A LASER IMAGE GENERATION SYSTEM FOR HELICOPTER NAP-OF-THE-EARTH FLIGHT TRAINING

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ABSTRACT

The training effectiveness of the camera-modelboard visual system for low-altitude, nap-of-the-earth (NOE) flights, particularly for helicopters, is well established. Traditional camera-modelboard technology, however, has a number of inherent limitations which have been overcome by using a laser image generator instead of a TV camera as in the current generation of camera-modelboard systems. The first full-scale Laser Image Generation (LIG) visual system, developed by Singer-Link under the AH-1S Cobra Helicopter Flight Weapons Simulator contract, will be delivered to the U.S. Army in the near future. This new visual system offers improvements in many areas, some of which are discussed in this paper, together with the visual system technology involved and performance parameters achieved on the AH-1S simulator.

INTRODUCTION

The effectiveness of helicopter weapons system and flight trainers employing modern flight simulation technology depends greatly on the ability to provide the pilot-trainee with a suitable visual environment in the simulator. This is particularly true for low-altitude, nap-of-the- earth (NOE) flight training, where sufficient scene content and high scene detail are needed to provide the necessary out-the-window (OTW) visual cues. It is well established that these types of training cues can be adequately provided by visual systems employing television cameras that view terrain models. However, the traditional TV-based camera-modelboard visual systems have several drawbacks which have made them less attractive when compared to other maturing products for visual simulation.

One inherent limitation of the first-generation camera-modelboard image generator was in the camera pickup tube, which typically had "third-field" image lags of 20-25 percent. This resulted in image smearing when dynamic scene conditions were encountered. This effect typically occurs when the simulated aircraft attitudes are changing rapidly.

Another limitation was due to the limited detail response of image pickup tubes which reduces the percentage modulation of the scene details displayed to the student-trainee.

A third limitation was the degree of image tube sensitivity achievable in conjunction with the other requirements of resolution, signal-to-noise ratio, lag, etc., needed for simulator applications. Since great depth of focus is required in camera-modelboard systems, the optical probe coupled to the camera usually has a very small relative aperture and transmits very little light. The net effect is that a very high light level is needed to adequately illuminate the modelboard.

In short, although the traditional camera-modelboard visual system provides excellent OTW visual cues for NOE flight training, it has limited dynamic resolution, provides a somewhat "soft" picture, and consumes a great deal of energy.

To overcome these limitations while retaining the desirable features of the camera-modelboard system, an IR&D program was conducted jointly by the Link and Librascope Divisions of The Singer Company to develop a new image generator that uses a laser beam to scan a terrain modelboard. The IR&D program culminated in a feasibility model that was demonstrated to the U.S. Army. Subsequently, a decision was made by the U.S. Army/PM TRADE to implement the Laser Image Generator (LIG) on the AH-1S Cobra Weapon System Trainer production contract, with the first simulator scheduled for training by early 1984.

AH-1S COBRA PRODUCTION SIMULATOR

The AH-1S Cobra production simulator has two separate cockpit trainee stations, one for the pilot and one for the copilot-gunner (CPG). The pilot's station is equipped with two adjacent display windows, one front window and one side window, each with a 48° horizontal by 36° vertical field of view (FOV). The CPG's station is supplied with only a single front window display.

Two separate LIG systems, each with a modelboard, provide two image channels that are switchable to either of the two forward display windows. The exact channel-to-display allocation depends on the training mode selected by the instructor. When the integrated training mode is selected, the pilot and CPG stations operate in unison and the two LIG channels are available to both of the pilot's displays. In this mode, the front channel is repeated for the CPG station also. In the independent mode of training, the pilot and the CPG each operate, in effect, a separate simulator, and a LIG visual system is available to each trainee.

The visual system provides a gaming area of approximately 10.5 by 4.5 nautical miles with terrain features designed for the required Cobra helicopter training missions, including NOE flight and confined area landings.

