21.1: *Invited Paper:* The Digital Revolution in Electronic Projection Display Technology

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Abstract

Although analog CRTs continue to enable most of the world's electronic projection displays such as US consumer rear projection televisions, digital AMLCD and DLP reflective mirror array projectors have rapidly created large non consumer markets - primarily for business. Recent advances in image quality, compactness and cost effectiveness of digital projectors have revolutionary implications for major consumer and entertainment markets as well. Fueled by advances in imaging panels, light sources and micro-optics, digital projection is improving at a rate 5X to 12X faster than flat panel plasmas and analog CRT projectors. Continued rapid improvement is expected due to relative immaturity and the wide diversity of technological improvements being pursued by materials suppliers, component suppliers and the projector manufacturers themselves. As a result digital projection is likely to dominate both the consumer HDTV and the cinema market by 2010. Shipments for all projection markets should exceed 10M units per year in 2010 with upside potential for 70M units shipments driven by high image quality, low depth, relatively low cost and the potential to be the primary large area high definition display in most of the worlds living rooms.

1. Introduction

Projection based on discrete pixel (digital) imaging panels is being widely accepted as a quality, growth technology and market. This has led a large number of companies to accelerate digital projection related developments, thereby intensifying internal industry competition. The internal competition has strengthened the industry, increasing the comparative advantage relative to potentially competitive alternative displays, primarily rear projection CRTs and flat panel plasma displays (PDPs). In this paper we discuss the major underlying trends and present reasons why the revolution is spreading and is likely to take a rapidly increasing share of mainstream consumer and entertainment display markets.

2. Digital Projection

Digital projection in the context of this paper refers to projectors based on matrix addressed imager panels with discrete pixels. Their projected images are pixelated. The pixels have fixed positions on the projection screen.

In contrast CRT projectors are generally based on analog scanning of a writing electron beam. The projected images have continuous, overlapping, variable pixel positions along each horizontal line scan

Digital projectors have separate light creation and image generation functions. This enables digital projectors to control much higher power light sources than can be generated and focused with the electron beam excited phosphors of analog projection CRTs. Thus digital and analog in this context refer to the type of pixel positions and not to the type of electronic input signal or signal processing.

A fundamental advantage of digital projection is the precisely delineated pixel positions enabling more accurate convergence of the three primary color images and therefore higher edge sharpness and modulation transfer function than can be achieved with analog systems. This can make the images look subjectively sharper. It can even increase apparent contrast and color saturation because of enhancement as the human vision process makes comparisons across the sharp line edges. Single panel digital projectors tend to have even better convergence and sharpness. Their convergence is limited mainly by aberrations in the optics.

3. The Digital Projection Revolution

The seven major electronic projector types are summarized in Figure 1 in terms of the key parameters light output and projector weight [1]. Imager panel types and the status of the digital projection revolution are also shown.

The top five categories are all front projectors. The two at the lower right are rear projectors. The digital projection revolution has already created the front projector categories and is now working its way through rear projection.

The most rapidly growing electronic projection market today is for projectors weighing under 10 lbs. and used by modern Road

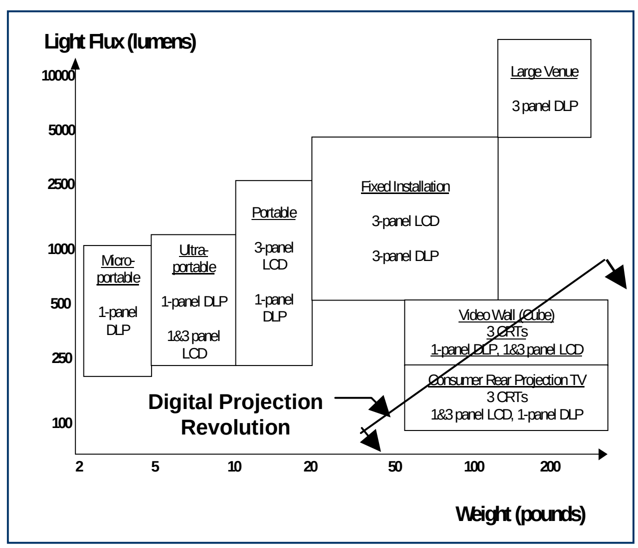

Figure 1. Current status of the digital projection revolution. Projector types are shown as a function of light output and weight. Principal imager panel technologies are indicated for each category.

