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**HUMAN SENSORY FEEDBACK LAB
TESTBED: MBASSOCIATES
EXOSKELETON/MERLIN ROBOT INTERFACE**

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FOR THE DIRECTOR



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13. ABSTRACT (Maximum 200 words) This report describes the MBAssociates Exoskeleton/Merlin Robot Interface used in the Human Sensory Feedback Lab Testbed for studies of human performance in coarse positioning tasks. The dual-armed, seven-degree-of-freedom (DOF) exoskeleton, worn by an operator, serves as a master device to control the end-effector position/orientation of a six-DOF Merlin slave robot. Kinematic position transformation matrices are detailed for both master and slave devices, as is the approach used for operator control of a six-DOF robot using a seven-DOF exoskeleton. The use of a desktop 386-33MHz type personal computer as a central system controller, user interface, and software development platform is described.				
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1.0 Introduction

Under contract F33615-89-C-0574 Task 08A "Human Sensory Feedback", Systems Research Laboratories provided engineering and scientific support to explore the utility of telerobotic systems in hazardous environments. A testbed was developed at the USAF Armstrong Laboratory's Human Sensory Feedback Lab at Wright Patterson AFB, to evaluate and research issues in course manipulation, bilateral teleoperation, force-control and man-machine interfaces.

2.0 Technical Description

The facility's testbed provides control of wrist position and end effector orientation for one six degree-of-freedom (DOF) American Cimflex Merlin industrial robot arm using a MBAssociates 7 DOF exoskeleton worn by a human operator. A Compaq 386 33 MHz computer serves as the host controller for the following functions:

- Computation of Cartesian position and orientation for various coordinate frames assigned at fixed locations on the exoskeleton, using joint angles received from the exoskeleton over a hardwire serial link at 38.4K bits/sec.
- Computation of joint angles required for the Merlin robot to achieve a desired wrist position and end effector orientation driven by the exoskeleton as a master.
- Provide user with system control functions.

3.0 MBAssociates Unilateral Exoskeleton

The MBAssociates exoskeleton was originally constructed by MBAssociates of San Ramon, CA under contract No. F08635-75-C-0027 with the United States Air Force, Armament Development and Test Center at Eglin AFB, Florida. The exoskeleton was part of a Manipulator Arms System comprised of an anthropomorphic two-armed teleoperator slave, powered by an electronically controlled hydraulic system and controlled by a two-armed exoskeletal type master. The master's grip and elbow joints on both arms provided force feedback by use of local hydraulic valves.

The Human Sensory Feedback Lab acquired the MBA exoskeleton through a long-term equipment loan arrangement with the Department of Energy's Oak Ridge National Laboratories.

Several modifications were performed on the MBA exoskeleton to enhance its use as a standalone device in the Human Sensory Feedback Testbed.

Since initial use of the MBA exoskeleton was planned for position control of the Merlin robot, the exoskeleton's force feedback hydraulic actuators and manifold system were removed to reduce operator fatigue due to the effects of gravity. A microprocessor based computer, residing in the exoskeleton's backpack, was developed to read joint angles from either arm, using optical encoders located at each arm's 7 joints plus gripper control, and send them over a serial hardware link to a host computer serving as the central controller for the exoskeleton and robot.

3.1 Backpack Computer Description

To provide the potential for the exoskeleton to be operated as a standalone device in a location remote from the Merlin robot, a 68000 microprocessor based computer with 2 asynchronous serial ports, battery backed SRAM and incremental optical encoder interface circuitry was developed to reside in the exoskeleton's backpack. Exoskeleton arm linkage joint angles, required to compute Cartesian position and orientation for exoskeleton coordinate frames, can be requested and received from a remote host controller over a 38.4K bits/sec hardware serial link.

Joint angles are sensed by incremental optical encoders with 1024 counts/rev for 1:1 ratio joints and 120 counts/rev for gear/belt joints. Incremental optical encoder interface circuitry effectively increases the counts/rev to 4096 and 480 respectively, by counting the rising and falling edges of both quadrature channels from a single encoder. Incremental type encoders were selected over the original potentiometers to increase joint angle resolution and reduce susceptibility to electrical interference. Incremental type encoders were chosen over absolute types for cost considerations with the tradeoff being the need to initialize each joint of the exoskeleton after loss of power.

Serial communications between the MBAssociates exoskeleton and an external computer are specified electrically as RS-422 differential type drivers and receivers for longer distance and higher noise immunity reasons. The default bits/sec rate is 38.4K with 1 Meg bits/sec possible by selecting a higher oscillator base frequency for the DUART serial communications chip.

3.2 Backpack Software Description

The 68000 microprocessor executable code is downloaded from the host controller via the hardwire serial link to the MBA exoskeleton backpack computer. This provides development flexibility in changing the software that initializes the incremental encoder interface circuitry, reads exoskeleton joint angle encoders and gripper switches on command, and communicates in real time with a host controller. Upon exoskeleton power-on/reset, a downloader routine, resident in EPROM (firmware) on the backpack's computer board, monitors the RS-422 serial port for a download command from the host computer and handles the transfer of 68000 executable code to an area in battery-backed SRAM. Once the download process is complete, the on-board 68000 CPU exits the downloader routine and begins execution of the downloaded code in SRAM.

The downloader software was developed on a Hewlett-Packard 64000 Development System with a 68000 microprocessor emulation pod. The emulation pod plugs directly into the 68000 microprocessor socket on the backpack computer board to allow development and testing of code on the target hardware, with finalized downloader code programmed into EPROM. All downloader software is archived on a Hewlett-Packard 9134 hard disk drive associated with the HP 64000 Development System.

Development of a backpack computer program to be downloaded is initiated using Aztec C high level "C" programming language with Borland Turbo C II as a development tool on a Compaq 386 PC. Using the Aztec C cross-compiler and linker, 68000 executable code is produced for downloading to the MBA exoskeleton backpack computer.

The downloading of 68000 executable code from the host Compaq 386 PC to the MBA exoskeleton backpack computer is handled by routines called by the program **merlin.exe** on the Compaq 386.

3.3 Forward Kinematics for MBAssociates exoskeleton

Forward kinematic transformation matrices were developed using the Denavit-Hartenberg convention as described in Reference[1].

