

**UNITED STATES AIR FORCE
ARMSTRONG LABORATORY**

**Microlaser-Based Projection Display
for Simulation**

**Charles G. Fink
Robert Bergstedt
Graham Flint
David Hargis**

**LASER POWER CORPORATION
12777 High Bluff Drive
San Diego CA 92130**

Philipp W. Pepler

**HUMAN RESOURCES DIRECTORATE
AIRCREW TRAINING RESEARCH DIVISION
6001 South Power Road, Building 558
Mesa AZ 85106-0904**

19970905 140

June 1997

Approved for public release; distribution is unlimited.

**Air Force Materiel Command
Armstrong Laboratory
Human Resources Directorate
7909 Lindbergh Drive
Brooks AFB TX 78235-5352**

NOTICES

When Government drawings, specifications, or other data are used for any purpose other than in connection with a definitely Government-related procurement, the United States Government incurs no responsibility or any obligation whatsoever. The fact that the Government may have formulated or in any way supplied the said drawings, specifications, or other data, is not to be regarded by implication, or otherwise in any manner construed, as licensing the holder, or any other person or corporation; or as conveying any rights or permission to manufacture, use, or sell any patented invention that may in any way be related thereto.

The Office of Public Affairs has reviewed this paper, and it is releasable to the National Technical Information Service, where it will be available to the general public, including foreign nationals.

This paper has been reviewed and is approved for publication.

PHILIPP W. PEPPLER
Project Scientist

DEE H. ANDREWS
Technical Director

LYNN A. CARROLL, Colonel, USAF
Chief, Aircrew Training Research Division

Please notify AL/HRPP, 7909 Lindbergh Drive, Brooks AFB, TX 78235-5352, if your address changes, or if you no longer want to receive our technical reports. You may write or call the STINFO Office at DSN 240-3877 or commercial (210) 536-3877.

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

Public reporting burden for this collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden, to Washington Headquarters Services, Directorate for Information Operations and Reports, 1215 Jefferson Davis Highway, Suite 1204, Arlington, VA 22202-4302, and to the Office of Management and Budget, Paperwork Reduction Project (0704-0188), Washington, DC 20503.

1. AGENCY USE ONLY (Leave blank)	2. REPORT DATE June 1997	3. REPORT TYPE AND DATES COVERED Final Report - March 1996 to November 1996	
4. TITLE AND SUBTITLE Microlaser-Based Projection Display for Simulation		5. FUNDING NUMBERS C - F41624-96C-5008 PE - 65502F PR - 3005 TA - HA WU - 61	
6. AUTHOR(S) Charles G. Fink Robert Bergstedt Graham Flint Philippp W. Pepler		8. PERFORMING ORGANIZATION REPORT NUMBER	
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) Laser Power Corporation 12777 High Bluff Drive San Diego CA 92130		10. SPONSORING/MONITORING AGENCY REPORT NUMBER AL/HR-TP-1997-0002	
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES) Armstrong Laboratory Human Resources Directorate Aircrew Training Research Division 6001 South Power Road, Building 558 Mesa, AZ 85206-0904		11. SUPPLEMENTARY NOTES Armstrong Laboratory Technical Monitor: Mr Philipp W. Pepler (602) 988-6561. This research was conducted under the Small Business Innovation Research (SBIR) Program as a Phase II effort. This paper documents a presentation at the 18th Interservice/Industry Training Systems and Education Conference, held 4-7 December 1996 in Orlando FL.	
12a. DISTRIBUTION/AVAILABILITY STATEMENT Approved for public release; distribution is unlimited.		12b. DISTRIBUTION CODE	
13. ABSTRACT (Maximum 200 words) Recent developments in microlasers now promise the means to construct a portable, efficient, and relatively low-cost laser projection display. The microlaser-based "direct write" projection display produces realistic images never before seen in simulators. The revolutionary improvement in image quality and brightness results from the development of high power red, green, and blue microlasers. These sources, combined with the high resolution, high contrast modulators produce a 24-bit color gamut capable of supporting the full range of real-world colors. The unique modulator and the optical scanner of the "direct-write" configuration produces the high resolution display required for the dynamic visual scene detail of the demanding simulation environment. The "picture window" imagery supported by this display will provide the detail required for fighter aircraft visual displays and will challenge the image generators to continue to improve source imagery. Laser Power Corporation, under a Small Business Innovation Research contract to Armstrong Laboratory's Aircrew Training Research Division, is developing a new microlaser-based projector for flight simulator displays.			
14. SUBJECT TERMS Displays; Display systems; Flight simulators; FY97 Phase II; Microlaser-based projectors; Microlasers; Imaging systems; Projectors; SBIR Program; Simulation;		15. NUMBER OF PAGES 14	
		16. PRICE CODE	
17. SECURITY CLASSIFICATION OF REPORT Unclassified	18. SECURITY CLASSIFICATION OF THIS PAGE Unclassified	19. SECURITY CLASSIFICATION OF ABSTRACT Unclassified	20. LIMITATION ABSTRACT UL

