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Introduction

1.1 Overview of Projection Displays

An electronic display is a device or system which converts electronic signal information representing video, graphics and/or text to a viewable image of this information. Displays are categorized as being direct-view, projection or virtual. Direct-view displays produce their images on the surface being viewed. The images from projection displays are formed on auxiliary surfaces, which are physically separated from the image-generating component. With a virtual display, there is no real image in space; the optical signal is brought to a focus only on the retina.

Projection displays produce larger images from electronic signals than are normally achieved by direct-view technologies. The images are created by light-emitting devices, such as cathode-ray tubes or lasers, or by modulating the light from an illumination system with a device called a light valve. Projection displays are traditionally thought of as having large images. The technologies involved are also being applied to very small portable systems, including head-mounted and helmet-mounted systems. These produce images perceived to be large because they occupy a significant fraction of the retinal field-of-view.

This book will only consider projection displays suitable for group viewing, i.e. a display capable of being viewed by two or more people simultaneously. The technologies to be described for group viewing projectors are directly applicable to personal use in, for example, a head-mounted display. However, these personal applications frequently have significantly different performance requirements and unique configurations. Few of these constructions are well documented in the technical literature.

Projection displays were among the earliest electronic information display technologies. Most early video receivers used projection to increase the viewed image size from that produced by the small CRTs used to generate the image (Wolf 1937). The other large screen technology, the Scophony system, used a scanned beam technology remarkably similar to a modern scanned beam laser projector (Okolicsanyi 1937). The first large image size, high luminance projector was described and demonstrated nearly seventy years ago (Fischer 1940). For a more complete review of the history of projection technology,

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see Brennesholtz (2007). Today, projection displays are used in a variety of configurations, including consumer products, presentation products for the institutional market, large theater displays, very large field-of-view systems for simulator application, and physically small displays for personal use, e.g. using a head- or helmet-mounted projection display. The luminous outputs of projectors range from just a few lumens to 30 000 lumens, with the higher outputs obviously being applied to larger screen sizes. When 30 000 lumen projector output is not sufficient, two high-output projectors can be stacked and converged at the screen. While projectors with more than 30 000 lumen output are seen as technically feasible, the markets for these extreme projectors are so small that, for the time being, projector stacking provides a more cost-effective solution.

Historically, projectors have served to produce the larger image sizes while direct-view displays have served to produce the smaller images. The correlation between size and technology appears to be breaking down. Ultra-large displays today are most commonly direct-view LED systems. At the 2008 Consumer Electronics Show a 150″ direct-view plasma system was demonstrated by Panasonic. 108″ direct-view LCD displays have also been demonstrated. The extreme high cost of these large direct-view flat panel displays means that most large images will continue to be generated by projection displays.

The reverse appears to be happening for small images. LCD, OLED and a host of other technologies can make cost-effective small displays, but they cannot make 20″ displays from a system that fits in a shirt pocket. So ‘pico-projectors’, typically the size of a cell phone, are beginning to appear in the marketplace.

The performances of projection displays continue to improve as the costs of manufacturing them continue to decrease. CRT-based projectors represent a declining fraction of the projection market due to availability of the high resolution, high brightness, high contrast and low prices of microdisplay-based projectors. These newer projectors, based on microdisplay and light-valve technologies, now dominate the market, as measured by manufacturers’ revenue. The high performance, thinner profile and low price of light-valve projectors is expected to largely drive CRT projectors out except in the few niche applications where CRTs retain advantages.

At the heart of all projectors is the light engine. This is the subsystem within the projector which converts the incoming electrical signal into the intensity-modulated two-dimensional optical image. In the following chapters, the systems, subsystems and component technologies used in the light engines of projection displays will be discussed. One of the objectives of this book is to provide the projector designer with the tools for evaluating the potential performance of a light engine design without having to commit to physical hardware. Models are developed which can evaluate the anticipated luminance and chrominance from component data.

