Woods, A.J., and Rourke, T., (2007) "The compatibility of consumer DLP projectors with time-sequential stereoscopic 3D visualization", presented at *Stereoscopic Displays and Applications XVIII*, published in *Stereoscopic Displays and Virtual Reality Systems XIV*, Proceedings of IS&T/SPIE Electronic Imaging Vol. 6490, San Jose, California, 29-31 January 2007.

The compatibility of consumer DLP projectors with time-sequential stereoscopic 3D visualisation

Andrew J. Woods* and Tegan Rourke
Centre for Marine Science & Technology, Curtin University of Technology,
GPO Box U1987, Perth WA 6845, Australia.

ABSTRACT

A range of advertised "Stereo-Ready" DLP projectors are now available in the market which allow high-quality flicker-free stereoscopic 3D visualization using the time-sequential† stereoscopic display method. The ability to use a single projector for stereoscopic viewing offers a range of advantages, including extremely good stereoscopic alignment, and in some cases, portability. It has also recently become known that some consumer DLP projectors can be used for time-sequential stereoscopic visualization, however, it was not well understood which projectors are compatible and incompatible, what display modes (frequency and resolution) are compatible, and what stereoscopic display quality attributes are important. We conducted a study to test a wide range of projectors for stereoscopic compatibility. This paper reports on the testing of 45 consumer DLP projectors of widely different specifications (brand, resolution, brightness, etc). The projectors were tested for stereoscopic compatibility with various video formats (PAL, NTSC, 480P, 576P, and various VGA resolutions) and video input connections (composite, SVideo, component, and VGA). Fifteen projectors were found to work well at up to 85Hz stereo in VGA mode. Twenty-three projectors would work at 60Hz stereo in VGA mode.

Keywords: stereoscopic, field-sequential; time-sequential; DLP projectors; 3D Video

1. INTRODUCTION

The capability for some DLP (Digital Light Processing) projectors to be used with time-sequential stereoscopic display has been known for some time[1]. This is due to the extremely fast pixel response time (~2µs) of the DMD (Digital Micro-mirror Device) chip[2], the fact that the whole of the screen updates at once, and the capability of some DLP projectors to correctly display an alternating sequence of discrete left and right images.

Several DLP projectors already available in the market are advertised as being "stereo-ready" and capable of 120Hz time-sequential stereoscopic display. Table 1 lists the (time-sequential) "stereo-ready" projectors available from Barco, Christie, and Infocus at the time of writing this paper.

It also recently became known that some consumer-grade single-chip DLP projectors could be used for time-sequential stereoscopic visualization (although at much lower refresh rates), however, it was not well understood which projector models were compatible and incompatible.

We therefore undertook a research project to sample a wide range of consumer-grade single-chip DLP projectors 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 DLP projectors, which in turn would aid users wishing to use DLP projectors for stereoscopic visualisation purposes. A parallel purpose would be to raise awareness of this stereoscopic capability amongst projector manufacturers with the hope that they would implement time-sequential stereoscopic display compatibility in future models as a standard feature (and list it in their specifications).

* A.Woods@cmst.curtin.edu.au; phone +61 8 9266 7920; fax +61 8 9266 4799; www.cmst.curtin.edu.au
† Also known as: field-sequential, frame-sequential, alternate frame, or active stereo.

Table 1: Commercially available (time-sequential) "stereo-ready" DLP projectors

Projector Make/Model	Resolution	Max Freq.	# DMD
Barco DP100	2048 x 1080	144 Hz	3 DMD
Barco Galaxy 7 Classic+	1400 x 1050	118 Hz	3 DMD
Barco Galaxy 12 HB+	1400 x 1050	118 Hz	3 DMD
Christie CP2000	2048 x 1080	144 Hz	3 DMD
Christie Mirage S+2K	1400 x 1050	120 Hz	3 DMD
Christie Mirage S+4K	1400 x 1050	120 Hz	3 DMD
Christie Mirage S+8K	1400 x 1050	120 Hz	3 DMD
Christie Mirage S+14K	1400 x 1050	120 Hz	3 DMD
Infocus DepthQ	800 x 600	120 Hz	1 DMD

2. EXPERIMENTAL METHOD

In this study we tested 45 different consumer-grade single-chip DLP projectors from various manufacturers. The age of the projectors ranged from units that were several years old to projectors that had only been recently released at the time of the tests.

