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Polyplanar Optical Display Electronics

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ABSTRACT

The Polyplanar Optical Display (POD) is a unique display screen which can be used with any projection source. The prototype ten inch display is two inches thick and has a matte black face which allows for high contrast images. The prototype being developed is a form, fit and functional replacement display for the B-52 aircraft which uses a monochrome ten-inch display.

In order to achieve a long lifetime, the new display uses a 100 milliwatt green solid-state laser (10,000 hr. life) at 532 nm as its light source. To produce real-time video, the laser light is being modulated by a Digital Light Processing (DLP™) chip manufactured by Texas Instruments. In order to use the solid-state laser as the light source and also fit within the constraints of the B-52 display, the Digital Micromirror Device (DMD™) circuit board is removed from the Texas Instruments DLP light engine assembly. Due to the compact architecture of the projection system within the display chassis, the DMD™ chip is operated remotely from the Texas Instruments circuit board.

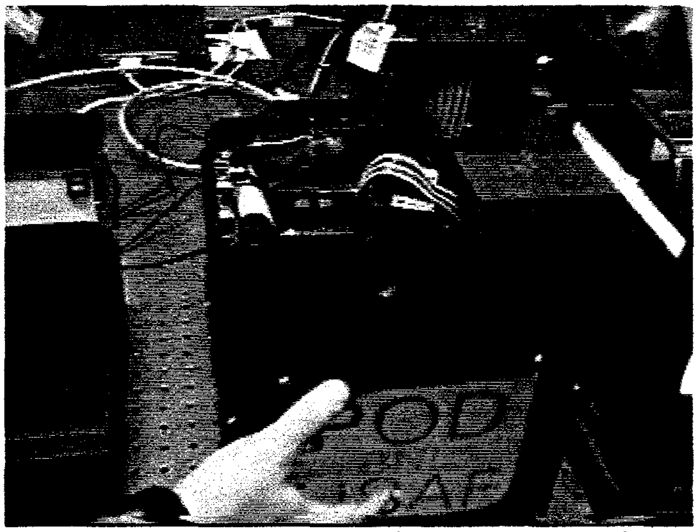
We discuss the operation of the DMD™ divorced from the light engine and the interfacing of the DMD™ board with various video formats (CVBS, Y/C or S-video and RGB) including the format specific to the B-52 aircraft. A brief discussion of the electronics required to drive the laser is also presented.

Keywords: DMD™, POD, Interface, Laser, Video

2. INTRODUCTION

The goal of the Polyplanar Optic Display team at Brookhaven National Laboratory is to develop a long life replacement for the B-52 display[1]. This development is being funded by the PRAM office at Wright Patterson Air Force Base (WPAFB) and will be done in two phases. The goal of Phase 1 was to deliver a breadboard prototype and Phase 2 promises to deliver a flight qualified display. To accomplish this we are using the latest in the state-of-the-art variety of technologies. To start with, the display screen itself will be a Polyplanar Optic Display (POD), invented and developed by James T. Veligdan at Brookhaven National Laboratory (BNL)[2]. The light source for the display is a first of its size 100mw diode pumped doubled YAG green laser, and the spatial light modulator is a Digital Micromirror Device (DMD™)[3], developed by Texas Instruments (TI).

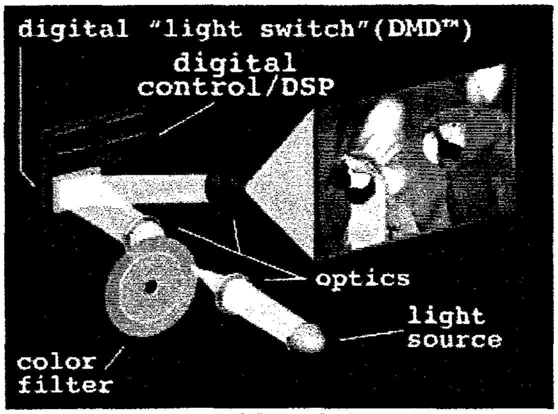
With the development of the DMD™, the decision was made to accelerate the PRAM project to full motion video as opposed to line drawn text as was called for in the contract for Phase 1. During the time frame of the Phase 1 program, the Texas Instrument's light engines were not commercially available in small quantities and we, therefore, waited for a projector manufacturer to introduce a DMD™ projector. *n*-View was the first company to market a projector that used the DMD™ chip, however, due to contractual agreements with Texas Instruments, *n*-View could not provide us with technical information related to the DMD™. In order to use the DMD™, we were required to design our own interface which we address in the following sections.



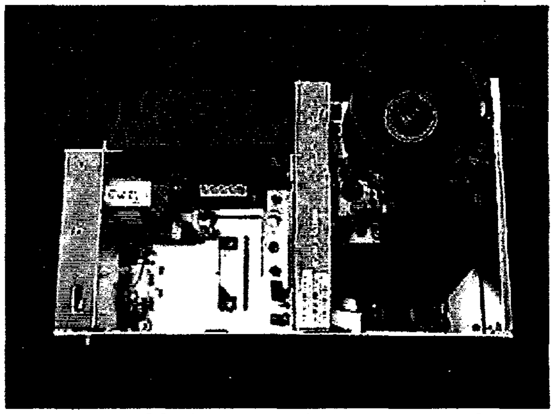
POD prototype undergoing final alignments prior to delivery to the PRAM office at Wright Patterson AFB.

