LASERS FOR DISPLAYS

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ABSTRACT

Over the past decade there have been several attempts to market laser television projectors. High cost, huge electrical power consumption and poor reliability have usually doomed these ventures. In order to be a viable alternative to commercially available projectors such as light valve and CRT projectors, the unique characteristics of lasers must be exploited. The laser projector should solve specific applications problems that cannot be solved by any other projector. Some of the unique characteristics of a laser are (1) high degree of collimation, (2) zero light persistence and (3) 100% color (hue) saturation.

This paper will describe how these unique characteristics are applied to solve specific training requirements for advanced weapons tactics trainers. These requirements include two full color targets and one monochrome target with dynamic distortion correction over the entire field of regard (360° horizontal, +90° to -50° vertical). Additional requirements include independent, non-interfering Night Vision Goggle training for the Pilot and Weapon Systems Officer. Recent developments toward achieving non-interfering full color area-of-interest displays for the Pilot and Weapon Systems Officer will be discussed.

The characteristics of available lasers will be reviewed and some recent improvements in electrical power conversion efficiency using upconversion, diode pumped second harmonic generation and fiber lasers will be described.

ABOUT THE AUTHORS

Kris Bentley is Manager of Research & Development, Hughes Training, Incorporated (HTI), Airport Operations with 15 years experience in simulation. Since 1990 he has been responsible for directing advanced display research for aircraft simulator programs. Prior to joining HTI in 1990, he contributed to the evaluation of advanced displays for fixed wing, helicopter and ground based systems at the Hughes Aircraft Company/Radar Systems Group Display Systems Laboratory. Prior to joining Hughes in 1980, he was employed as an Operations Research Analyst at the Combined Arms Center at Fort Leavenworth, Kansas supporting war game development. Mr. Bentley holds a BS and MS in Mathematics both from Morehead State University.

David Ansley is a Senior Scientist, Hughes Training, Incorporated, Airport Operations with 27 years experience in optical engineering. Since 1980 he has consulted on the F/A-18 Weapons Tactics Trainer. He contributed to the design of the target projector lens, two sky/earth lens, air-to-ground lens and the laser target projector. He is the co-inventor of the Two Pilot Night Vision Goggle Display. Previously, he was Visual Engineering Manager at Singer Link Flight Simulation responsible for CIG, camera model and film displays. He is the author of several papers on optical engineering, coherent optical data processing and holography. Dr. Ansley holds a Ph.D in Electrical Engineering (Modern Optics option) from the University of Michigan, a MS in Electrical Science from the University Michigan, a MS in Physics from the University of Michigan and a BS in Optics from the Institute of Optics at the University of Rochester.

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INTRODUCTION

Advanced Weapons Tactics Trainers have evolved along with the evolution of fighter aircraft. The trainers are installed in various configurations. Example configurations include single dome, dual dome, single seat cockpit and dual seat cockpit. The requirement for 720° field-of-regard and dual seat single dome have placed unique requirements on the display system. In order to meet the 720° field-of-regard requirement, the sky/earth (background) projectors are placed outside the dome.

The placement of the sky/earth projectors outside the dome provides the pilot with a view of the dome's screen surface obstructed only by the target projectors located around the base of the cockpit platform. Dual seat aircraft require a provision for independent, non-interfering Night Vision Goggle training for the Pilot and Weapon Systems Officer. A laser display provides a unique solution to this requirement.

The laser display provided the following enhancements to the training environment:

1) Removal of the target projectors from inside the dome

2) Projection of two color targets and one

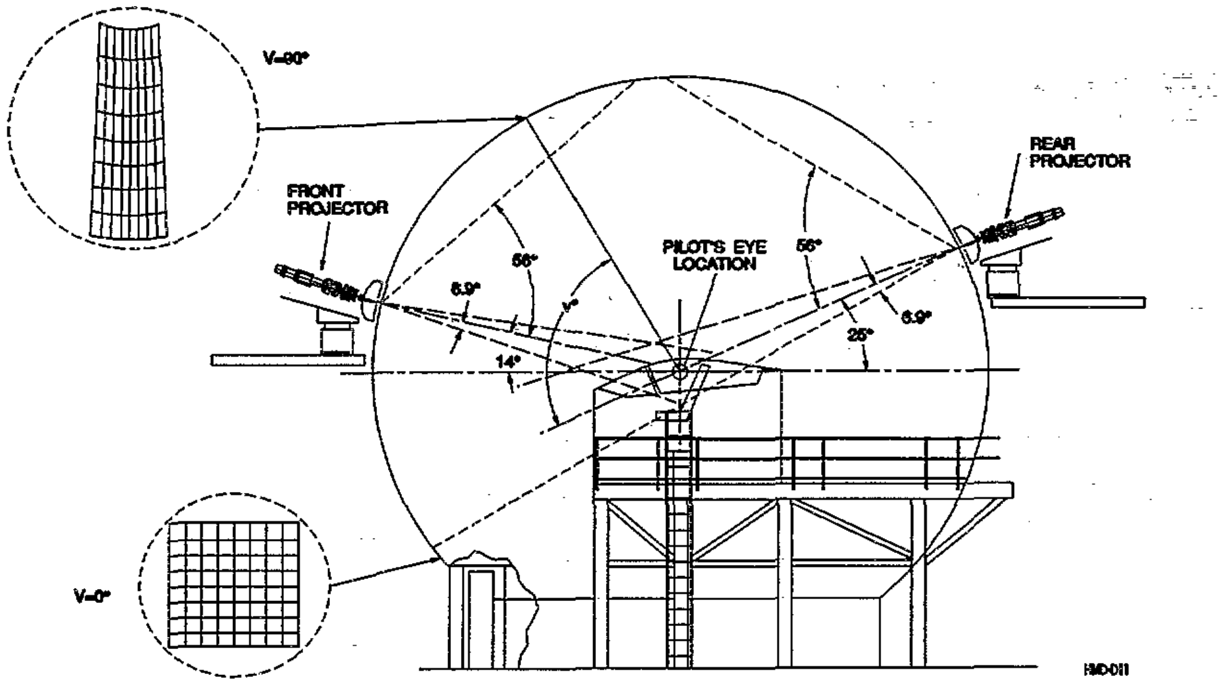

Figure 1. Advanced Weapons Tactics Trainer Laser Display Configuration

monochrome target through a single dome opening (hole)

3) Two independent, non-interfering displays for Night Vision Goggle training

4) Independent dynamic distortion correction over the entire field-of-regard for each target/pilot

5) Provision for two independent non-interfering color displays for day light training

CHARACTERISTICS OF LASER PROJECTORS

Lasers have several characteristics that are beneficial to solving the problems associated with providing unobstructed viewing of targets and areas-of-interest. These include:

1) Point Source. Laser light emanates from a point. Therefore, the f-number of the optics can be very high. The benefit is that the optical design is simplified and the size of the lenses is reduced. For the advanced WTT where projection is through a small hole in the dome, most of the light would be blocked if an extended illumination source such as a Xenon lamp were used. Table 1 shows the amount of light that would pass through a small opening for a GE Light Valve Projector. The laser projector allows for 100% of the light to pass through the opening.

Field Of View As Seen From Dome Center	% Of Light Passing Thru Hole In Dome
20°	4%
25°	6%
40°	16%
50°	25%
60°	36%
100°	100%
200°	100%

Table 1. Fraction Of Light Passed Through Dome Hole For GE Light Valve Projector

2) Zero Persistence. Unlike phosphors or deformable oil films, a laser display has zero persistence. The benefit is that moving images do not smear and blur. The MTF of a moving image is as good as that of a stationary image. Zero persistence also provides for fast switching between images (e.g., target hand-off across hemisphere boundaries). It is not necessary to wait 10-20 milliseconds for the image of the first projector to fade away.