The test equipment layout is shown in Figure 1. Equipment used for testing included: two custom built photodiode sensor pens (based on an Integrated Photomatrix Inc. IPL10530 DAL), an oscilloscope (Goldstar OS-3000), 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 PC equipped 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[3], Powerstrip[4], and Stereoscopic Player[5].

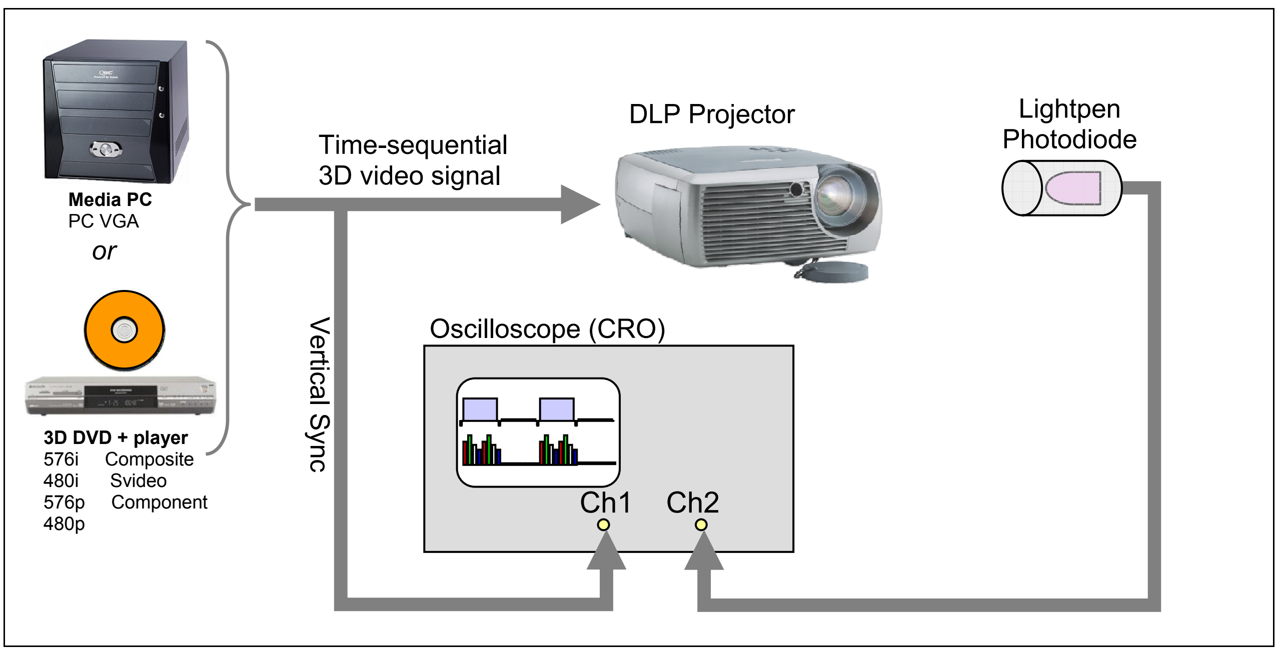

Figure 1: Schematic diagram of the experimental setup.

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 colour 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 DVDs were used. In the case of the PC, custom created JPS (Stereoscopic JPEG) files or stereoscopic (side-by-side) AVI files were used.

Each projector was tested to establish: (1) whether the frame rate of the projector synchronized with the incoming video signal, (2) whether the colour-wheel synchronized with the incoming video signal, (3) whether there was crosstalk between alternate fields or frames, (4) the maximum frequency at which the projector would work in stereo (VGA only), (5) the time delay between the incoming video signal and the displayed images, (6) whether the projector converted interlaced video sources to progressive format in a 3D compatible way, and (7) the colour-wheel speed at various video input frequencies. 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 input connections were not tested because a method of extracting the vertical sync signal from the DVI-D cable was not available.