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Warriors primarily for business presentations The first major product for the Road Warrior market was introduced in early 1993. It weighed 40 lbs., very light for that time, and had a specified light output of 100 lumens, good for that time as well. Its actual light output was probably closer to 60 ANSI lumens. The images from this luggable, breakthrough VGA (640x480) projector had to be viewed on a relatively small screen in a room with subdued lighting.

Today we can buy the BarcoReality 6400DLC, a 3400 ANSI lumen SXGA (1280x1024) projector introduced in 1999 and weighing 39 lbs. This corresponds to a compounded 86% per year increase in light output. In addition information content (pixels) for this Fixed Installation projector increased a compounded 27% per year. The BarcoReality produces images suitable for viewing in bright conference rooms and moderate to large auditoriums and ballrooms

The lightest computer resolution projector on the market is the Compaq MP1600, a 600 ANSI lumen XGA (1024x768) unit weighing only 4.2 lbs. and also introduced in 1999. It boasts a 10X increase in light output and a 9.5X decrease in weight vs. the 1993 benchmark, i.e., a 95X improvement in a little over 6 years. This corresponds to about a 100% improvement per year plus a 17% per year increase in information content.

The 4.2 lb projector's image is suitable for use in small offices and conference rooms with moderate lighting. It is one of the first entries in a new class of under 5 lb Microportable projectors shown in Figure 1. By the end of the year 2000 it is likely that additional projectors weighing as little as 3 lbs. with light outputs in the low to mid 100s of ANSI lumens will be added to this category.

By plotting the log of projector lumen output vs. year of introduction Kahn International first reported in late 1997 that under 40 lb. LCD projector light outputs had been following a log linear trend line and increasing at 87 to 100% per year since early 1993 [2]. Now almost 2.5 years later, that trend is still continuing. We also found that light output divided by projector list price had been increasing at about 70% per year [3].

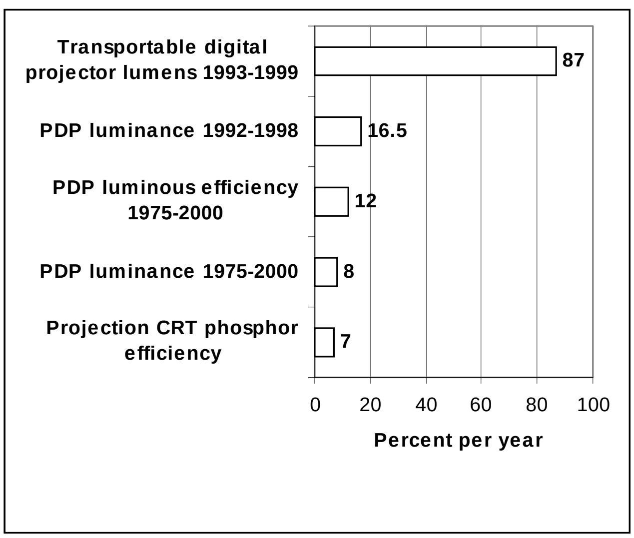

Figure 2. Comparison of historical improvement rates for transportable (under 40 lbs.) digital LCD and DLP projectors, plasma display panels (PDPs) and projection CRT phosphors.

These revolutionary advances are increasing 1.5X more per year than the 59% per year improvements of Moore's law which says ICs improve 2X every 18 months. More importantly, as shown in Figure 2, they are proceeding at 5X to 12X the rates of improvement that we have determined for the most competitive large area technologies analog CRT projectors and flat panel plasma displays (PDPs) [4,5].

