TECHNICAL REPORT: NAVTRAEEQPCEN IH-338

HELMET MOUNTED DISPLAY FEASIBILITY MODEL

John H. Allen and Richard C. Hebb
Advanced Simulation Concepts Laboratory
Naval Training Equipment Center
Orlando, Florida 32813

FINAL REPORT February 1983

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Visual Display
Helmet Mounted Display
Laser Video Projector
Area of Interest Display
Instantaneous Field of View

Computer Image Generated Display
CIG
Head Tracker
Eye Tracker

A feasibility model of an advanced visual display system for flight simulation is described. The feasibility model is comprised of a video projector mounted on a pilot's helmet which projects a computer generated image onto a spherical screen. The video projector utilizes a laser light source in forming the projected video raster. The display is slaved to the viewer's head pointing direction via a magnetic head tracking device, and results in imagery that is generated and displayed for the instantaneous viewing.
direction of the observer. Since the computer image generator requires a
measureable period of time to create an image for a specific head pointing
direction, an undesirable display orientation error is induced each time the
viewer moves his head. A method of continuously compensating for this image
display error was provided and is described. This feasibility model has
demonstrated successfully, on a small scale, the helmet mounted display
concept. This concept will be utilized in a full scale development model
scheduled for delivery under contract in 1985.
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SECTION I

CONSIDERATIONS FOR A VISUAL SIMULATION

In general, the need for improved high resolution, wide field of view displays in visual simulation systems exists because of the increasing necessity for training combat missions in flight simulators. Total duplication of the rich visual environment present everywhere outside the cockpit during actual nap of the earth missions or any other low level mission, though, is not possible using current visual simulation technology. Nor, in all probability, will it ever be. Due to technological and physical restrictions a visual display is only a representation or simulation of the actual visual environment. The choice of what should be simulated and how it should be done is not easy due to the number, nature and variety of visual cues available to and used by a veteran pilot during the performance of an actual mission. Until our understanding of the human visual system and its interactions with the real world are more complete, visual simulation systems will be designed to provide as much realism and fidelity as is possible with available funding and technology. Under these conditions, it seems reasonable to conclude that a display which provides eye limited resolution and high detail over the entire available field of view will supply the essential elements of a fully adequate visual simulation system.\(^1\)

Typically, a high resolution, wide field of view display is created by butting together several computer generated video displays. Each display is separately created by a single image generator channel feeding video to either a video projector or to a conventional CRT monitor. The displayed video image is derived from a digital representation of a mathematically modeled landscape or gaming area depicting the training scene. This digital portrayal is more simply known as a data base. Depending upon the particular training requirements, the data base may be modeled from existing terrain information from some known location or, it can be entirely fictitious. In the usual case, then, a wide field of view simulation system consists of a number of video displays and their associated computer image generator channels, each channel obtaining visual information from a common data base. For a given area of visual display, or equivalently, field of view, increasing the number of the video displays and image generator channels improves the resolution of the whole display and increases the quantity of detail available to the viewer. Unfortunately, the visual simulation is improved at the expense of doing so with a more costly, complicated visual simulator system.

Another method of providing a wide field of view display with high resolution and detail utilizes a movable high resolution inset display. Two prin-

Principal types are target tracked (moved to follow some displayed target) and head/eye tracked (moved to follow the observer's head and eye position).

A target tracked display is usually projected upon or inset into a background low resolution, wide field of view display. In this way, imagery for the entire visual simulation can be furnished by a two-channel image generator, one channel driving the movable high resolution display, the other sourcing the low resolution background display. The position of the target tracked display that is within the background display is a function of target location. In other words, the display is servo driven in some manner so as to place a target image in the proper position within the background display. Target imagery can consist of an enemy missile site or even an accompanying friendly aircraft. Its visual content is entirely dependent upon the simulated mission. The advantages of this visual simulation system is that it provides some of the benefits of wide field of view and high resolution using a limited number of image generation channels. The primary disadvantage to such a system is that each additional high resolution object/target that is to be displayed requires still another target tracked high resolution display and image generator. As a result of this constraint, a target tracked display may be inefficient for certain kinds of training tasks.

A head/eye tracked display is tracked or moved about in direct response to the trainee's head and eye pointing direction. The visual display appears only where the observer happens to be looking. Further, if the display area is large enough to cover the observer's field of view, a visual simulation can appear to take place throughout the available viewing volume of the simulator, while in fact, the actual display covers only the immediate area available to the viewer. If a second smaller display, also head and eye tracked, is inserted at the center of the display mentioned above, high resolution imagery can be made available to the viewer along his line of sight. Since the human visual system detects high resolution imagery only in the small central foveal region of the eye, proper design of a two-channel head/eye tracked visual display results in the illusion that a high resolution, wide field of view visual simulation is omnipresent.

When the NAVAIR funded Helmet Mounted Display task started in 1978, its primary goal was to determine the feasibility of developing a fully operational dual channel, head/eye tracked, pilot helmet mounted display. Through the efforts of an in-house team a preliminary prototype or feasibility model was designed and built. Successfully demonstrated at a preproposal conference in November 1981, the feasibility model served as a test bed for many concepts, some of which were included in the specifications for the advanced development model, the Visual Display Research Tool, now in the procurement cycle.2

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2. For additional information on the advanced development model, see articles entitled "Helmet Mounted Laser Projector" in the Proceedings of the 1981 Image Generation Display Conference II (AFHRL) and the 3rd Interservice/Industry Training Equipment Conference.
The Visual Display Research Tool, 6.3 funded by NAVAIP, is targeted for incorporation into the Visual Technology Research Simulator (VTRS) in early 1985. This advanced visual simulation system contains only two computer generated displays, yet it provides both a wide angle field of view and high resolution. The high resolution inset display contains high detail scene content and is presented only at the observer's point of gaze or, equivalently, area of interest. The surrounding low resolution display, containing low detail scene content, fills the remainder of the observer's field of view. Visually, the composite display will tend to match the acuity profile of the human eye by generating high resolution imagery only along the foveal axis, and low resolution imagery in the periphery.

An artist's concept of the proposed system is depicted in Figure 1. The flight simulator cockpit is enclosed by a spherical screen. Two displays are projected onto the highly retro-reflective interior surface of the sphere. The scenes in both the high resolution Area of Interest (AOI) display and the surrounding Instantaneous Field of View (IFOV) display are computer generated according to the pilot's line of sight. His line of sight, with reference to the ground, at any one moment in time, is a consequence of his cockpit referenced head and eye position, as well as the attitude and position of the simulated aircraft. Each display is an interlaced video raster composed of 1023 horizontal scan lines. Instead of being projected by a conventional high resolution video projector, though, they are formed from video modulated laser beams which are projected and scanned from the pilot's helmet.

Figure 1. Artist's Concept of an Area of Interest, Instantaneous Field of View Dome Display.
A computer image generator channel generates a blue, a green and a red
video signal to form the full color visual scene within each display. Six
video signals are required for the two displays, two of each color. Each of
the video signals drives an acousto optic modulator. The six acousto optic
modulators, in turn, modulate the intensity of two blue and two green laser
beams from a remotely located argon laser, and two red laser beams from a
companion dye laser. The three modulated, red, green, and blue laser beams
that form each of the two displays are optically combined so as to create a
single composite full color, beam for each display. Each of the two composite
beams are then arranged so as to strike the facets of a rotating high speed
scanner mirror. Here the composite beams for each display are horizontally
line scanned. After being formed, the line scans for each display are then
suitably focused onto the polished ends of two coherent flat fiber optic
ribbon cables for subsequent relay to the helmet mounted projector.

The far end of each flat fiber optic ribbon is attached to the pilot's
helmet. There, the two separate, full color line scans emerge and are verti-
cally frame scanned by oscillating scanner mirrors as they are projected onto
the interior surface of the spherical screen.

The display that the pilot/trainee's attention will be most focused upon,
the Area of Interest (AOI), will occupy a viewing area of approximately 25
degrees square and will resolve approximately 3 arc minutes per TV line pair.
Covering the surrounding display area, the Instantaneous Field of View (IFOV)
fills a 125-degree horizontal by 110-degree vertical viewing volume. The
resolution of the larger display changes across the field, but the average is
approximately 15 arc minutes per line pair. In order to smooth the abrupt
transition from one display into the other, the two displays are blended with
each other in a 5-degree blend region within the border of the Area of Inter-
est (AOI) display. Blending of the displays is accomplished by gradually
reducing or increasing the brightness of the AOI within the blend region, and
simultaneously increasing or reducing the brightness of the IFOV. In this
way, equal luminance is obtained throughout the blend region as one display
gradually fades into another. Further, the blending should reduce or elimi-
nate any visual artifacts caused by low detail, low resolution data base
models changing into high detail, high resolution data base models when the
transition is made between the IFOV and AOI.

The pilot's head and eye positions are determined by lightweight helmet
mounted head and eye trackers. A fixed emitter, helmet mounted sensor system
determines azimuth, pitch and roll of the pilot's head with respect to the
simulator cockpit. An invisible, infrared light source illuminates the pilot
eye. His vertical and horizontal eye position is determined by imaging the
reflected infrared light from his eyeball onto the face of a helmet mounted,
infrared sensitive detector. The digital outputs from both trackers are
vectorially combined in order to form the cockpit referenced pilot viewing
direction. This viewing direction is combined with the instantaneous attitude
and position of the simulator aircraft within the data base to arrive at a
data base (ground) referenced pilot line of sight for which the image gener-
ator creates a visual display.
In order to investigate the technological areas of risk, and, to a somewhat lesser extent, determine the psychophysical requirements for the proposed Visual Display Research Tool (VDRT), a small helmet mounted display feasibility model was designed and built in-house.

The feasibility model, known in-house as the Helmet Mounted Display or HMD, was not as elaborate as the previously described VDRT. Instead of two full color head and eye tracked displays, the HMD produced only a single monochromatic head tracked display. Like the proposed VDRT, the HMD was a laser scanned, helmet mounted visual display system.

An artist's sketch of the completed feasibility model is shown in Figure 2. A six-watt water-cooled argon laser provides a green laser beam which is intensity modulated by an acousto optic modulator (AOM). The video information used to drive the modulator is produced by one channel of a dual channel computer image generator (CIG) which derives its information from an appropriate data base. The video modulated laser beam is collected.
collimated and shaped by a lens system so that it fills the aperture of an acousto optic beam deflector (AOBD). Here, the horizontal line scans which eventually form the displayed video raster are formed. The video modulated, horizontally scanned beam is again collected and focused by another series of lens elements onto one polished end of a coherent fiber optic ribbon bundle. The opposite end of the flexible two meter bundle is attached to the observer's helmet. Emerging from the helmet end of the fiber optic bundle, the line scan is projected towards a helmet mounted scanning qavonometer mirror which optically deflects the line scan onto the retro reflective interior of the surrounding dome screen. As it moves, the scanning mirror sweeps the fully formed horizontal laser line scans downward on the screen, completing the displayed video raster.

Head pointing direction (HPD) is provided by a helmet mounted sensor, cockpit mounted emitter system. Electromagnetic fields radiated by the emitter are coupled into the sensor and by processing the signals obtained from the sensor, head orientation is determined.

Since flight dynamics are not included, and the cockpit controls are inactive, no simulation of an actual aircraft is possible; however, a simple joystick allows the viewer wearing the helmet to change his relative coordinates and attitude within the visual data base. The subject, then, does have control over the cockpit location and attitude within the simulated visual environment.

Before the image generator creates the display, the line of sight of the cockpit seated observer is determined. Both head pointing direction and joystick position are sampled at a 60 Hertz rate and are vectorially combined by the computer image generator in order to determine the instantaneous line of sight that the display will be created for.

Production of the video imagery filling the viewer's display requires a certain amount of processing time. The displayed video raster consists of a single video frame which is composed of two interlaced video fields. A single video field requires approximately 67 milliseconds of processing time, 16.7 milliseconds of which are for scanning and display. The video fields are produced one after the other at a 60 Hertz rate, but delayed by the 67 milliseconds processing time. To combat this induced image generator lag, a compensation system was designed and fabricated to place the viewed display along the old line of sight it was created for rather than projecting it at the observer's current line of sight.