3. RESULTS AND DISCUSSION

The 3D compatibility results of the tested projectors were wide and varied. The overall results of the 3D compatibility testing are listed in Table 2. The ‘Composite & SVideo’ column indicates whether the projector would correctly display field-sequential 3D video (PAL or NTSC) entered via the composite and SVideo connector. The results for composite and SVideo are combined in the same column because there was no difference between composite and SVideo results across all the tested projectors. The ‘Component Interlaced’ column indicates whether the projector would correctly display field-sequential 3D video (derived from PAL or NTSC DVD) entered via the component connector. The ‘Component Progressive’ column indicates whether the projector would correctly display frame-sequential 3D video (576P 50Hz or 480P 60Hz) entered via the component connector. There was no difference in 3D compatibility between PAL and NTSC (50/60Hz) in all of the tests for all of the tested projectors so those results are combined in the composite/SVideo and component columns. The VGA 60Hz and 85Hz columns indicate whether the projector would correctly display frame-sequential 3D video entered via the VGA connector (in almost all cases the video resolution was set to the native resolution of the projector). The bottom row of the table indicates the percentage of all tested projectors that were time-sequential 3D compatible in that video mode.

Regarding Table 2, some projectors were totally incompatible with time-sequential 3D video in all video modes and all video connections. This was generally due to the frame output of the projector not synchronizing with the incoming video signal. In most cases where this happened the input video signal was resampled to the native frequency of the projector (usually ~60Hz) – this resampling process usually destroys the 3D video signal.

Some projectors would work with progressive time-sequential 3D video signals but not interlaced time-sequential 3D video signals. This suggests that the projector uses a deinterlacing (interlaced to progressive conversion) routine which is not time-sequential 3D compatible. Fortunately the internal deinterlacer can be bypassed by feeding the projector with a progressive video signal.

In most instances where the projector was 3D incompatible in interlaced mode, it could be seen that the colour-wheel was synchronising to the incoming video signal but the odd and even fields were being mixed during the deinterlacing process. Since DMDs are progressive devices, any interlaced video signal input to the projector must be deinterlaced (converted from interlaced to progressive).

Table 2: Time-sequential 3D compatibility results for the 45 DLP projectors tested. (a green tick indicates that mode was time-sequential 3D compatible, a red cross indicates that mode is not 3D compatible, a dash indicates that mode was not tested, 'n/a' indicates that connection or mode was not available on that projector)

Brand	Model	Composite & S-Video	Component Interlaced	Component Progressive	VGA 60 Hz	VGA 85 Hz
Acer	PD322	x	x	√	√	√
Acer	PD523	x	x	√	√	√
Acer	PD723P	x	x	√	x	x
Acer	PH110	x	x	√	√	√
BenQ	MP 610	x	x	√	√	√
BenQ	PB 6240	x	x	√	√	√
BenQ	PE 7800	x	x	x	x	x
BenQ	PE 8700	x	x	x	x	x
Boxlight	Raven	x	x	√	√	√
Casio	XJ 360	x	x	√	√	√
Casio	XJ 560	x	x	√	x	x
Dell	3200 MP	x	-	-	x	x
IBM	C400	x	n/a	n/a	x	x
Infocus	LitePro 620	√	n/a	n/a	x	x
Liesegang	DDV 2111 Ultra	√	n/a	n/a	x	x
Liesegang	DDV 3200	x	x	√	x	x
Liesegang	e.Motion 4100	x	x	√	x	x
Liesegang	LuxorPlus	x	x	√	x	x
Liesegang	Multi800	x	n/a	√	x	x
Mitsubishi	HC3000	x	x	√	√	x
Mitsubishi	XD450U	x	x	√	x	x
NEC	HT 1100	x	x	√	√	x
NEC	LT 35	x	x	√	√	√
NEC	LT 100	√	√	√	x	x
Optoma	EP719	-	-	-	√	√
Optoma	EP739	-	-	-	√	√
Optoma	EP759	x	x	√	x	x
Optoma	H27	x	x	√	-	-
Optoma	H57	x	x	√	x	x
Optoma	HD72i	x	x	√	√	x
Panasonic	PT-D 5500E	x	x	√	√	x
PLUS	U4-237	x	n/a	n/a	√	√
PLUS	U5-112	x	x	√	√	√
Projection Design	Action! Model 2 Mk2	x	n/a	√	√	x
Projection Design	Evo 2 SX+	x	x	√	√	x
Projection Design	F1+ SX+	x	x	√	√	x
Projection Design	F3 SXGA+	x	x	√	√	x
Sharp	XR10X	x	x	√	√	√
Sharp	XV-Z2000	√	√	√	x	x
Sharp	XV-Z9000E	x	x	√	x	x
Studio Experience	SE 30 HD	x	x	√	x	x
Studio Experience	SE 50 HD	x	x	x	x	x
Toshiba	TDP-S8	x	x	√	√	√
Yamaha	DPX-1300	x	x	√	x	x
Yamaha	DPX-530	x	x	√	√	√
	% 3D compatible:	9%	5%	83%	52%	34%

Some projectors were compatible with time-sequential 3D Video (input via the composite, SVideo or component connectors) but not 3D VGA. This would suggest that there is a small quirk in the firmware of the projector. A small change to the firmware could probably allow the projector to work for both 3D Video and 3D VGA. This is not something that 2D projector manufacturers would normally check – but hopefully this will change.