General form of ${}^{i-1}_i T$:

$${}^{i-1}_i T = \begin{bmatrix} c\theta_i & -s\theta_i & 0 & a_{i-1} \\ s\theta_i c\alpha_{i-1} & c\theta_i c\alpha_{i-1} & -s\alpha_{i-1} & -s\alpha_{i-1} d_i \\ s\theta_i s\alpha_{i-1} & c\theta_i s\alpha_{i-1} & c\alpha_{i-1} & c\alpha_{i-1} d_i \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

Where:

a_i = the distance from Z_i to Z_{i+1} measured along X_i

α_i = the angle between Z_i and Z_{i+1} measured along X_i

d_i = the distance from X_{i-1} to X_i measured along Z_i

θ_i = the angle between X_{i-1} and X_i measured about Z_i

c = cosine

s = sine

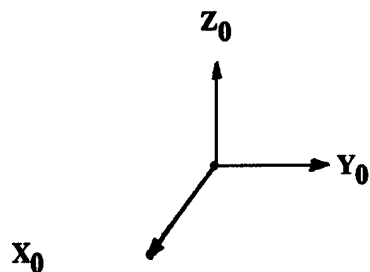
Location of Frame $\{i\}$'s Z_i axis was chosen to be along the optical encoder output shaft of joint $\{i\}$. The direction of X_i was chosen to insure that the value of θ_i increases/decreases in the same direction as the encoder counts. Encoder counts increase with clockwise rotation of the shaft as viewed from the encoder body out towards the shaft.

Frame assignments and matrices are shown for each joint of each arm to notate the sparse composition of most matrices and to relation program execution times for kinematic computations.

3.3.1 Left Arm

Reference Frame {0}

The Origin of Reference Frame {0} is at the countersunk screw located top center on the MBA's backplate. (See figure 1)



$$a_0 = 0$$

$$\alpha_0 = 0^\circ$$

$$d_0 = \text{Does not exist}$$

$$\Theta_0 = \text{Does not exist}$$

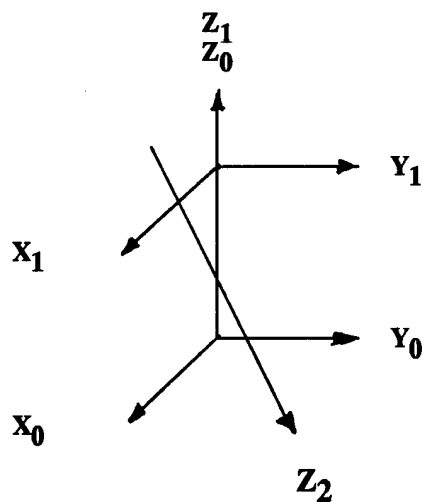
Left Frame {1}

$$a_1 = +l_3$$

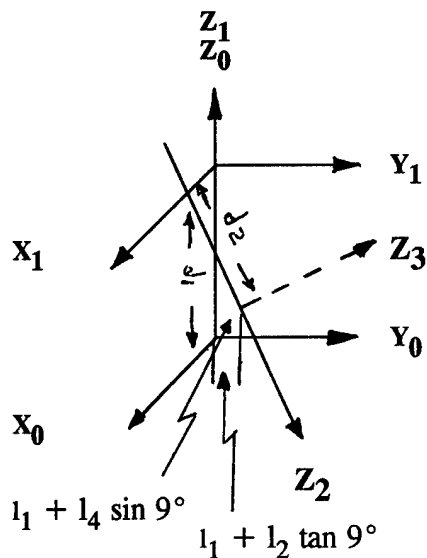
$$\alpha_1 = +189^\circ$$

$$d_1 = (l_1 + l_2 \tan 9^\circ) / \tan 9^\circ$$

$$\Theta_1 = 0^\circ$$



YZ View



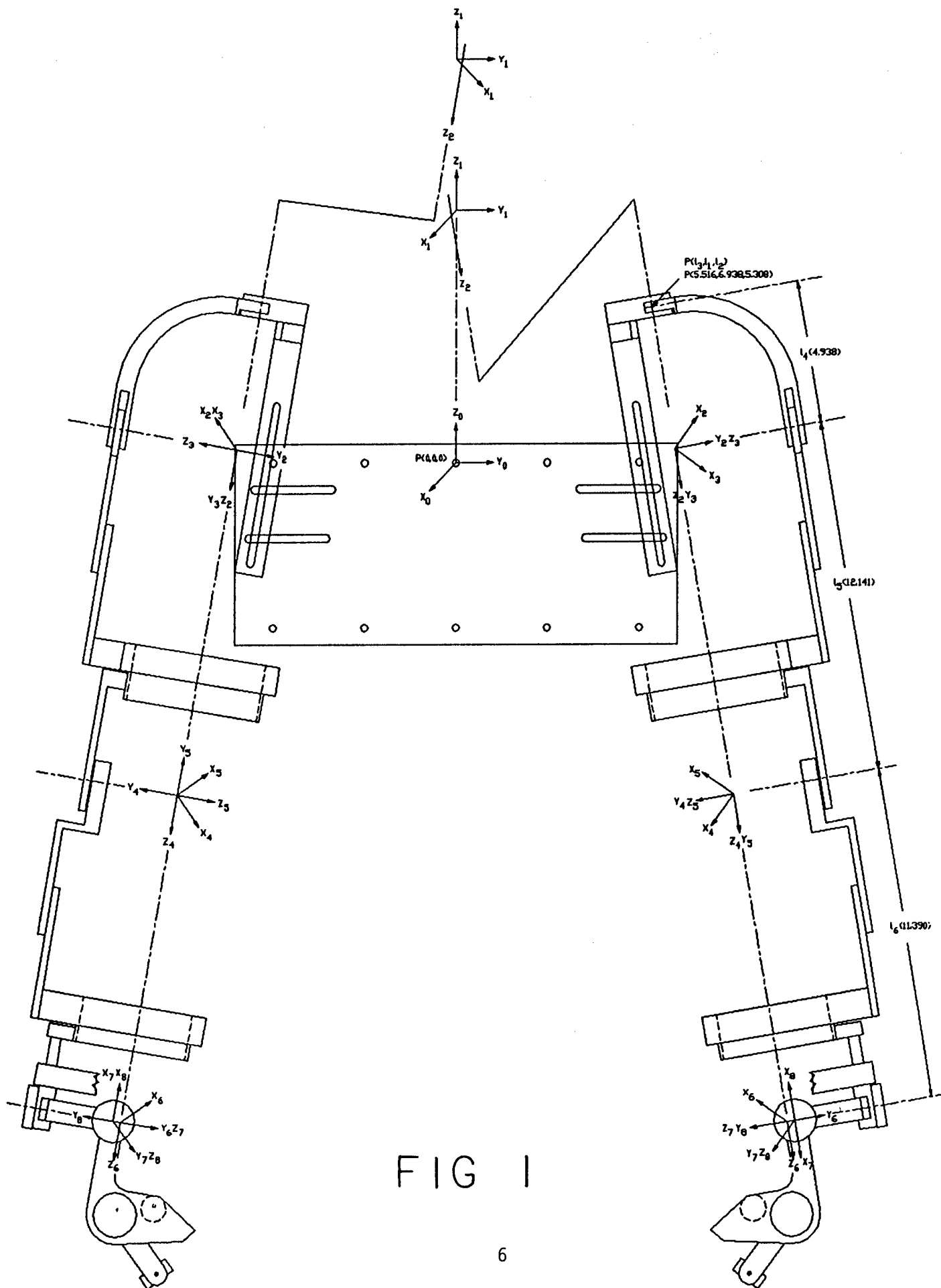


FIG 1

To solve for d_1 ,

$$d_1 = (l_1 + l_2 \tan 9^\circ) / \tan 9^\circ$$

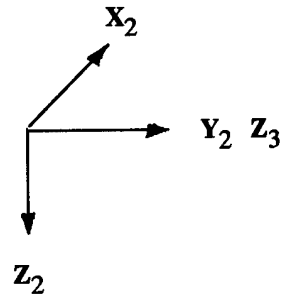
where : (See Figure 1)