LIG SYSTEM CONFIGURATION

An artist's conception of the Laser Image Generator is shown in Figure 1, and a simplified block diagram of the LIG system is provided in Figure 2. A single LIG channel will be discussed here to describe the system configuration and principles of operation.

The major difference between the LIG visual system and the conventional camera-modelboard system is the replacement of the television camera with a laser image generator consisting of a laser table, a laser transmission subsystem, and a laser scanning unit mounted on the gantry. Also, the bank of lights that is required to illuminate the terrain modelboard is replaced with a bank of photomultiplier tubes (PMT's) for image pickup. The AH-1S LIG system consists of:

1) A laser table light source
2) Laser beam transmission subsystem
3) Laser scanning unit
4) Optical projection probe with Scheimpflug tilt/focus correction
5) Gantry transport
6) 24-foot by 64-foot terrain modelboard scaled at 1000:1
7) Photomultiplier tube bank
8) Video signal processing
9) Special effects, including cultural lights
10) Color CRT infinity displays

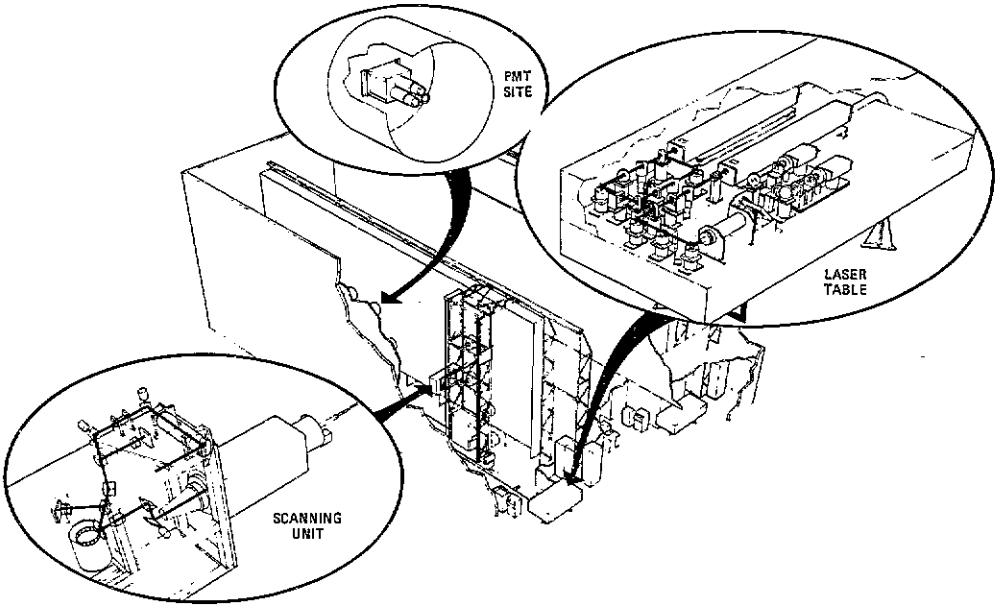

Figure 1 ARTIST'S CONCEPTION OF LASER IMAGE GENERATOR (LIG)