3. PHASE ONE

Due to the time schedule for delivery of the Phase 1 prototype and the late arrival of the DMD™ equipped projector and laser, we decided to modify the *n*-View interface for use in the B-52 prototype display. The major obstacle to be overcome in Phase 1 was to fit the DMD™, its circuit board, and the *n*-View interface into a B-52 display chassis along with the laser light source, its power supply and support electronics. This was inherently difficult because the display chassis is 9 in. x 8 in. x 14 in. and the TI light engine is 7 in. x 12 in. x 10 in., including its power supply. The TI light engine consists of a circuit board containing the DMD™ chip, a 270 watt nickel halide arc lamp, a motorized color wheel, input and output optics, the frame to which it all mounts, and several cooling fans.



Components of the TI light engine

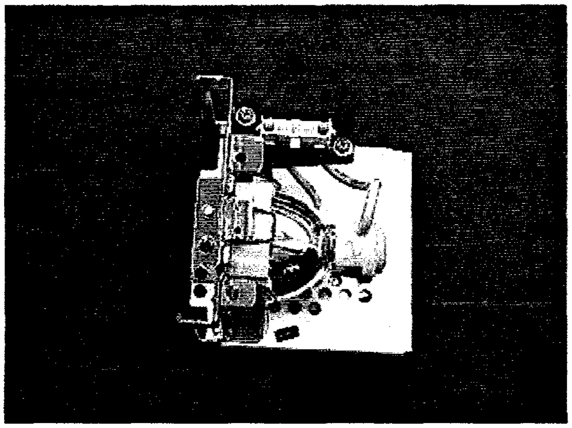


Actual light engine (lamp is removed from left side)

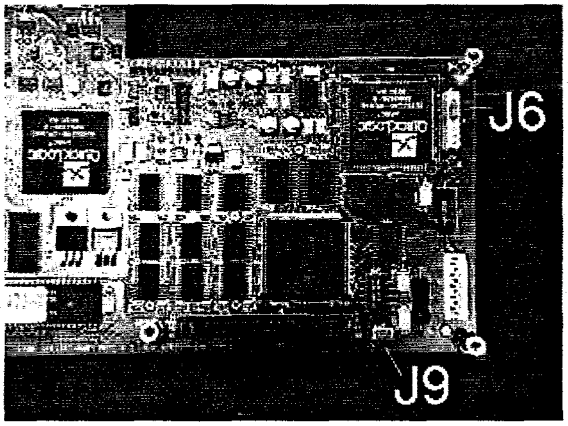
To fit into the Air Force display chassis, the entire light engine must be disassembled and re-configured. The optics for illuminating the DMD™ and the optics for imaging the output were completely re-engineered to meet our needs. In order to remove the DMD™ board from the light engine, the *n*-View interface and TI light engine received the following modifications.

4. LIGHT SOURCE

As delivered from the manufacturer, the TI light engine uses a 270 watt nickel halide short arc lamp. Since we are using a 100 mw laser for the light source we can eliminate the arc lamp. When the lamp and its power supply are removed from the light engine a jumper must be added to J6 pins 5 and 6 to bypass the lamp's power supply interlock. Also, a jumper must be added to J9 pins 1 and 2 to bypass the thermal interlock .

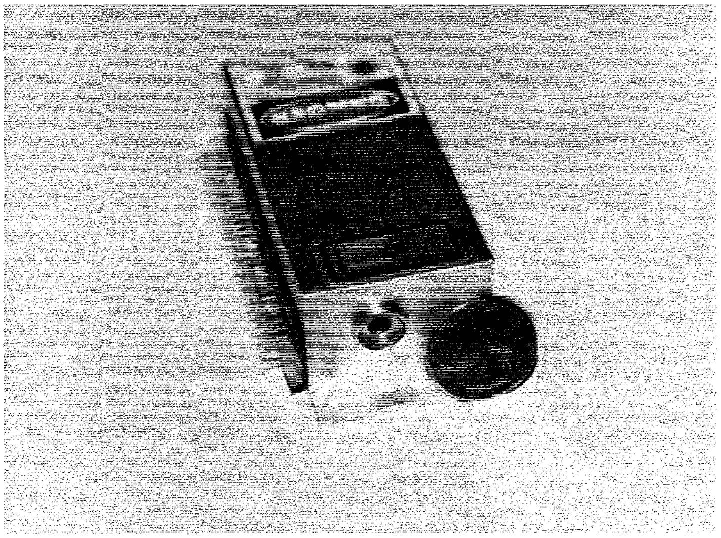


270 watt arc lamp



Lamp interlock jumpers on DMD™ board

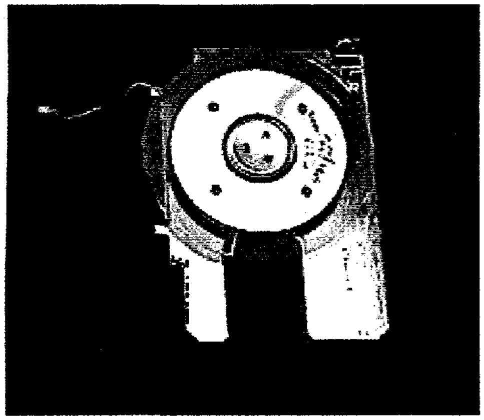
The arc lamp is being replaced, in our display, by a small frequency doubled Nd:YAG laser operating at 1064 doubled to 532 nm wavelength, built by Coherent (Model DPY315M). The Nd:YAG laser is pumped by a diode laser which is temperature tuned to optimize the performance of the Nd:YAG crystal. This laser produces 100mw, cw, at a wavelength of 532 nm in the green portion of the spectrum. It measures only 1 in. x 1.5 in. x 3.5 in. and has an output beam diameter of 0.012 in. In addition, it has a small controller that measures 1 in. x 2 in. x 3 in. and a 28 volt DC power supply that is 1 in. x 3 in. x 11 in. The laser controller is capable of varying the laser output power from 35 mw to 100 mw. For our application we hard wired the laser to continually output maximum power. Because of the thermal tuning that the laser must undergo during turn on, the first 30 to 60 seconds of operation may not be stable. Long term testing found the laser's power stability to be within ±2%.