Given the rapid rate of digital projection improvement relative to PDPs and analog CRTs and the continued relatively high cost of PDPs, we expect digital projection to continue to expand its markets significantly. Of course there is always the potential for breakthroughs in these alternative technologies. A listing of potential breakthrough was presented elsewhere. However, non seem to be imminent in coming to market except for evidence at the Consumer Electronics Show in January 2000 that some analog CRT rear projection television manufacturers may be willing to accept very small profit margins in order to promote sales of their new high definition and 4:3 aspect ratio high resolution systems.

4. Underlying Technologies

The rate of improvement of digital projectors is the product of contributions from material, process, and component suppliers as well as from the projector engine developers and manufacturers themselves. Areas of major improvement have included:

Lamps – smaller, brighter, longer lived arc lamps such as the Philips UHPs have enabled efficient collection of light by increasingly compact imager panels such as the DLPs

Illuminators – improved collection systems with parabolic and elliptical reflectors and rod and prism or microlens array integrators

Polarization conversion – increase of light throughput up to 70% in LCD projectors by converting most of the light into the required polarization state.

Imager panels with high throughput due to increased aperture ratios, reflective mode operation or operation without polarized light. Some transmissive LCDs use microlens arrays to squeeze light through the relatively narrow apertures resulting in up to 50% increase in light throughput.

Tilted dichroic illuminators and holographic optical element (HOE) illuminator-collectors - enable single imager panel projection systems without the use of absorbing filters to create color. These illuminators increase the light throughput up to 4X vs. color creation with absorbing filters.

Higher numerical aperture projection lenses with F/#s as low as F/1.7 result in increased throughput of 5X or more vs. early projection lens systems.

Integrated light valves such as DMDs on SRAM, LCOS and p-Si TFT LCDs enabling more compact, yet relatively high throughput projectors - Thus DLPs , p-Si TFT LCDs, and LCOS imager panels, many with diagonals under 1" and some as small as 0.5"D have replaced the original 2.8"D to 10.4" D non integrated a-Si TFT LCDs. The smaller panels have enabled lighter, more compact, and cheaper projectors. Super high pressure mercury arcs with emission areas as small as 1mm have replaced the larger 3mm to 7mm metal halide arcs of early projection systems. Xenon arc sources have also improved and tungsten incandescent lamps have been virtually eliminated.

Thus while the relatively mature analog CRT projectors struggle for 5 and 10 percent improvements to get a 2X output increase each decade, many of the digital projection improvements listed above have increased throughput 50% or more on their own and some by several hundred percent. This division of effort which continues today has been able to maintain the 85 to 100% per year digital projector progress to date.

Emerging improvements include new imager panels based on advanced technologies such as MEM (microelectromechanical) gratings and low T p-Si variants, CGS (continuous grain silicon) and lateral solidified Si, reflective polarizers, the Digilens ASIL optical switches and routers, upgraded optical components and architectures for reflective LCOS projectors, continued improvement in compact arc lamps and, interestingly enough, larger area panels for Fixed Installation and Large Venue projectors.

Eventually this rate of progress will decelerate. Plotting the log of lumen output vs. year of projector introduction will provide advanced warning. There is no warning sign yet.

5. Consumer HDTV

In seven years digital LCD and DLP projectors have created the five major business and presentation markets shown in the top part of Figure 1. Nevertheless the largest electronic projection market in both units and dollars is rear projection consumer television, largely a North American industry due to the relatively large North American rooms that can accomodate 50" D screens. These screens first start to look good at viewing distances over 18 feet for NTSC (480 active line) 4:3 aspect ratio consumer television as shown in Figure 3. At shorter distances, the eye will resolve the individual scan lines. Analog CRT rear projectors have dominated this market because they are cost effective.