- $l_1 = 6.9375$ distance from Z_0 in $+Y_0$ direction
- $l_2 = 5.3075$ distance from Z_0 in $+Z_0$ direction
- $l_3 = 5.5156$ distance from back plate to Z_2 in $+X_0$ direction
- $l_4 = 4.9375$
- $l_5 = 12.141$

$${}^0_1 T = \begin{vmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & (l_1 + l_2 \tan 9^\circ) / \tan 9^\circ \\ 0 & 0 & 0 & 1 \end{vmatrix}$$

Left Frame {2}

Located at Shoulder Azimuth and Shoulder Elevation Axes point of intersection.



$$a_2 = 0$$

$$\alpha_2 = -90^\circ$$

$$d_2 = (l_1 + l_4 \sin 9^\circ) / \sin 9^\circ$$

$$\theta_2 = \text{Shoulder Azimuth Joint}$$

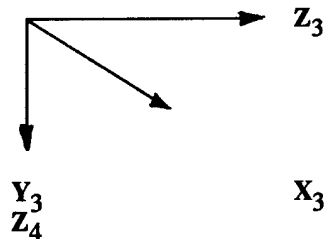
$+90^\circ$ all the way back

$+225.9^\circ$ all the way forward

$${}^1_2 T = \begin{vmatrix} c\theta_2 & -s\theta_2 & 0 & l_3 \\ -s\theta_2(.988) & -c\theta_2(.988) & .156 & .156(l_1 + l_4 \sin 9^\circ) / \sin 9^\circ \\ -s\theta_2(.156) & -c\theta_2(.156) & -.988 & -.988(l_1 + l_4 \sin 9^\circ) / \sin 9^\circ \\ 0 & 0 & 0 & 1 \end{vmatrix}$$

Left Frame {3}

Located at the shoulder Elevation & Upper Arm Roll Intersect.



$$a_3 = 0$$

$$\alpha_3 = -90^\circ$$

$$d_3 = -.0938$$

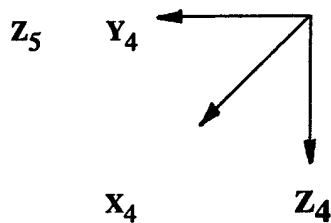
$$\theta_3 = \text{Shoulder Elevation}$$

+178° all the way back
+46.4° all the way forward

$${}^2_3 T = \begin{vmatrix} c\theta_3 & -s\theta_3 & 0 & 0 \\ 0 & 0 & 1 & -.0938 \\ -s\theta_3 & -c\theta_3 & 0 & 0 \\ 0 & 0 & 0 & 1 \end{vmatrix}$$

Left Frame {4}

Located at upper arm roll and elbow intersect.



$$a_4 = 0$$

$$\alpha_4 = -90^\circ$$

$$d_4 = l_5$$

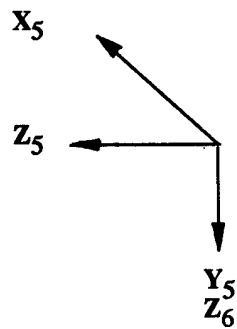
$$\theta_4 = \text{Upper arm Roll}$$

-43.9° cw Hard Stop
173.7° ccw Hard Stop

$${}^3_4 T = \begin{vmatrix} c\theta_4 & -s\theta_4 & 0 & 0 \\ 0 & 0 & 1 & l_5 \\ -s\theta_4 & -c\theta_4 & 0 & 0 \\ 0 & 0 & 0 & 1 \end{vmatrix}$$

Left Frame {5}

Located at Elbow and Lower Arm Roll Intersect



$$a_5 = 0$$

$$\alpha_5 = -90^\circ$$

$$d_5 = -.313$$

$$\theta_5 = \text{Elbow Joint}$$

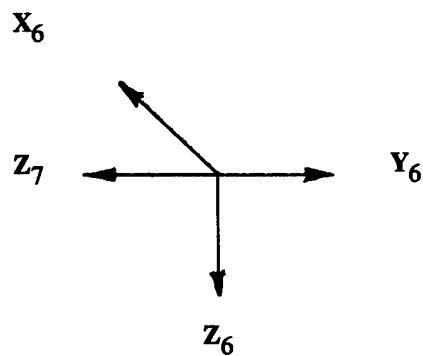
+46° All the way back

+316.1° All the way up

$${}^4_5 T = \begin{bmatrix} c\theta_5 & -s\theta_5 & 0 & 0 \\ 0 & 0 & 1 & -.313 \\ -s\theta_5 & -c\theta_5 & 0 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

Left Frame {6}

Located at Lower Arm Roll and Wrist Radial Intersect



$$a_6 = 0$$

$$\alpha_6 = 90^\circ$$

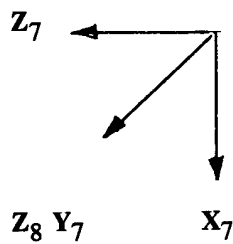
$$d_6 = l_6 = 11.250$$

$$\theta_6 = \text{Lower Arm Roll Joint}$$

$${}^5_6 T = \begin{bmatrix} c\theta_6 & -s\theta_6 & 0 & 0 \\ 0 & 0 & 1 & l_6 \\ -s\theta_6 & -c\theta_6 & 0 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

Left Frame {7}

Located at Wrist Radial and Wrist Flex Intersect

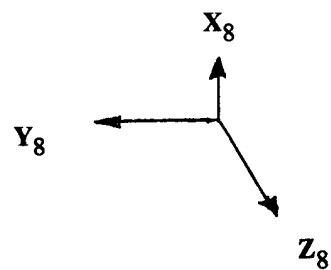


$$\begin{aligned} a_7 &= 0 \\ \alpha_7 &= -90^\circ \\ d_7 &= -.184 \\ \theta_7 &= \text{Wrist Radial} \end{aligned}$$

$${}^6_7 T = \begin{bmatrix} c\theta_7 & -s\theta_7 & 0 & 0 \\ 0 & 0 & -1 & .184 \\ s\theta_7 & c\theta_7 & 0 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