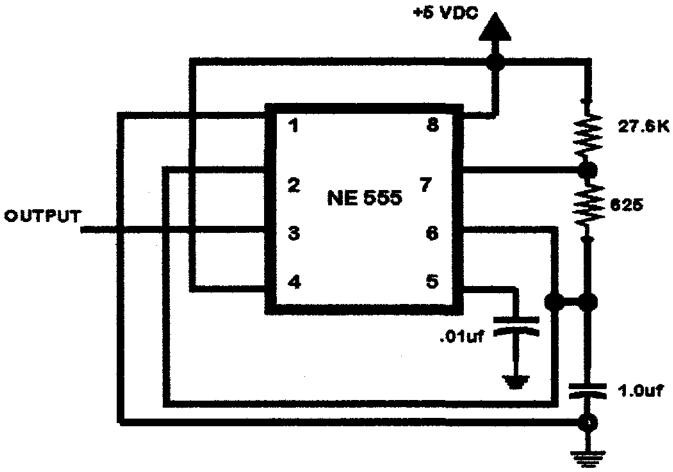
100mw green laser next to a quarter

5. COLOR WHEEL

The TI light engine creates 24 bit color by projecting three images of 8 bit grayscale for each frame, one image for each color of the wheel (red, green, blue). The Air Force requires a monochrome display, thus eliminating the need for the three color wheel. However, the color wheel also provides a necessary vertical sync signal by way of an optical sensor. Since our monochrome display does not require the color wheel, it can be replaced by a pulse generating circuit made with one NE555 timing chip and a few components. The stepper motor connected to J1 on the DMD™ circuit board can be disconnected and the motor removed. The optical sensor can then be disconnected from J2 and the NE555 circuit can be connected to the DMD™ circuit board through J2. In order to complete the replacement of the color wheel, connect J2 pin 1 to +5 VDC. Then J2 pin 3 is connected to GND, and J2 pin 2 is connected to the output of the NE555 pulse generating circuit. The NE555 circuit can be adjusted for any sync rate from 50 to 60 Hz.



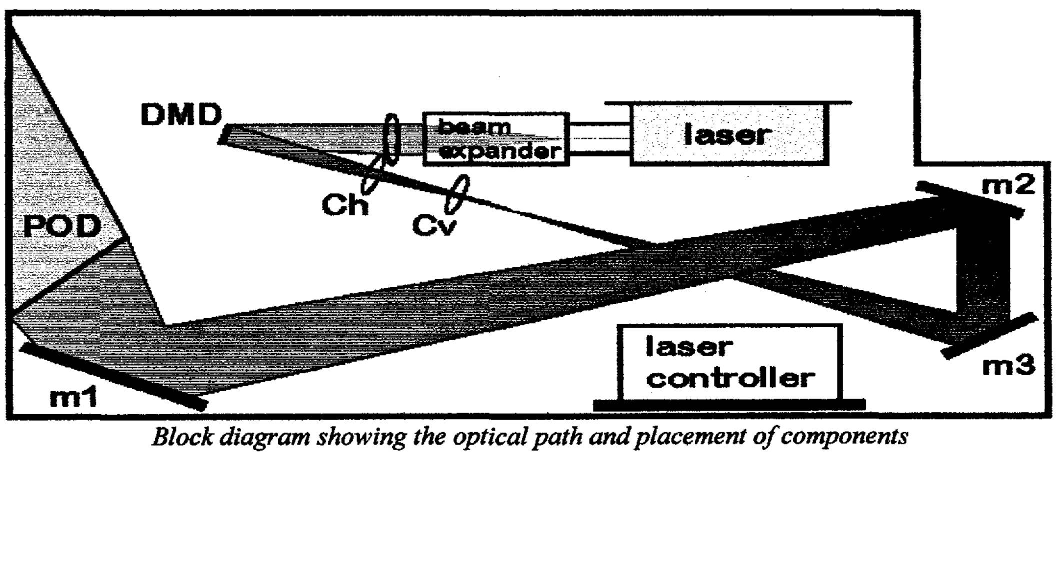
Color wheel from n-View projector



555 pulse generator circuit to replace color wheel

6. OPTICS

As supplied by TI, the input and output optics are completely inadequate for our application. The input optics for the laser must expand the 0.012 in. diameter beam to illuminate the DMD™ with a spot size of 0.75 in. diameter. The angle of the illuminating light must be 18.6 degrees from the normal in the vertical and also 18.6 degrees from the normal in the horizontal. This comes out to 26.6 degrees coming in on a diagonal. The anti-reflective coatings on the first lens must be of a high enough quality as not to become damaged under the high power density of the laser.