The design of a projector requires key components to execute the light engine. These include the image forming devices, lamps, and optical components. The positive and negative attributes of these components and modules strongly influence the system performance characteristics. The more important of these are discussed in detail before the models are developed.

The design and fabrication of a projector is truly a multidisciplinary activity. Table 1.1 illustrates some of these requisite technologies to implement a projection system. The breadth of the technologies required for execution of a design is belied by the simplicity of the listing given in this table. Within each of the technological categories in Table 1.1, there are far larger sublists of technologies which are required for successful implementation. For some technologies employed in projection systems, dedicated industries are required to provide the technical infrastructure for success. Among these are CRTs, light valves, lamps and some aspects of optics.

A projector based on emissive image sources, such as CRTs, is illustrated in Figure 1.1. This type of projector will typically use separate sources for generation of the three primary colors, red, green and blue. One of the characteristics of emissive image sources is light-on-demand. Light is only generated in response to an appropriate signal. This attribute is valuable in producing images with large white-to-black dynamic ranges. The three images created by systems with emissive devices can be combined internally before the projection lens to form the full color image or the recombination can be done by superposition of the three-color images at the screen plane.

Table 1.1 Projection system technologies.

Subsystem	Technologies
Image generation	• Emissive image sources, such as cathode-ray tubes and lasers, or • Light modulating devices, including liquid crystal devices and micro-electromechanical devices with • Silicon or other semiconductor material backplanes for the imagers and • Very large, very flat transparent substrates.
Optics	• Light collection and utilization, and • Light polarization separation and recovery, and • Spectral filtration, separation, and recombination, and • Lenses, and • Screens
Lamps	• Lasers, • LEDs • Tungsten-halogen lamps, or • High intensity discharge (HID) lamps, with • Lamp ballasts for HID lamps and drive circuitry for lasers or LEDs
System	• System design, incorporating • Human factors and interfaces, including luminance, colorimetry, and resolution, and • Artifact minimization
Electronics	• Signal processing and conditioning, and • Interface electronics between microdisplay, light valve or CRT and signal electronics, and • External video interface circuits, and • Power supplies
Mechanics	• Thermal design, and • Materials, and • Stable opto-mechanical light-engine construction, and • Projector packaging

The lamp or other light source in a microdisplay or light-valve projector, on the other hand, continuously generates internally the peak intensity light. This light is attenuated by the microdisplays or light valves to a level appropriate for the input signal at that image point. The range of this attenuation determines the white-to-black dynamic range. These light modulating projectors are based on one, two, three, or more light valves. Figure 1.2 illustrates a generic light-valve projector, showing different light paths for the primary colors.

The illumination system in these projectors provides high intensity light, using lamps or other light sources normally specifically developed for projector application. Optical components separate this light into three color bands, corresponding to the primary spectral colors. The microdisplay(s) spatially modulate this light by varying the amount of light passing through an image point that enters the entrance pupil of the projection lens. For those systems which use more than one microdisplay or light valve, the color images must be superimposed to form a single full color image projected onto the screen.

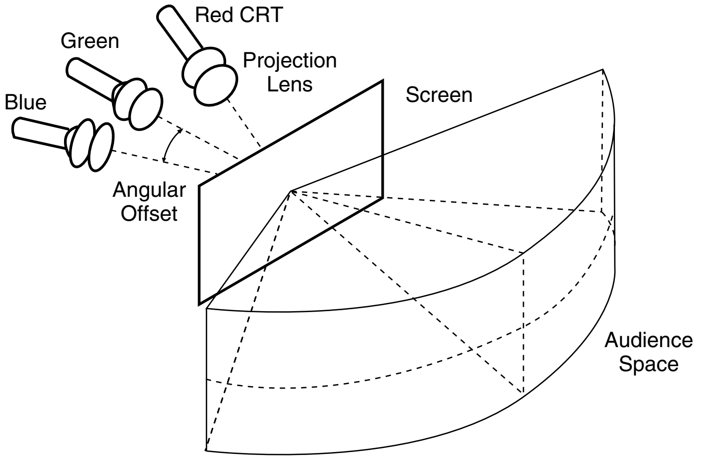

Figure 1.1 Schematic of CRT rear-screen projection system. The screen provides wide-angle horizontal viewing.