CONTENTS

	PAGE
INTRODUCTION	1
HISTORICAL PERSPECTIVE	1
MICROLASER-BASED DIRECT WRITE PROJECTION	3
CONCLUSION	6
REFERENCES	6

FIGURES

Figure

No.

1 Microlaser-based projection display configuration	3
2 Microlaser configuration	
3 Representations of the color gamuts of competitive display technologies	5

TABLES

Table

No.

1 Display efficiency	2
2 Military projection display requirements	6

PREFACE

This report documents work conducted by Laser Power Corporation for the Armstrong Laboratory's Aircrew Training Research Division (AL/HRA) in Mesa, AZ, under Small Business Innovation Research (SBIR) Contract F41624-96-C-5008. This effort was conducted under SBIR Work Unit Number 3005-HA-61, Microlaser-Based Projector for Flight Simulators. The laboratory contract monitor was Mr Philipp W. Pepler. The principal investigator was Mr Robert Bergstedt.

Military pilots are trained to scan the surrounding airspace and terrain for threats, targets, and friendly aircraft. However, modern flight simulator visual displays do not provide adequate definition to identify other aircraft, ground vehicles, roads, and bridges at realistic tactical ranges or to properly assess their aspect angle. Laser Power Corporation is developing a new microlaser-based projector for flight simulator displays to address this requirement. This paper documents a presentation on this research effort at the 18th Interservice/Industry Training Systems and Education Conference (I/ITSEC) held in Orlando FL on 4-7 December 1996.

MICROLASER-BASED PROJECTION DISPLAY FOR SIMULATION

Charles G. Fink, Robert Bergstedt, Graham Flint and David Hargis
Laser Power Corporation
San Diego, California

Phil Pepler
Armstrong Laboratory, USAF
Mesa, Arizona

INTRODUCTION

Air-to-air and air-to-ground weapon delivery training in a flight simulator requires visual cueing, detail, and target definition not currently available. The Air Force Air Education and Training Command defines acceptable air-to-air cues as being those allowing the user to judge aspect angles out to 12,000 feet slant range. Recent visual evaluations show that current flight simulator visual displays only provide adequate detail to around 2,200 feet slant range. Certainly, this gap falls drastically short of anyone's definition of high fidelity training. A major advance in display brightness, contrast, resolution, and detail is required to overcome the shortfall.

The current research and development project is focused on developing a new microlaser-based projector for flight simulator displays to address this requirement. Recent developments in microlaser and spatial light modulator technologies now provide the capability to produce a portable and cost-effective visual display with the potential for daylight brightness, increased contrast, very high resolution, and large real world color gamuts. In the near future, microlaser-based projector systems will revolutionize flight simulator visual displays and will lead to "picture window" imagery with detail adequate for air-to-air and air-to-ground mission training.