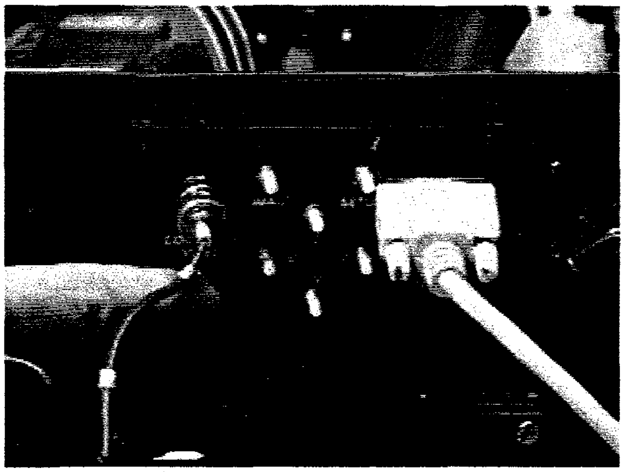


Block diagram showing the optical path and placement of components

Because the POD has a variable focal plane in the horizontal dimension and a fixed focal plane in the vertical, the output image passes through a Scheimphlug lens system, which focuses the vertical and the horizontal components separately through respective cylinder lenses. Also, because the input face of the POD is narrower in the vertical than in the horizontal, the image must be compressed in the vertical. By compressing the image in the vertical it can be folded to achieve a 30 in. focal path in only 12 inches. Once the image enters the POD, the optics of the POD will decompress the image to its normal aspect ratio. A detailed discussion of the optical system has been presented in a previous paper[4].

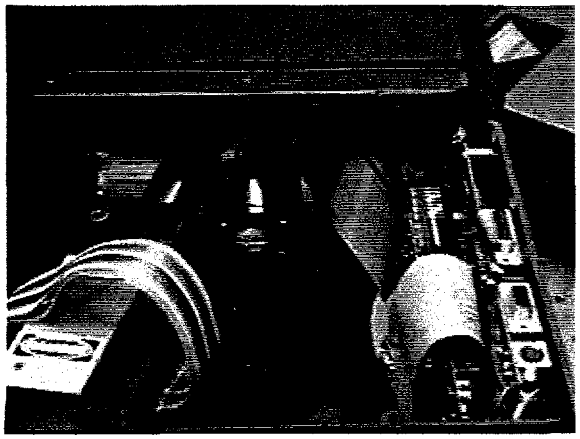
7. *n*-View INTERFACE

In order to demonstrate the prototype display as a stand alone device it was necessary to provide various types of video inputs. Since the display was delivered with a VHS video tape player and a laptop computer, the interface to the display had to be capable of multiple inputs. The interface which we provided was capable of accepting S-video or Composite video from a VCR or a video camera, and also RGB from a laptop computer. The first step in designing our own interface to the DMD™ board was to try to understand the existing *n*-View interface, and how it interacts with the DMD™ board. To accomplish this task we used a video pattern generator to inject a specific recognizable pattern into the RGB input to the *n*-View interface board. Using an oscilloscope this pattern was traced to the three (red, green and blue) analog-to-digital converters. From there the 8-bit digital outputs (MSB through LSB) of each analog-to-digital converter were identified with their respective pins on the 80-pin connector (J8) of the DMD™ board. The horizontal and vertical sync signals, as well as the S-video and the Composite video were examined in the same manner. Although these signals are converted into YUV (Chrominance/Luminance) signals prior to the conversion to RGB, they are fed to the same pins on J8 that the original RGB signals were fed. In the process of understanding the *n*-View interface we gained enough information to design our own interface. But due to the late acquisition of the *n*-View projector, and the time frame of delivery to the Air Force, we were pressed for time to design and fabricate our own video interface. Since we had enough room in the B-52 display chassis we decided to modify the *n*-View interface for Phase 1. The composite video and the RGB video inputs were brought from the *n*-View board to the back panel of the display along with the switches for selecting the menu options.

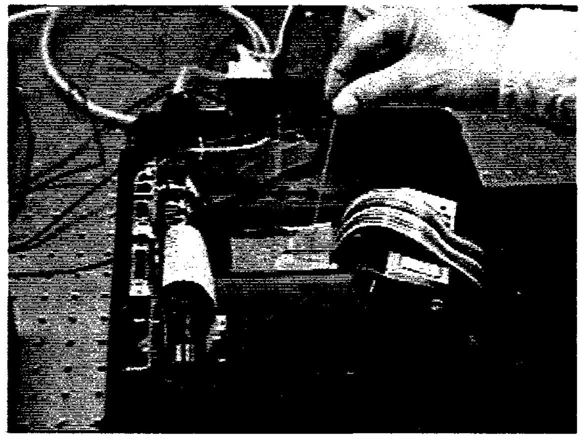


Composite video or RGB inputs are selected on the back panel along with some diagnostic controls.

The *n*-View board and the DMD™ board were sandwiched together and mounted on the inside wall of the display. This was the optimum location after considering the imaging path and available space.



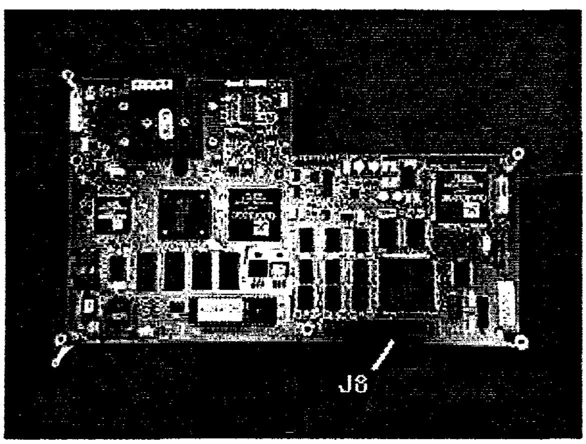
DMD™ board and n-View board on right
100mw laser on left