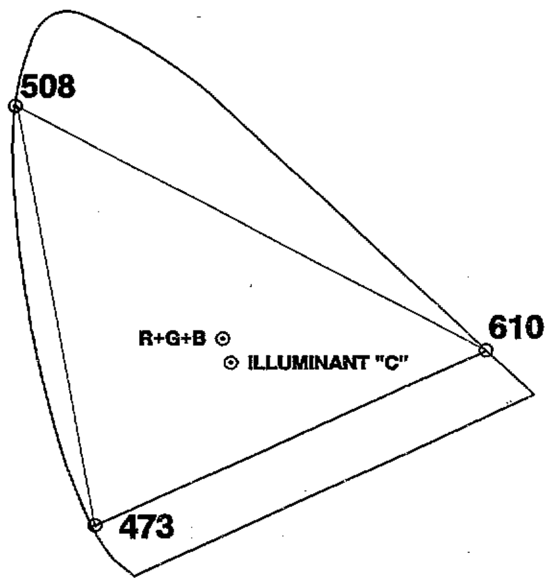

Figure 2. Representative Plot Of Laser Display On CIE Chromaticity Diagram

3) Pure Colors. Each laser wavelength is monochromatic and plots on the boundary of the ICI (CIE) Chromaticity Diagram. This maximizes the color space available for displaying highly saturated colors. Pure color also enables chroma multiplexing. Narrow band rejection filters can be placed on the pilot's visor to prevent him from seeing the other pilot's display.

These unique characteristics result in an effective light source utilizing a large color space. The use of pure colors provides for a true black level providing a contrast ratio in excess of 200:1.

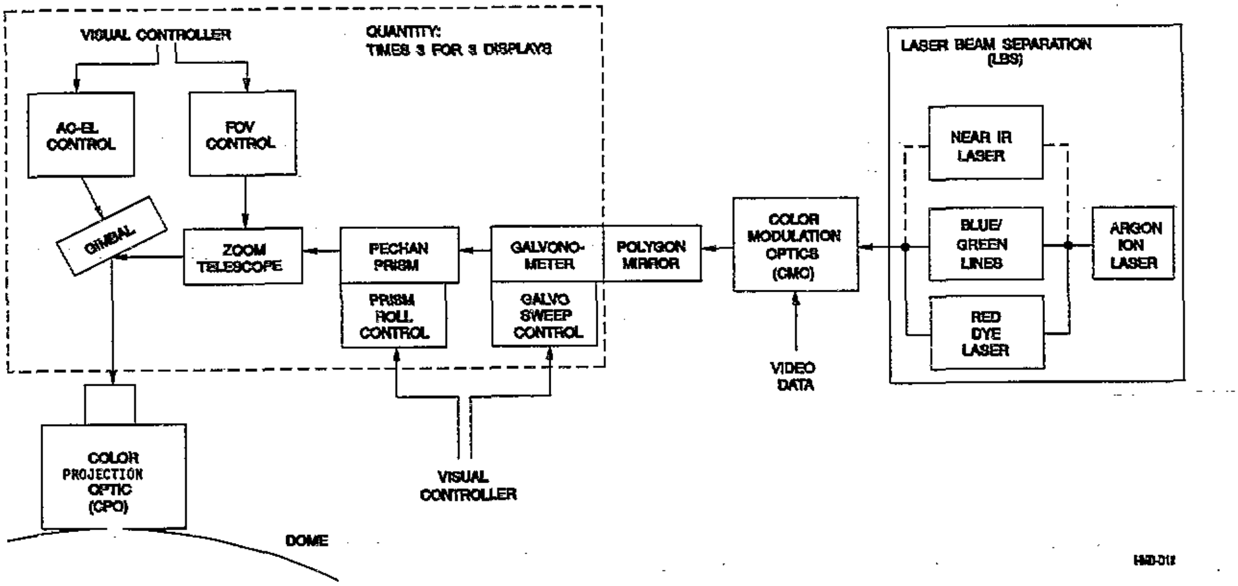

Figure 3. **Laser Projector Block Diagram**

WTT DISPLAY REQUIREMENTS AND LASER PROJECTOR SOLUTION

The laser projector was developed to provide a solution to the following training requirements:

1) Two full color targets and one monochrome target with dynamic distortion correction over the entire field-of-regard

2) Non-interfering Night Vision Goggle training for both Pilot and Weapon Systems Officer

3) Non-interfering full color area-of-interest display for both Pilot and Weapon Systems Officer

Two projectors are used to provide a 720° field-of-regard (360° horizontal, +90° to -50° vertical). Both projectors are located outside the dome (see Figure 1). The front projector projects on the rear hemisphere. Similarly, the rear projector projects on the forward hemisphere.

