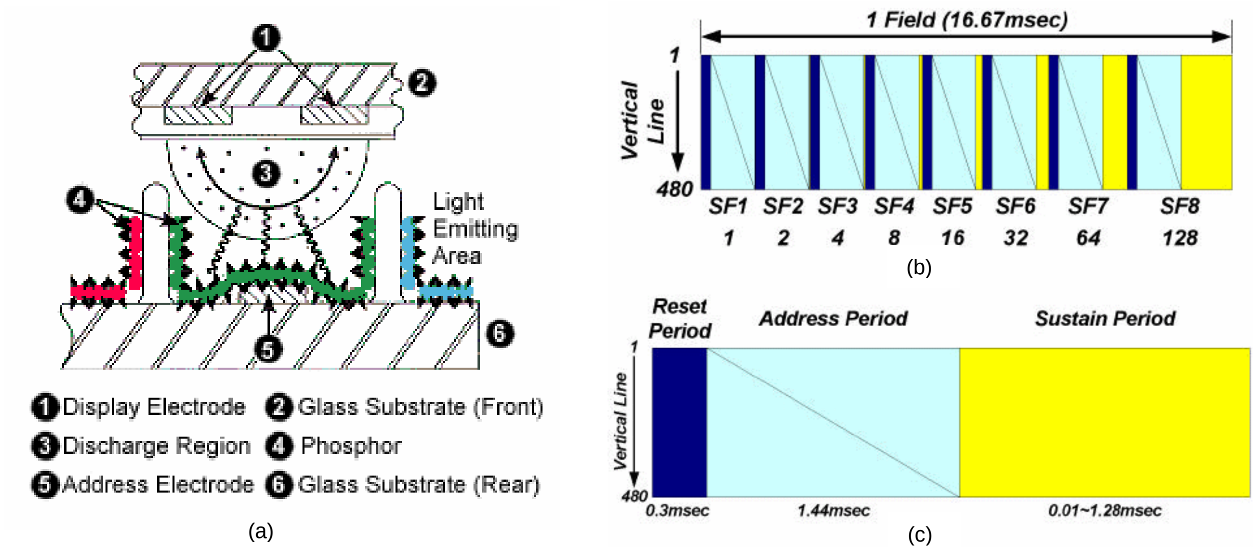

Figure 1: (a) The layout of a typical AC plasma display sub-pixel[5], (b) an illustration of the time-domain drive scheme of an example plasma display panel using 8 sub-fields during one TV-field[6], and (c) the time-domain structure of a single sub-field[6].

As was mentioned above, all sub-pixels of a plasma display can be driven simultaneously, however unlike a CRT which only drives each pixel to emit light once per field, a plasma display can be driven to output light multiple times per field (8 times per field in the example above, although different plasma displays use a different number of sub-fields per TV-field, and different sub-field timing). This means that plasma displays act somewhat like a cross between a hold-type display and an impulse-type display. CRTs are an impulse-type display and LCDs are a hold-type display.

2. EXPERIMENTAL METHOD

In this study we tested 14 different consumer-grade plasma displays from nine different manufacturers. The age of the displays ranged from units that were several years old to units that had only been recently released at the time of the tests.

Equipment used for testing included: two custom-built photodiode sensor pens (based on an Integrated Photomatrix Inc. IPL10530 DAL), two oscilloscopes (a Goldstar OS-3000, and a TiePie Engineering Handyscope HS3 digital USB oscilloscope), and a custom-built LCS 3D glasses driver box capable of adjustable phase and duty cycle. Equipment used to generate the time-sequential 3D video signals consisted of a small form factor PC fitted with a stereoscopic capable graphics card (NVIDIA 6600GT) and a Panasonic 'DMR-E65' DVD recorder/player. The Panasonic DMR-E65 was chosen because it is known to convert interlaced video signals to progressive in a 3D compatible way when the component progressive output is selected via the internal menu. Software on the PC consisted of Windows XP, the NVIDIA 3D Stereo Driver[7], the NVIDIA JPS Viewer[7], and Powerstrip[8]. The test equipment layout is shown in Figure 2.