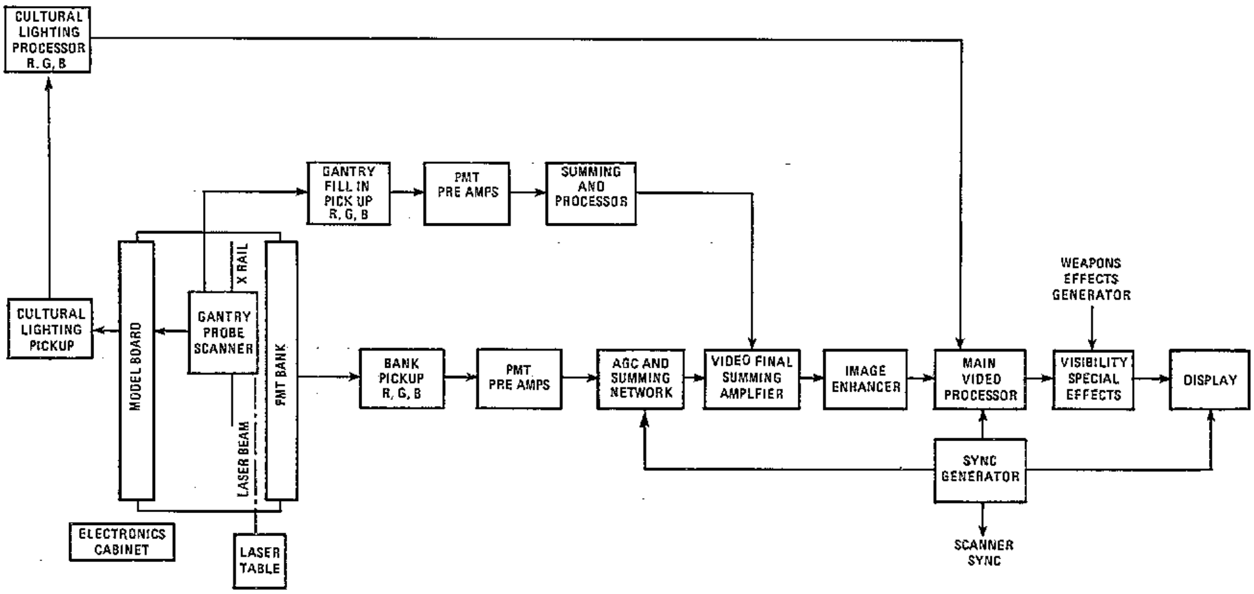

Figure 2 LIG SYSTEM BLOCK DIAGRAM (SINGLE CHANNEL)

PRINCIPLES OF LIG OPERATION

As in a TV camera-modelboard visual system, the LIG system generates a picture by viewing a scaled terrain modelboard. The source of illumination for the modelboard is the laser beam. As shown in Figure 3, the laser beam originates at the laser table and is directed along the rail on which the gantry is transported, traversing the modelboard in the long (X) axis. At the gantry location, the laser beam is transmitted up the gantry, along the short modelboard axis (Y). Here, the laser beam is relayed onto the gantry-mounted laser scanning unit which forms a scanning raster by deflecting the beam horizontally and vertically. The laser scanning raster is projected through the probe onto the modelboard, illuminating the area defined by the FOV, as seen from the trainee's eyepoint. The gantry positions the simulated eyepoint to the correct X, Y, and Z coordinates, while the probe optics provide the roll, yaw, and pitch of the simulated aircraft.

The scattered, reflected light from the modelboard is picked up by the bank of PMT's, each sensing the reflected light simultaneously with the others and generating an output electrical signal. The outputs from all the PMT's are then summed, producing a single time-varying video signal as the gantry duplicates the flight path of the simulated aircraft. This video signal is equivalent to the signal generated by the television image pickup tubes and preamplifiers of the conventional camera-modelboard system. The video signal is used as an input to the main video processor where the special effects, including sky, horizon, visibility, and weapons effects, are inserted. The signal levels are then properly scaled to drive the displays in the simulator cockpit. The display raster and the laser scanning raster are synchronized so that as the laser beam scans a picture element on the modelboard, the display CRT addresses the corresponding picture element in the display raster.

Cultural lighting is simulated by implanting properly scaled fiber optics in the modelboard as in conventional camera-modelboard systems. The signals from the fibers, however, are picked up by PMT's that are located behind the modelboard and away from the main PMT bank. The cultural lighting signal is separate from the model terrain information and can be processed independently. This processing flexibility permits cultural lights to be brilliantly displayed against a darkened terrain background under tactical night flight training conditions.

DESCRIPTION OF LASER IMAGE GENERATOR COMPONENTS

The Singer-Link LIG system development took full advantage of proven camera-modelboard hardware such as the servoed gantry system, the terrain modelboard, and the Farrand 60° Scheimpflug optical probe modified for laser projection. The major components that required design and development effort are those related to the laser image generation process. The new subsystems are the laser table, the laser beam transmission system, the laser scanning unit, and the PMT bank.