The two laser projectors are used in conjunction with three GE Light Valve projectors. Two of the light valve projectors are used to project background scenes on the dome surface. The third light valve projector provides a high resolution insert fixed on the forward dome surface. Each projectors utilizes a small, non-discernable opening to project imagery onto the dome.

Three Targets With Dynamic Distortion

Figure 3 provides a block diagram of the laser projector solution to this problem. The logical flow for the diagram is right to left.

Laser Beam Separation. An argon/ion laser is used to provide laser energy to drive the projector system. The energy from the laser is used to provide a variable blue/green pump and drive a red dye laser.

Color Modulation Optics. The color modulation optics accepts video data from a computer image generator. This signal is used to modulate the red, green, and blue lasers via acoustic optical modulators. This generates the grey scale for the laser display. Each of the modulated red, green and blue laser beams are combined into a single "white" beam. The computer image generator data is pre-distorted via a digital buffer and synchronized with the polygon mirror.

Polygon Mirror. The polygon mirror provides a scanning mirror surface that generates the horizonal sweep for the display. Only one polygon mirror is used to provide three independent horizontal scans. Each horizonal scan is 960 pixels wide.

Galvanometer/Pechan Prism/Visual Controller. The galvanometer and associated mirror provide the vertical sweep for the display. The galvanometer is interfaced to the visual controller which provides a variable speed control. It is through the use of the visual controller variable speed control of the galvanometer and the variable time pixel read-out of the digital buffer that dynamic distortion is accomplished. There are 875 TV lines.

Pechan Prism. The pechan prism is used to provide a mechanism for keeping the display raster lines horizontal. This pechan prism performs a rotation of the full image based on the location of the target on the dome surface.

Zoom Telescope. The telescope provides for a variable target size. Targets can range from 4° to 40°. The telescope can travel from a 4° to a 40° field-of-view in one second. Eye limiting resolution is provided for target sizes less than 14°.

Gimbal. A two-axis gimbaled mirror is used to position each target on the dome surface. The gimbals can traverse 370°/second at an acceleration of 6000°/second^2.

Color Projection Optics. This subsystem provides the final interface of the laser image to the dome surface. All three targets are projected through a single dome opening.

Figure 3 represents a single target projector. The components contained in the dashed box are replicated in order to obtain three targets. The monochrome target uses only a green wavelength.

Non-interfering Night Vision Goggle Training

The laser projector provides an ideal solution for the training of night vision goggles. The Pilot and Weapons System Officer wear goggles during training in the same dome. An acceptable training environment must provide an undistorted