HISTORICAL PERSPECTIVE

A revolution in display technology is required to address the demands of future display systems. Existing technologies are close to reaching their ultimate potential. Although there is significant effort to optimize all the parameters available to current display technologies, their fundamental limitations impede their ability to be implemented into the high end systems of the future. To better understand the nature of these limitations, it becomes instructive to preface our discussion of what we expect to be the next generation of projection system, namely direct write microlasers, with a review of the operating characteristics of current

contenders in the image projection arena. In order of review, these can be identified as cathode ray tubes (CRT), liquid crystal light valve (LCLV), active-matrix liquid crystal display (LCD) panels, solid state deformable light modulators, and related laser based approaches.

There are several projection display technologies which are candidates for high resolution, high brightness projection display applications. Projection CRTs are a major element of today's display market. However, CRT projectors are limited in brightness and require careful shielding to reduce x-rays emission. Liquid crystal light valve projectors decouple the bright light source which results in a higher brightness display. However, this technology primarily relies upon advances in lamps to improve brightness, and upon improvements in filter technologies to expand color performance, yielding a complex large projection technology. Active-matrix LCD (AMLCD) projection displays typically lose an initial 50 percent in efficiency through the use of unpolarized light from broadband lamp, as a result they only recently have accomplished greater than 1 lumen/watt efficiencies. There is significant money invested in scaling this liquid crystal technology to higher resolutions; however, the current state of the art is electronic workstation (1280 by 1024). Additionally, image artifacts, such as "trails" behind fast moving objects, can result from the slower response time of the liquid crystal modulator. Also the discrete pixelization of the active-matrix LCD display devices, makes tiling of the displays difficult. Finally, the new digital micromirror device (DMD) technology is currently being introduced in VGA (840 by 480) resolution. However, scaling this technology beyond electronic workstation resolution and achieving more than 50% device efficiency represents a formidable challenge for this developing digital micromirror device technology.

Laser based display systems, first were introduced in the early 1970s, when major companies such as

RCA, Zenith, Hitachi, NHK, and others began programs to produce full color gas laser based displays. These systems employed argon-ion and krypton-ion gas lasers, acousto-optic or electro-optic modulators, high speed polygon scanners, and galvanometric deflection to produce NTSC resolution images (the current US national transmission standard). They used single beams in each of the primary colors which were amplitude modulated independently to achieve the requisite gray levels. These three primary colors were then combined to produce a full color pixel, and then scanned in two dimensions to display the final image. The limitations encountered in further developing these systems were the large size and cooling requirements of gas laser systems, and the high cost of the scanning and modulating components.

Single laser beam scanning displays currently are limited to electronic workstation or lower resolution. This limit is due to the polygon scanners which must spin at rates in the vicinity of 100,000 rpm and must contain a high number of facets thus increasing the polygon size or decreasing the scanner efficiency. The systems actually built, demonstrated the superiority of laser systems in producing high brightness together with an extended color gamut. However, their size and power consumption made hopes of commercialization remote. It was apparent that an order of magnitude improvement in resolution and efficiency, as well as a significant reduction in price, would be required to make the laser based projection displays competitive. Consequently, the early laser based approaches fell by the wayside.

Recent advances in solid state laser technology and in electro-optic modulators have reinstated the laser based projection as a viable contender. These technological advances in light modulators, combined with our work in the development of microlaser devices, renews the opportunity for the pursuit of laser-based displays. In current display development programs, we are pursuing a parallel scanning/modulation approach which promises to relax the high scan rate limitations imposed upon high definition systems. In this approach, multiple beamlets are independently modulated and scanned to form the image. The number of beamlets produced is a fraction of the number of lines required in the image format. This parallel scanning/modulation approach has the effect of reducing the scan speed requirement of the polygon to a few thousand rpm, depending on the specific video format

Table 1 summarizes the luminous efficiencies of competing display technologies. A medium size display is defined as requiring 1,000 lumens and a large screen requiring 10,000 lumens. While CRT, LCD, liquid crystal light valve and actuated mirror array technologies continue to evolve and improve, microlasers represent a revolutionary improvement in display technology. The luminous efficiency of microlaser-based displays, the scalability to high resolutions, the compactness and the expanded color gamut give microlaser technology a strong potential to emerge as the premier projection display for the future.