As can be seen in Table 2, 52% of the tested projectors were compatible with 60Hz 3D VGA signals, and 34% of the tested projectors were compatible with 85Hz 3D VGA signals. 85Hz stereo from a consumer projector is a significant result. The problem with 60Hz stereo is that generally this will produce a lot of flicker. With 85Hz stereo, the amount of flicker will be less, but generally not totally flicker-free. Perceived flicker can be reduced by reducing room brightness and image brightness. However, 100Hz or 120Hz stereo is generally required for totally flicker-free operation.

One other specification that was measured during the projector tests was the time offset from the trailing edge of the vertical sync signal to the start of image display by the projector – i.e., the phase of the displayed images relative to the vertical sync pulses. This aspect is important because if the LCS glasses are switched at the incorrect timing relative to the displayed images, a significant amount of ghosting can be introduced. Table 3 lists the time offset for the projectors that were found to be VGA 3D compatible at either 60Hz or 85Hz.

Table 3: Time offset for consumer DLP projectors found to be compatible with 60Hz and/or 85Hz VGA time-sequential stereoscopic display.

Projector Make/Model	**Time Offset @ 60Hz (ms)**	**Time Offset @ 85Hz (ms)**	**Resolution**
Acer PD322	0.28	0.96	1024x768
Acer PD523	0.33	0.96	1024x768
Acer PH110	0.30	0.31	854x480
BenQ MP610	~0.36	0.58	800x600
BenQ PB6240	~0.36	0.55	1024x768
Boxlight Raven	not measured	not measured	800x600
Casio XJ-360	0.29	0.35	1024x768
Mitsubishi HC3000	0.39	x	1280x768
NEC HT 1100	~0.83	x	1024x768
NEC LT35	~0.36	0.42	1024x768
Optoma EP719	not measured	not measured	1024x768
Optoma EP739	not measured	not measured	1024x768
Optoma HD72i	~0.40	x	1280x768
Panasonic PT-D 5500E	~1.02	x	1024x768
PLUS U4-237	not measured	not measured	1024x768
PLUS U5-112	0.32	0.94	800x600
Projection Design Action! Model 2 Mk2	~0.63	x	1280x720
Projection Design Evo 2 SX+	~0.91	x	1400x1050
Projection Design F1+ SX+	~0.91	x	1400x1050
Projection Design F3 SXGA+	not measured	x	1400x1050
Sharp XR-10X	0.26	0.30	1024x768
Toshiba TDP-S8	~0.45	0.53	800x600
Yamaha DPX-530	~0.24	0.42	1024x576

The largest time offset measured at 85Hz was 0.96ms, which corresponds to 8% of the time period for one 85Hz frame (11.8ms) – this could result in a noticeable amount of crosstalk if not corrected. LCS glasses are usually switched very close to the time of the vertical sync pulse (0.1 ms after the trailing edge of the vertical sync pulse for a H3D glasses VGA dongle). With the glasses switching at 0.1ms and the projector switching between views at 0.96ms, this would result in approximately 8% ghosting purely due to the phase difference between the LCS glasses and projector. A custom LCS glasses driver "smart dongle" was developed as part of this project to allow the switching of the LCS glasses to be time-offset by an adjustable amount and hence minimise ghosting due to incorrect LCS switching phase.

It is interesting to note that time offset is vastly different between different projectors and also between different modes of the same projector. The time offsets for other 3D compatible modes were measured but are too complicated to report in this paper - they are reported in Reference 6.

One other item of interest is that the maximum resolution of any consumer projector that was 3D compatible at 85Hz was 1024x768 (XGA). For any projector of a higher resolution than 1024x768, if it would do time-sequential 3D, it would only do so at 60Hz.