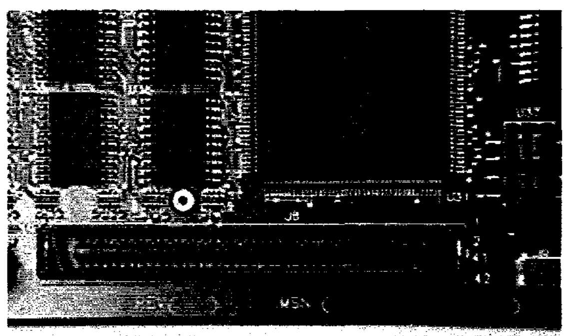
Checking to see that light path clears
electronic circuit boards

8. REMOTE OPERATION OF THE DMD™

The video input to the DMD™ board is in the form of digital 8-bit RGB signals. Also included are digital inputs for the vertical and horizontal sync, while a clock signal is also required for synchronization with the analog to digital converter board. The DMD™ board also requires +12 volt DC at 200 milliamps and +5 volt DC at 2.5 amps. Of the 80 pins on the DMD™ circuit board's input connector, 32 of them are grounds. In the ribbon cable this puts a ground between every pair of digital video lines to reduce crosstalk.

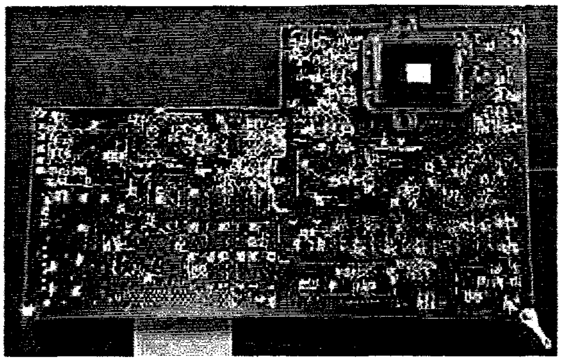


DMD™ board showing the 80 pin connector

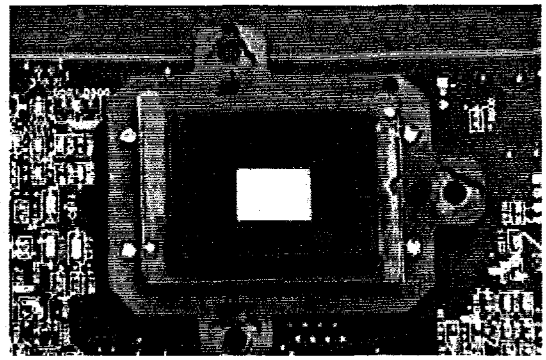


Close up of 80 pin connector

Because of the position of the DMD™ board with respect to the optical layout, it was necessary to remove the DMD™ chip from the circuit board and extend it on a ribbon cable. This was difficult because the chip and the circuit board both had flat gold land areas. Although it would have been easy to solder to, using surface mount techniques, we were concerned about damaging the board or the chip. Another reason for not making the extension permanent was that TI had advised us not to remote the chip too far from the board, no more than 3 inches. And if this was to fail we wanted to be able to return the DMD™ chip to the circuit board undamaged so we could look at a different approach. Thus, in order to be conservative, we devised a method to temporarily connect the 114 pin DMD™ to various lengths of test cables.



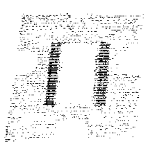
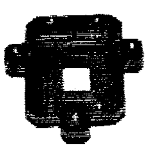
DMD™ circuit board with chip at upper right



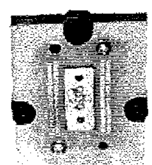
Close up of chip and its bezel

Initially we were able to remote the chip eight inches from the board, but later it was decided that the chip needed to be 12 inches from the board. This also was met with success. To make the electrical connection from the board to the ribbon cable and then from the ribbon cable to the chip, we used the same type of pressure sensitive conductor that was used by TI. This conductor material is made up of alternating layers of flexible conductor and insulator and is available commercially. We also had small circuit boards custom designed and manufactured which had the exact conductor pattern as the DMD™ circuit board and chip, with the addition of tiny plated through holes to attach ribbon cable.

The flexible conductor material was then sandwiched between the DMD™ circuit board and the board connected to the ribbon cable. The other end of the cable was connected in the same manner to the DMD™ chip, although the heat sink on the chip had to be reduced by 50%.

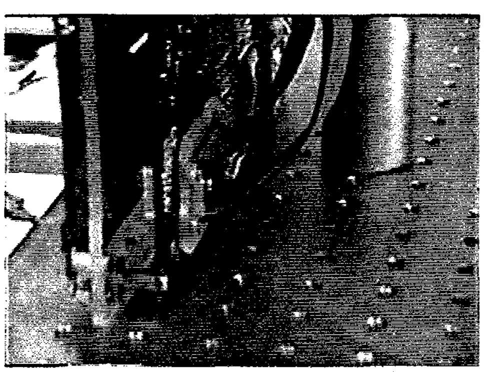



Custom board *Bezel* *Conductor* *Chip*

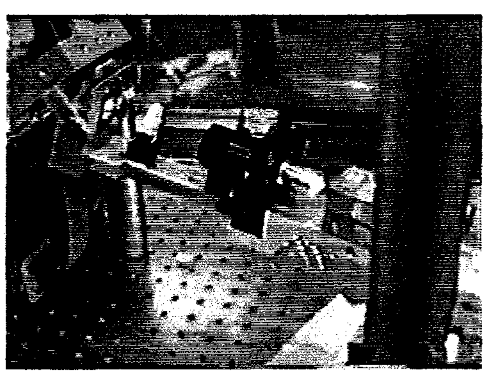


DMD™ chip assembly

It is crucial that these little boards line up precisely with the chip so we pinned the board to the chip with precision dowel pins. With the chip on the end of this cable it was possible for the chip to be displaced three inches out from the surface of the board, four inches up along the plane of the board and turned at a right angle to its original position on the circuit board. This allowed everything to be packaged into the Air Force display chassis.