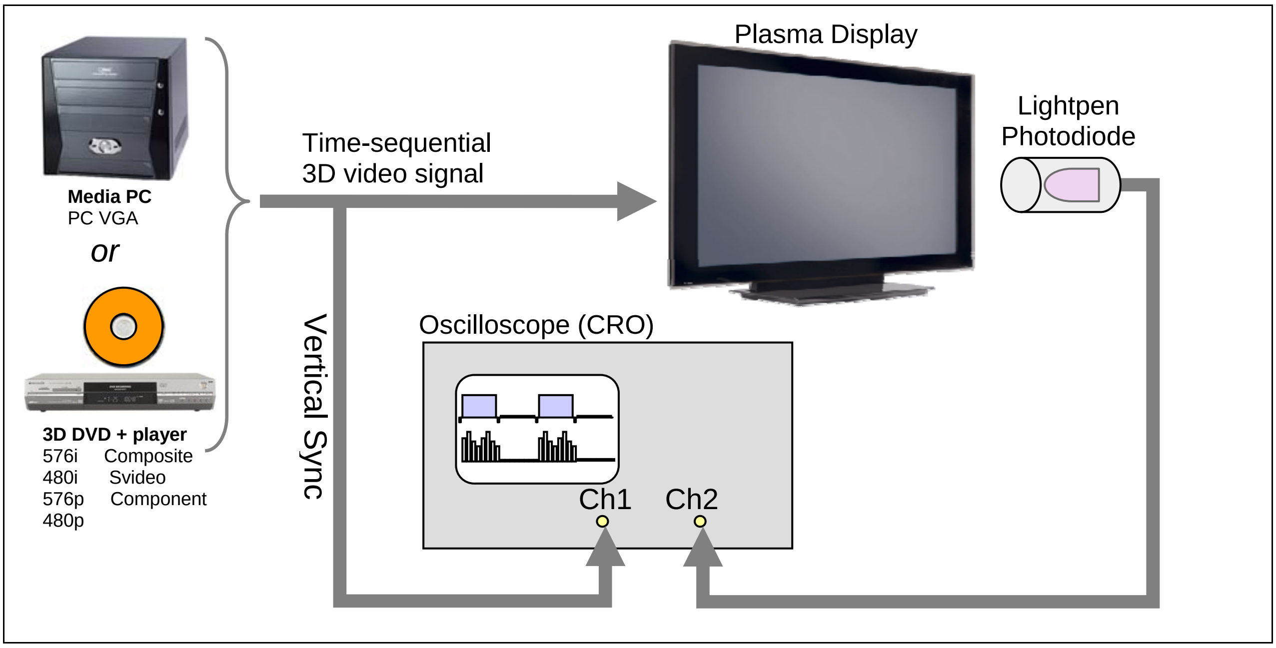

Figure 2: Schematic diagram of the experimental setup.

Test signals consisted of alternating sequences (at field or frame rate) of red and black, blue and black, green and black, white and black, or RGB color bars and black (i.e., in the case of "red and black", one field of red, one field of black, and repeat). In the case of the DVD player, custom written NTSC and PAL 3D DVDs were used. In the case of the PC, custom created JPS (Stereoscopic JPEG) files were used.

Each plasma display was tested to establish: (a) whether the output frame rate of the display synchronized with the incoming video signal, (b) whether there was electronic crosstalk between alternate fields or frames, (c) the maximum frequency at which the display would work in stereo (VGA only), (d) the time delay between the incoming video signal and the displayed images, (e) whether the display de-interlaced interlaced video sources in a 3D compatible way, and (f) the amount of phosphor decay exhibited by the display. These properties were tested for various video input connections (composite, SVideo, component, and VGA), various video formats (NTSC (480i), PAL (576i), 480P, 576P), and various VGA resolutions/frequencies.