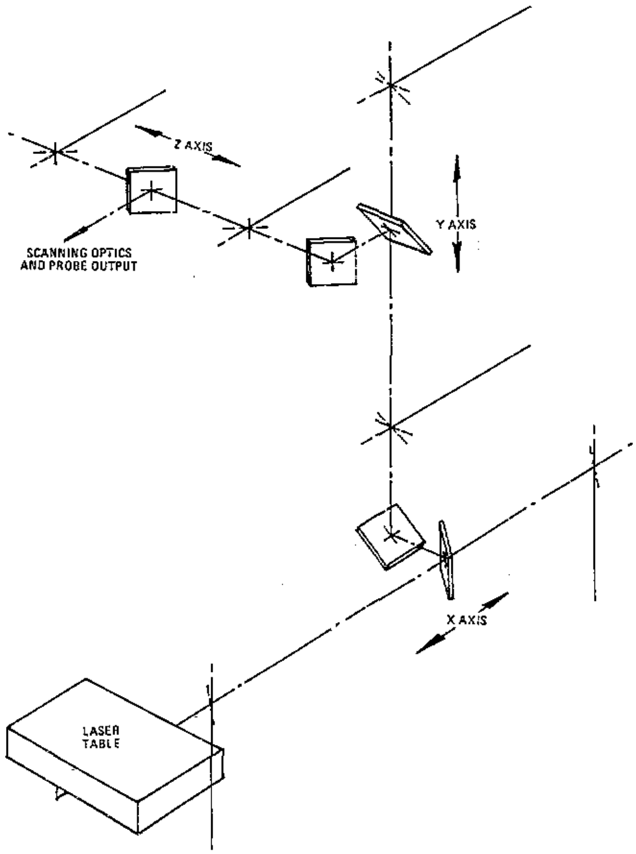

Figure 3 LASER BEAM TRANSMISSION SYSTEM SCHEMATIC

Laser Table

The laser table is an optical bench where three laser beams are combined to provide a single, concentric "white light" beam consisting of four major laser spectral lines with the following frequencies:

Blue	457.9 nm and 476.5 nm
Green	514.5 nm
Red	647.1 nm

Because it is not practical to mount the laser table directly on the gantry, it is located on the floor.

Two ion lasers are used to provide the needed colors. An argon laser generates the blue and green lines and a krypton laser supplies the red line. Each ion laser is equipped with a self-regulating light control system that monitors the laser output and maintains it at a preset level.

The optical arrangement for the laser table is shown in Figure 4. Notice that each laser beam is individually shuttered to permit easy alignment and maintenance. Three beam controller units are provided, one for each laser color. Each beam controller performs the