Ribbon cable connection to DMD™ board



DMD™ extended on a ribbon cable being illuminated by the laser on the test bench

On 15 January 1997 the display was delivered to the PRAM office at WPAFB concluding Phase 1.

9. PHASE 2

The major difference between the display delivered in Phase 1 and the display that will be delivered in Phase 2 is the fact that the Phase 2 display will be a form fit function replacement for the multi-functional display used in the B-52. This means that the video will be driven from the aircraft's video distribution unit and not from a VCR or laptop computer. Although the modified *n*-View interface board worked well in Phase 1, it will not be used for Phase 2. Instead we will remove the *n*-View board and replace it with our own custom video interface board that will take up considerably less space inside the display chassis. Also, for Phase 2 we will be drawing power from the aircraft so the space inside the chassis for power supplies can now be utilized for more or larger illuminating lasers.

10. VIDEO INTERFACE

The Digital Micromirror Device is truly that, digital. In order to interface with the DMD™ circuit board everything must be performed digitally. This means that the analog video signal must be digitized into a form that the DMD™ can understand. To do this we will design a circuit containing a multi-functional video analog-to-digital converter.

The one chip front end SAA7110A, from Philips Semiconductor, is a digital multistandard color decoder with two integrated analog-to-digital converters, a clock generation circuit and brightness contrast saturation control. The block diagram in Figure 1 shows that we supply an analog video signal to the input of the SAA7110A chip and produce a 16-bit YUV digital video output. In Figure 2 we see the processing that goes on to accomplish the conversion from analog video to the Chrominance/Luminance, YUV digital signal. This YUV signal serves as the input for the next stage of the interface.

The Digital Color Space Converter (DCSC) SAA7192A, also from Philips Semiconductor, is a digital matrix which is used to transform the 16-bit digital signals, Y(Luminance) and UV(Chrominance), into the RGB format that is required by the DMD™ circuit board. In Figure 1 we see that the SAA7192A has as its inputs the YUV output of the SAA7110A. Figure 3 shows the process of conversion from YUV to RGB. Once the SAA7192A has converted the signal to the RGB format it can be fed directly into the DMD™ circuit board.

11. LOSSES

As we developed this display we encountered many losses along the way and the minimization of these losses will be a major concentration of the efforts in Phase 2 of this project.

One of the greatest losses of light in the single DMD™ light engine is the fact that color is produced by passing white light through the color wheel. The color wheel is divided into four filter panels one for red, one for green and two for blue. Not only are the filters of the color wheel a source of light loss but each frame of video has to be divided into the *red*, *green* and *blue* images, and then passed through the color wheel during the proper time. During the four transitions of colors in the color wheel, the DMD™ does not image light through the output lens. Because the Air Force requirement is for a monochrome display, we have the advantage of eliminating the color wheel and reducing the light attenuation. The mirrors are switched off during the transition between the colors and these off times during the transitions are something that we cannot control from outside the DMD™ board. The one thing we can control is the digital image that is fed to the DMD™ board. Since the image is input to the DMD™ board in a 24-bit digital RGB format (8-bit red; 8-bit green; 8-bit blue) , and the DMD™ board only images one color at a time for one-third of the frame time to produce 16.7 million colors, the DMD™ is effectively off for two-thirds of the frame time for any of the three colors. For our purpose, 8-bit video grayscale (256 gray levels) is sufficient, so we will attempt to make the 8-bit video grayscale image available on each of the digital RGB inputs to the DMD™ board. This should project the full image three times per frame as opposed to projecting a color component of the image three times per frame.

12. CONCLUSION

In conclusion, we have successfully interfaced with the Texas Instruments DMD™ circuit board and adapted it for use in our display. We demonstrated the ability to operate a DMD™ without its color wheel while using a solid-state laser as the light source to produce real time video images. The challenge of the next year will include a way to optimize the operation of the DMD™ chip itself. There are some features of the DMD™ that have not yet been explored and yet other features that we believe could be modified to enhance the operation of the DMD™ in a monochrome mode.

13. ACKNOWLEDGMENTS

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14. REFERENCES

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2. J. T. Veligdan, "Flat or Curved Thin Optical Display Panel" U. S. Patent Number 5,381,502 , Associated Universities, Inc., January 10, 1995.