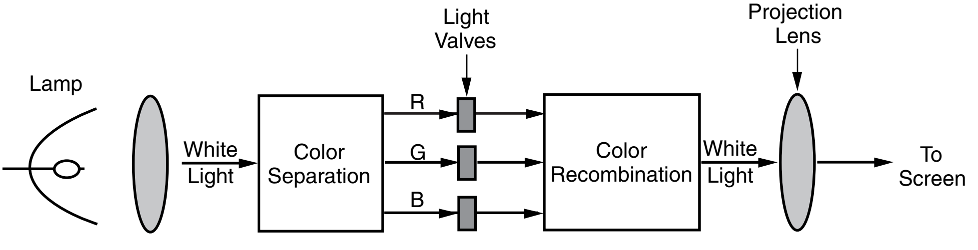

Figure 1.2 Schematic representation of a light-valve projector.

1.2 Book Organization

This book is divided into 14 chapters and four appendices, as described in Table 1.2.

1.3 What is not Covered

Several types of projectors will not be discussed in this book. These include the overhead projector and projector-type systems intended to produce virtual images for personal use. These systems are often called HMDs for Head or Helmet Mounted Displays. Since the technologies used in these systems are similar to the technology used in normal projection systems, the discussions in this book should provide the designers of these systems with requisite information. For more details on the use of microdisplays in near-to-eye systems see Armitage *et al*. (2006).

The overhead projector by itself is nothing more than a projector with very large format static images on film. It can become an electronic projector when coupled with an image generating device such as an active-matrix display like the ones used for laptop computers. Since the displays have been designed and manufactured independently of the illumination source (the overhead projector), it is difficult to discuss the performance of these systems without specific details of both the light modulator and the projector. Another reason for not covering these displays is that they have nearly vanished from conference rooms and have been replaced by full electronic projectors.

Table 1.2 Chapters in *Projection Displays*.

Chapter	Contents
Chapter 1	Introductory material on this book
Chapter 2	Very brief introduction to the markets and market requirements for projection displays
Chapter 3	Cathode ray tubes as an image source for projection displays
Chapter 4	Liquid crystal devices as image sources for projection displays
Chapter 5	Micro-electro-mechanical (MEMs) devices as image sources for projection displays
Chapter 6	Optical components for projection displays, part 1, including filters, polarizers and integrators
Chapter 7	Optical components for projection displays, part 2, including projection lenses and projection screens
Chapter 8	Lamps and solid-state light sources
Chapter 9	The architectures of emissive projection systems
Chapter 10	Architectures for microdisplay, light-valve and light-amplifier projection systems
Chapter 11	Techniques for modeling and predicting the lumen throughput and colorimetry of projection systems
Chapter 12	Numerical examples of the modeling techniques developed in Chapter 11
Chapter 13	The characteristics of projection displays important to their performance and how to measure these characteristics
Chapter 14	The image artifacts present in some projection displays, plus how to evaluate and avoid them
Appendix 1	Background information on photometry and radiometry
Appendix 2	Background information on colorimetry
Appendix 3	Derivation of a semi-empirical model used to forecast the lumen throughput of étendue limited projectors
Appendix 4	A glossary of terms and acronyms related to projection design and the projection industry in general.

Also not covered in this book are the electronics and electronic technologies associated with making a projector. These may include analog and digital signal processing, input signal formats (NTSC, PAL, VGA, ATSC, HDTV, DCI, etc.), signal sources, power supplies, tuners, and others which are required to make a light engine into a projection product. For more information on these topics see Berbecel (2003); Myers (2003) or any of the many other standard texts.

References

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