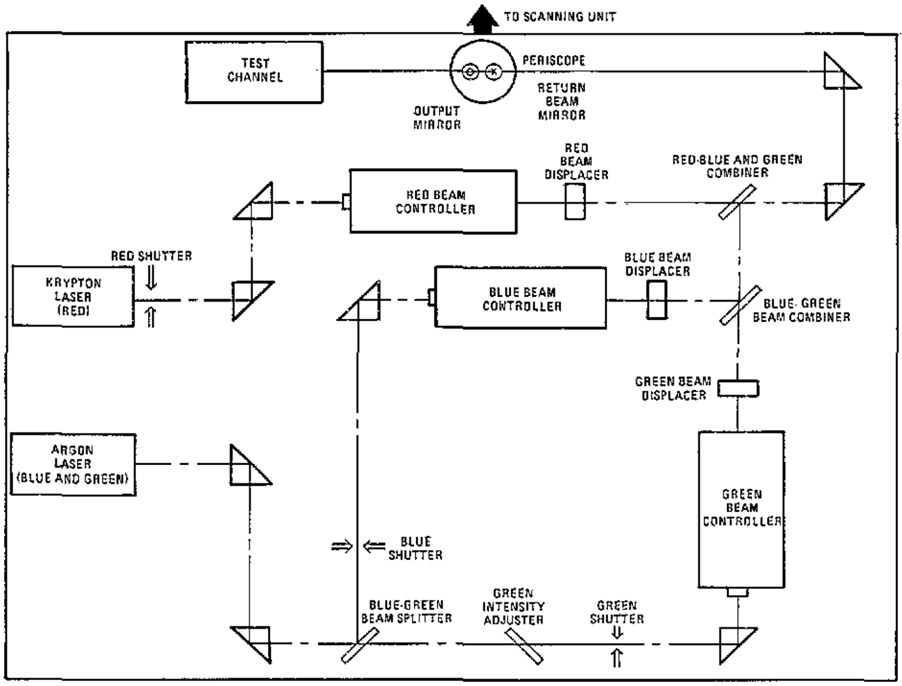

Figure 4 LASER TABLE OPTICAL LAYOUT

functions of expanding the beam to a suitable size for transmission to the gantry and provides adjustments for zoom, focus, and angular steering. The beam expansion is set up so that a beam "waist" is achieved for each color at a fixed distance from the table. The zoom adjustment controls the optical invariant of each color so that the three color beams will match in size and divergence. The focus adjustment shifts the waist of the beam along the transmission axis. It also compensates for the small residual spherical power in each optical path. The angular steering adjustment provides color convergence at infinity for the three beams. It is effected at the exit pupil so that the pupil position is not affected. With the colors converged at both the pupil and infinity, the color is converged for any gantry position.

The three beams of color are combined into a single coaxial beam before being transmitted through the periscope, where the composite beam is aligned in angle and translational displacement so that it matches the gantry rail alignment. Routine maintenance and alignment checks are greatly facilitated by the use of a built-in optical test channel. Figure 5 is a photograph of the production laser table.

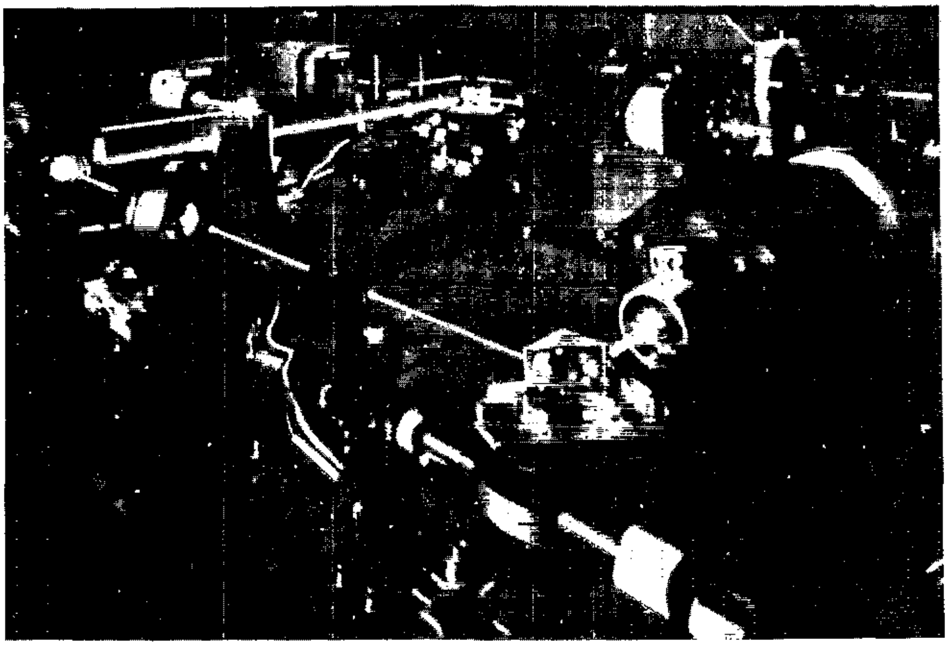

Figure 5 PRODUCTION LASER TABLE HARDWARE

Laser Beam Transmission System

One of the technical challenges met by the LIG system design was the design of a system to transmit the laser beam from the laser table to the moving gantry-mounted laser scanning unit. The resulting transmission system design accommodates all gantry motions expected under normal simulator operations and maintains correct laser beam pointing to within acceptable tolerances. The design accommodates a transmission path that varies greatly in length, depending on gantry position. The desired results have been achieved by expanding the laser beam from the nominal beam size of 1.3 mm to the chosen beam waist diameter and then routing the beam along the X-axis, up the Y-axis gantry tower, along the Z-axis, and into the entrance pupil of the scanning unit.