The viewer wearing the Helmet Mounted Display sees a square video display which always remains in a forward viewing position regardless of head position. The contents of the display are updated according to where the viewer is looking and what commands the joystick is given. The appearance is much like a green tinted window that is free to move about in response to head movement.
This system is not optimal. Certain components have been judged to be unacceptable for the final system. Some approaches which initially appeared feasible proved to be cumbersome but remained in the helmet mounted display feasibility model only for the sake of system continuity. A more critical detailed examination of the system follows in the next section.
SECTION III
FEASIBILITY MODEL SYSTEM DESCRIPTION

In this section, the major systems involved, their basic components, and their inter-relationships will be addressed.

IMAGE GENERATOR

The completed feasibility model utilizes a General Electric Compuscene Computer Image Generator (CIG) which was made available from NAVTRAUCIPSCEN's Visual Technology Research Simulator (VTRS) facility. The CIG provides a real-time video image of a digitally stored environmental data base to the helmet mounted laser projector.

The Helmet Mounted Display Feasibility Model relies upon the CIG to create the visual simulation contained within the display. The CIG provides the visual imagery that is updated at a 60 Hertz video field rate to reflect changes in the observer's head pointing direction (HPD) within the cockpit as well as changes in the simulated cockpit attitude and location within the environmental data base. In the Helmet Mounted Display (HMD), the visual display is not in a fixed location with respect to the simulator cockpit. If it were, the image contained within the display would be a direct result of the movement of the joystick by the observer. Instead, the head tracked visual scene is projected in the direction the pilot-observer happens to be looking and is updated according to both head and cockpit/joystick movement.

All of the visual scenery displayed by the HMD is the end result of processing the information contained within an environmental data base. In general, environmental data bases are composed of a number of two- and three-dimensional objects or models depicting, in a mathematical fashion, ground and cultural features. It is sufficient for the purposes of this report to consider a model to be composed of a number of flat polygons called faces. The perimeter of each polygon is composed of a number of short line segments which are joined at several points called vertices. A model is defined by the location of its vertices within the data base; the more complex a model is, the greater the number of faces and vertices it contains. In addition, each face is assigned three values representing the amounts of red, green and blue comprising its color and brightness.

The data base contains two types of coordinate systems, fixed and moving. The fixed coordinate system serves as the reference system and uniquely locates every object within the data base. A moving coordinate system is also referenced to the fixed system, but is assigned to the pilot-observer's joystick. By manipulation of the joystick, the observer is actually altering the position and orientation of a moving coordinate system within the environmental data base.
As an observer moves his head, he changes his head pointing direction which is provided by the head tracking system. Equivalently, he is altering the orientation of a vector within the moving coordinate system. For ease in visualization, we can refer to this vector as the observer's line of sight.

Each television raster field output by the image generator requires three processing cycles. Running at a 60 Hertz update rate, each cycle requires approximately a field time or 16.7 milliseconds for completion. The cycles operate simultaneously on sequential television fields, outputting them at a 60 Hertz rate one after another in a pipeline fashion. Due to timing constraints between the first and second processing cycles, however, the pipeline process actually requires 4 field times or 66.7 milliseconds.

During the first cycle, the CIG retrieves the head tracker and joystick data, processes it, and determines the observer's position and line of sight. Visual fading factors derived from this data, fog and other environmental effects, are also determined. The data is not ready until 5 milliseconds into the next cycle, so it is held over one additional cycle until the start of the next full second cycle.

In the second cycle, position and line of sight data are utilized to determine the objects that are visible within the data base. Priorities are resolved (which object obscures which), and the vertices of the visual models are mapped onto a two-dimensional display plane which lies normal to the observer's line of sight. The size of the display plane or view window is determined by the physical size of the helmet mounted laser display - about 20 degrees square. Its rotation about the observer's line of sight is a consequence of head rotation. In addition, the second cycle computes sun angle, face shading and color. The data mapped onto the plane will eventually form the visual display.

The third cycle completes the transformation from digital data to video. It receives a block of data in a raster line format indicating edges of faces, location, priority and color. Using the fading information and the data contained within the block, it generates one video field corresponding to the observer's field of view along his line of sight.


4. ibid., pp. 50-57.

5. ibid., pp. 57-67.
Figure 3 depicts the whole process in a timing sequence. During the first television field "0" the head tracker generates head pointing direction data, and along with the joystick data, it is transferred to the CIG for the start of cycle one processing during field "1". During field "2" the data generated by cycle one processing is buffered until the start of the next full field, field "3." Cycle two processing starts in field "3." The data block generated during field "3" is used during field "4" by the third processing cycle to output the video to the helmet mounted laser projector.

It is essential to understand that a video image being generated by the CIG is not displayed until 4 fields or 66.7 milliseconds after the point in time it was generated for. In essence, the image "lags" the point in time that the observer's line of sight and data base location were sampled. Without lag compensation for the image delay, the viewer will never see a correct display, and the illusion of flying through a scene with joystick control over position and attitude is lost.

Real aircraft dynamics are not included in this developmental system, instead, the joystick is used to represent movement of the observer's "aircraft" through the data base. Viewer HPD is provided by the Polhemus head tracking device, for which special hardware interfaces were designed and built to handle the data flow from the head tracker to the CIG. These interfaces provide the conversion and buffering of the data as required by the CIG data format and program timing.

LASER VIDEO PROJECTOR

Video imagery provided by the CIG is displayed by a laser video projector designed and constructed in-house. The system projects a 20 by 20 degree monochromatic TV raster display from a projector, mounted on a military flight helmet worn by the observer, onto the interior of a one meter radius dome. A beaded retro-reflective material covers the interior of the dome and provides high screen gains in the direction of the observer. The system is designed to operate at a 60 Hertz field rate, with the line rate adjustable for CIG video rates of 525 to 1023 lines per frame.

![Diagram of processing sequence for a CIG display](image)

Figure 3. Processing Sequence for a CIG Display.
Figure 4 is a block diagram of the laser video projector. The major components of the projection system are as follows:

Argon Laser
Acousto-Optic Modulator (AOM)
Acousto-Optic Beam Deflector (AOBD)
Coherent Fiber Optic Bundle
Mirror Galvanometer Frame Scanner

Each one of these system components is discussed below.

The argon laser, a Control Laser Corporation model number 553, is operated in a monochromatic mode through the use of a Littrow prism as the rear cavity mirror, yielding a single green wavelength of 5145 angstroms. The laser beam has a diameter of 1.6 mm and a divergence of 0.4 milliradians.
The output of the laser is intensity modulated with video information from the image generator by an acousto-optic modulator, manufactured by the Intra-Action Corporation (model number 125).6

The video modulated laser beam is expanded by the use of a Tropel Beam Expander to a 22 mm. diameter collimated beam, and then compressed to a 22 mm. line by a cylindrical lens. This 22 mm. line is focused into the crystal of the acousto-optic beam deflector system, which deflects the first order diffracted beam through an angle of 30.6 milliradians, creating the video line scan.7 The deflection of the beam is controlled by a 275 - 475 MHz frequency chirp centered at 375 MHz. The chirp, or frequency sweep, is provided by a voltage controlled oscillator (VCO) manufactured by Radio Development Laboratories. A voltage ramp controls the range of the frequency sweep, its linearity, and the time required to run a full sweep. Since the horizontal video line rate varies from 1023 to 525 lines per frame depending upon the resolution of the display, the period of the voltage ramp is variable from 25.6 to 63.5 microseconds.

The AOBs was manufactured by the Harris Corporation and is made of tellurium dioxide (TeO2). Its maximum throughput efficiency of only 15 percent places a limitation on the brightness of the final display. In addition, in order to achieve a linearly deflected, focused beam from the AOBs, it must be driven by a linearly incremented frequency sweep.8 In order to avoid unintentional modulation of the laser line scan by the AOBs, the output power of the voltage controlled oscillator must remain constant throughout the duration of the sweep. At the sweep rates required, the in-house designed driver for the AOBs is neither uniform in power, nor does it provide a linear sweep (the linearity required is about .01 percent). The end result is a severe loss of resolution, vertical intensity banding, and distortion in the final projected display. In Figure 5 these effects can be seen, with distortion appearing as a slight "S" shape in the normally flat runway.

After the AOBs, the beam is recollimated by the use of a second cylindrical lens to reform the 22 mm. diameter beam. A focusing lens is then used to focus the beam down to an approximate 20 micron spot size, which, due to the scanning effect of the AOBs, results in a 10 mm. wide line scan.9

7. ibid., pp. 9-15.
8. ibid.
9. ibid., p. 16.
This line scan is arranged to fall on the polished faceplate of either a full frame fiber optic bundle or a flat ribbon fiber optic bundle depending upon the particular setup in use. Both coherent bundles serve the same purpose, which is to optically transport the laser line scan to the observer’s helmet. The full frame coherent fiber optic bundle is manufactured by the American Optical Company. The bundle consists of individual 10 micron fibers drawn in 5 by 5 arrays which are then arranged into a rectangular grouping with dimensions of 10 mm. by 8 mm. on the faceplates. Each fiber is one meter long and has a numerical aperture of 0.56. Transmission through the bundle is limited to approximately 45 percent and mobility of the helmet mounted projector is somewhat restricted due to the stiffness of the bundle. A flat coherent fiber optic ribbon manufactured by Galileo Electrooptics Corporation is also being used. A number of 6 by 6 arrays of 10 micron fibers are arranged in a 2-meter long ribbon that is 12 fibers thick and 1002 fibers wide. The numerical aperture is .68. Mobility is much improved over the previously described “full frame bundle,” although the irregularity of the fiber spacing and the number of broken fibers further reduces the resolution, and places dark vertical stripes on the display (see Figure 5.)
The second face of the fiber bundle is mounted to the helmet and arranged to lie in the focal plane of a 15 mm. projection lens. After the projection lens, the laser line scan encounters a closed loop, moving iron galvanometer mirror scanner obtained from General Scanning, Inc. (model number 100PD). Servo controlled by a General Scanning controller (model number CCX-102), and driven by the 60 Hertz vertical sync from the CIG, the scanner mirror deflects/sweeps the laser scan lines vertically as they are projected onto the interior surface of the dome screen, providing the vertical scanning required to form the completed TV raster previously referred to in Figure 5.10

HEAD TRACKER

The head tracker, a SHMS III-A procured from Polhemus Navigation Sciences, Inc., computes the observer's head pointing direction with respect to the simulator cockpit. Known in-house as the Polhemus head tracker or "PHT," the basic system consists of a magnetic field radiator, a magnetic field sensor and a controller - the electronic systems unit. Mounted on the observer's helmet, the small, lightweight sensor moves within a magnetic field generated by the cockpit mounted radiator. As the orientation and position of the helmet mounted sensor changes, the magnetic field coupling between the emitter and sensor also changes.

The sensor as well as the radiator each consist of three small orthogonal coils. Excited sequentially by a 10.6 kHz. frequency burst, the radiator produces three magnetic fields whose axes are orthogonal to each other. Each orthogonal radiator coil emits a magnetic field for a small period of time and, during the time the field is active, each one of the sensor coils is sampled.

The field generated by the active radiator coil is symmetrical about an axis that coincides with the axis of the radiator coil. The orientation and position of each sensor coil within the generated field determines the amount of current induced to flow in the sensor coil. By performing a mathematical operation upon the signals obtained from the three sensor coils, the sensor's orientation relative to the axis of the emitting field can be determined. Its position relative to the axis is not yet fully determined due to the symmetry of the field about the axis. This operation is performed three times, once for each field generated. When the above operation has been performed for each of the three radiated fields, the position and orientation of the sensor relative to a three axis coordinate system can be determined.

The sequence which determines the position and orientation of the sensor relative to the radiator is an iterative process which is initiated by the vertical sync signal once every 16.7 ms. Figure 6 depicts the process in a general fashion.

10. ibid., p. 18.
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Figure 6. Basic SHMS III-A Processing
The magnetic field generated by a radiator coil oriented along the "Y" axis (the observer's forward axis) for instance, can be described at some arbitrary point as a vector referenced to the radiator coordinate system. The sensor, which happens to be located at that point, will have different currents induced in its coils by the field. These currents will describe the vector in terms of the sensor coordinate system. Each time a radiator coil becomes active and generates a field, it is described by the sensor coordinate system, arbitrarily located at some point within the field, as a vector. After the three fields have been emitted sequentially, and described in terms of three vectors referenced to the sensor coordinate system, they are operated upon by an inverse magnetic field transfer function.