Standard Definition (SD) video formats were tested because there is a reasonable range of commercially available field-sequential 3D DVDs and it is important to know which displays can be used with these 3D DVDs. VGA modes were tested because the projector can be driven at its native resolution and frame rate with this interface. DVI-D and HDMI input connections were not tested because a method of extracting the vertical sync signal from these interface cables was not available.

3. RESULTS AND DISCUSSION

The 14 plasma displays tested in this study are listed in Table 1 along with some basic specifications.

Table 1: The Plasma displays tested in this study, their basic specifications, and an arbitrary identification tag.

Tag	**Manufacturer**	**Model**	Screen Diagonal (inches)	Native Display Resolution	VGA Input Resolution
D01	LG	DT-42PY10X	42	1024 x 768	1024 x 768
D02	Fujitsu	P50XHA51AS	50	1366 x 768	1360 x 768
D03	NEC	PX-50XR5W	50	1366 x 768	1360 x 768
D04	Panasonic	TH-42PV60A	42	1024 x 768	1024 x 768
D05	Samsung	PS-42C7S	42	852 x 480	800 x 600
D06	LG	RT-42PX11	42	852 x 480	800 x 600
D07	NEC	PX-42XM1G	42	1024 x 768	1024 x 768
D08	Sony	PFM-42V1	42	852 x 480	800 x 600
D09	Sony	FWD-50PX2	50	1366 x 768	1360 x 768
D10	Hitachi	55PD8800TA	55	1366 x 768	1024 x 768
D11	Hitachi	42PD960BTA	42	1024 x 1080	1024 x 768
D12	Pioneer	PDP-507XDA	50	1366 x 768	1360 x 768
D13	Pioneer	PDP-50HXE10	50	1366 x 768	1360 x 768
D14	Fujitsu	PDS4221W-H	42	1024 x 1024	1024 x 768

3.1 Synchronization

In order for time-sequential 3D video to work correctly on a particular display, it is necessary for the display's update of video frames to synchronize with the input video signal. It has been found that in some cases the display has its own native frequency of display (usually ~60Hz) and all other input frequencies are resampled to this native frequency – this resampling process usually destroys the 3D video signal.

Table 2 lists the synchronization test results. The 'Component 50Hz Progressive' column indicates whether the display would correctly synchronize to 576P 50Hz frame-sequential 3D video (derived from a PAL 3D DVD) entered via the component connector. The 'Component 60Hz Progressive' column indicates whether the display would correctly synchronize to 480P 60Hz frame-sequential 3D video (derived from an NTSC 3D DVD) entered via the component connector. The VGA 60Hz column indicate whether the display would correctly synchronize to frame-sequential 3D video entered via the VGA connector (in almost all cases the video resolution was set to the native resolution of the display). The bottom row of the table indicates the percentage of all tested projectors that would synchronize in that video mode.

It is worth noting that none of the tested plasma displays were 3D compatible with interlaced video sources (576i or 480i field-sequential). This is undoubtedly due to the display using a 3D incompatible 'interlaced to progressive scan' converter. Fortunately the 3D incompatible 'interlaced to progressive scan converter' can be bypassed by inputting a progressive video signal into the display.

Regarding Table 2, it can be seen that some of the tested displays (D01, D04 and D06) would not synchronize to the incoming video signal in any video mode or video connection, and hence would not be time-sequential 3D compatible. It is surprising to see this result because non-synchronization would also cause problems for regular 2D content – in scenes of continuous smooth motion, a regular stutter or glitch in the motion would be visible.

Table 2: Display synchronization test results for the 14 plasma displays. (A green 'YES' indicates that the display did synchronize with the incoming video signal, a red 'NO' indicates that the display did not synchronize in those modes, and a dash indicates that mode was not tested (either because that mode was not available on that display, or a necessary cable or connector was not available).