3. DMD™ and DLP™ are trademarks of Texas Instruments Corp.

4. L. Beiser and J. T. Veligdan, "Ten Inch Polyplanar Optic Display", SPIE, 1996, Vol. 2734.

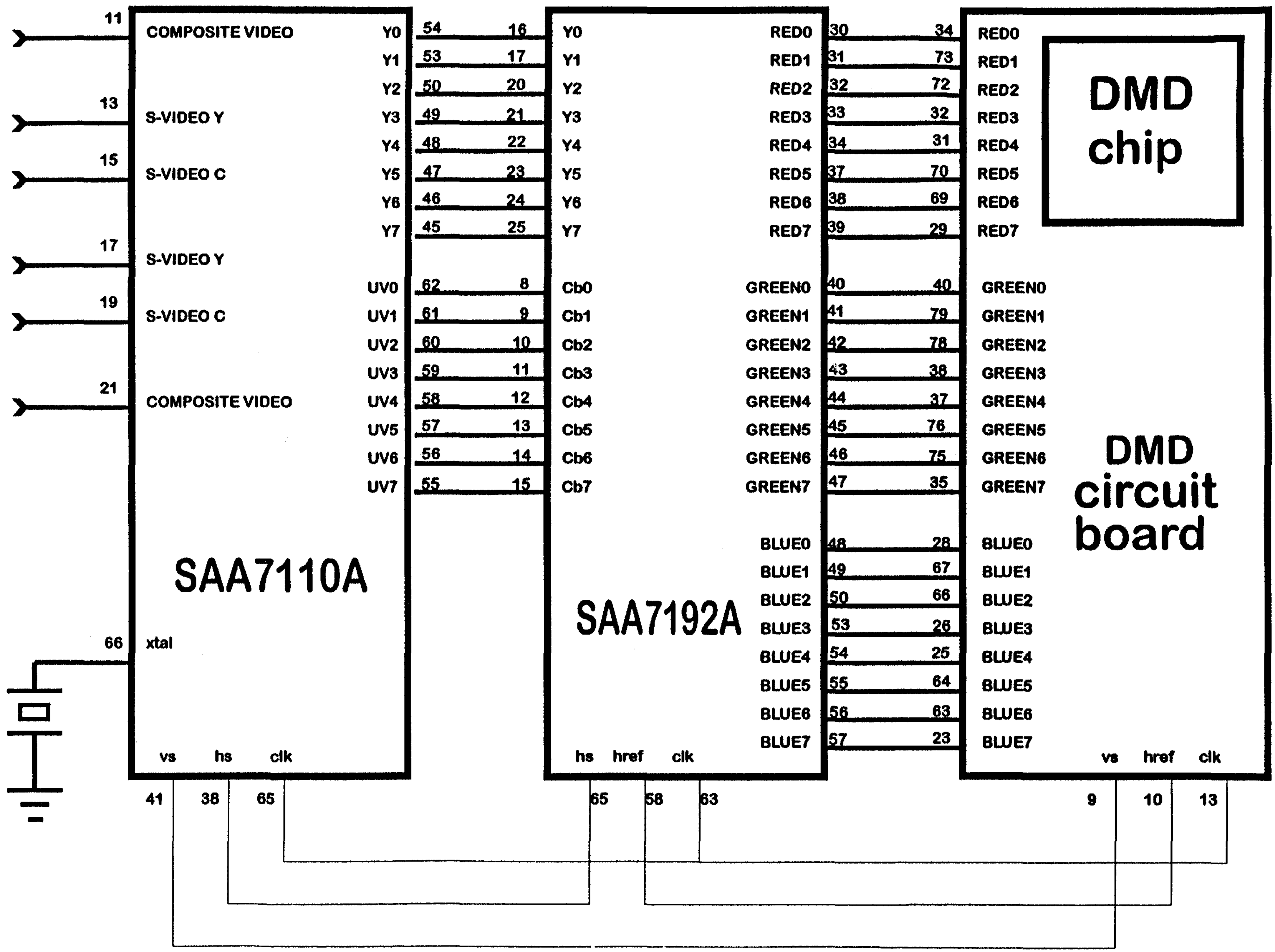

Fig. 1 Block diagram.