For simplicity, the inverse transfer function will not be described in any great detail. Instead, it will be described as a mathematical operation that is a function of sensor position (alpha and beta) and orientation (psi-azimuth, theta-pitch, and phi-roll) with reference to the radiator coordinate system. For a given current, driving a radiator coil with some fixed dimension and number of turns, there is an associated magnetic field. This field can be fully described, using a suitable coordinate system, as a vector at any point distant from the coil. In a like manner, the three orthogonal fields generated by the radiator are also fully describable at any point with reference to the radiator coordinate system. Suppose a second moving coordinate system, the sensor coordinate system, is introduced. As long as its orientation and position with respect to the fixed radiator coordinate system is known, the field vector can also be described in terms of the moving sensor coordinate system. Figure 6 depicts a mathematical operation on the vector which is in terms of the radiator coordinate system. The output of this operation is the vector in terms of the sensor coordinate system. The operator is the transfer function "T" which is a function of position and orientation of the sensor with respect to the radiator. If the output of the previous operation is operated upon by the inverse transfer function, "T-1", the result is the vector with respect to the radiator once again. In effect, the inverse transfer function has undone the previous operation.

Looking at Figure 6 once again with particular attention to the processing sequence, the vectors as referenced to the sensor are multiplied by the last known correct inverse transfer function, using the last known alpha, beta, psi, theta, and phi. The output of the operation, if the position and orientation are correct, is the characteristic field known to be emitted by the radiator. If the last alpha, beta, psi, theta and phi are incorrect, the outputs are not the correct field vectors with respect to the radiator, and the difference is linearly related to the true alpha, beta, psi, theta and phi.

phi. The new position and orientation angles are computed and output, and the
inverse transfer function is updated for the next iteration. Range is deter-
mined by adjusting the current to the radiator coils and/or sensor gain in
such a manner that the vector measured by the sensor always has some constant
length. A more rigorous treatment of the processing sequence may be found in
Reference 12.

In the HMD system, the sensor is mounted on the helmet and the radiator
placed immediately behind the cockpit seat. Hence, sensor orientation is
analogous to head orientation or more concisely, HPD.

As previously described in the section entitled "Image Generator"
(page 12), the cockpit referenced HPD is used by the CIG to compute the
observer's line of sight. Although both position and orientation of the
sensor are provided by the SHMS IIIA, only the sensor orientation is used to
determine the observer's line of sight. Strictly interpreted, this simplifi-
cation is not mathematically correct. It is simply expedient, since in the
case of the feasibility model, the extreme range at which objects within the
data base are typically viewed precludes the visual effects of minor head
translation.

Because the head tracking system relies upon magnetic field coupling,
there are limits to the extent of the radiator/sensor separation. This is
referred to in Polhemus literature as the "motion box." The range extends
16 inches forward of the radiator (X direction), plus or minus 8 inches from
to side to side (Y direction) and 8 inches downward from the radiator (Z direc-
tion). Operation outside these limits results in performance degradation.
When the head tracker is installed in the Helmet Mounted Display Feasibility
Model, the following performance specifications are met:

<table>
<thead>
<tr>
<th>Description</th>
<th>Specification</th>
</tr>
</thead>
<tbody>
<tr>
<td>STATIC ANGULAR ACCURACY</td>
<td>plus or minus .5 degrees at 50 percent CEP</td>
</tr>
<tr>
<td></td>
<td>(50 percent of the time, the output is within</td>
</tr>
<tr>
<td></td>
<td>+/- .5 degrees)</td>
</tr>
<tr>
<td>ANGULAR JITTER</td>
<td>1/10 degrees peak to peak (roughly equivalent to 1</td>
</tr>
<tr>
<td></td>
<td>bit out of 12 bits)</td>
</tr>
</tbody>
</table>

12. Raab, Fredrick H.; Blood, Ernest B.; Steiner, Terry O.; and Jones,
Herbert R. Magnetic Position and Orientation Tracking System, in IEEE
Transactions on Aerospace and Electronic Systems, Vol. AES-15 No. 5,
September 1979, pp. 709-718.
UPDATE RATE
synchronized to CIG 60 Hertz video field rate (SHMS IIIA can free run at faster rates, however, cycle time is irregular)

DYNAMIC ANGULAR ACCURACY
for normal head rates (600 degrees per sec or less) essentially defined by the number of degrees that the head moves during the 16.7 ms. required to compute HPD.

Formatted serially, the digital data consists of six 17-bit words output in the following order: yaw, pitch, roll, X (forward direction from the radiator) Y (lateral movement), and Z (vertical motion). The first 12 bits of each 17-bit word are significant data, the next 4 are noise, and the last bit is a parity bit. The hexadecimal values for the rotational data are as follows:

<table>
<thead>
<tr>
<th>HEX VALUE</th>
<th>C000Hex</th>
<th>8000Hex</th>
<th>4000Hex</th>
</tr>
</thead>
<tbody>
<tr>
<td>Yaw</td>
<td>Right 90 degrees</td>
<td>Center</td>
<td>Left 90 degrees</td>
</tr>
<tr>
<td>Pitch</td>
<td>Up 90 degrees</td>
<td>Center</td>
<td>Down 90 degrees</td>
</tr>
<tr>
<td>Roll</td>
<td>Right 90 degrees</td>
<td>Center</td>
<td>Left 90 degrees</td>
</tr>
</tbody>
</table>

About 14 to 15.5 ms. after the initial sampling procedure, the SHMS III-A provides a "data ready" pulse. This is a signal to the interfacing hardware that the processing is complete, and the head pointing direction (HPD) data is available. In the current configuration, the in-house designed interfacing hardware clocks out the data before the beginning of the next sync pulse (vertical sync) which occurs every 16.7 milliseconds (see Appendix). This sync pulse starts a new HPD data gathering cycle. During operation, the head tracker delivers HPD data at a 60 Hertz rate with a delay of approximately one field time between the sampled HPD and the HPD data output.
During the development of the feasibility model, the problem of scene instability quickly became apparent. Without compensation, due to the time required for head tracker and CIG computations, there exists an error in image placement during head motions. Since the problem is especially apparent during a rapid head movement by the observer/pilot wearing the helmet mounted projector, the solution to this problem came to be known as Rapid Head Motion Compensation (RHMC). The compensation mechanism involves the use of a microprocessor with software that controls the relative projection angle of the imagery from the viewer's helmet in response to image displacement error. Change in the image projection direction is accomplished via offsets input into the vertical and horizontal sweep of the laser video projector. In this section, an examination of the cause, effects, and the solution devised for scene instability will be discussed.

The problems that arise from rapid head motions are due to the discrete sampling of the head pointing directions and the finite time involved in providing an updated image via the CIG. This results in an image placement error coinciding with head motion and is manifested in an apparent motion of what should be stationary objects in the subject's FOV. With no compensation, objects appear to "swim" during the start and finish of a head motion and are displaced during the actual head motion.

Consider the viewer to be at some stationary position within the data base. Further, consider the head of the viewer to be stationary with an image projected onto the screen from the HMD. Objects within the displayed image are stable as long as the viewer does not move his head because the displayed image is being computed and displayed for a fixed line of sight. Returning to Figure 3, when the viewer changes his head pointing direction (HPD), at the start of field "0," the head tracker doesn't compute a new HPD until just before the next vertical sync. This new set of yaw, pitch, and roll data reflects the HPD of the viewer at the sampling time, not at the time of the HPD output. The time between the sampling and output of the HPD data, one field time or 16.7 ms., is one source of delay in updating the image. Another source of delay in updating the image after the occurrence of a head motion is the time required for the CIG to take in new head pointing data and then to compute an image based on the new viewer line of sight. As previously described in the "Image Generator" section, the CIG requires 4 fields to generate and display the image.

If the viewer has moved his head during the five field times that occur between HPD sample time and the display of the image based on that sample, he will observe an incorrectly displayed image. A 5 field, or 83.5 ms., time lag exists between the old line of sight the image is created for and the current line of sight the image is being projected towards.
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To visualize the effects of the 83.5 ms. time lag, suppose that the projected image contains a tree as an object in the center of the display. Without compensation, a head motion to the right of 2 degrees during the above time interim between sampling and display will result in the tree also moving 2 degrees to the right. All objects in the image will retain the same orientation they had before the head motion and the scene will be incorrectly displayed until the process of computing a new HPD and subsequent CIG image display for the new line of sight is completed. When the viewer completes the head motion, the tree will at that moment be displaced to the right followed by a gradual movement of the tree to the left as the CIG generates the correct image for that particular line of sight. Obviously, this effect can be very disorienting to the viewer, for trees should be rooted in the ground and stationary. Not only objectionable from a subjective standpoint, it is highly probable that an improperly placed image can result in negative training cues to the prospective trainee. As a consequence, it is desirable that the image lag be reduced to some tolerable level.

The Rapid Head Motion Compensation System reduces the previously described image delay problem. Essentially the hardware, under software control, moves the raster in such a manner as to keep objects in the FOV from moving as the pilot changes his HPD. The RHMC system performs compensation based on the current HPD sample compared with the HPD that was used to compute the image to be displayed next. The difference between these HPDs is massaged by software and sent to raster shifting hardware to shift the projected imagery horizontally and vertically opposite the direction of head motion. The system attempts to place the display physically along the old line of sight it was created for.

For the HMD feasibility model, the angular error in line of sight amounts to the movement of the viewer's head over five video field times. The software that corrects this error has been named "5THPREV," referring to the number of video fields delay involved. The software is written in 8085 assembly language and is designed to provide raster shift values within the timing restraints shown in Figure 7 (see Appendix A for flowcharts and additional detail). This timing diagram shows the initialization of the PHT data gathering and calculation cycle by the vertical sync of the video, followed by a "data ready" some 15 milliseconds later. The software then takes the HPD from the PHT data controller (see Appendix A) and, after processing, outputs the raster shift values before the next vertical sync. In general, the program is configured to allow compensation for any number of "fields" delay (depending on the specific CIG delay) and is referred to as "NTHPREV."
A graphical illustration of the effects of compensation on the display is provided by the graphs in Figure 8. Consider the simulator cockpit to be fixed at some point within the environmental data base used to create the visual display and for simplicity, consider all angular motion relative to the simulator cockpit. In the first graph, an arbitrary horizontal head movement by a viewer wearing the helmet mounted projector is followed one field later by the head tracker output. Three fields after the head pointing direction (HPD) data is made available, the CIG completes the processing, and during the fourth field, the generated image is displayed. Since the projector is physically attached to the observer's head, the projector heading (i.e., its projection axis) is identical to the viewer's head pointing direction. In the graph the first curve to the left represents actual head motion, the second curve, the PHT output, and the third curve, the angular heading for which the image being displayed was calculated. The vertical separation between the viewer head motion curve and the CIG image heading curve represents the uncompensated angular image lag, which the viewer observes as an incorrectly positioned image. As previously mentioned, the image lag is equivalent to the angular distance traveled by the head during five TV fields or 83.5 milliseconds.

The second graph in Figure 8 depicts the operation of the rapid head motion compensation system. It can be understood as follows: since the image lag amounts to five fields of head travel, the heading of the helmet mounted projector needs to be shifted back five fields of head travel in order to
Figure 8. Effects of Lag Compensation.
coincide with the heading of the displayed image. The projector heading is changed by offsetting the position of the horizontal line scan. The offset is performed during the vertical blanking interval just prior to actual display of the image. The most recent head position information available is received just before the occurrence of vertical sync. The difference between the most recent HPD data and the fifth previous piece of HPD data amounts to the angular change in head position over five fields. Essentially then, the projector heading is changed using the most recent five field head position change available. This operation is graphically illustrated by noting that the five field difference “DIFF 5” (see Appendix A, RHMC Software) is added to the actual head position at the beginning of the display field via horizontal raster shifting. This produces a compensated projector heading, where the difference between the compensated heading and the CIG image heading is angular discrepancy still remaining after compensation. Note that although the compensation is not perfect, the remaining image lag is considerably less than the uncompensated image lag, and the image is generally compensated when the viewer’s head has completed the motion.