Display	Component 50Hz progressive	Component 60Hz progressive	VGA	VGA input resolution
D01	No	No	No	1024 x 768
D02	Yes	Yes	Yes	1360 x 768
D03	No	Yes	No	1360 x 768
D04	No	No	No	1024 x 768
D05	Yes	Yes	No	800 x 600
D06	No	No	No	800 x 600
D07	Yes	Yes	Yes	1024 x 768
D08	-	-	Yes	800 x 600
D09	-	-	Yes	1360 x 768
D10	-	No	No	1024 x 768
D11	Yes	-	No	1024 x 768
D12	Yes	Yes	No	1360 x 768
D13	-	-	No	1360 x 768
D14	No	Yes	Yes	1024 x 768
% of displays that synchronize the display output to the input video signal	**50%**	**60%**	**38%**	

3.2 Time Delay

With some displays there is often a time delay between the video information being received at the display via one of the video input connectors, and light being output on the display for that particular frame. This effect is shown for an example plasma display in Figure 3. Table 3 lists the time delay measurement for the tested plasma displays with different input video sources.

Most drivers for LCS 3D glasses assume that there is no such delay (which is correct for CRTs). If LCS 3D glasses with no delay are used to view time-sequential 3D images on a display with a significant amount of time delay, a great deal of ghosting can be present. As mentioned earlier, we developed a smart dongle which allows the time delay of the LCS 3D glasses to be adjusted.

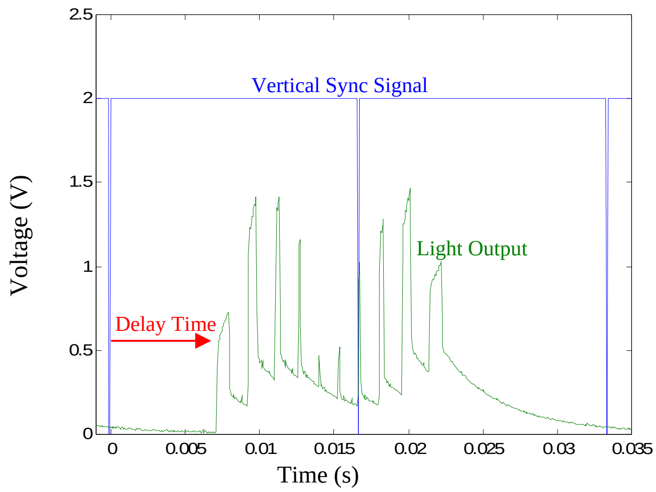

Figure 3: This graph illustrates the delay time between the vertical sync from the VGA video signal (blue trace) and light output on the display (green trace) was measured as 23.7ms for monitor D14. The vertical axis of the graph is brightness for the Light Output trace, and Voltage for the Vertical Sync trace. In this instance one frame period = 16.7ms (60Hz) and the delay time is approximately 7ms.

Table 3: This table shows the measured time delay between the trailing edge of the vertical sync and the start of light output on the screen, measured in milliseconds. ('N.S.' means the display would Not Synchronize with the video signal, and '-' means this video mode could not to be tested)

Display ID	Component (50Hz)	Component (60Hz)	VGA (60Hz)	Maximum Resolution
D01	N.S.	N.S.	N.S.	1024 x 768
D02	30.0	26.7	26.7	1360 x 768
D03	N.S.	26.0	N.S.	1360 x 768
D04	N.S.	N.S.	N.S.	1024 x 768
D05	22.0	19.0	N.S.	800 x 600
D06	N.S.	N.S.	N.S.	800 x 600
D07	39.2	32.4	33.9	1024 x 768
D08	-	-	30.0	800 x 600
D09	-	-	25.2	1360 x 768
D10	-	N.S.	N.S.	1024 x 768
D11	21.6	-	N.S.	1024 x 768
D12	40.2	45.6	N.S.	1360 x 768
D14	N.S.	23.4	23.7	1024 x 768