Table 1: Display Efficiency¹.

Display Type	Efficiency (lumens/Watt)	Power Required (Watts)	
		Medium-Size Screen	Large-Size Screen
		(1,000 Lumens)	(10,000 Lumens)
Gas Laser	0.1	10,000	100,000
Gas Plasma	0.25	4,000	No
CRT Projector	0.5	2,000	No
LCD Projector	1.5	667	6,667
DMD Projector	1.5	667	6,667
LCLV Projector	2.0	500	5,000
Microlasers	10.0	100	1,000

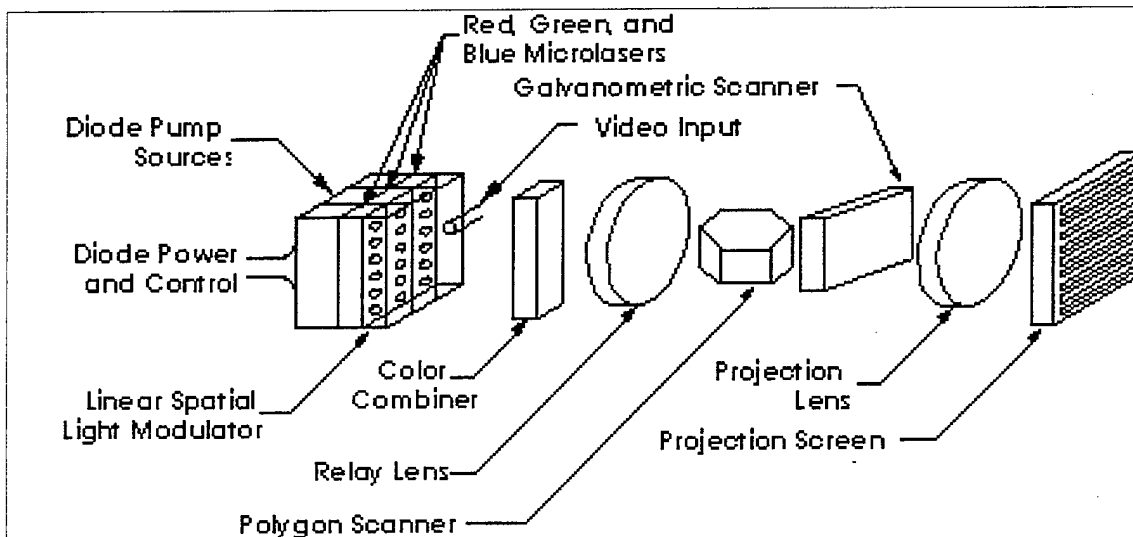


Figure 1. Microlaser based projection display configuration

MICROLASER BASED DIRECT WRITE PROJECTION

The parallel modulated direct write microlaser based display is illustrated in Figure 1. The image formation starts on the left hand side of the illustration with the three color microlaser sources. The continuous microlaser sources are amplitude modulated by the linear spatial light modulator to produce 8 bit dynamic gray scale. The light transmits through the spatial light modulator and then propagates through the color combiner, which merges the three color channels into "white" light using a color combining prism. After the color combiner, a collimator lens forms a pupil on the polygon facet. The spatial light modulator amplitude modulates the light as the scanning subsystem forms an image by scanning the parallel pixels across the screen in the horizontal dimension using the polygon scanner and in the vertical dimension using the galvanometric scanner. A two dimensional image is formed and then re-imaged by the projection lens onto the display screen. □□

At the heart of the high resolution projection display lies the new visible microlaser technology. Several approaches to producing a microlaser based high resolution display have been examined theoretically and experimentally to determine the optimum parameters with respect to cost, size, and weight. The blue, green and red microlaser sources, each operating at a primary color, provide the most efficient, high brightness projection source for display applications to date. A diagram of a typical solid state microlaser is shown in

Figure 2. Such devices employ well developed, low cost, near-infrared diode laser technology as a pump source for rare earth ion-doped solid-state microlasers. This facilitates the conversion of broadband, non-diffraction limited near-infrared diode emission into coherent, narrow band, diffraction limited visible light. The high quality beams of these microlaser sources are critical as they form the pixels in the direct write projection display.