Further information detailing the implementation of both the software and the hardware in Rapid Head Motion Compensation can be found in the Appendices of this report.
It's clear that neither fiber optic bundle transmits a totally acceptable line scan. The full frame bundle, utilized because of its in-house availability, offers many redundant rows of fibers on which a line scan can be focused. Still, finding a row or group of rows which has no broken fibers is impossible. Unlike the full frame bundle, the ribbon bundle provides improved mobility, but at the expense of unevenly spaced fibers, a quantity of broken fibers and poorly polished fiber ends. Despite these contrary observations, a coherent fiber optic ribbon bundle should be available and suitable for future use with development of appropriate manufacturing techniques.

The Acousto Optic Beam Deflector (AOBD) produces an unevenly focused, non-linear horizontal line scan. This is due to the VCO's inability to supply a linear frequency chirp with a power variation of less than ± 2db. Power variation results in a line scan that varies in brightness. Non-linearity in the chirp produces a non-linear line scan that varies in focus. Attempts were made to linearize the line scan by suitably shaping the ramp signal that served as the input to the VCO. One promising method involves the use of a fast digital to analog converter. The in-house efforts, however, met with little success. At present, the best alternative seems to involve the use of a high speed, rotating scanner mirror system manufactured by Speedring, a division of Schiller Industries, Inc., which is now planned for use in the Visual Display Research Tool.

The display distortion and lack of resolution was judged objectionable by most viewers. Display distortion was far more than the typical viewer would observe on his own home television although exact measurements were not made. Figure 9 shows a test grid as displayed by the HMD system. The distortion occurs both vertically and horizontally, although the horizontal distortion is more extreme. The resolution was determined to be approximately 200 TV line pairs under the most optimal conditions.

The head tracker utilized is acceptable for this particular visual display. Some minor modifications were made which reduce the HPD data filtering. This decreases the settling time for small angular step changes but increases the jitter in the HPD data. Since the resolution of the feasibility model's display is low, the jitter is not directly observable by a subject wearing the helmet. In order to preserve the resolution of the imagery presented by the follow-on VORT, it has been determined that a head tracker with at least 14-bit accuracy or better is required to keep the jitter at a pixel or sub-pixel level. If the helmet mounted sensor and cockpit mounted emitter are properly placed, the aluminum housing of the projector (a moving metallic mass) does not appear to significantly affect the accuracy of the HPD data. Generally, it is felt that the absolute accuracy of the head tracker is less important than its ability to resolve small angular changes and provide low noise data rapidly.
The overall effect of the RHMC system is an increase in scene stability during head motions of the observer. During the testing, tweaking and evaluation of the feasibility model, many people viewed the display with RHMC both operational and non-operational. With the compensation system functioning, most indicated the image lag was not directly observable; when the compensation system was switched off, all viewers were acutely aware of the swimming effects caused by the lag. Those intimately familiar with the system could cause lag effects simply by exceeding the shifting capability of the RHMC system. Although a cause of concern at first, no compensation was provided for head roll. It seems that most viewers were incapable of achieving roll speeds at which the effects might be observable or, the display was too small to observe them. No roll compensation is planned for the VDRT.

Several major issues remain unresolved. An eye tracker will be required in the VDRT; yet, there is no known method which combines the properties of rapid update and unobtrusive measurement. Raster shifting will produce some display distortion when used in a wide FOV system (such as the VDRT). The distortion correction, if any, that may be required of the CIG remains to be determined. One additional issue concerns data base modeling. In the VDRT,
objects within the environmental data base will consistently be making the transition from the low resolution IFOV, where they are modeled in relatively low detail, into the high resolution AOI where they become high detail models. The blend region around the AOI should reduce the problem somewhat, but unfortunately, the change in detail will take place in the motion sensitive peripheral viewing region of the eye. It is not clear at this point how to model objects within a data base to make the transition unobtrusive. Still more investigation and research is needed for answers.
The software for RHMC has two functions. One function is to keep a record of past HPO values and then to calculate the required amount of raster shifting for proper image placement. This function is interrelated with the PHT and CIG video timing, with the vertical sync of the CIG video being the master timing signal for the software and PHT. The second function is essentially transparent to the logic flow of the software and concerns the loading of three data buffers for the transfer of HPD data to the CIG.

The software has several tasks in order to accomplish raster shifting. First is the initialization and updating of two tables in RAM for the storage of past and present HPDs. These two tables, one each for vertical and horizontal data, are shown in Figure A1. The most recent (or present) values, W-0, are placed at the top of the tables and moved down to the W-1 position when a new HPD data set is obtained. This downwards movement of an HPD value in the tables continues each time a new data set is obtained (W-1 to W-2, W-2 to W-3, W-3 to W-4, W-4 to W-5) until the data is no longer needed and is discarded. Initialization of the tables is performed by subroutine TABLESET which loads the boresight values (zero degrees) into the two tables. The downward movement of the table values is accomplished via the subroutine FIFO during the time that the PHT is calculating the new HPO values.

The length of the tables determines the number of HPD values to be stored, and at the same time, implies the number of field times delay for which the program will compensate. For a five field delay in PHT to CIG image presentation, the tables must store the five previous HPD samples plus the present sample for a total of six HPD words per table. The error in image placement, for an exact five field delay, is simply the difference between the present sample (W-0) and the W-5 sample. With the present sample always at the top of the table and the fifth previous sample always at the bottom, the error value is found by subtracting the last word in the table from the first word. Below each table there are two reserved bytes of RAM that are used to store the sign of the angular error and the value of the shift word to be sent to the output DACs for shifting the raster.

Figure A1 also shows the reserved RAM areas for a table of input values which are used to determine the length of the HTABLE and VTABLE and to set up needed constants. The values (H or V)INITIAL and (H or V)FINAL are the first and last RAM addresses used to store HPD samples (2 bytes per sample). For five fields delay and the required six sample storage, 12 bytes are needed per table. In the figure, the HINITIAL value is 2020hex and HFINAL is 2028hex. The (H or V)SOURCE values are used by FIFO to point to the first byte to be moved two addresses downward, with the (H or V)INITIAL values indicating the last byte to be moved. Constants in the Input Table are as follows:
**Figure A1. NTHPREV Reserved RAM Inputs and Tables.**
(H or V)CONTROL - provides for the fine adjustment of shift values sent to DACs (see subroutine ADJUST).

(H or V)CENTER - centering values for raster to be sent to the DACs.

(H or V)ZERO - the boresight (or zero degree value) used to initialize the tables.

MASK - value used in setting 8085 mask for interrupt priority.

(H or V)MAX - limit the shift values sent to the DACs (must be set less than 3Bhex).

There are also four bytes reserved below the Input Table for temporary storage purposes designated as SCRATCH1 and SCRATCH2.

Once the HTABLE and VTABLE are initialized and an update is received from the PHT, the process of computing the two 8-bit words for controlling the raster placement on the target plane of the projection lens begins. This process is performed by subroutines HSHIFT and VSHIFT for the horizontal and vertical offset values. Referring to the flowchart for HSHIFT in the appendices, the first step is to find the difference, HDIFF, between the present and fifth previous horizontal samples as explained previously. The next step is to use the HDIFF value to calculate the HSHIFT offset value.

The HSHIFT value is dependent on the target plane raster size, the projections lens, and the reference voltage for the DACs. The HSHIFT value for the laser based HMD system is calculated according to the focal length of the lens and the required displacement of the raster to effect an angular shift of the projected image equal to the HDIFF value. Suppose that the HDIFF value represents a 1-degree movement of the viewer's head. This corresponds to a 16-bit value of 0080hex (or 176decimal) for HDIFF. HDIFF must then be scaled to the proper value which will shift the raster horizontally on the target plane and result in an angular shift of the imagery being projected by 1 degree.

To find the scale factor for the horizontal channel, the 8-bit word required to displace the raster line one quarter of its length was experimentally determined to be 32hex or 50decimal. Knowing the focal length (8 mm.) at the target plane, an offset of 32hex results in a 7.6 degree shift of the projected imagery. This corresponds to a 0.15 degree shift of the image per unit offset increment sent to the horizontal digital to analog converter (HDAC). Therefore, to shift the image by 1 degree, an offset value of approximately 07hex is needed. Hence, a scale factor of 1/26 decimal is needed to scale the HDIFF value of 0080hex to its proper value of 07hex before being sent to the HDAC. However, due to the limited instruction set of 8085 up, division by 26 is not directly accomplished. To solve this problem, the
direction taken was to add a percentage of the HDIFF value to itself (in the form of N*HDIFF/32 or N*3 percent of HDIFF) and then to divide this new adjusted HDIFF, NHDIFF, by 32 (by shifting NHDIFF 5 bits to the right) to effect an approximate division by 26. This adjustment is performed by subroutine ADJUST, which also allows minor adjustment in the RHMC shifting to account for delays which are not integer multiples of field times. After the magnitude of the horizontal offset value is found, the sign of the angular difference is used to determine whether to add or subtract the offset value to or from the raster centering value. This decision determines the shift direction to be either to the right or left depending on the direction of head motion.

The VSHIFT value, however, is not dependent on the projection lens or the raster size. This is due to the fact that the angular shifting of the image in the vertical direction is performed by offsetting the central positioning of the frame scanning mirror, which is located after the projection lens. Here, the 8-bit word required to shift the image in the vertical direction by 4 degrees was experimentally determined to be 16hex (or 22decimal), resulting in a 0.18 degree shift per unit offset sent to the VDAC. These constants indicate that the scale factor for the vertical channel should be 1/29decimal. Once again, the ADJUST subroutine allows for an effective approximate division of VDIFF by 29 and minor adjustment of the shift value magnitude. When the VOFFSET magnitude is calculated, the sign of the angular difference is used to determine whether to add or subtract the VOFFSET magnitude to or from the vertical raster centering value.

The overall effect of the RHMC system was an increase in scene stability during head motions of the observer. Once the system had been incorporated into the HMD, subjective experiments were performed to fine tune the compensation effect by varying the control words for the ADJUST subroutine. These control words were found to be valuable in adjusting for changes in the focal length of the final projection lens, as well as for their intended use of providing a means to compensate for CIG-PHT delays that are integer multiples of a field time.

Sometime just before or during the pending vertical sync, the RHMC program finishes calculating the two 8-bit words representing respectively the horizontal and vertical raster shift (HSHIFT and VSHIFT). Then the system enters a loop and waits for the next occurrence of vertical sync (7.5 interrupt); when vertical sync occurs, the program responds by outputting the two 8-bit words to the horizontal and vertical digital to analog converters (HDAC and VDAC). The voltage output of the DACs control the extent of the raster shift required. The output of the HDAC frequency shifts the chirp that drives the acousto optic beam deflector (AOBD), causing an offset of the horizontal line scan. Shifting the helmet mounted mirror scanner with the VDAC raster is done only during the vertical retrace time (i.e., during the vertical sync). By introducing a shift during the time that the video is blanked, the whole raster is shifted as a unit and tearing or separation of the displayed raster is avoided.
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ARMS 3 F3 LPREV SRC DEBUG MOD 05

ISIS-11 8080/6800 MACRO ASSEMBLER. V3 8

LPPMV

LOC OBJ  LINE  SOURCE STATEMENT

1  NAME LPREV
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5  UPDATED FOR LASER PROJECTOR JULY 2 1981.
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***************
*
*
LPREV *
*
***************

THIS PROGRAM IS A MODIFICATION OF LHPREV FOR THE LASER DISPLAY SYSTEM

LHPREV IS THE MAIN PROGRAM FOR RAPID HEAD MOTION COMPENSATION. THE PROGRAM COMPENSATES
FOR CIG DELAY TIME IN THE PHOT-CIG-VIEWER LOOP. THE BASIC ALGORITHM USES THE
DIFFERENCE IN HEAD AZIMUTH AND ELEVATION FROM THE PRESENT VIDEO FIELD TO THE
LHPREVIOUS FIELD. THIS DIFFERENCE IS USED TO OFFSET THE PASTED IMAGE OPPOSITE
THE DIRECTION OF HEADING CHANGES (VERT AND HORIZ ONLY)

THIS OFFSET IS ADJUSTABLE VIA THE EQUATION

OFFSET = DIFF * N * (DIFF/16)

WHERE N IS A CONTROL VALUE WITH AN ALLOWED RANGE OF +31 FOR EACH INDIVIDUAL OFFSET
(SEE ROUTINE ADJUST).