Similarly rear CRT projectors have dominated the rear projection video wall market. However, in the last year, numerous product introductions of DLP and LCD rear projection cubes have made a significant penetration of this market for reasons such as higher image quality, ease of use and lower maintenance, lighter weight, lower depth and even lower cost. 3-CRT rear projectors are being displaced. A revolution in video walls is in progress.

As shown in Figure 1, the digital revolution is now entering consumer rear projection television. Digital rear projection systems may be particularly advantageous in the emerging digital HDTV segment of this market. Digital projectors can be sharper, lower depth, lighter weight and, longer term, even lower cost than the analog CRT RPs (rear projectors). As TV moves to higher resolution, it is becoming increasingly more difficult for analog CRT RPs to maintain image quality factors such as sharpness, modulation transfer function and color convergence. Also it is very difficult to reduce the weight and depth of the RP CRT TVs to enable them to fit into ordinary sized rooms. This will be important in spreading rear projection TV with large area >37"D screens to ordinary sized US and foreign rooms. This is a great opportunity because by 2007 all US broadcasting is currently scheduled to be digital. Digital high definition broadcasting will spread throughout the world.

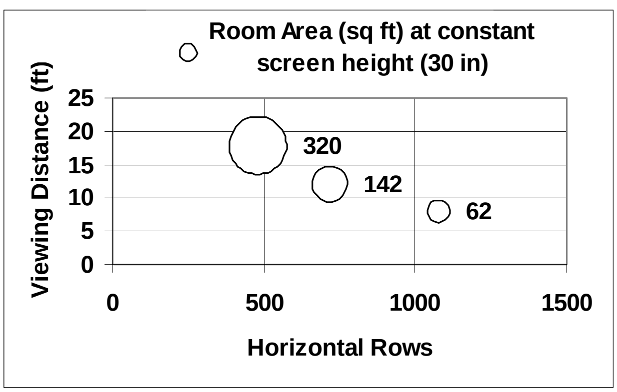

Figure 3. Viewing distance versus number of horizontal rows for NTSC and HDTV (720p, 1080i) for a constant screen height of 30". This screen height corresponds to a 50"D 4:3 aspect ratio NTSC TV and a 61"D 16:9 aspect ratio HDTV. The circle areas shown as a parameter represent the required room area for each viewing distance which has been approximated as the square of the viewing distance.

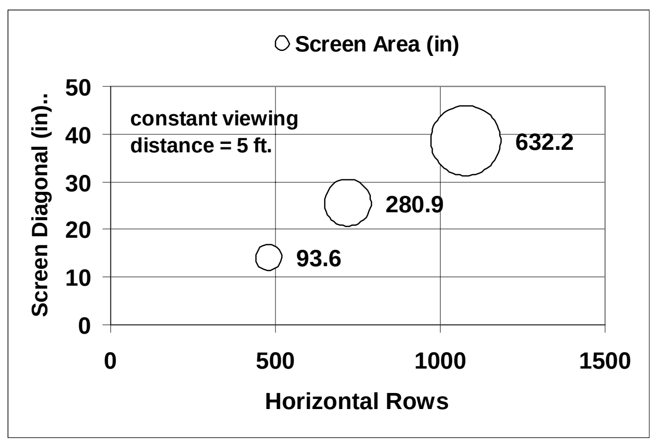

Figure 4. Screen diagonal versus number of horizontal rows for NTSC and HDTV (720p, 1080i) for a constant viewing distance of 5 feet, corresponding to a very small room or viewing location. The circles correspond to the screen area. The importance of HDTV and especially 1080i HDTV for enabling the viewing of large area screens even in very modest sized viewing locations is illustrated. Digital rear projection could enable these large area screens to fit in these locations and to be affordable.