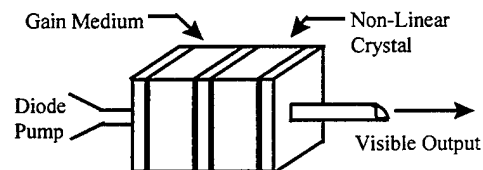


Figure 2. Microlaser Configuration

We are actively pursuing several novel approaches for obtaining RGB microlaser emission. The microlasers are based upon frequency doubling of the near-infrared emission of a laser material. Near-infrared diode lasers are used to pump the microlaser, consisting of two crystals, a gain medium and a nonlinear crystal. Dielectric coatings are used to define the resonant cavity, and are deposited directly upon the surfaces of the active media, typically around 1 mm in length. Diode laser output can be tuned to cause lasing action to occur at approximately 1300 nm, 1060 nm, and 900 nm. Using conventional frequency doubling, visible light is obtained at approximately 650 nm, 530 nm, and 450 nm. The

front surface of the laser crystal are anti-reflection coated for the pump wavelength to allow for maximum absorption of pump radiation. The back surface of the nonlinear crystal are high-reflection coated at the fundamental wavelength to maximize its intracavity power density and therefore allow for the maximum conversion efficiency.

To date, we have demonstrated over 0.75 W from a blue microlaser. To our knowledge, this power level is the highest average power for an all solid-state, continuous wave, blue laser ever demonstrated. Additionally, we have demonstrated over 3.0 W from a green microlaser. The research and development continues for the red microlaser sources. The results to date are greater than 0.6 W (1.0 W peak) from red microlaser sources. An estimate of the overall electrical to optical efficiency of these devices is 5%, corresponding to an overall efficiency of 10 lumens/Watt.

A 2000 lumen D₆₅ white image using RGB microlasers corresponds to average microlaser power requirements of 1.8 W blue light, 2.4 W of green light, and 8.4 W of red light for a total optical power requirement of 12.6 W. In contrast, current desktop projectors typically use arc lamp sources whose output powers are rated at 1000W to produce 2000 lumens on the screen. The microlaser power requirements represent the optical power at the exit aperture, so that the resulting source powers must be scaled to compensate for any losses due to the modulator, scanning, and optical subsystems.

The multiple beamlets of light are modulated by the spatial light modulator. We are developing a new electro-optic linear spatial light modulator for parallel write displays. The near term requirement is to achieve electronic workstation (1280 by 1024) and High Definition TV (1920 by 1080) image resolution. However, this modulator technology has demonstrated high bandwidth performance which is capable of generating images with greater than 5,000 by 4,000 pixel resolution at 72 Hz frame rate. This high resolution is also well within the existing scanner technology.

The parallel write configuration requires that the image data be transformed into parallel channels. The data from the image generator source is reformatted through the use of a double buffered memory board that transforms the serial input data into parallel output data. For a higher resolution display, the number of parallel channels can be

increased. It also will be advantageous for the data from the image generators to be transmitted in a parallel data structure. This technology could interface very effectively with the new digital parallel data transmission protocols of the future.