THE SHIFTING OF THE PASTED IS ACCOMPLISHED BY CHANGING THE VERTICAL AND HORIZONTAL
SYNC SIGNALS DURING THE VERTICAL RETRACE TIME. THE AMOUNT OF OFFSET IS LIMITED BY
MAX AND VMAX VALUES WHICH SHOULD BE SET AT A MINIMUM OF 64 DECIMAL
BEFORE RUNNING THIS PROGRAM BE CERTAIN THAT THE RESERVED PAM LOCATIONS ARE FILLED
WITH THE PROPER INFORMATION THAT DEFINE THE STORAGE TABLES. CONTROL VALUES, AND
MAXIMUM SHIFT VALUES. THIS MAY BE DONE VIA ROUTINES INT4, INT5, OR INT6

REJECT

31
NAVTRAQIPCEN IH-338

NTHPREV

START

DISABLE INTERRUPTS

SET STACK POINTER

INITIALIZE STORAGE TABLES

VIA TABLESET:

LOAD RESTART INSTRUCTIONS

CENTER RASTER

RESET VSYNC TRIGGER

RESET S/P INTERFACE

SET INTERRUPT MASK

RESET 7.5, UNMASK 6.5

INDICATE HORIZONTAL FIRST

ACC = 0

NOP LOOP #1

WAIT FOR 6.5 INTERRUPT (PHT DATA READY)
7.5

MOVE HSHIFT TO HDAC

MOVE VSHIFT TO VDAC

- - VERTICAL AND HORIZONTAL SYNC OUTPUT

- - VIA FIFO:

- - Table

RESET S/P INTERFACE

RESET VSYNC TRIGGER

SET INTERRUPT MASK

- - RESET 7.5 ENABLE 6.5

ACC = 0

- - INDICATE HORIZONTAL NEXT

1 --> RETURN

34
NAVTRAEQUIPCEN IH-338

1:15-II 0880/0885 MACRO ASSEMBLER, V3.0
LPREV

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<thead>
<tr>
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</table>
**NAVTRAEOUIPCEN IH-338**

**ISIS-11 2808/2805 MACRO ASSEMBLER, V2.0**

**LOC OBJ**

**LINE**

**SOURCE STATEMENT**

0000 F1 56 CSEG

0001 210000 E 57 LPREY. DI

0002 210000 E 58 LXI SP, STK

0004 210000 E 59 ; **DISABLE INTERRUPTS**

0007 220000 E 60 LXI HFIRST

0008 215400 C 61 SHLD RST658

0009 220000 E 62 LXI HINSEG

0010 210000 E 63 SHLD RST65A

0011 210000 E 64 LXI HFIRST

0013 220000 E 65 SHLD RST75E

0016 21C200 C 66 LXI HOUTPUT

0019 220000 E 67 SHLD RST758

001C 290000 E 68 LHLD HZERO

001D 290000 E 69 YCHB

0020 300000 E 70 LDA HFINAL

0023 290000 E 71 LHLD HINITL

0026 CD0000 E 72 CALL TBLSB

002D 290000 E 73 LHLD VZERO

002C ED 74 YCHB

0030 300000 E 75 LDA VFINAL

0033 CD0000 E 76 CALL TBLSB

0036 300000 E 77 LHLD VINITL

0033 CD0000 E 78 ; INITIALIZE VTABLE WITH VZERO

0036 300000 E 79 ; INITIALIZE VTABLE WITH VZERO

0039 320000 E 81 LDA HCENTR

003C 300000 E 82 STA HDAC

003F 320000 E 83 LDA VCENTR

0042 320000 E 84 STA VDAC

0045 320000 E 85 ; SEND CENTER VALUE TO HDAC

0048 3E1D 86 STA RST5P

004B 3C0000 E 87 STA VSYNC

004F 00 88 MOV A, IVH

0052 00 89 MOV A, IVL

0051 C34E00 C 90 ; SET INTERRUPT MASK

0054 3C0000 E 91 ; RESF SERIAL TO PARALLEL BOARD

0058 3C0000 E 92 ; AND VSYNC TRIGGER

005B 3E1D 93 MOV A, IIH

005E 00 94 LOOP1: NOP

0061 00 95 NOP

0068 00 96 NOP

0061 C34640 C 97 JMP LOOP1

0065 3E1D 98 ; THEN GO TO MAIN SEGMENT

0069 C43F00 C 99 ; " " " " MAIN SEGMENT " " " "

006A 2B10 100 CPI BHL

006AF C37B00 C 101 JZ VERT

006AF E120 102 CPI BSN

006B C35E00 C 103 JZ ROLL

006F C34E00 C 104 REJECT

0070 35
<table>
<thead>
<tr>
<th>LOC</th>
<th>OBJ</th>
<th>LINE</th>
<th>SOURCE STATEMENT</th>
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</thead>
<tbody>
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<tr>
<td>107</td>
<td>RSET:</td>
<td>108</td>
<td>SET UP TO GRAB NEXT VSYNC</td>
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<td>111</td>
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<td>RESET VSYNC TRIGGER</td>
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**NAVTRAQUIPECEN IH-338**

ISIS-I1 99M/N5CRO
LOC 08,1 LINE SOURCE STATEMENT 105 1066 067 RET.

0865 320000 E 108 STA VSYNC

0866 3E1D     111 MVI A.10H

0863 30     112 SIN

0864 2D0000 E 114 HORIZ: LHLD HINPUT

0867 3E     115 XCHG

0868 2D0000 E 116 LHLD HINITL

0869 73     117 MOV M.E

086C 23     118 INX H

086D 7A     119 MOV A.D

086E 17     120 RAL

086F 3F     121 CMC

0870 1F     122 RAR

0871 77     123 MOV M.A

0872 320000 E 124 STR GETELV

0873 3E81     125 MVI A.01H

0877 FB     126 EI

0878 C9     127 RET

0879 2D0000 E 129 VERT: LHLD VINPUT

087C 3E     130 XCHG

087D 2D0000 E 131 LHLD VINITL

0880 73     132 MOV M.E

0881 23     133 INX H

0882 7A     134 MOV A.D

0883 17     135 RAL

0884 3F     136 CMC

0885 1F     137 RAR

0886 77     138 MOV M.A

0887 3E62     139 MVI A.02H

0889 320000 E 140 STR GETELV

0890 C8     141 EI

0890 C9     142 RET

0891 2D0000 E 144 ROLL: LHLD RINPUT

0891 EB     145 XCHG

0892 21EE20     146 LXI H.28EH

0895 73     147 MOV M.E

0896 23     148 INX H

0897 7A     149 MOV A.D

0898 17     150 RAL

0899 3F     151 CMC

089A 1F     152 RAR

089B 77     153 MOV M.A

089C 2D0000 E 154 REJECT
LOC | OBJ | LINE | SOURCE STATEMENT
---|-----|------|-----------------|
155 | CALCULATE SHIFT VALUES (VERTICAL AND HORIZONTAL ONLY):
156 |                  |
157 | LDLT 0INITL      |
158 | (0.E) POINTS TO VINITIAL ADDRESS
159 | LDLT 0FINAL      |
160 | (0.L) POINTS TO VWORD FINAL
161 | CALL 0SHIFT      |
162 | CALCULATE VSHIFT VALUE
163 | PUSH PSW         |
164 | SAVE VSHIFT IN STK|
165 | LDLT 0INITL      |
166 | (0.E) - VINITIAL ADDRESS
167 | LDLT 0FINAL      |
168 | (0.L) - VWORD FINAL ADDRESS
169 | CALL 0SHIFT      |
170 | CALCULATE HSHIFT VALUE
171 | PUSH PSW         |
172 | HSHIFT TO STK:   |
173 | ENABLE 7 5 INTERRUPT (VSYNC)
174 | POP PSW          |
175 | ACC CONTAINS HSHIFT
176 | E1                |
177 | LOOP2: NOP       |
178 | --- LOOP 82 ---  |
179 | STA 080SH        |
180 | ON READY FOR OUTPUT
181 | NOP               |
182 | THEN GO TO OUTPUT SEGMENT
183 | JMP LOOP2        |
184 | OUTPUT SEGMENT FOR SYNC VALUES
185 | POP H            |
186 | REMOVE 7 5 RETURN ADDRESS
187 | HSHIFT MOVED TO HAC
188 | POP PSW          |
189 | ACC CONTAINS VSHIFT
190 | STY VORC         |
191 | HSHIFT MOVED TO VORC
192 | REJECT
LOC OBJ LINE SOURCE STATEMENT

191 ROTATE.

0063 320000 E 192 LDA VINITL
0065 47 193 MOV B, A
0066 2A0000 E 194 LHLD HSPC
0067 EB 195 XCHG
0068 2A0000 E 196 LHLD HFINAL
0069 CD0000 E 197 CALL FIFO
190 ,

0068 300000 E 199 LDA VINITL
0069 47 200 MOV B, A
006A 2A0000 E 201 LHLD VSPC
006B EB 202 XCHG
006C 2A0000 E 203 LHLD VFINAL
006D CD0000 E 204 CALL FIFO
205 ,

006E 320000 E 207 STA RSTSP
208 ,

006F 3E8D 209 MVI a, 00H
006F 3E8E 218 SIM
006F 3E8F 211 NOP
006F 3E90 212 NOP
006F 3E91 213 NOP
006F 3E92 214 NOP
006F 3E93 215 NOP
006F 3E94 216 NOP
006F 3E95 217 NOP
006F 3E96 218 MVI a, 00H
219 ,

006F FB 220 EI
006F C9 221 RET
222 ,

223 6 TITLE (" YSHIFT ")

224 REJECT
**VSHIFT**

<table>
<thead>
<tr>
<th>LOC</th>
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<th>LINE</th>
<th>SOURCE STATEMENT</th>
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<td>229</td>
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<td><code>YSHIFT</code></td>
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<td>MODIFIED FOR LASER PROJECTOR JULY 2 1981</td>
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<td>236</td>
<td></td>
<td></td>
<td><strong>VSHIFT IS USED TO CALCULATE THE VERTICAL SHIFT VALUE TO BE SENT TO THE VERTICAL DAC</strong></td>
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<td>238</td>
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<td></td>
<td><strong>VSHIFT = VCENTER - VOFFSET</strong></td>
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<td>240</td>
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<td></td>
<td><strong>VOFFSET = VDIFF ± N * (VDIFF/16)</strong></td>
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<td><strong>32</strong></td>
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<td></td>
<td><strong>VSHIFT USES SUBROUTINES : TISUB, STOREL, D1V16, DIV16, ADJUST, MAX</strong></td>
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<td><strong>INPUTS:</strong></td>
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<td>249</td>
<td></td>
<td></td>
<td><strong>(O,E) CONTAINS THE ADDRESS OF V WORD 0</strong></td>
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<td>250</td>
<td></td>
<td></td>
<td><strong>(H,L) CONTAINS THE ADDRESS OF V WORD FINAL</strong></td>
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<td>251</td>
<td></td>
<td></td>
<td><strong>BOTH WORDS ARE TWO BYTE</strong></td>
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<td>253</td>
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<td></td>
<td><strong>VCENTER, VMARK AND VCONTROL MUST BE IN THEIR PROPER LOCATION IN RAM</strong></td>
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<td><strong>OUTPUTS:</strong></td>
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<td>256</td>
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<td></td>
<td><strong>HDIFF AT SCROLH ( VDIFF ± VCONTROL*VDIFF/16 )</strong></td>
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<td>257</td>
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<td></td>
<td><strong>HOFFSET AT SCROLH ( HDIFF/32 )</strong></td>
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<td>258</td>
<td></td>
<td></td>
<td><strong>THE SIGN OF HDIFF, VOFFSET IS STORED AT (H,L) + 2</strong></td>
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<td>259</td>
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<td></td>
<td><strong>VSHIFT IS IN THE ACC. AND AT (H,L) + 3</strong></td>
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<td>261</td>
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<td><strong>REJECT</strong></td>
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**NASVTRA-EQUIPCEN IH-338**
SUBROUTINE VSHIFT

START

CALL TBSUB:

CALL STORE 1:

CALL DIV32:

ACC ← VCONTROL

CALL ADJUST:

CALL DIV32:

CHECK SIGN

SUBTRACT VOFFSET FROM VCENTER

ADD VOFFSET TO VCENTER

STORE VSHIFT

RETURN
NAVTRADEQPCEM 1H-338

IS15-II 00680/0095 MICRO ASSEMBLER, V.2.0 LREX

LOC OBJ LINE SOURCE STATEMENT

262 : 263 : 264 : CSEG
265 : VSHIFT:
087 E3 266 : PUSH H ; SAVE (H.L)-Y WORD FINAL ADDRESS
086 C0078 E 267 : CALL TSUB ; FIND YDIFF
086 C0078 E 268 : CALL STOREL ; STORE YDIFF AT SCRATCH
086 C0078 E 269 : CALL DIV16 ; MDIFF/YDIFF = MDIFF/YDIFF
270 : 0181 306000 E 271 : LDA VCONTR ; ACC GETS VTCTRL
0184 C0078 E 272 : CALL ADJUST ; MDIFF = MDIFF + MDIFF/YDIFF
273 : 0187 C0078 E 274 : CALL DIV22 ; YOFFSET = MDIFF/YDIFF/22
275 : 018A 3D0000 E 276 : LDA VMAX ; ACC GETS MAXIMUM OFFSET
018D C0078 E 277 : CALL MAX ; CHECK FOR MAXIMUM SHIF T VALUE
278 : 018D 300000 E 279 : LDA VCONTR ; ACC GETS CENTER VALUE
018E 4F 280 : MOV C,A ; (H.L) POINTS TO SIGN ADDRESS
0194 E1 281 : POP H ; ACC GETS SIGN-POS. X-HEX
0195 23 282 : INX H
0196 23 283 : INX H ; ACC GETS SIGN-POS. X-HEX
0197 7E 284 : MOV A.N ; COMPARE SIGN WITH ZERO
0198 EE00 285 : CPI 000H ; IF SIGN IS POSITIVE SUBTRACT
01A A C02201 C 286 : JZ MINUS ; YOFFSET FROM CENTER
287 :
288 :
289 ; IF SIGN IS NOT ZERO ADD (PLUS-MINUS) AND FINISH ARE USED BY VSHIFT AND HSHIFT)
290 :
291 PLUS:
01A D 79 292 : MOV A.C ; ACC GETS CENTER VALUE
01A E 80 293 : ADD B ; ADD OFFSET TO CENTER
01A F C02401 C 294 : JMP FINISH ; FINISH SUBROUTINE
295 :
296 : 297 :
298 299 FINISH:
01B 4 79 300 : MOV A.C ; ACC GETS CENTER VALUE
01B 5 90 301 : SUB B ; SUBTRACT OFFSET FROM CENTER
309 : 310 FINISH:
01B 0 23 301 : INX H ; POINT PAST SIGN OF DIFF
01B C 77 302 : MOV A.N ; STORE SHIF T VALUE
313 ;
01B E 39 304 : RET ; RETURN TO CALLING PROGRAM
315 ;
316 ;
317 TITLE (' HSHIFT ') ;
318 REJECT
319
42
HSIFT