Left Frame {8}

Located at Wrist Flex



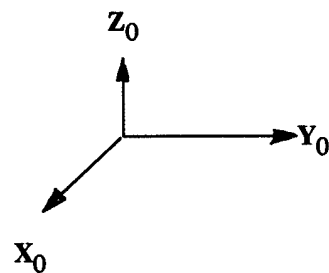
$$\begin{aligned} a_8 &= \text{Not Defined} \\ \alpha_8 &= \text{Not Defined} \\ d_8 &= 0 \\ \theta_8 &= \text{Wrist Flex} \end{aligned}$$

$${}^7_8 T = \begin{bmatrix} c\theta_8 & -s\theta_8 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ -s\theta_8 & -c\theta_8 & 0 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

3.3.2 Right Arm

Reference Frame {0}

The Origin of Reference Frame {0} is at the countersunk screw located top center on the MBA's backplate. (See figure 1)



$$a_0 = 0$$

$$\alpha_0 = 0^\circ$$

$$d_0 = \text{Does not exist}$$

$$\Theta_0 = \text{Does not Exist}$$

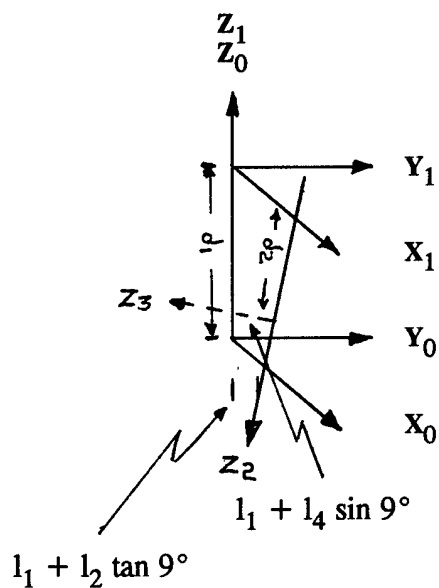
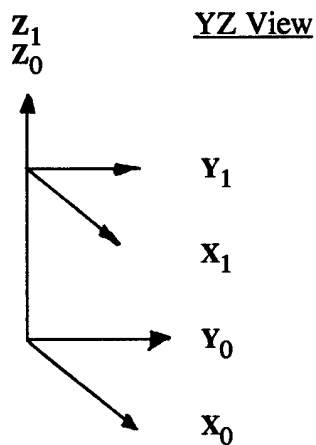
Right Frame {1}

$$a_1 = +l_3$$

$$\alpha_1 = +171^\circ$$

$$d_1 = (l_1 + l_2 \tan 9^\circ) / \tan 9^\circ$$

$$\Theta_1 = 0^\circ$$



To solve for d_1 ,

$$d_1 = (l_1 + l_2 \tan 9^\circ) / \tan 9^\circ$$

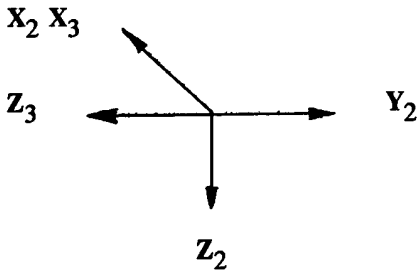
where:

- $l_1 = 6.9375$ distance from Z_0 in $-Y_0$ direction
- $l_2 = 5.3075$ distance in $-Z_0$ direction from Z_0
- $l_3 = 5.5156$ distance in X_0 direction from back plate to Z_2
- $l_4 = 4.9375$
- $l_5 = 12.141$

$${}^0_1 T = \begin{vmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & (l_1 + l_2 \tan 9^\circ) / \tan 9^\circ \\ 0 & 0 & 0 & 1 \end{vmatrix}$$

Right Frame {2}

Located at Shoulder Azimuth and Shoulder Elevation Axes point of intersection.



$$a_2 = 0$$

$$\alpha_2 = 90^\circ$$

$$d_2 = (l_1 + l_4 \sin 9^\circ) / \sin 9^\circ$$

$$\theta_2 = \text{Shoulder Azimuth Joint}$$

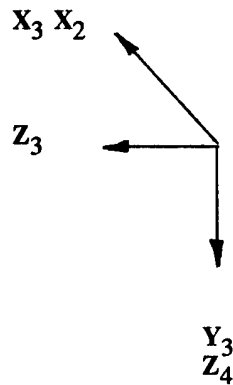
$$+270^\circ \text{ all the way back}$$

$$+134.1^\circ \text{ all the way forward}$$

$${}^l_2 T = \begin{vmatrix} c\theta_2 & -s\theta_2 & 0 & +l_3 \\ -s\theta_2(.988) & -c\theta_2(.988) & .156 & .156(l_1 + l_4 \sin 9^\circ) / \sin 9^\circ \\ -s\theta_2(.156) & -c\theta_2(.156) & -.988 & -.988(l_1 + l_4 \sin 9^\circ) / \sin 9^\circ \\ 0 & 0 & 0 & 1 \end{vmatrix}$$

Right Frame {3}

Located at the shoulder Elevation & Upper Arm Roll Intersect.

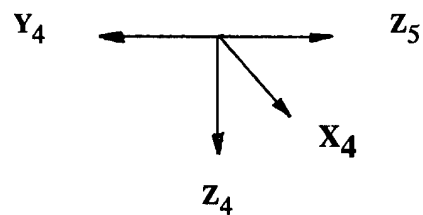


$$\begin{aligned} a_3 &= 0 \\ \alpha_3 &= -90^\circ \\ d_3 &= -.032 \\ \theta_3 &= \text{Shoulder Elevation} \\ &+2^\circ \text{ back} \\ &+133.6^\circ \text{ forward} \end{aligned}$$

$${}^2_3 T = \begin{bmatrix} c\theta_3 & -s\theta_3 & 0 & 0 \\ 0 & 0 & -1 & -.032 \\ -s\theta_3 & c\theta_3 & 0 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

Right Arm Frame {4}

Located at upper arm roll and elbow intersect.