Microlaser displays utilizing red, green, and blue sources at about 650 nm, 530 nm, and 450 nm, respectively, promise much larger color gamuts than any other existing display technologies. This large color gamut insures that the color capability required for Society of Motion Picture and Television Engineers High Definition Television standards can be met with microlaser display, while conventional LCD and CRT projection systems still fall short of this goal. The fundamental concept of laser displays is to combine spatially red, green and blue laser radiation onto a viewing screen. By simply adjusting the relative amplitudes of these primaries one can obtain a large range of colors. The color gamut of the different technologies are represented relative to the 1976 C.I.E. chromaticity diagram in Figure 3. In this diagram the color becomes more "pure" or saturated in the areas nearest the edges of the diagram. In other words, to reproduce a deeply saturated red rose on a display, the technology must be able to generate the red color in the upper right hand corner of the chromaticity diagram. Thus, a side-by-side comparison of alternative display technologies would lead the viewer to choose the microlaser-based display due to the accurate color reproduction which results in a more realistic view. As shown, the microlaser approach provides saturated colors in the three primary colors: red, green, and blue. Optical sources based upon these wavelengths provide a larger color gamut than conventional CRTs, LCDs and other display technologies.

The image uniformity across the display demonstrated with the current microlaser projection display has many benefits. Current displays can have more than a 50% fall off from center to edge. This fall-off is noticeable particularly when tiling multiple displays. In contrast, the microlaser based displays have excellent uniformity which improves the realistic appearance of the images. The image uniformity also enables tiling of multiple display systems such as "video walls" or tiling simulators. The microlaser based displays also inherently maintain color consistency from projector to projector. This color consistency and the image uniformity of the microlaser displays enables seamless tiling of multiple displays, typical of large area simulators.

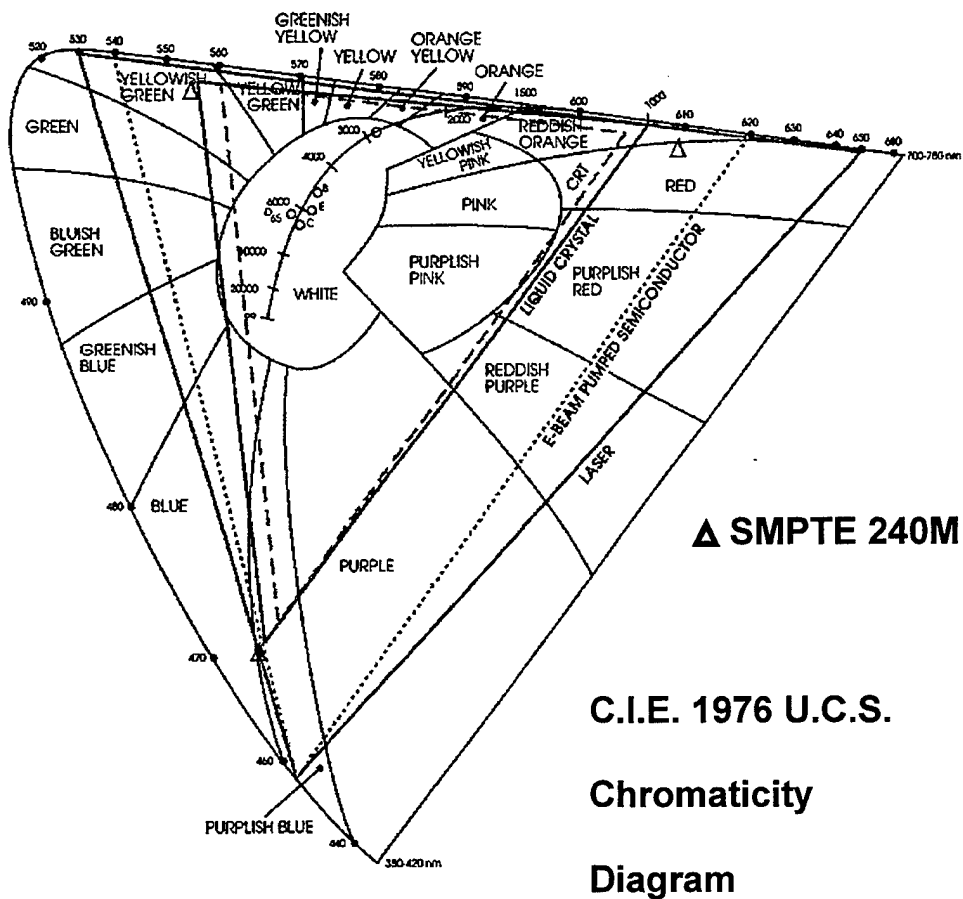


Figure 3. Representations of the color gamuts of competitive display technologies.
 (Note that the laser display provides the largest color gamut.)