3.3 Phosphor Decay

Like CRTs, plasma displays also use phosphors to generate visible light. And as with CRTs, phosphor decay (aka: phosphor persistence, phosphor afterglow) can also be a problem with plasma displays. Figure 4 shows the time-domain response of an example plasma display (D14). It can be seen from the graph that this particular display has 10 sub-fields per TV-field (count the peaks), but more importantly for this section, after each peak the red and the green color primaries exhibit a significant amount of phosphor decay. In this example, the blue color primary doesn't have any noticeable phosphor decay. This type of graph was very common among the displays that were tested. The red and green phosphors typically had phosphor decays with long time constants, whereas blue usually exhibited almost no phosphor afterglow.

Long phosphor decay when combined with time-sequential 3D viewing produces ghosting since the light from one eye view leaks into the time period of the other eye view.

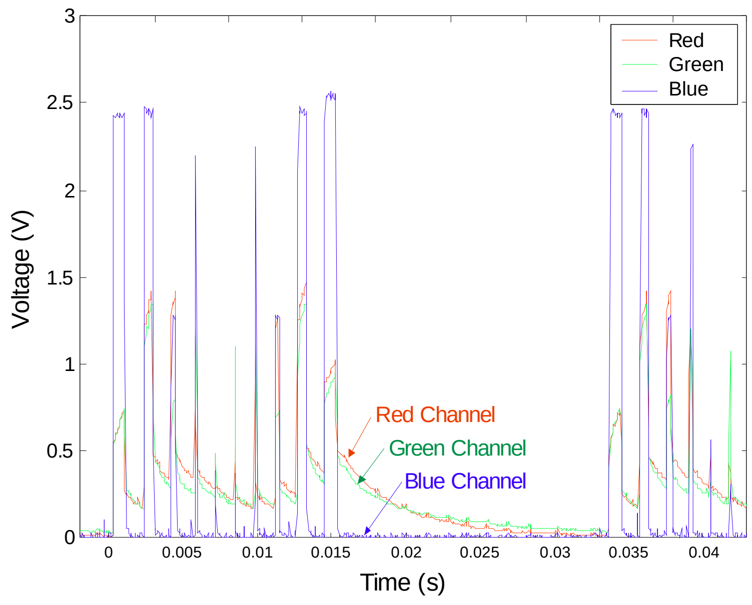

Figure 4: The time-domain light output of an example plasma display (D14) (for alternate frames of 100% red, green and blue with black). The vertical axis is brightness of the each of the color channels as measured in volts by the photo sensor, and the horizontal axis is time (seconds).

3.4 Crosstalk

Most of the plasma displays tested exhibited significant amounts of crosstalk when viewing time-sequential 3D images using LCS 3D glasses. The main reason for the excessive crosstalk is the significant amount of phosphor afterglow. Figure 5 below shows the time-domain light output for a red frame (followed by a black frame) for display D02, along with the transmission response of an example pair of LCS 3D glasses for both eyes (in this case a pair of NuVision 3DSpex glasses driven by the Curtin smart dongle). In Figure 5, it can be seen that from 0 to 17ms the left eye of the LCS glasses is transmissive and the right eye of the LCS glasses is opaque. At about 17ms, the LCS glasses switch from one state to the other, and in the example of Figure 5 the afterglow of the phosphors is still decaying from the first field, hence light from the left eye image will leak into the right eye producing crosstalk.