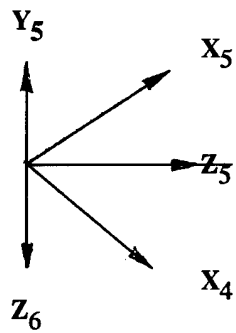


$$\begin{aligned} a_4 &= 0 \\ \alpha_4 &= 90^\circ \\ d_4 &= l_5 \\ \theta_4 &= \text{Upper arm Roll} \\ &0^\circ \text{ Rotated Inward} \\ &217.6^\circ \text{ Rotated Outward} \end{aligned}$$

$${}^3_4 \mathbf{T} = \begin{vmatrix} c\theta_4 & -s\theta_4 & 0 & 0 \\ 0 & 0 & 1 & l_5 \\ -s\theta_4 & -c\theta_4 & 0 & 0 \\ 0 & 0 & 0 & 1 \end{vmatrix}$$

Right Frame {5}

Located at Elbow and Lower Arm Roll Intersect



$$a_5 = 0$$

$$\alpha_5 = 90^\circ$$

$$d_5 = 0$$

$$\theta_5 = \text{Elbow Joint}$$

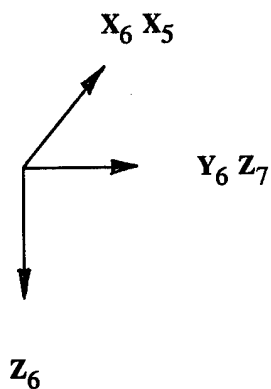
+46° All the way up

+316.1° All the way back

$${}^4_5 \mathbf{T} = \begin{vmatrix} c\theta_5 & -s\theta_5 & 0 & 0 \\ 0 & 0 & -1 & 0 \\ s\theta_5 & c\theta_5 & 0 & 0 \\ 0 & 0 & 0 & 1 \end{vmatrix}$$

Right Arm Frame {6}

Located at Lower Arm Roll and Wrist Radial Intersect

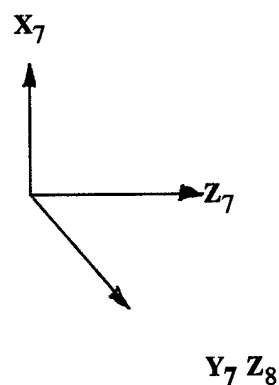


$a_6 = 0$
 $\alpha_6 = -90^\circ$
 $d_6 = l_6 = 11.330$
 $\theta_6 = \text{Lower Arm Roll Joint}$
 Range of Motion:
 -97.32° Inward
 119.91° Outward

$${}^5_6 T = \begin{bmatrix} c\theta_6 & -s\theta_6 & 0 & 0 \\ 0 & 0 & -1 & -l_6 \\ s\theta_6 & c\theta_6 & 0 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

Frame {7}

Located at Wrist Radial and Wrist Flex Intersect

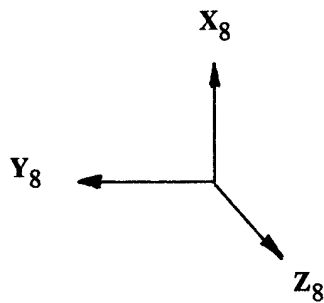


$a_7 = 0$
 $\alpha_7 = -90^\circ$
 $d_7 = -.160$
 $\theta_7 = \text{Wrist Radial}$
 73.84° Up
 105.57° Down

$${}^6_7 \mathbf{T} = \begin{vmatrix} c\theta_7 & -s\theta_7 & 0 & 0 \\ 0 & 0 & 1 & -.160 \\ -s\theta_7 & -c\theta_7 & 0 & 0 \\ 0 & 0 & 0 & 1 \end{vmatrix}$$

Frame {8}

Located at Wrist Flex



$a_8 = \text{Not Defined}$

$\alpha_8 = \text{Not Defined}$

$d_8 = 0$

$\theta_8 = \text{Wrist Flex}$

-47.35° Outward

42.74° Inward

$${}^7_8 \mathbf{T} = \begin{vmatrix} c\theta_8 & -s\theta_8 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ -s\theta_8 & -c\theta_8 & 0 & 0 \\ 0 & 0 & 0 & 1 \end{vmatrix}$$

4.0 Inverse Kinematics for Merlin Robot

The position of Merlin's wrist (coincident origins of frames $\{4\}\{5\}\{6\}$) with respect to Merlin's fixed reference frame $\{0\}$ is driven by the position of MBA frame $\{6\}$ origin (wrist radial) with respect to MBA's fixed reference frame $\{0\}$.

Orientation of Merlin's wrist (tool roll frame $\{6\}$) with respect to Merlin's fixed reference frame $\{0\}$ driven by the orientation of the MBA exoskeleton's wrist (wrist flex frame $\{8\}$ with respect to the MBA's exoskeleton's fixed reference frame $\{0\}$.

4.1 Approach

Merlin's wrist position determined by driving Merlin's frames $\{1\}$ (waist), $\{2\}$ (shoulder), and $\{3\}$ (elbow) directly from the results of the following inverse kinematics.

Utilize Z-Y-Z Euler angle convention to describe Merlin's wrist orientations. Z-Y-Z Euler angles with respect to Merlin's elbow frame $\{3\}$ can be used directly to drive Merlin's wrist roll, wrist flex & tool roll revolute joints $\Theta_4, \Theta_5, \Theta_6$ respectively. Derivation of Z-Y-Z Euler angles to describe the MBA's wrist (wrist flex frame $\{8\}$) starting with MBA $\{8\}$ coincident with MBA elbow frame $\{5\}$ will result in an orientation of the Merlin wrist $\{6\}$ different from the MBA wrist $\{8\}$. Therefore, a phantom frame $\{A\}$ was defined on the MBA with an origin coincident at MBA $\{6\}$. Now the orientation of MBA frame $\{8\}$ wrist flex can be described by Z-Y-Z Euler angles from frame $\{A\}$, thereby yielding results that can be used directly to drive Merlin's $\Theta_4, \Theta_5, \Theta_6$ to orient Merlin's wrist.

MBA Exoskeleton

$\{5\}$ = elbow
 $\{A\}$ =
 $\{8\}$ = wrist flex

Want : $Global_0R$ =

Know : ${}^0_5R$ ${}^0_3R$

Need : ${}^0_AR$ = ${}^0_3R$

Solve for:

$${}^0_AR = {}^0_5R {}^5_AR = {}^0_3R$$

$${}^5_AR = {}^0_5R^{-1} {}^0_3R$$

Need : A_8R

Know : ${}^5_8R$ & ${}^5_AR$

So :

$$A_8R = A_5R {}^5_8R$$

Solve for:

$$A_5R = {}^5_AR^{-1}$$

Then:

$$A_8R = \begin{vmatrix} r_{11} & r_{12} & r_{13} \\ r_{21} & r_{22} & r_{23} \\ r_{31} & r_{32} & r_{33} \end{vmatrix} = R_{z y z} (\alpha, \beta, \tau)$$

$$\beta = \text{Atan2} (\sqrt{r_{31}^2 + r_{32}^2}, r_{33}) = \text{wrist flex } (\Theta_4)$$

$$\alpha = \text{Atan2} (r_{23} / \sin \beta, r_{13} / \sin \beta) = \text{wrist roll } (\Theta_5)$$

$$\tau = \text{Atan2} (r_{32} / \sin \beta, -r_{31} / \sin \beta) = \text{tool roll } (\Theta_6)$$

Merlin Robot

$\{3\}$ = elbow

4.2 High Speed Host Interface

The High Speed Host Interface developed by American Cimflex provides a parallel shared memory interface between the Compaq 386 host controller computer and the Merlin controller's master CPU. The HSHI software, executing on the Merlin controller's master CPU board, performs motion related commands and provides status for each robot joint.