One aspect of interest about the operation of most of the 85Hz capable projectors listed above is that the colour-wheel speed drops down from 2x at 60Hz to 1.5x at 85Hz. "2x colour wheel speed" means that the colour wheel performs two colour cycles per frame. "1.5x colour wheel speed" means that the colour wheel performs one and a half colour cycles per frame. It can be seen in Figure 2 that for 85Hz the left eye will see two red segments and two green segments whereas the right eye will only see one of each. The opposite occurs for the white and blue segments. Images for each eye will therefore have a slightly different colour bias. The effect is noticeable but slight, and may be ameliorated by the auto-white-balance capability of the human eyes.

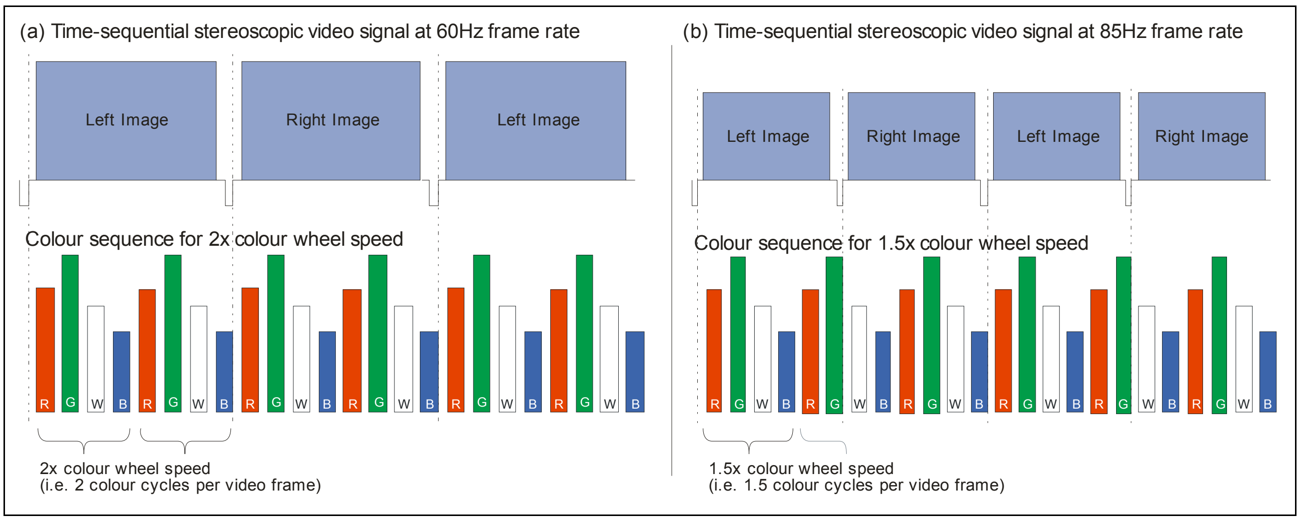

Figure 2: Illustration of (a) 2x and (b) 1.5x colour wheel speed at frame rates of 60Hz and 85Hz respectively (for an example 85Hz stereo capable single-chip DLP projector).

It is fair to ask why some of the projectors are incompatible with time-sequential 3D in various modes. Most of the projectors are incompatible with interlaced sources because they use an interlaced to progressive algorithm which is not time-sequential 3D compatible – an interlaced to progressive algorithm which is optimised for 2D video will not necessarily operate successfully with time-sequential 3D video.

The reason that some projectors are incompatible with progressive 60Hz 3D video sources is usually due to the colour-wheel (and frame rate) of the projector not synchronising with the incoming video signal. Since all DLP projectors are based on the DMD chip from Texas Instruments and likely follow a common reference design, it is thought that this incompatibility is mainly due to a firmware setup issue in the projector configured by the projector manufacturer. It is thought there are two main reasons why not all of the projectors were 85Hz stereo compatible: firstly it could relate to the firmware setup of the projector by the manufacturer, and secondly with resolutions greater than XGA, there is understood to be a bottleneck in the DLP engine which limits the data rate (and therefore the frame rate at higher resolutions). This data bottleneck is also thought to be the reason that correct 120Hz stereo was not possible on any of the projectors tested – however, obviously the designers of the DepthQ projector have been able to overcome this limitation. It is hoped that future DLP chipsets and reference designs will overcome this limitation.