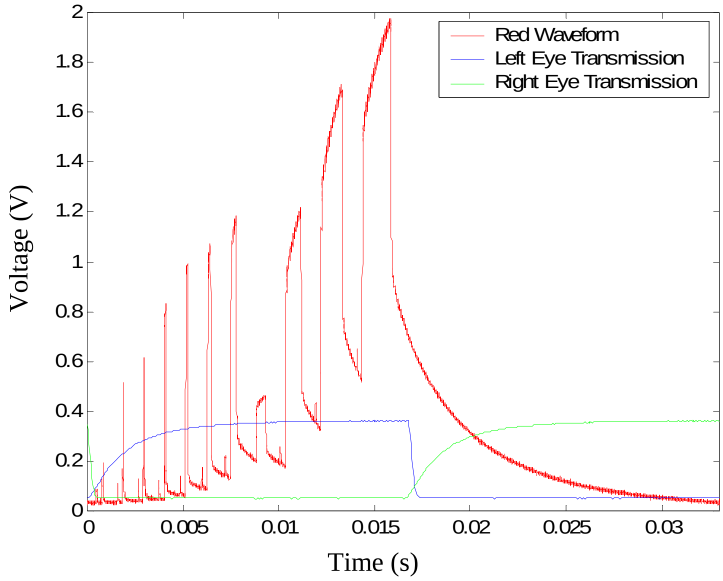

Figure 5: Diagram showing the LCS 3D glasses transmission states for both eyes and the time-domain light output for a red frame (followed by a black frame) for display D02. The vertical axis is brightness of the each of the color channels as measured in volts by the photo sensor, and the horizontal axis is time (seconds). In this instance one frame period = 16.7ms (60Hz).

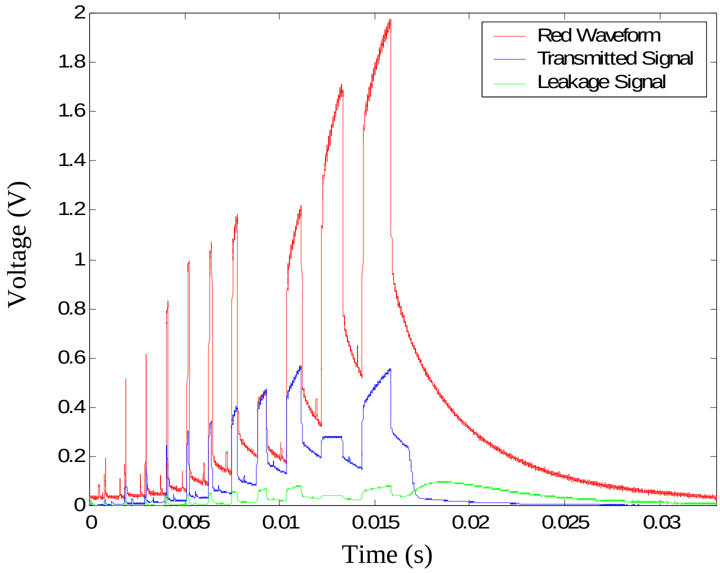

Figure 6: Diagram showing the original red waveform of monitor D02 (red), the transmitted signal to the left eye (blue), and the crosstalk signal to the right eye (green)

Figure 6 shows the result of multiplying the red waveform amplitude with the transmission response of the LCS glasses (left eye, and right eye) – firstly the transmitted (desired) signal in blue, along with the leakage (undesired) signal in green. Division of the area under the leakage curve by the area under the transmitted curve will give the crosstalk measure.

The calculated time-sequential 3D crosstalk factors for each of the plasma displays tested is listed in Table 4. As can be seen in the table, monitor D08 exhibits the least crosstalk, and monitor D10 exhibits the most crosstalk. The crosstalk performance for an example DLP projector is also provided for comparison purposes. The switching of DLP projectors is almost perfect with negligible leakage between frames due to the DLP engine, which means that essentially all of the crosstalk for DLP projectors is due to the glasses. The crosstalk factor for D08 is only a few points higher than DLP which is a reasonable result. On the other hand, results such as the 38.3 crosstalk factor figure for D10, will mean that a time-sequential 3D image would be severely affected by crosstalk.