4.3 Hardware and Configuration

The American Cimflex MR6500 Merlin robot is equipped with stepper type motors for each of the six joints. The Waist, Shoulder, and Elbow joints are actuated with Sigma 802-D42-802-8780 steppers, and the three wrist joints are actuated by Sigma 802-D28698 steppers. Sigma Motion Control Products was bought out by Pacific Scientific in Rockford, IL 815-226-3100.

The Bit3 PC/AT to VME link is configured with Dual Port Ram (DPR) located at address 100000H on VME board. Jumper diagrams appear in Appendix C. Note: PC Memory extension software drivers such as EMM386 may not be compatible with PC side of Bit3. (See Reference [6] Bit3 IBM PC/AT VME Adaptor Model 403 Manual)

HAL Engineering VME to Versabus Adapter Card installed in Merlin Control Cabinet Versabus. Bit3 VME card is installed into Adapter card.

HSHI Eproms (2716 2Kx8) must be installed for each axis on Merlin's Axis Control Boards. (See Reference [4] HSHI Manual)

Editing a HSHI Executive System Disk

(See Reference [4] ARBASIC Manual)

- 1) MAGIX SYSTEMS DISK in Merlin Controller's DRIVE 0
- 2) AR-BASIC in DRIVE 1
- 3) Front Panel key switch in "PROG" position
- 4) Power on Merlin Controller Circuit Breaker
- 5) Depress Front Panel "Power On" button
- 6) MAGIX OS and AR-BASIC will auto-load
- 7) If Front Panel "CAL" button blinks, Merlin's calibration procedure must be performed by engaging the motors and pressing the Front Panel "CAL" button. Merlin will jostle all joints and return AR-BASIC prompt "<" on the CRT.
- 8) With the AR-BASIC prompt "<" on the CRT, replace the AR-BASIC disk with the HSHI disk to be edited.

- 9) To tell MAGIX OS to track disk changes, type "F LIST /etc/"
- 10) Type "LOAD /usr/etc/sysexec.def". The HSHI Executive System file contents will appear on the CRT's top window.
- 11) To edit the file for the HSHI Menu Option:
 - Press "F1" to enter CRT edit window
 - Edit the file as follows:

```

!
! boot HSHI initially ...
! Echo Booting HSHI
!   hshi -m 100000
!   Kill JOAN
! Host mode
      
```
- 12) To edit the file for auto-boot of HSHI Host mode @ power-on


```

!
! boot HSHI initially ...
! Echo Booting HSHI
!   hshi -m 100000
!   Kill JOAN
! Host mode
      
```
- 13) Press "F1" to return to AR-BASIC's command line on CRT
- 14) Type "SAVE /usr/etc/sysexec.def"
- 15) Type "M DELETE \$pgm" to remove file from editor memory
- 16) Type "BYE" to exit AR-BASIC

4.4 Troubleshooting

Merlin Robot

Sympton - Joint drifts/ non responsive

Correction - If green LED on motor controller card is not "on", replace/repair motor controller card.

- If green LED on motor controller card is "on", remate all motor and encoder connectors in junction box at robot base.

Intecolor 2400 Series Terminal

Refer to "Maintenance Manual for Intecolor 2400 Series Terminals with ColorTrend 220 Supplement"

5.0 Host Controller Compaq 386 33MHz

5.1 Hardware and Configuration

(See Figure 2)

A Compaq 386 33 MHz desktop PC serves as the system host controller, software development computer and operator interface to the testbed.

The MBA exoskeleton is linked to the system host via a 38.4 K bits/sec RS-422 asynchronous serial link.

The Merlin robot controller is linked to the system host through a parallel link using dual port ram provided by a Bit 3 Model 403 PC/AT-VME Adaptor.

The JR3 Univeral Force/Moment System is linked to the system host controller via a 9600 bits/sec RS-232 asynchronous serial link.

5.2 MBA/Merlin control program

Program execution times for **merlin.exe** on a Compaq 386 33 Mhz computer with floating point numeric coprocessor:

- MBA exoskeleton's forward kinematic algorithm	0.732 mS
- Merlin robot inverse kinematic algorithm	0.960 mS
- Serial transmission time to transfer 7 joint angle readings from exoskeleton right arm. This time is transparent to total control loop time as it is interrupt driven. 7 joints * 2 integer bytes/joint * 10 bits/integer value transmitted * 38.4 Kbits/sec	(3.64 mS)
- Time for serial interrupt servicing, pre-processing of joint angle readings for forward kinematics, limit and error checking on inverse kinematic results and operator display updates.	8.18 mS
Total control loop time	9.87 mS

The 9.87 mS (101 Hz) total control loop time is greater than the Merlin's 4 mS (250 Hz) servo loop time achievable under optimal HSHI operation. This difference in loop times means the Merlin is not receiving motor encoder servo values fast