**SOURCE STATEMENT**

```
389: 318 311
312:
313:
314: **************
315: *
316: *
317: *
318: **************
319: MODIFIED FOR LASER PROJECTOR JULY 2 1981
320:
321: HSHIFT IS USED TO CALCULATE THE HORIZONTAL SHIFT VALUE TO BE SENT TO THE HDAC
322: 323: HSHIFT = HCENTER - HOFFSET
324: 325: HOFFSET = HDIFF + N * (HDIFF/16)
326: 327: HSHIFT USES SUBROUTINES: TBSUB, DIV32, DIV16, STOREL, ADJUST, MAX, PLUS, MINUS, FINISH
328:
329: INPUTS:
330: 331: (D,E)- CONTAINS THE ADDRESS OF H WORD 0
332: 333: (H,L)- CONTAINS THE ADDRESS OF H WORD FINAL
334: 335: BOTH WORDS ARE 2-BYTE
336:
337: HCENTER, HMARK, AND HCOLUMN MUST BE IN THEIR PROPER LOCATION IN RAM
338:
339: OUTPUTS:
340: 341: NHDIFF AT SCRCH1 (HDIFF + HCOLUMN+HDIFF/16)
342: 343: HOFFSET AT SCRCH2 (NHDIFF/32)
344: 345: THE SIGN OF HOFFSET-NHDIFF IS STORED AT (H,L) + 2
346: 347: HSHIFT IS IN THE ACCUMULATOR AND AT (H,L) + 3
348: 349: #EJECT

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```
SUBROUTINE HSHIFT

START
CALL TBSUB:  \[ \text{HDIFF} = \text{HW}_0 - \text{HW}_1 \]
CALL STORE1:
CALL DIV32:  \[ \text{HDIFF/32} \]
ACC \rightarrow \text{HCONTROL}
CALL ADJUST:  \[ \text{NHDIFF} = \text{HDIFF} + N \times (\text{HDIFF/32}) \]
CALL DIV32:  \[ \text{HOFFSET} = \text{NHDIFF/32} \]
CHECK SIGN
SUBTRACT HOFFSET FROM HCENTER
ADD HOFFSET TO HCENTER
STORE HSHIFT
RETURN
LOC OBJ  LINE  SOURCE STATEMENT

347 ;
348 ;
349  CSEG
350 HSHIFT:
351 PUSH H. ;(H.L) SAVED IN STK
352 CALL TBSUB ;CALCULATE HDIFF
353 CALL STOR1 ;STORE HDIFF AT SCRATCHL
354 ;
355 CALL DIV16 ;HDIFF/16
356 ;
357 LDA HCONTR ;ACC GETS HCONTROL VALUE
358 CALL ADJUST ;HDIFF=HDIFF-+(HDIFF/16)
359 ;
360 CALL DIV32 ;HOFFSET=HDIFF/32
361 ;
362 LDA HMAX ;ACC GETS MAXIMUM H SHIFT VALUE
363 CALL MAX ;DETERMINE IF MAX IS REACHED
364 ;
365 LDA HCENTR ;LEAVE HOFFSET IN B REGISTER
366 MOV C.A ;C GETS H CENTER VALUE
367 POP H ;H WORD FINAL ADDRESS OFF STK
368 INX H ;(H.L) POINTS TO H SIGN LOCATION
369 INX H ;
370 MOV A.M ;ACC GETS SIGN VALUE (0-POS.1-NEG)
371 CPI #00H ;COMPARE SIGN WITH ZERO
372 JZ MINUS ;IF SIGN IS POSITIVE SUBTRACT
373 ;
374 ;
375 ; IF SIGN IS POSITIVE ADD HCENTER TO HOFFSET
376 ;
377 JMP PLUS ;ADD THEN FINISH SUBROUTINE
378 ;
379 REJECT

45
EXTERNAL SYMBOLS
ADJUST E 0000 DIV16 E 0000 DIV32 E 0000 FIFO E 0000 FIRST E 0000 GETELY E 0000 HCENTP E 0000
HCENT E 0000 HMRC E 0000 HFINAL E 0000 HINPUT E 0000 HINPUT E 0000 HINPUT E 0000
LZERO E 0000 INPUTS E 0000 MAX E 0000 MESS E 0000 REGOUT E 0000 RINPUT E 0000 RST758 E 0000
RST759 E 0000 RST75E E 0000 RSTSP E 0000 SREGC E 0000 SREGC E 0000 SREGC E 0000 STK E 0000
STORES E 0000 TBADD E 0000 TBLSET E 0000 TBSUB E 0000 VCENTR E 0000 VCONTR E 0000 VDRC E 0000
VFINIL E 0000 VINITL E 0000 VINPUT E 0000 VMAX E 0000 VSRC E 0000 VSYNC E 0000 VZERO E 0000

USER SYMBOLS
ADJUST E 0000 DIV16 E 0000 DIV32 E 0000 FIFO E 0000 FIRST E 0000 GETELY E 0000 HCENTP E 0000
HCENT E 0000 HCONTR E 0000 HFINAL E 0000 HINPUT E 0000 HINPUT E 0000 HINPUT E 0000
HORIZ C 0064 HSHIFT C 8127 HSRCD E 0000 HZERO E 0000 INPUTS E 0000 INPUTS E 0000 INPUTS E 0000
LPREV C 0000 MAX E 0000 MESS E 0000 MINUS E 0000 MSEG C 0054 OUTPUT C 00C2 PLUS C 011D
REGOUT E 0000 RINPUT E 0000 ROLL C 008E ROTATE C 00C8 RSET C 008E RST758 E 0000 RST758 E 0000
RST759 E 0000 RST75E E 0000 RSTSP E 0000 SCROMLE 0000 SCROMLE 0000 SCROMLE 0000 STK E 0000
TBADD E 0000 TBLSET E 0000 TBSUB E 0000 VCENTR E 0000 VCONTR E 0000 VDRC E 0000 VZERO E 0000
VFINIL E 0000 VINITL E 0000 VINPUT E 0000 VMAX E 0000 VSRC E 0000 VSYNC E 0000
VZERO E 0000

ASSEMBLY COMPLETE, NO ERRORS
<table>
<thead>
<tr>
<th>LOC</th>
<th>OBJ</th>
<th>LINE</th>
<th>SOURCE STATEMENT</th>
</tr>
</thead>
<tbody>
<tr>
<td>373</td>
<td>;</td>
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<td>374</td>
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<tr>
<td>381</td>
<td>;</td>
<td>;</td>
<td>THIS SUBROUTINE EVALUATES THE MATHEMATICAL EXPRESSION</td>
</tr>
<tr>
<td>382</td>
<td>;</td>
<td>;</td>
<td>$Z \leftarrow X + (N + Y)$</td>
</tr>
<tr>
<td>383</td>
<td>;</td>
<td>;</td>
<td>WHERE $X$ AND $Y$ ARE TWO BYTE WORDS STORED AT RAM LOCATIONS SCRATCH1 AND SCRATCH2. RESPECTIVELY. $N$ IS A VARIABLE WHICH IS PASSED TO THE SUBROUTINE IN THE ACCUMULATOR; $N$ HAS AN ALLOWABLE RANGE OF $-31$ WITH THE SIGN INDICATED BY THE MSB (BIT 7) OF THE ACC. SET TO 0 FOR POSITIVE OR 1 FOR NEGATIVE. THE RESULT $Z$ IS STORED AT THE ORIGINAL LOCATION OF $X$ (SCRATCH1)</td>
</tr>
<tr>
<td>384</td>
<td>;</td>
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<td>385</td>
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<td>394</td>
<td>;</td>
<td>;</td>
<td>INPUTS:</td>
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<tr>
<td>395</td>
<td>;</td>
<td>;</td>
<td>ACC CONTAINS THE VARIABLE WORD $N$</td>
</tr>
<tr>
<td>396</td>
<td>;</td>
<td>;</td>
<td>MSB $\leftarrow X$ LSB $\leftarrow N$</td>
</tr>
</tbody>
</table>
| 397 | ;   | ;    | \begin{align*} 7 & 6 & 5 & 4 & 3 & 2 & 1 & 0 \ \text{BIT} & \ 0 \\
| 398 | ;   | ;    | S & \leftarrow \text{RANGE}=31 |
| 399 | ;   | ;    | \begin{align*} 1 & \\
| 400 | ;   | ;    | G & \\
| 401 | ;   | ;    | N & \begin{cases} \text{IF BIT07=0, N IS POSITIVE} \\
| 402 | ;   | ;    | \text{IF BIT07=1, N IS NEGATIVE} \\
| 403 | ;   | ;    | \begin{align*} 0 & \text{BITS 6 AND 5 ARE NOT USED (AND VALUE IF HEX DROPS THEM)} \\
| 404 | ;   | ;    | \begin{align*} 0 & \\
| 405 | ;   | ;    | X & \leftarrow \text{CONTAINED IN RAM LOCATIONS SCRATCH1, SCRATCH1 + 1} |
| 406 | ;   | ;    | \begin{align*} 0 & \\
| 407 | ;   | ;    | Y & \leftarrow \text{CONTAINED IN RAM LOCATIONS SCRATCH2, SCRATCH2 + 1} |
| 408 | ;   | ;    | \begin{align*} 0 & \\
| 409 | ;   | ;    | \begin{align*} 0 & \\
| 410 | ;   | ;    | OUTPUT: |
| 411 | ;   | ;    | Z \leftarrow \text{CONTAINED IN RAM LOCATIONS: SCRATCH1 (LO) AND SCRATCH1 + 1 (HI)} |
| 412 | ;   | ;    | \begin{align*} 0 & \\
| 413 | ;   | ;    | \begin{align*} 0 & 

47
NAVTRAEEQUPECN 1H-338

ADJUST

START

LOAD SCRATCH1 AND SCRATCH2 ADDRESSES

? SUBTRACT OR ADD

DROP BITS 7, 6, 5 OF CONTROL WORD

RETURN IF N = 0

CALL TBADD:

CALL STORE1:

N = N - 1

RETURN IF N = 0

RELOAD SCRATCH1 AND SCRATCH2 ADDRESSES

DROP BITS 7, 6, 5 OF CONTROL WORD

RETURN IF N = 0

CALL TBSUB:

CALL STORE1:

N = N - 1

RETURN IF N = 0

RELOAD SCRATCH1 AND SCRATCH2 ADDRESSES

... CHECK HI-BIT OF CONTROL WORD (N)

... MAXIMUM VALUE OF N SET TO 31DECIMAL

... STORE RESULT AT SCRATCH1 ADDRESS

RESULT = SCRATCH1 + N * SCRATCH2
ISIS-11 8088/8085 MACRO ASSEMBLER. V2.0

SUBS

LOC OBJ LINE SOURCE STATEMENT

414 CSEG
415 ADJUST

0088 110000 E 416 LXI D: SCRCH1
0088 210000 E 417 LXI H: SCRCH2

0090 17 419 RAL

0091 DARC00 C 420 J C NEG

0094 0F 423 PPC

0095 661F 424 ANI 1FH

0097 C8 425 RZ

0098 F5 426 PUSH PSW

0099 C06F00 C 427 XPLUSV.

009C C06200 C 428 CALL TBADD

009F F1 430 POP PSW

00A0 3D 431 DCR A

00A1 C8 432 RZ

00A2 F5 433 PUSH PSW

00A3 110000 E 434 LXI D: SCRCH1

00A6 210000 E 435 LXI H: SCRCH2

00A9 C39900 C 436 JMP XPLUSV

00A C 0F 439 PPC

00AD 661F 440 ANI 1FH

00AF C8 441 RZ

00B0 110000 E 442 PUSH PSW

00B3 C0200 C 443 CALL TBADD

00B4 C0200 C 445 CALL STORE1

00B7 F1 446 POP PSW

00B8 3D 447 DCR A

00B9 C8 448 RZ

00BA F5 449 PUSH PSW

00BB 110000 E 450 LXI D: SCRCH1

00BE 210000 E 451 LXI H: SCRCH2

00C1 C3B100 C 452 JMP XPLUSV

453
454 #TITLE ("TABLE_SET")
455 #EJECT

49
THIS PROGRAM IS DESIGNED TO TEST THE POLHEMUS HEAD TRACKED SNPS-III-A IN CONJUNCTION WITH AN INTERFACE BOARD THAT CONVERTS THE PAT'S SERIAL DATA TO PARALLEL DATA.


08H - HORIZONTAL DATA (AZIMUTH)
09H - VERTICAL DATA (ELEVATION)
0AH - ROLL DATA

THIS STORAGE CONTINUES UNTIL THE RAM USED FOR STORAGE IS FILLED (RAM 28000 - 28FFF).

SINCE EACH PAT WORD IS TWO-BYTE THE PROGRAM STORES 128 VALUES OF DATA. AFTER 128 VALUES ARE STORED THE PROGRAM DROPS OUT OF THE STORE MODE AND INTO THE NON-STORE MODE.

IN THIS MODE, THE SAME TYPE OF DATA, AS INDICATED BY THE C-REGISTER, IS PULLED ONTO THE INPUT PORTS BUT IS NOT STORED. WHEN THIS DATA IS ON THE PORT, THE BIT PATTERN CAN BE READ FROM LED'S ON THE S/P BOARD. IN ORDER TO SEE THESE BIT PATTERNS. A DELAY LOOP IS ENTERED TO WAIT BEFORE PULLING IN NEW DATA, ALLOWING THE DATA TO BE ON THE PORT LONG ENOUGH TO CAUSE THE LED'S TO REMAIN LIGHTED AND TO ALLOW ONE TO SEE THE BIT PATTERN.

DEFINE CONSTANTS

0FF1:
   41 DELAY EQU 0FF1H ADDRESS OF MONITOR DELAY ROUTINE
2000:
   42 COUNT EQU 2000H DELAY COUNT VALUE (APPROX. SEC)
001D:
   43 MASK EQU 01H STM MASK VALUE
08FF:
   44 ENDDST EQU 0FFH END OF STORAGE VALUE
2000:
   45 BEGIN EQU 2000H BEGINNING OF STORAGE

DEFINE EXTERNAL VALUES

49 EXTRN RST65: RST65: INPUT, GETELV: RST65: STC: FIRST
51 TITLE ("PATHAPP")
52 REJEC

50
PHTMAP

START

DISABLE INTERRUPTS

SET STACK POINTER

RESET S/P INTERFACE

INITIALIZE COUNTER TO ZERO

LOAD RESTART INSTRUCTIONS

IDENTIFY 1st STORAGE ADDRESS

NOP LOOP #1

--WAIT FOR 6.5 INTERRUPT (PHT 'DATA READY')

*--NOTE
TO SELECT ONE OF THE THREE ANGLES (YAW, PITCH, ROLL), A CONSTANT
MUST BE LOADED INTO REGISTER C BEFORE RUNNING PHTMAP INDICATING
THE ANGLE DESIRED ACCORDING TO:
00HEX - YAW DATA
01HEX - PITCH DATA
03HEX - ROLL DATA
6.5

LOAD PHT DATA

NO

REQUEST NEXT DATA WORD
ADD ONE TO COUNTER

1

YES

B = C

STORE LO-BYTE OF DATA
INCREMENT ADDRESS
STORE HI-BYTE

? ENDSTO = ADDRESS

NO
INCREMENT ADDRESS
RESET S/P INTERFACE

1

YES
NOSTOR

52
PHTMAP CONT.

- **NOSTOR**
- **NOP LOOP #2**
- **WAIT FOR 6.5 INTERRUPT (PHT 'DATA READY')**
- **JADD2**
- **LOAD PHT DATA**
- **NO**
- **B = C**
- **YES**
- **WAIT TO ALLOW VIEWING OF DATA ON LED's**

- **REQUEST NEXT DATA WORD**
- **INCREMENT COUNTER**
- **2**

- **CALL DELAY:**
- **RESET S/P INTERFACE**

- **RESET COUNTER**
- **2**
WAVTRAEQUIPCEN
IN-338
ISIS-1l
9096/8885 HM ASSEMBLE,
Y.
PNTI
LoD 06, LINE
SUM
STATENENT
53
CSG
54 PNTIN
SF3
55 DI, DIABLE INTERCPTS
t81 319688
E
56
LXI
SP, STY
;SET STACK POINTED
57
LXI K, FIRST
;HOL CONTENTS PROGRAM
SW 228688
E
58
LXI
H, FIRST
;HOL CONTENTS START LOCATION
59
SC8
32888
E
60
MVX
B, ORN
;INITIALIZE COUNTER TO 20PC
61
LXI
H, FIRST
;HOL CONTENTS DI, JMP INSTRUCTIONS
62
SXL
RST50
;STORE 1ST PART OF DI JMP INSTRP
63
LXI
H, MOD1
;HOL CONTENTS ADDRESS FOR JMP
64
SXL
RST50
;STORE 2ND PART OF DI JMP ADDRESS
65
LXI
D, BEGIN
;DI CONTAINS 1ST STORAGE LOCATION
66
LXI
D, BEGIN
;DI CONTAINS 1ST STORAGE LOCATION
67
NOP:
68
;*** LOOP #1 ***
69
NOP:
70
NOP:
71
NOP:
72
MVX
A, MASK
;UNMASK 6.5 INTERUPT
73
MVX
A, FIRST
;ENABLE INTERCEPTS
74
MVX
A, FIRST
;** WAIT FOR 6.5 INTERRUPT **
75
JMP
NOP1:
76
;MOD1:
77
LXI
MINPUT
;HOL GETS INPUT (PULLS DOWN 6.5)
78
MOV
A, B
;DOES B = C ?
79
MOV
A, B
;DOES B = C ?
80
MOV
A, B
;DOES B = C ?
81
JZ
STORE
;IF EQUAL, STORE INPUT
82
;MOD1:
83
STR
GETELY
;IF NOT EQUAL, REQUEST NEXT NOPD OF DATA
84
ADI
85
B, IN
;THEN, ADD 1 TO COUNTER
85
MOV
B, A
;AND
86
RET
;RETURN TO MOD1 LOOP
87
;STORE:
88
XCHG
;DI CONTAINS MEMORY ADDRESS
89
;CONTAINS MEMORY ADDRESS
90
MOV
M, E
;STORE OL-BYTE OF INPUT
91
MOV
M, E
;MEM = MEM + 1
92
;STORE:
93
MOV
M, E
;ACC GETS HI-BYTE OF INPUT
94
RCL
;COMPLEMENT MSB OF INPUT
95
ROR
;AND STORE IN MEMORY
96
MOV
M, A
;CHECK FOR END OF STORAGE
97
NOV
M, A
;DOES REG. 1 EQUAL END ?
98
NOV
M, A
;IF EQUAL, GO TO NOSTORE MOD
99
NOV
M, A
;CONTAINS INPUT ; USE, L) CONTAINS MEMORY ADDRESS
100
MVX
A, ENDSSTO
;STORE LD-BYTE OF INPUT
101
CNP
L
;MEM = MEM + 1
102
JZ
NOSTOR
;END OF STORAGE
103
REJECT

54
LOC OBJ       LINE       SOURCE STATEMENT

003D 23       184       INX  H   IF NOT EQUAL (SET UP FOR MORE STORAGE)
003E EB       185       XCHG   : (D,E) POINTS TO MEMORY
003F 320000   186       STA  RSTSP   : RESET SERIAL TO PARALLEL BOARD
0042 0668     187       MVI  B.00H   : RESET COUNTER TO ZERO
0044 C9       188       RET   : RETURN TO NOP1 LOOP
0045 80       189       NOP   :*** LOOP #2 ***
0046 213F80    190       LXI  H.JA002   : (H,L) GETS NEW JUMP ADD FOR 6.5