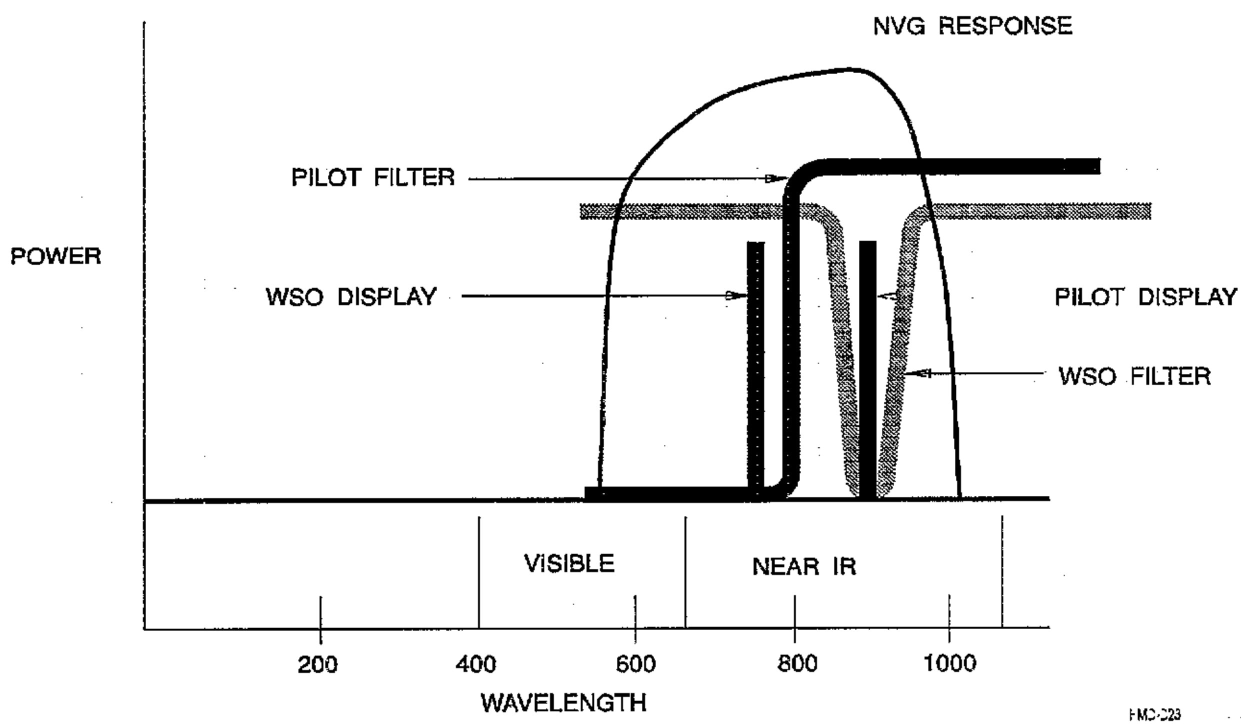

Figure 4. **Night Vision Goggle Response And Filter Pass/Rejection Curves**

display. Near-infrared lasers operating at different wavelengths allow the laser projector to provide two independent undistorted images. With the use of filters that pass/reject different wavelengths placed over the goggles, the Pilot/Weapons System Officer is able to see his own display without interference from the other trainee. By using the target projector at a 40° target size, head-tracking interfaced to the two-axis gimbaled mirror, and the dynamic distortion correction coupled with the near-infrared laser, the Pilot/Weapons System Officer can utilize his night vision goggles at full dynamic range.

Non-interfering Full Color Area-Of-Interest Displays

Two independent full color displays utilize the two full color target channels of the laser display. In this training mode the laser wavelengths are utilized such that the Pilot's and Weapon Systems Officer's display each utilitize separate red, green and blue laser wavelengths. Bandpass interference for each (3 x 2) wavelength (10 nm wide) is provided while maintaining a 70% transparency (see through). Each trainee uses a visor that have filters applied to prevent the transmission of the wavelengths utilized by the area-of-interest display. Figure 5 illustrates the visor used by each trainee.

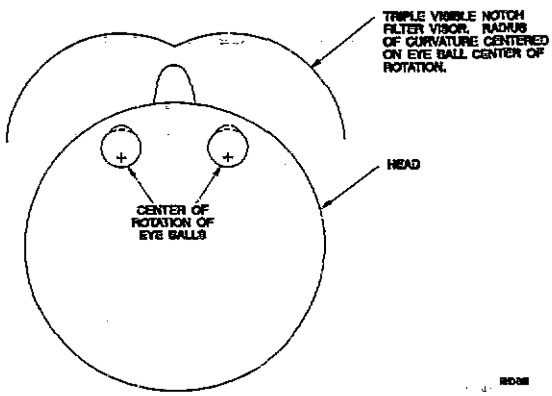

Figure 5. Visor Worn For Non-interfering Full Color Displays

RECENT IMPROVEMENTS IN ELECTRICAL POWER CONVERSION

Over the past decade there have been several attempts to market laser television projectors. High cost, huge electrical power consumption and poor reliability have usually doomed these ventures. To ensure the continued viability of the presented laser projector, advances must be made to reduce the cost and environmental demands required. This section addresses recent advancements in laser research indicating that the future will provide smaller and more efficient lasers.