MBA/MERLIN TESTBED BLOCK DIAGRAM

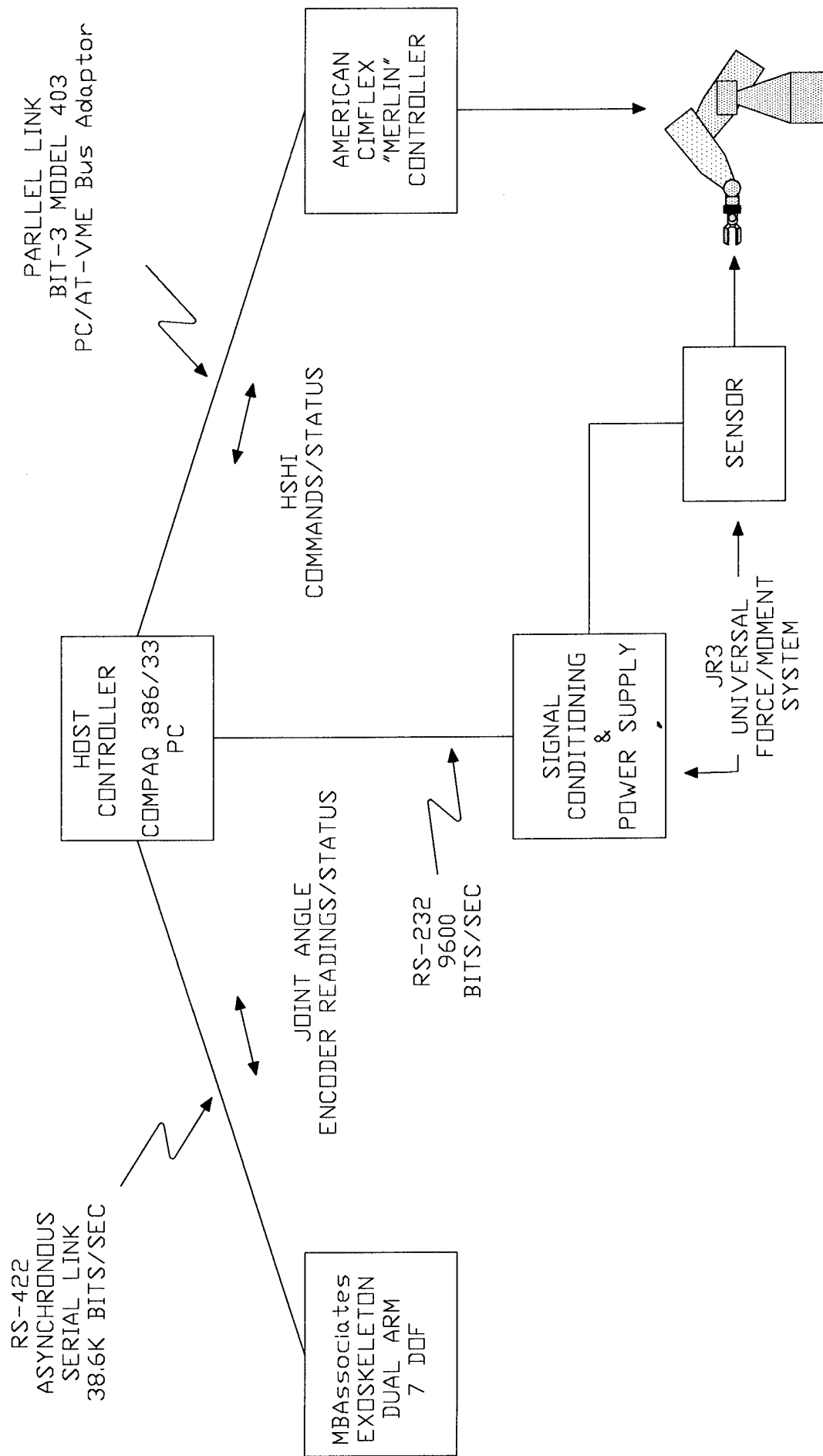


Figure 2

enough from the host controller. Better real time response in positioning motions may result by decreasing this difference to slightly less than 8ms or 4ms to hit the Merlin's 4ms update window.

6.0 JR3 Universal Force/Moment Sensor System

A six axis force/moment sensor system mounted on the Merlin's tool faceplate, provides 3 force components (F_x, F_y, F_z) and 3 moment components (M_x, M_y, M_z) from the Merlin's end effector interaction with its environment. Additionally, the sensor is used as a safety limit device to avoid damage to the Merlin's gripper and/or a testbed fixture. Force/Moment data is transmitted to the host system controller via a 9600 bits/sec RS-232 serial link.

7.0 Suggestions for Future Work

Currently, course positioning experiments using the MBA exoskeleton to control the Merlin robot are somewhat limited by the response of the Merlin to rapid changes in position. With the Merlin end effector's position and orientation controlled by individual joint axis controllers servoing only to achieve a commanded motor encoder count (motor shaft position) using a fixed velocity profile, Merlin's end effector response is degraded by velocity lag or positional overshoot.

The HSHI option provides a Motor Velocity Command that could be utilized to improve Merlin's response. This would require the host system controller (Compaq 386) to close the control loop on the robot side by commanding the Merlin's individual joint axis controllers to achieve wrist position/velocity and end effector orientation/angular velocity. Merlin motor shaft position would be used in the servo loop.

8.0 References

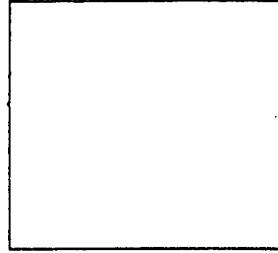
- [1] Craig, John J. Introduction to Robotics: Mechanics and Control Reading, Massachusetts: Addison-Wesley Publishing Co., 1986
- [2] D'Souza, A. Frank/ Vijay K. Garg Advanced Dynamics Modeling and Analysis Englewood Cliffs, New Jersey: Prentice-Hall Inc. 1984
- [3] "Operations and Maintenance Manual Manipulator Arms System," MBA MBAssociates, San Ramon, CA, 6 April 1976
- [4] American Cimflex Operating/ARBASIC/Service/HSHI Manuals
- [5] JR3 Universal Force/Moment Sensor System Manual
- [6] Bit3 Corporation IBM PC/AT VME Adaptor Model 403 Manual.

9.0 Appendix A: MBAssociates Backpack

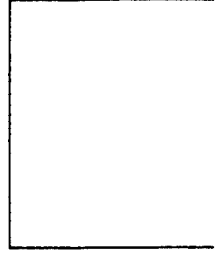
9.1 Electronic Schematics

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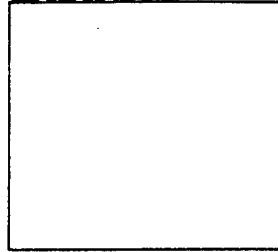
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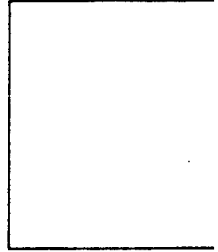
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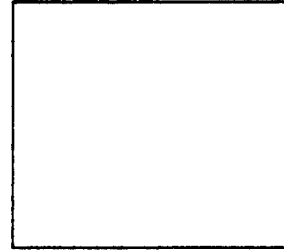
LINK FROM AND LINK FROM



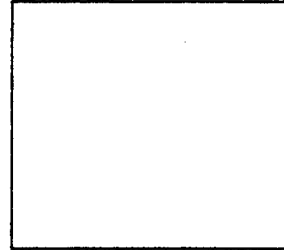
POPPED SWITCHES



ROUTER BOARD LAYOUT



MBA PARTS LIST



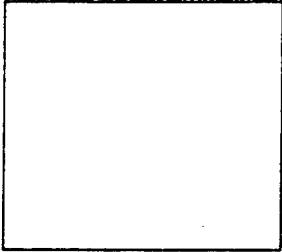
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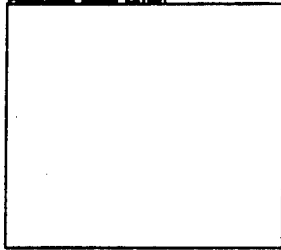
COUNTER, STRIPPER, LED, FOUR PHASE CLK



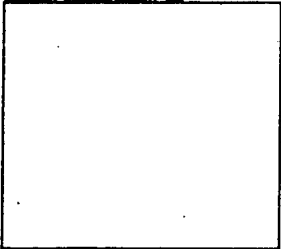
PROC., SERIAL I/O, SENS. BATT., HALT/RESET