Table 4: Calculated time-sequential crosstalk factors with 50% duty cycles (green, yellow and orange cells indicate overall crosstalks of <10%, 10-20% and >20% respectively)

Display	*Duty Cycle*	*Total Crosstalk*	*Red Crosstalk*	*Green Crosstalk*	*Blue Crosstalk*
D01	50	22.6 ± 2.1	11.7 ± 0.8	10.5 ± 1.2	0.4 ± 0.1
D02	50	27.9 ± 3.0	12.2 ± 1.3	15.1 ± 1.6	0.6 ± 0.1
D03	50	21.8 ± 2.3	8.6 ± 0.9	12.7 ± 1.4	0.5 ± 0.1
D04	50	26.9 ± 2.7	8.1 ± 0.8	18.3 ± 1.8	0.5 ± 0.1
D05	50	14.3 ± 1.5	7.2 ± 0.8	6.6 ± 0.6	0.6 ± 0.1
D06	50	21.6 ± 2.1	9.2 ± 1.0	12.0 ± 1.0	0.4 ± 0.2
D07	50	22.5 ± 2.4	9.6 ± 1.0	12.2 ± 1.3	0.7 ± 0.1
D08	50	9.9 ± 1.0	5.6 ± 0.6	3.3 ± 0.4	1.0 ± 0.1
D09	50	14.8 ± 1.5	6.5 ± 0.7	7.9 ± 0.8	0.5 ± 0.1
D10	50	38.3 ± 4.0	13.9 ± 1.5	23.8 ± 2.5	0.6 ± 0.1
D11	50	14.8 ± 1.5	6.0 ± 0.6	8.4 ± 0.9	0.4 ± 0.1
D45	50	23.2 ± 2.5	10.0 ± 1.1	12.5 ± 1.4	0.8 ± 0.1
DLP	50	5.5 ± 0.7	3.7 ± 0.4	1.3 ± 0.1	0.5 ± 0.1

In all of these examples, the glasses have been switched with a 50% duty cycle. Some simulations were also performed by reducing the duty cycle of the LCS glasses but these results are reported separately[9].

4. CONCLUSION

The purpose of this study was to determine the compatibility of plasma displays with stereoscopic visualization. Results show that approximately half of all displays tested are partially compatible with progressive time-sequential stereoscopic viewing. Approximately half of the plasma displays tested were 3D incompatible because the display output did not synchronize to the input video signal. Of the displays that did synchronize with a time-sequential 3D video signal, most produced large amounts of crosstalk – only two displays exhibited acceptably low levels of crosstalk. None of the displays were able to refresh at frequencies above 60Hz, which would generally result in noticeable flicker. None of the plasma displays tested were compatible with interlaced time-sequential 3D video signals (as provided by field-sequential 3D DVDs). For the reasons mentioned above, it is unlikely that any of the tested plasma displays will be useful for commercial time-sequential stereoscopic applications.

Some plasma displays can be used for stereoscopic applications, however, the level of 3D compatibility is incredibly variable from one display to another. Flicker-free time-sequential 3D is not possible in the displays that we tested, as the maximum frame rate is limited to 60Hz. For this reason, the tested plasma displays would not be considered ideal for use with time-sequential 3D viewing.

It was ironic to find that the plasma display which offered the best performance of all the displays was a Sony (D08), but Sony decided to stop making plasma displays in 2006.

The research reported in this technical paper was completed in February 2007, and although we did not find any plasma displays that could be directly used for flicker-free time-sequential 3D display, the results did indicate that it was technically feasible. It was therefore heartening to hear in early January 2008, when this technical paper was being completed, that Samsung will be releasing several consumer "3D Ready" plasma displays in March 2008[10]. The displays use LCS 3D glasses to view the time-sequential 3D image which updates at 120Hz. As yet we have not been able to test one of these new Samsung "3D Ready" plasma displays, but obviously Samsung have been able to successfully implement 120Hz synchronous operation in a plasma display, and presumably they have also been able to minimize phosphor afterglow which was identified as a problem with most of the commercial plasma displays that we tested.

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