Expansion of the beam for transmission is done for several reasons. First, over a long transmission path, the laser beam diameter would increase as a result of diffraction dispersion, with the percentage increase a function of the beam diameter as well as the transmitted distance. Small beams expand very rapidly, large beams more slowly. For the chosen transmission beam size, variation in beam diameter over the total travel distance is less than 6 percent. This is well within the limits established by optical aperture design considerations and the system resolution requirement which is dependent on the spot size of the scanning laser beam. A second advantage of the expanded beam is that any lateral displacements of the beam caused by gantry motion are of a smaller percentage as compared to the increased beam diameter, so that motion-induced displacements of the beam have a smaller effect on beam movement at the probe exit pupil.

On the other hand, if the size of the transmission beam is too large, problems will be caused by wave front distortions which are exaggerated when the large beam is reduced back to the small size required to generate the scanning raster. In addition, a large beam reduction ratio would result in a large magnification of beam pointing angular errors introduced in the transmission process. Even at the chosen beam diameter and beam reduction ratio, the residual beam pointing error at the entrance pupil of the laser scanning device would be unacceptable without correction. A beam correction servo is incorporated into the design of the gantry-mounted scanning unit, as described below.

Laser Scanning Unit

The expanded laser beam is transmitted from the laser table and received by the gantry-mounted laser scanning unit. This unit generates the actual scanning raster prior to its projection onto the modelboard via the Scheimpflug optical probe. In preparation for scanning, the transmitted laser beam is reduced in diameter and the residual angular (pointing) errors are removed. As shown in Figure 6, this is accomplished by first routing the beam through a reducer which converts the beam diameter back to 1.3 mm and then using beam position sensors to detect beam pointing errors in two orthogonal directions. Each position sensor consists of a beamsplitter that diverts a small amount of laser light (less than 1 percent) onto the optical sensor (a silicon lateral-effect photodiode) via imaging optics. The error signals generated are used to drive two beam-steering-correction galvanometers, one for each of the two perpendicular axes, as a feedback system to achieve the calibrated null position.

The corrected laser beam is directed to the rotating head of the high-speed scanner where it is deflected by a polygon mirror, made up of 24 facets, rotating at approximately 76,000 revolutions per minute. Since air bearings are used for the rotating polygon, a support system consisting of an air compressor, holding tank, and vacuum pump is required, along with a small water cooling unit to remove heat generated. A fail-safe interlock system is provided to protect the high-speed scanner. The exit beam from the scanner facet provides the horizontal (or fast) sweep of the scanning raster. The vertical or slow sweep is provided by a galvanometer driven at the 60-hertz field rate, deflecting the relayed output beam from the high-speed scanner to provide the vertical sweep.