0049 220000   191       SHLD RSTSR   : AND THEN IS MOVED TO 6.5 START AREA
004C E1       192       POP  H   : REMOVE NOP1 RETURN ADDRESS
004D 0600     193       MVI  B.00H   : RESET COUNTER TO ZERO
004E 320000   194       STA  RSTSP   : RESET SERIAL TO PARALLEL BOARD
0050 0668     195       MVI  B.00H   :** WAIT FOR 6.5 INTERRUPT **
0052 80       196       NOP   : *** LOOP #2 ***
0053 3E1D     197       MVI  A.MASK   : masks 6.5 INTERRUPT
0055 3B       198       SIM   : ENABLE INTERRUPTS
0056 FB       199       EI   :** WAIT FOR 6.5 INTERRUPT **
0057 C35000   200       JMP  NOP2   :*** LOOP #2 ***
0059 200000   201       LHLD HINPUT   : (H,L) GETS INPUT FROM PHT
005D 78       202       MOV  A.B   : DOES B = C ?
005E 89       203       CMP  C   : IF EQUAL, WAIT BEFORE RESETTING
005F DA0900   204       JZ  DISPLAY   : IF NOT EQUAL, REQUEST NEXT NOP2 OF DATA
0062 320000   205       STA  GETELY   : AND RETURN TO NOP2 - LOOP #2
0065 C681     206       MVI  B.R   : INCREMENT COUNTER
0067 47       207       NOP   : AND RETURN TO NOP2 - LOOP #2
0068 C9       208       RET   :*** LOOP #2 ***
0069 110020     209       LXI  D.COUNT   : (C,D) CONTAINS DELAY COUNT
006C CDF185   210       CALL DELAY   : WAIT SPECIFIED TIME PERIOD
006F 320000   211       STA  RSTSP   : RESET SERIAL TO PARALLEL BOARD
0072 0668     212       MVI  B.00H   :** RETURN TO NOP2 - LOOP #2
0074 C9       213       RET   :*** LOOP #2 ***
NAVTRAACIPCCN IH-338

ISIS-II 0000/0005 MICRO ASSEMBLER, V3.0

PUBLIC SYMBOLS

EXTERNAL SYMBOLS
FIRST E 0000 GETELV E 0000 HINPUT E 0000 RST65B E 0000 RST65A E 0000 RSTSP E 0000 STK E 0000

USER SYMBOLS
BEGIN A 2000 COUNT A 2000 DELAY A 001 DISPLAV C 0069 ENSTO R 00FF FIRST E 0000 GETELY E A000 HINPUT E 0000 JADD1 C 0028 JADD2 C 005A MASK A 001D NOP1 C 0018 NOP2 C 0052 NOSTOR C 0045

ASSEMBLY COMPLETE. NO ERRORS

56
THIS SUBROUTINE IS USED TO SHIFT A TABLE CONTAINING DATA WORDS DOWN IN RAM OVERWRITING THE LAST WORD, BUT PRESERVING THE FIRST WORD. THE LENGTH OF THE WORDS InvOLVED IS CONSIDERED IN THE INPUT VALUES THAT ARE PASSED TO THE SUBROUTINE. FOR EXAMPLE, CONSIDER THIS TABLE CONTAINING THREE TWO-BYTE WORDS:

<table>
<thead>
<tr>
<th>Addr</th>
<th>Table</th>
<th>Source Address</th>
</tr>
</thead>
<tbody>
<tr>
<td>2000H</td>
<td>MB-L</td>
<td>2000H MB-L</td>
</tr>
<tr>
<td>2001H</td>
<td>MB-H</td>
<td>2001H MB-H</td>
</tr>
<tr>
<td>2002H</td>
<td>ML-L</td>
<td>2002H ML-L</td>
</tr>
<tr>
<td>2003H</td>
<td>ML-H</td>
<td>2003H ML-H</td>
</tr>
<tr>
<td>2004H</td>
<td>M2-L</td>
<td>2004H M2-L</td>
</tr>
<tr>
<td>2005H</td>
<td>M2-H</td>
<td>2005H M2-H</td>
</tr>
</tbody>
</table>

INPUTS:
- (D,E) - CONTAINS THE SOURCE ADDRESS (ADD. OF HI-BYTE OF NEXT TO LAST WORD)
- (L.L) - CONTAINS THE ADDRESS OF THE HI-BYTE OF THE LAST WORD IN THE TABLE
- B - CONTAINS THE ADDRESS OF THE FIRST TABLE LOCATION
- ** - THIS ROUTINE CANNOT SHIFT TABLES THAT CROSS HI-BYTE ADDRESS BOUNDARIES.

OUTPUT:
- THE DESCRIBED TABLE IS SHIFTED.

57
NAVTRAEPICENT 1H-338

FIFO

START

LOAD ACC WITH DATA AT SOURCE ADDRESS

MOVE DATA TO DESTINATION ADDRESS

? SOURCE = INITIAL

NO

SOURCE ADDRESS

DESTINATION ADDRESS

YES

RETURN

DECREMENT SOURCE AND DESTINATION ADDRESS

INPUT:  (D, E) ← SOURCE ADDRESS
         (H, L) ← DESTINATION ADDRESS
         B ← INITIAL ADDRESS

OUTPUT:  TABLE IS SHIFTED DOWNWARDS IN RAM
          (NUMBER OF LOCATIONS MOVED IS IMPLIED BY DIFFERENCE BETWEEN SOURCE AND DESTINATION ADDRESSES)
FIFO

LOC OBJ | LINE | SOURCE STATEMENT
---|---|---
00001A | 535 |.
00001B | 536 | CSEG
00001C | 537 | FIFO:
00001D | 538 | LDAX D
00001E | 539 | MOV M,A
00001F | 540 |.
00002A | 541 | MOV A,B
00002B | 542 | CMP E
00002C | 543 | RZ
00002D | 544 |.
00002E | 545 | DAX D
00002F | 546 | DAX H
000030 | 547 | JMP FIFO
000031 | 548 | REJECT

LOAD ACC WITH DATA AT SOURCE ADDRESS
MOVE SOURCE DATA DOWN TWO POSITIONS
MOVE ADD OF FIRST WORD TO ACC
AND COMPARE WITH SOURCE ADDRESS
RETURN IF FIRST WORD HAS BEEN MOVED

IF MORE TO SHIFT, POINT TO NEXT SOURCE
AND DESTINATION ADDRESS
THEN SHIFT NEXT PIECE OF DATA
THIS SUBROUTINE IS USED TO FILL A GROUP OF RAM LOCATIONS WITH AN INITIAL VALUE.

WORD WHICH IS TWO-BYTES LONG.

INPUTS:

(D,E) - CONTAINS THE INITIAL VALUE
(H,L) - CONTAINS THE FIRST ADDRESS FOR INITIALIZATION
ACC - LO-BYTE OF FINAL ADDRESS IN THE TABLE

** - TABLE CANNOT EXTEND ACROSS THE HI-BYTE BOUNDARY

OUTPUT:

RAM LOCATIONS FROM THE FIRST ADDRESS TO THE FINAL ADDRESS ARE FILLED
WITH THE INITIAL VALUE IN (D,E)

CSEG

MOV M.E
INC H
MOV M.D
CMP L
RZ
JMP TBLSET

TITLE ('FIFO')

EJECT
THIS SUBROUTINE COMPARES A TWO-BYTE WORD WITH A ONE-BYTE WORD (MAX).

IF THE TWO-BYTE WORD IS GREATER THAN THE MAX WORD, THEN THE MAX
WORD IS RETURNED TO THE CALLING PROGRAM. IF THE TWO-BYTE WORD IS LESS
THAN THE MAX WORD, THEN THE LOW-BYTE OF THE TWO-BYTE WORD IS RETURNED
TO THE CALLING PROGRAM.

INPUTS:
ACC - CONTAINS THE MAXIMUM VALUE (ONE-BYTE)
(H.L)- CONTAINS THE TWO-BYTE WORD FOR COMPARISON

OUTPUT:
B - CONTAINS THE LESSOR OF THE MAXIMUM VALUE OR THE TWO-BYTE WORD

CSEG
MAX:

; B GETS MAXIMUM VALUE
MOV B.A

; ACC GETS HI-BYTE C-VALUE
MOV A.H

; IF HI-BYTE IS NOT ZERO,
CP1 00H

; RETURN WITH MAX IN B
POR

; ACC GETS LO-BYTE C-VALUE
MOV A.L

; COMPARE WITH MAXIMUM
CMP B

; RETURN IF L IS GREATER THAN MAXIMUM
POR

; ELSE MOVE L TO B
MOV B.L

; RETURN WITH LESSOR VALUE IN B
RET

TITLE ('STORE1')
REJECT
An Intel SDK-85 development board is used as the micro-controller for the RHMC system -- primarily because it provides a ready-made micro system at a reasonable cost. The microprocessor is an Intel 8085A, which is capable of addressing only 512 bytes of RAM, 2000 bytes of monitor ROM and 2000 bytes of Erasable Programmable Read Only Memory (EPROM). The 8085A is in communication with an in-house designed board which provides two digital to analog converter (DAC) channels for raster shift, EPROM for RHMC program storage, address decoders, and vertical sync for both the Polhemus Head Tracker (PHT) and the microprocessor. In addition, the system contains the Polhemus head tracker (PHT) data controller which allows head pointing direction (HPD) data transfer from the PHT to the microprocessor, and a separate data buffer board than enables the CIG system to take in HPD data transparent to the operation of the 8085 microprocessor system. Figure B1 shows a block diagram of the RHMC and interface hardware.

The PHT data controller (see schematic and timing diagram) controls the format and the distribution of Head Pointing Direction data from the Polhemus Head Tracker. About 15.5 ms. after the sync signal (vertical sync) is sent to the PHT, initiating its position sampling sequence, the PHT indicates that the data is ready by sending, appropriately, a "data ready" pulse to the data controller. The PHT orientation and positional data is then ready to be clocked out of the serial port. A "data acknowledge" signal is returned to the PHT by the controller and a 500 kHz. burst consisting of 17 clock pulses is also sent which clocks out the first 17-bit word, "yaw." This serial string of bits is clocked into dual, 10-bit, serial in, parallel out shift registers. At the end of the 17th clock pulse, the clock is inhibited, and the first 16 bits of the 17-bit word are transferred to dual 8-bit data buffers. These buffers, when full, send an interrupt (Rst. 6.5) to the 8085 microprocessor. The micro, meanwhile, has been patiently waiting in a loop for the data. Upon receipt of the Rst. 6.5 interrupt, the micro addresses the buffers and pulls the data into memory for future processing. The micro writes to memory location (8xx2) which sends a "get data" pulse to the controller and the micro returns to the loop to await further data. Again, the controller sends out a burst of 17 pulses, clocking in the next word, "pitch." In the same sequence as before, the 8085 stores this next word and requests the roll data. At the end of this sequence, "data acknowledge" is cleared and the 8085 begins the computation cycle which eventually determines the 8-bit values sent to the horizontal and vertical, raster shifting, digital to analog converters (HDAC and VDAC). These values are latched into the DACs during the vertical retrace of the laser video projector. Vertical sync (or retrace) is acknowledged as a 7.5 interrupt by the microprocessor.

Again returning to the system block diagram in Figure B1, the offset signals from the HDAC and VDAC are routed to summing circuits; a summer feeding the VCO for the horizontal shift, and a summing point within the scanner controller for the vertical shift.
Figure B1. RHMC and Interface Hardware.
The horizontal offset signal from the HDAC is summed with the output of the ramp generator. The voltage shift of this signal frequency shifts the voltage controlled oscillator which outputs a frequency chirp centered at 375 mHz. Spanning some 200 mHz, the frequency chirp can be shifted up or down in frequency as much as 25 mHz. After suitable amplification, the Acousto Optic Beam Deflector (AOBD) receives the shifted chirp and shifts the horizontal line scan accordingly. The voltage controlled oscillator (VCO) is required to output a chirp, or frequency sweep at a horizontal line rate. As previously mentioned, the VCO is a non-linear device when operated at these line rates (15 to 30 kHz.). Since the VCO is non-linear, its driving signal must be carefully selected and conditioned to achieve a linear output, i.e., a linear frequency chirp. A linear frequency chirp applied to the AOBD results in a sharply focused, linear horizontal sweep. The task of providing a linear frequency chirp is difficult enough; providing a signal which produces a shiftable linear frequency chirp at the output of the VCO proved to be impossible. The subsequent non-linearity produces noticeable display distortion, reducing both the resolution and linearity of the display.

A minor modification of the scanning controller, which drives the frame scanner, allows the vertical offset signal from the VDAC to shift the angle at which the frame scanner begins its vertical scan. This provides the required vertical raster shift.

Both the CIG and RHMC system require head pointing direction (HPD) data every field (16.7 ms.). The data buffer (see schematic and timing diagram) allows the CIG to take in HPD data relatively independent of the operation of the RHMC system. It holds the pitch, roll and yaw data until the CIG sends a request for data. Basically, the data buffer counts the number of Rst. 6.5 interrupts emitted by the PHT data controller and loads one of three 16-bit buffers on each rising edge. When the third buffer has been loaded with data from the PHT data controller bus, a “data ready” is sent to the CIG system indicating that a complete set of HPD data is ready to be transferred, and the first data word, azimuth, is placed on the 16-bit CIG/buffer bus. When the CIG system accepts the data, it returns a “data acknowledge,” which places the next data word, elevation, on the bus. This action, in turn, sends another “data ready” to the CIG system. When the final data word, roll, is received by the CIG, and a “data acknowledge” is returned, the three buffers are cleared. The data buffer is then ready for another set of HPD data.
PHT (SHMS III) DATA CONTROLLER
TIMING DIAGRAM
NAVTRAUEIPCEIH-338

DATA BUFFER TIMING DIAGRAM

U28 PIN 6 (RESET)
U14 PIN 1 (RST 6.5)
U37 PIN 13 (LATCH AZ DATA)
U37 PIN 4 (LATCH EL DATA)
U37 PIN 1 (LATCH ROLL DATA)
U30 PIN 23 (ROLL DATA LATCHED)
U40 PIN 6
U39 PIN 13 (DATA ACK)
U37 PIN 10
U41 PIN 15
U41 PIN 14
U41 PIN 13
U38 PIN 8 (AZ + EL + ROLL)
U39 PIN 4
U42 PIN 5
U40 PIN 10 (AUTO RESET)
U39 PIN 10 (RESET)
NAVTRADEQUIPCEN IH-338

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