Diodes

Diodes show promise for smaller displays but will most likely not be utilized for applications as described here. Red diodes presently exists, and likely to be good sources for displays. There is substantial work to be done on the 635-nm sources, but it seems to be developmental and evolutionary. A 635 nm 1.5 mW diode is commercially available from Phillips. Hamada has reported 630 nm 33 mW diode operational at room temperature[1]. Spectra Diode Labs have demonstrated 690 nm 8.5 W diodes at room temperature[2]. 670 nm 1 W diode at room temperature has been reported by MDAC[3].

Blue-green semiconductor diodes based on II-VI technology similar to AlGaAs/GaAs diodes in the infrared, i.e., namely cw operation, 10-30% wall-plug efficiency, room temperature operation and thousands of hours lifetime. When this actually happens is a matter for speculation. 3M has reported blue-green diodes at 490 nm at low temperatures[4]. Brown/Purdue University have demonstrated capabilities of 490 nm at 120 mW at 77K, and 30 mW at 273K[5].

Frequency Mixing

Frequency mixing processes are more complicated than diodes and likely to remain more costly. They are a near-term solution to the production of miniature and small blue and green lasers. They may not scale in power as easily as some sources. IBM has reported blue at 460 nm, 2-4 mW by sum frequency mixing[6]; and blue 429 nm, 55 mW doubled diode lasers[7]. A green diode-pumped YAG doubled into green 534 nm 100mW is commercially available. Hitachi has reported a green mini-diode pumped $NdYVO_4$ intracavity doubled to 534 nm with 5 mW of green for 50 mW of diode power[8].

Upconversion Lasers

The primary attractions of the upconversion lasers are that they have the advantages of the semiconductor diodes and are much simpler than the non-linear processes. In principle, they will consist of a diode butted against a laser medium. The laser medium may have 20% optical to optical efficiency and the diode 30% for an overall efficiency of 6%. Current lasers operate at an overall efficiency of less than 1%.

Upconversion lasers in fibers[9] are attractive in that they provide a small and simple means of providing a laser source. The pump wavelengths for the demonstrated upconversion lasers in fibers are not completely convenient and questions of fiber damage at high powers remain. Hughes Research Laboratory has demonstrated a titanium-sapphire pumped 1.1 Watt at 551 nm at 50K[10] and 100 mW diode-pumped 551 nm at 50K[11]. Amoco Technology has reported 478-483 nm 60 mW[11] and French Telephone reports a green 540-545 nm 60 mW[11].

SUMMARY/CONCLUSIONS

This paper has described the laser display developed for advanced weapons tactics trainers and provides a solution that meets the following display requirements:

1) Location of projectors outside the dome

2) Projection of multiple targets through a single opening

3) Full color target images scalable from 4° to 40° providing for eye-limiting resolution for targets less than 14°

4) Dynamic distortion correction

5) Operation at near-infrared wavelengths for Night Vision Goggle training

6) Independent non-interfering daylight color area-of-interest displays

7) Large color pallet with a true black level providing a contrast in excess of 200:1.

In conclusion, the laser display described in this paper provides a new and unique solution to the two-pilot training requirement. The use of a laser area-of-interest projector, wavelength specific filters, and head tracking provides both pilot and co-pilot/weapon system officer independent high resolution imagery.

The night vision goggle training mode provides for the first time a display without artifacts that excites the full dynamic range of the night vision goggles. In night vision goggle mode, pilots now can be exposed to the effects of blooming and automatic gain control in a safe environment.

Daylight training tasks no longer require two domes or a degraded environment for training of two pilots. Advantages of non-interfering full color area-of-interest displays are presentation to pilot and weapon systems officer/co-pilot of high resolution imagery in all training scenarios, the presentation of a more realistic environment providing for additional cues such as non verbal communications, and the cost savings provided by not requiring two full up domes for high fidelity training.

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