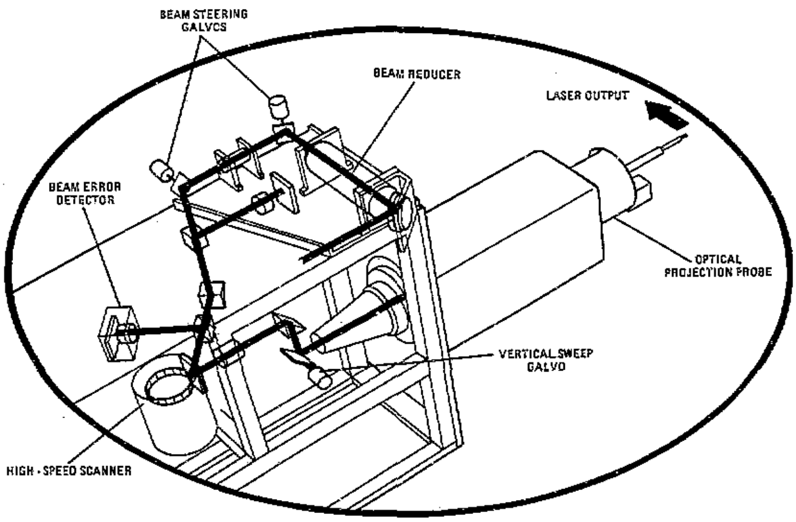

Figure 6 LASER SCANNING UNIT

A laser scanning raster is therefore formed at the entrance pupil of the optical probe, corresponding to the displayed field of view of a single window (scaled for 48 degrees horizontal by 36 degrees vertical). The scanning laser beam is projected onto the modelboard, illuminating only what is within the FOV, as seen from the simulated eyepoint. The production AH-1S laser scanning unit is shown in Figure 7.

Figure 7 PRODUCTION LASER SCANNING UNIT HARDWARE

PMT Bank

The light reflected by the terrain model is picked up by the PMT bank, which generates the video signal for electronic processing and display. The PMT bank consists of arrays of PMT sites, arranged as four rows by eleven columns and staggered as shown in Figure 8 to provide uniform signal distribution. Each PMT site contains a triad of 2-inch PMT's clustered in a triangular pattern. A red, green, and blue color filter is provided, one for each tube in the triad, to give a three-primary (red-green-blue) color system. Selection of the color filters, transmission optics, and modelboard paints, together with the chosen laser wavelengths, was originally made after comprehensive colorimetry analysis, supported by empirical results. The choice of colors has since proved to be very satisfactory on the full-scale production system.

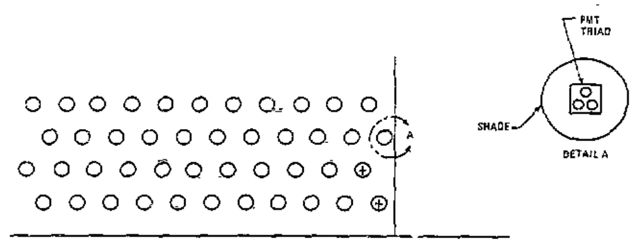

Figure 8 PMT ARRAY AND MODULE

The AH-1S PMT bank design of 44 sites represents a reasonable compromise among performance parameters such as S/N ratio and signal uniformity versus the number of PMT sites required, which would directly impact hardware complexity and cost. Performance specifications were established for a S/N ratio of 40 decibels or better, and a design objective was set to have typically no more than a 15 percent signal amplitude variation caused by shadows. The PMT bank was designed to meet these requirements.

Figure 9 AH-1S LIG MODELBOARD/GANTRY SYSTEM

LIG PERFORMANCE RESULTS

The first production AH-1S LIG visual system has been undergoing system integration and test for some time and is being prepared for U.S. Army acceptance. Preliminary results show that all the performance specifications for the LIG are met, and often exceeded. The quality of the picture on the production unit is superior even to that achieved on the laboratory prototype. Although a formal reliability and maintainability (RAM) assessment and demonstration is yet to be conducted, experience accumulated on the new visual system so far indicates that significant RAM improvements over previous-generation camera-modelboard systems have been achieved. In addition, the test results show superior performance in many important areas, as discussed below.

Dynamic Resolution

Static limiting resolution measurements taken on the production LIG system show better than 6 arc minutes per optical line pair (OLP), only a slight improvement over the 7 arc minutes/OLP on previous camera-modelboard systems. However, image lag effects are absent in the LIG system, except for the negligible effects of very short decay time for the display phosphor. For the LIG, therefore, the dynamic resolution is the same as the static resolution, resulting in a dramatic improvement for dynamic scenes with fast-moving objects.