Six different HDTV digital rear projection products or prototypes based on 1-panel and 3-panel projection engines were shown at CES 00 in January. The new digital rear projections systems were lighter and had lower depth than the equivalent CRT rear projection HDTVs. Some of them were sharp as well. Although some of the sets had outstanding image quality, most showed at least some residual artifacts related to the basic digital imaging technologies. More work remains to be done by all manufacturers.

In the year 2000 at least four major consumer television manufacturers plan to introduce digital RP HDTV products at prices competitive with analog CRT rear projection HDTVs. Thus although digital RP HDTVs still have considerable room for improvement, the shift of digital rear projection from the laboratory to the mainstream consumer entertainment marketplace is already underway. Those that haven't announced products have development programs under way.

The major intrinsic advantages of digital RP TVs for consumer TV markets are illustrated in Figure 3 and 4. The Figures show that a principal advantage of HDTV is the ability to view large screens in ordinary sized rooms. For example, in Figure 3 the viewing distance is about 8 feet for the 61"D 16:9 aspect ratio 1080i HDTV and about 18 feet for the 50"D 4:3 aspect ratio 480 line NTSC TV. The former corresponds to a relatively ordinary room and the latter to a large one. In Figure 4, a 38.5"D 1080I screen is suitable for a modest 5 foot viewing distance.

The advantage of digital rear projectors is that they can be 1/2 to 2/3s the depth of a CRT RP projection TV, i.e., 14.5" to 19.5" deep vs. 29" deep for a typical 61"D 16:9 set. The lower depth sets will fit much more easily into small rooms and will be much less imposing. Therefore we see HDTV, especially 1080i, as being particularly important in enabling the majority of the world's population who live in smaller rooms to enjoy large screen TV. Digital projection is the technology that will enable large screens to fit in those rooms. Given the rapid rate of technological progress and cost reduction in digital projection, it is likely to provide the most affordable high definition large screens of the future.

Significant penetration of consumer television together with the rapid growth ultraportable and microprojector markets could result in a 4X unit growth of projection shipments to 10M units in 2010. If foreign consumer television markets take off as suggested here, shipments in the range 50M to 70M units could result.

6. Electronic Cinema

In addition to consumer television, digital front projection has demonstrated that it can deliver superior image quality to film in local cinemas. Some improvement in image quality is needed to compete with film in the highest end theaters. However with the rapidly increasing image quality and the significant savings expected from film distribution, on the order of $2000 per movie print, it seems like the spread of electronic cinema is inevitable once distribution methods, standards and financing are worked out.

7. Summary and Conclusion

The digital revolution in electronic projection technology is spreading rapidly from business markets into the consumer television market driven by high image quality, low depth and the ability to facilitate large screen HDTV in small rooms at moderate prices. The technology base developed in the business markets is now being applied to consumer TV and electronic cinema. More work is required on the consumer projectors but the level of effort and record of past progress implies a reasonably good chance for success in creating a major HDTV projection market, not just in the US, but worldwide. For a detailed summary see the Abstract.

8. References

[1] Figure 1 is a modification of the classification scheme of Dash, S. We have also added the "digital projection revolution." Market trends in the projection display industry. To be published in Projection Displays VI, Ming H. Wu, Editor, Proceedings of SPIE Vol. 3854, (2000)

[2] Kahn, F. Projection Trends (1) The lumen: quantity, efficacy, cost in Kahn International Private Line Report on Display Technology and Markets, Oct. 1997, pp. 1-10.

[3] Kahn, F. Projection Display Market and Technology Trends: Looking Toward 2010, Proceedings Asia Display 98, pp. 265-270 (1998). Also see Kahn, F. Projection Display Technology and Product Trends, Projection Displays V, Ming H. Wu, Editor, Proceedings of SPIE Vol. 3634, (1999)

[4] Uchiike, H. Recent Advances of Color Plasma Displays and the Status of the Plasma Display Industry in Japan, Proc. EuroDisplay pp. 379-383 (1999)

[5] Yamazaki, E. CRT Projection, SID 93 Digest, pp. 201-2