4. CONCLUSION

This study has revealed a relatively large number of consumer single-chip DLP projectors that can be used for time-sequential stereoscopic display – some at image refresh rates as high as 85Hz. Although 85Hz stereo is not generally totally flicker-free, the knowledge that low-cost consumer DLP projectors can be used for time-sequential stereoscopic viewing will open up stereoscopic visualisation to a wider range of users and applications. Such users and applications can graduate to higher-end flicker-free "stereo-ready" projection systems when requirements dictate and funds allow.

Unfortunately most of the projectors tested are not directly compatible with field-sequential 3D DVDs (using common video interfaces: composite, SVideo and component interlaced), however, it was found that 83% of tested projectors could be used to display field-sequential DVDs if the 3D DVD was played back from a 3D compatible progressive output DVD player. Not all progressive output DVD players convert from interlaced to progressive in a 3D compatible way, however, it is known that some Panasonic DVD players do (such as the Panasonic DMR-E65, Panasonic DVD-S55 (NSTC only), and Panasonic DVD-S47 (possibly NTSC only)). It would be useful to develop a list of 3D compatible progressive output DVD players, but that is beyond the scope of this paper.

85Hz stereo via the VGA connector will be of use to a wide range of computer-based stereoscopic imaging applications, the most prominent probably being gaming. Over a thousand different PC games can be played in stereo with the use of an NVIDIA graphics card and the NVIDIA 3D Stereo driver[7].

Currently the 3D compatibility of consumer DLP projectors is not advertised or listed in product specifications by manufacturers or distributors. Additionally, we did not find any consumer projectors that were capable of 100/120Hz stereo operation. It is hoped that in the near future both of these factors will change.

5. ACKNOWLEDGEMENTS

This work was supported by iVEC (the hub of advanced computing in Western Australia), Jumbo Vision International, and ISA Technologies.

We also wish to thank the multitude of companies and individuals who lent DLP projectors for testing: Kim Kimenkowski, Jumbo Vision International; Sil La Puma and Simon Beard, ISA Technologies; Con Parente, West Coast Hi-Fi O'Connor; David Tuttle, Optoma USA; Geoff Frampton, Essential Office Products; Roger Castle, Castle Funding; Evan Papantoniou, Thames Computer Group; Vaughan Doyle and Adam Thackrah, J Mills Distribution; Nic Beames, Dynamic Digital Depth; Simon, Shriro Australia; Brendan, Perth Audio Visual; Marc Störig, AVCE Liesegang Australia; Will Rossiter and Duncan Boekhold, Yamaha Music; Brian Wood, West Coast Hi-Fi Joondalup; Chris Malcolm, John Curtin Prime Ministerial Gallery; Martin Todd, NEC Australia; Ross Sawatzky and Jayne Schröder, Advanced Visual Design; Alan, Direct National Business Machines; Peter Cutts, PCA Marketing; Adam Byrne, Toshiba Australia; Mike Butler, ComputerCorp; John Voss and Leigh, Rexel Australia; Peter Shilkin, Panasonic Australia; Claudio Cardile, Mitsubishi Australia; Darren Goble, LG Electrical; and Jason Burns, Douglas Hi-Fi.

6. REFERENCES

1. I. McDowall, M. Bolas, D. Corr, T. Schmidt, "Single and Multiple Viewer Stereo with DLP Projectors", in Stereoscopic Displays and Virtual Reality Systems VIII, Proc. SPIE Vol. 4297, pg 418-425, San Jose, California (2001).
2. L. J. Hornbeck, "Current Status and Future Applications for DMD-Based Projection Displays", in Proceedings of the Fifth International Display Workshop IDW '98, Kobe, Japan (1998).
3. NVIDIA 3D Stereo Driver http://www.nvidia.com/object/3d_stereo.html
4. Powerstrip software http://entechtaiwan.net/util/ps.shtm
5. Stereoscopic Player software http://www.3dtv.at/Products/Player/Index_en.aspx
6. T. Rourke, A. J. Woods, "Compatibility of Consumer DLP Projectors with Time-Sequential Stereoscopic Visualisation", Technical Report CMST 2006-17, Curtin University of Technology, Perth, Australia (2006).
7. D. Cook, "Stereoscopic Gaming: Technology and Applications", Keynote Presentation at Stereoscopic Displays and Applications XV conference, 19-21 January 2004, San Jose, California. (Presentation only).