S/N Ratio

A S/N ratio of better than 40 decibels has been measured for each color channel, with the argon and krypton lasers operating at less then half the rated output power. This allows a twofold increase in laser power to further improve the S/N ratio or operation at one-half power to prolong their useful life and increase reliability.

Picture Contrast

In addition to the improved dynamic resolution, the detail response of the image (or the modulation transfer function, MTF, of the system) is significantly enhanced, particularly in the low and middle frequency regions. This translates directly into a more vivid picture, remarkable for a TV system, which will greatly enhance the training value of the LIG-equipped simulator. The enhancement is achieved primarily because limitations previously posed by the camera pickup tube have been removed. With properly designed laser optics, the system resolution and MTF are now constrained by other system components, such as the optical probe and the display CRT.

Color Rendition

The subject of color rendition using only three discrete laser lines has been given much attention throughout the LIG development effort. Starting with the original colorimetry analysis, continuing through the feasibility model empirical verifications, and finally culminating with the production design, choices were carefully made in selecting every component that would affect the final color presentation. The end product offers an exceptional, high-quality color image.

Color Registration

Free of the difficulties associated with registering a color camera, particularly at the corners of the picture, the LIG offers a sharply registered picture. Color misregistration could result if the red, green, and blue laser beams become misaligned, but this does not happen under normal conditions because the optical system for the composite laser beam is a simple and stable design, and the optical elements are used primarily on-axis. The Farrand Optical probe, fully color-corrected, performs well for the selected laser frequencies, which are within its original design capabilities (broadband television camera applications).

Energy Consumption

The final significant improvement is in the reduced energy requirement for the LIG. Since the laser illuminates only what is within the FOV, no energy is wasted on lighting what the pilot-trainee cannot see, and power consumption is reduced by more than 80 percent. Compared to the previous camera-modelboard systems utilizing high-intensity lamp banks, the 80-percent energy reduction is quite attractive. Removing the lamp bank eliminates almost 200 kilowatts of power per modelboard, plus the corresponding reduction in facilities air-conditioning needed to remove the heat generated.

As examples of the picture quality provided by the LIG visual system, photographs of typical AH-1S display scenes are shown in Figures 10 and 11. A summary of LIG system performance specifications and preliminary test results is given in Table 1.

CONCLUSION

The first AH-1S Cobra simulator to be equipped with a LIG visual system will be delivered to the U.S. Army in the spring of 1984. The laser image generation visual system offers improvements over the traditional camera-modelboard system in many areas, including a more vivid picture (higher detail modulation), freedom from picture smearing caused by image lag, improved picture registration, and significantly reduced energy consumption. The LIG system provides very high scene detail and modeling fidelity. It offers an attractive solution to those training needs where visual cues of this nature are required for effective training.

ABOUT THE AUTHOR

Mr. Hin Man Tong is the Director of Visual Systems at Link Flight Simulation Division of The Singer Company. He is responsible for the visual product line within Link's Government Simulation Systems operation in Binghamton, New York. He has over 17 years of experience in television systems and visual simulation technology, leading the development of visual products that included one of the first commercial low-light-level surveillance TV cameras, a high-resolution camera-model visual system for simulation, and the Laser Image Generator. Mr. Tong holds a BSEE degree from the City College of New York and an MBA degree from the State University of New York.

Figure 10 AH-1S LIG DISPLAY SCENE OF A WEAPONS DELIVERY AREA

Figure 11 TYPICAL AH-1S LIG DISPLAY SCENE

Table 1 LIG TECHNICAL PERFORMANCE SUMMARY

PARAMETER	PERFORMANCE
System Resolution	Better Than 6 Arc Min/OLP
S/N Ratio	Greater than 40 dB @ 50% Rated Laser Power
Contrast Ratio	Greater than 15:1
Gray Scale	10 Shades
System Geometry	Within 2.5% Over Entire FOV
Minimum Simulated Eye Height	6.5 Ft
Display FOV	48°H x 36°V (Per Channel)
Display Brightness	7 Ft-L
Display Color Convergence	Within 0.1% for Central Circle of Picture Height, Within 0.2% Elsewhere.

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