As a result of the image quality and uniformity, greater resolution and brightness, new high end display applications can be realized and improved. The demanding requirements of day/night visual simulation and training can be improved and enhanced. Air and ground vehicle simulations with high resolution targets can be demonstrated. Also, high end commercial markets can be developed, such as electronic cinema. The filmless movie theater of the future is limited currently by the quality of the existing projection display technology. The microlaser based high resolution display will enable this high end application to become a reality.

One of the exciting extensions of this microlaser based technologies is in night vision training and simulation. It can be shown that the addition of a fourth source can extend this full color display into a "Color + Near Infrared" display for night vision

training. The four color display could be used simultaneously for human observers, night vision goggles and night vision instrument training and evaluation. The generation of near infrared radiation is technically feasible and the modulation and scanning of near infrared radiation is a direct extension of the current display technology.

There is a near term requirement for high resolution, high brightness displays in military projection applications. Table 2 provides a brief review and comparison of the required specifications for future display systems. These data are taken from the U.S. Army Research Laboratory sponsored Military Display Workshop. It is apparent that, since the requirements are formidable, current systems will struggle to reach them. Microlaser-based systems, on the other hand, have the potential for meeting and exceeding all of the parameters specified.

Table 2. Military projection display requirements.

<i>Parameter</i>	<i>Military Display Workshop Requirements</i>	<i>Current Systems</i>	<i>Microlaser-based Projector</i>
<i>Luminous Efficiency</i>	3 lm/W (FY97) 5 lm/W (FY98)	2 lm/W	10 lm/W
<i>Size</i>	Not specified for projectors	21 in x 28 in x 54 in (320S)	8 in x 18 in x 24 in
<i>Weight</i>		360 lb (320S)	40 lb
<i>Brightness</i>	50 fL on 254 cm screen (1667 lm)	2300 lumens (320S)	2000 lm >50 fL
<i>Resolution</i>	1280 x 1024 (FY97) 1920 x 1080 (FY98) 2560 x 2048 (FY00)	1600 x 1200 (320S)	2560 x 2048 (Phase III) >2560 x 2048
<i>Color Gamut</i>	Not specified	RGB	u'v'(.05), .58; .60; .51; .19; .07)
<i>Contrast</i>	Not specified	200:1 (320S)	200:1
<i>Dynamic Range</i>	8-bit/color	8-bit/color	8-bit/color

CONCLUSION

Most advances in today's display systems are extensions of fairly old technologies. This has the advantage of building on a mature foundation, but the disadvantage of encountering difficult performance limits. Breakthroughs are needed to solve certain basic problems before these technologies can be extended into brighter, higher resolution projection displays. The microlaser, with its intrinsic high efficiency, compactness and excellent beam quality, positions this new direct write display system for the demanding high performance display applications.

As the demand for information continues to increase, current display technologies will reach fundamental limitations, making them unsuitable for future display systems. Tomorrow's visual displays promise to be "picture window" quality, allowing simulation and training, and virtual environment applications to become a military and commercial reality. To create this type of environment, visually stringent technological requirements such as high resolution, large color gamut, and reproducible color must be met. The microlaser based display systems include the critical technologies which promise to enable a giant step toward future military display requirements. This high resolution display technology must be tightly integrated with the source data and the image generators. Together these systems can achieve the 20/20 visual acuity objective of high end simulation and future information display systems.

Acknowledgments - this work was supported by Proxima Corporation, by the Department of Commerce, Advanced Technology Program and by a Small Business Innovative Research grant through Armstrong Laboratory/ Aircrew Training Research Division, USAF.

REFERENCES

- 1) Modified from William Glenn (1993), "Displays, High Definition Television and Lasers", *Proceeding from Optical Society of America, Compact Blue-Green Laser Conference*, pp.CTuA2/5-7.