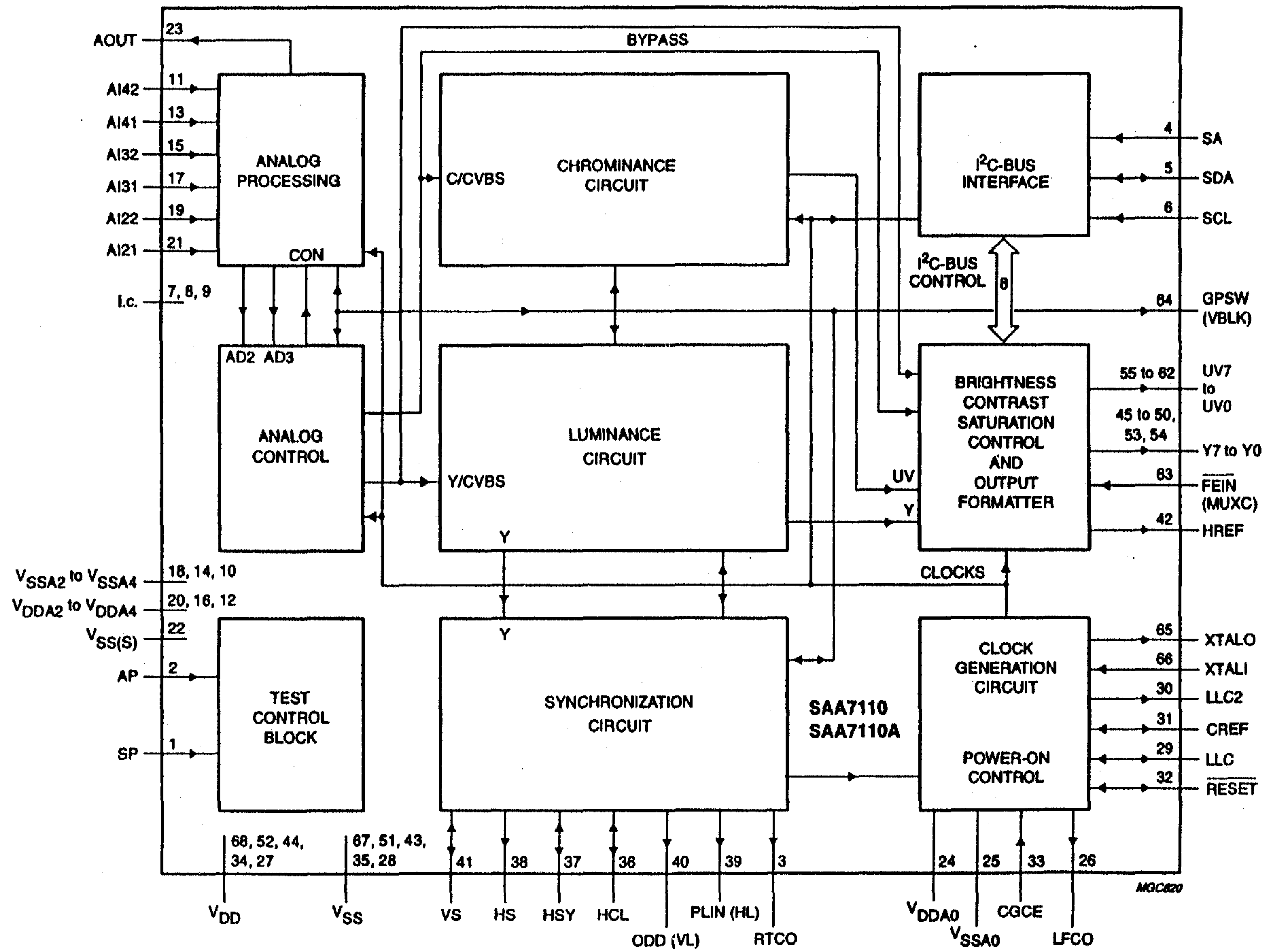

Fig.2 Block diagram.

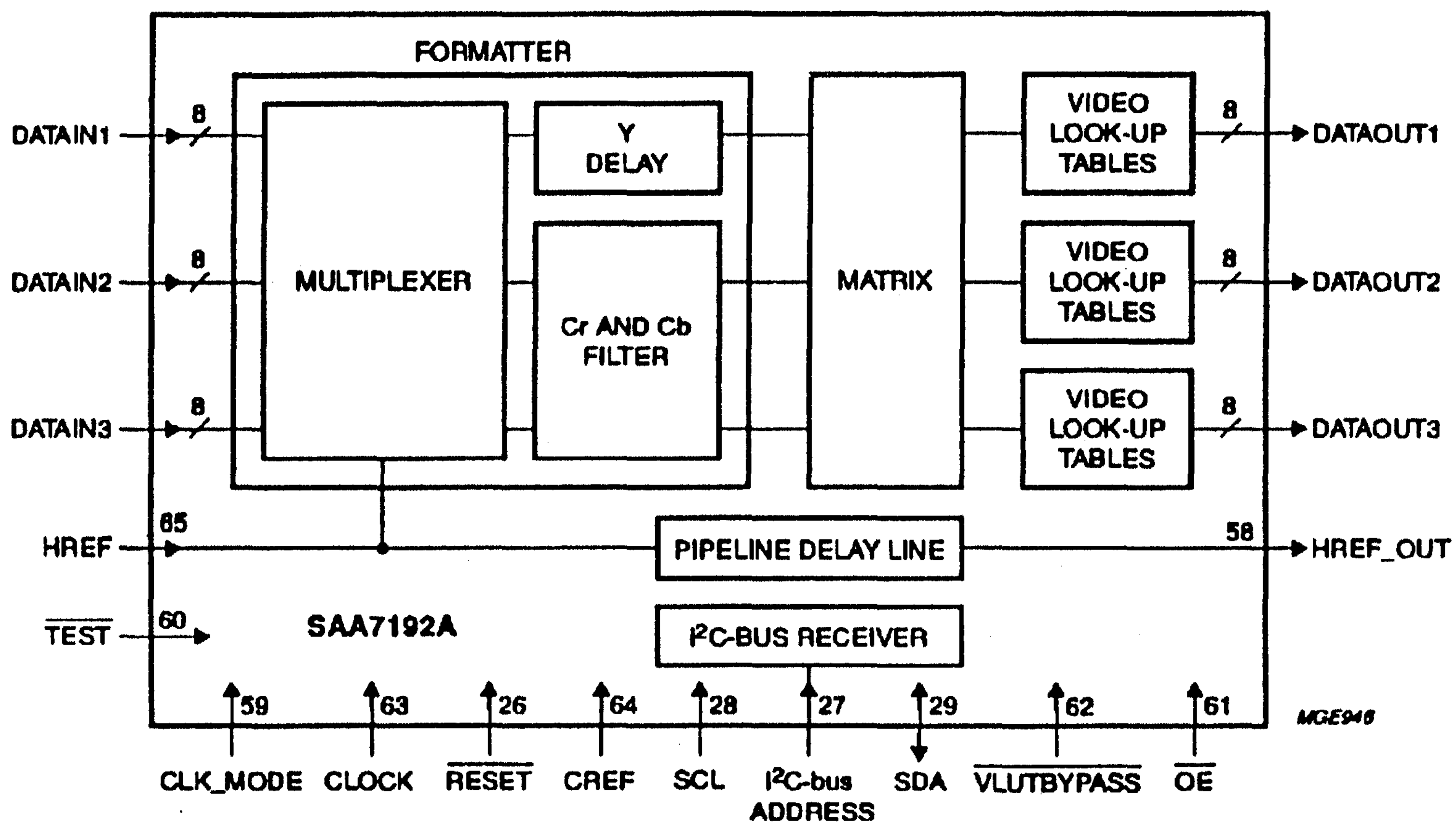

Fig.3 Block diagram.