PROCESSOR BOARD LAYOUT



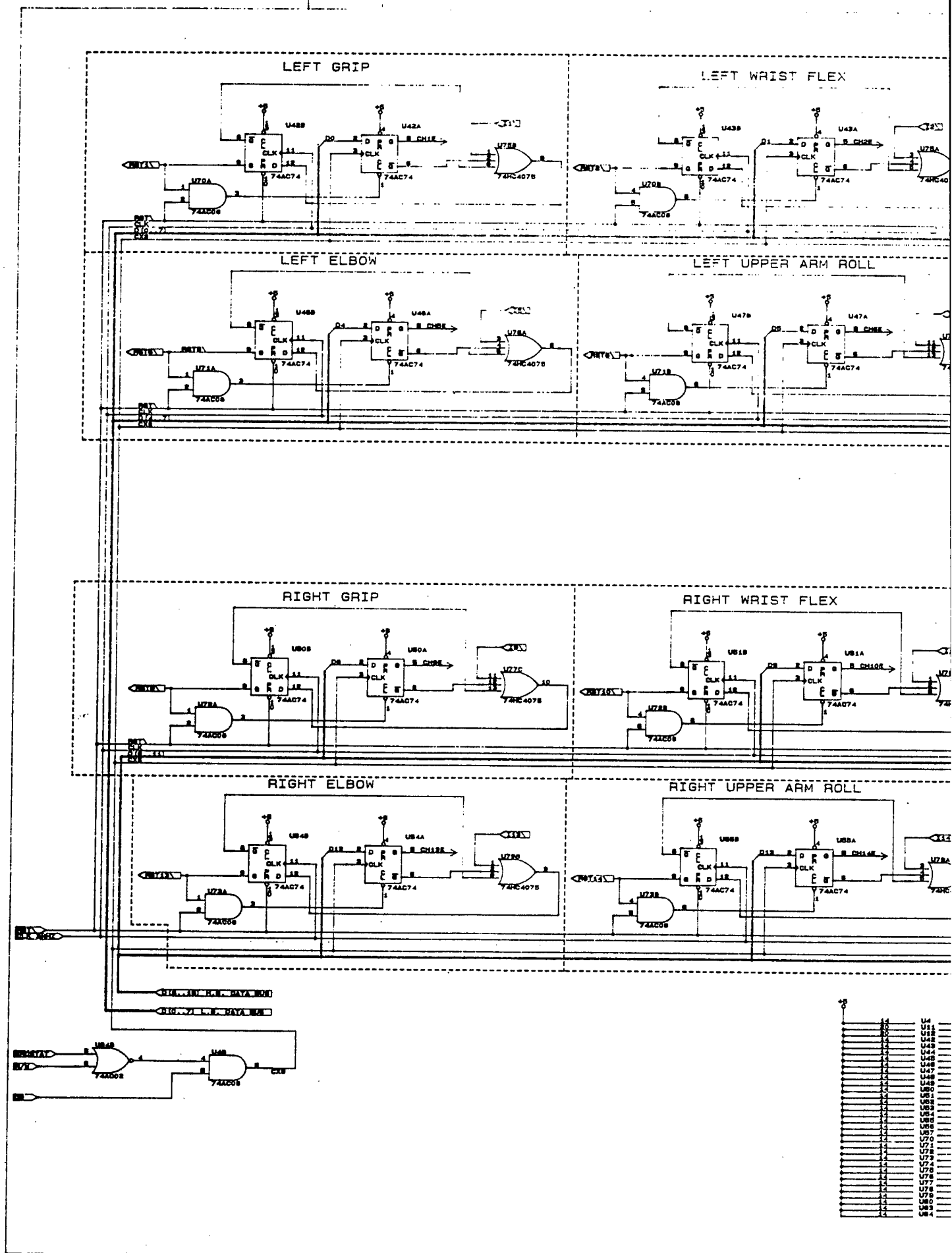
PROCESSOR VISION/IMAGERY MAP

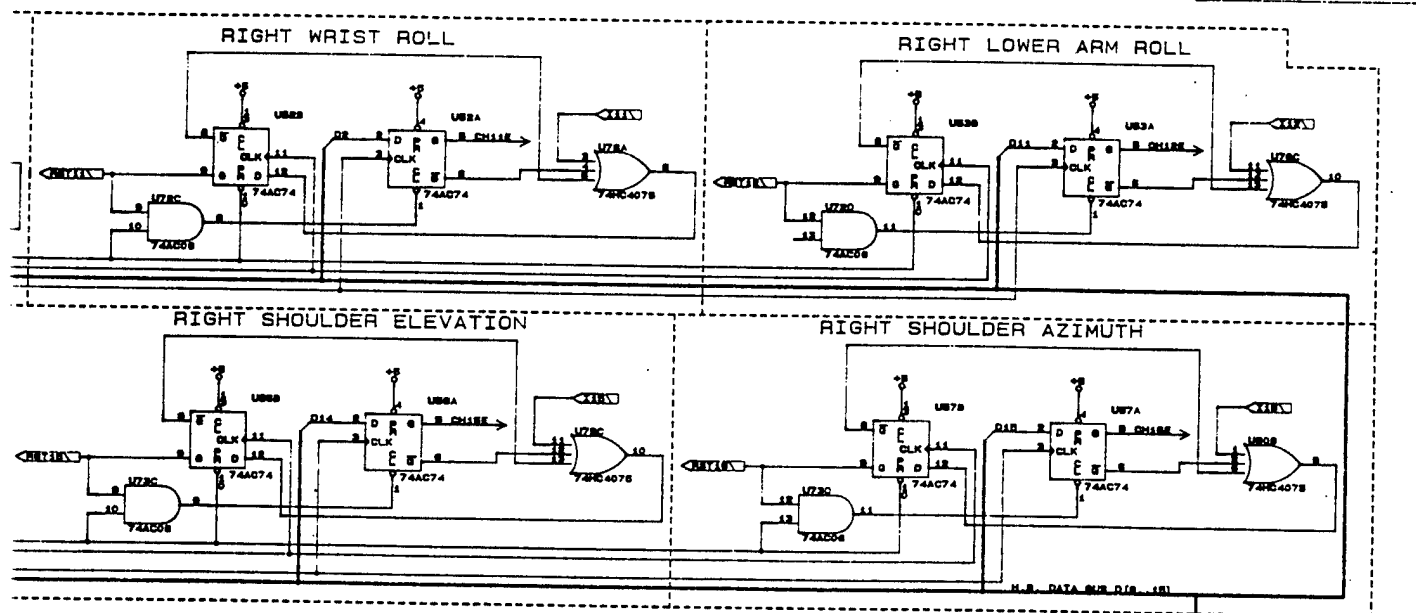
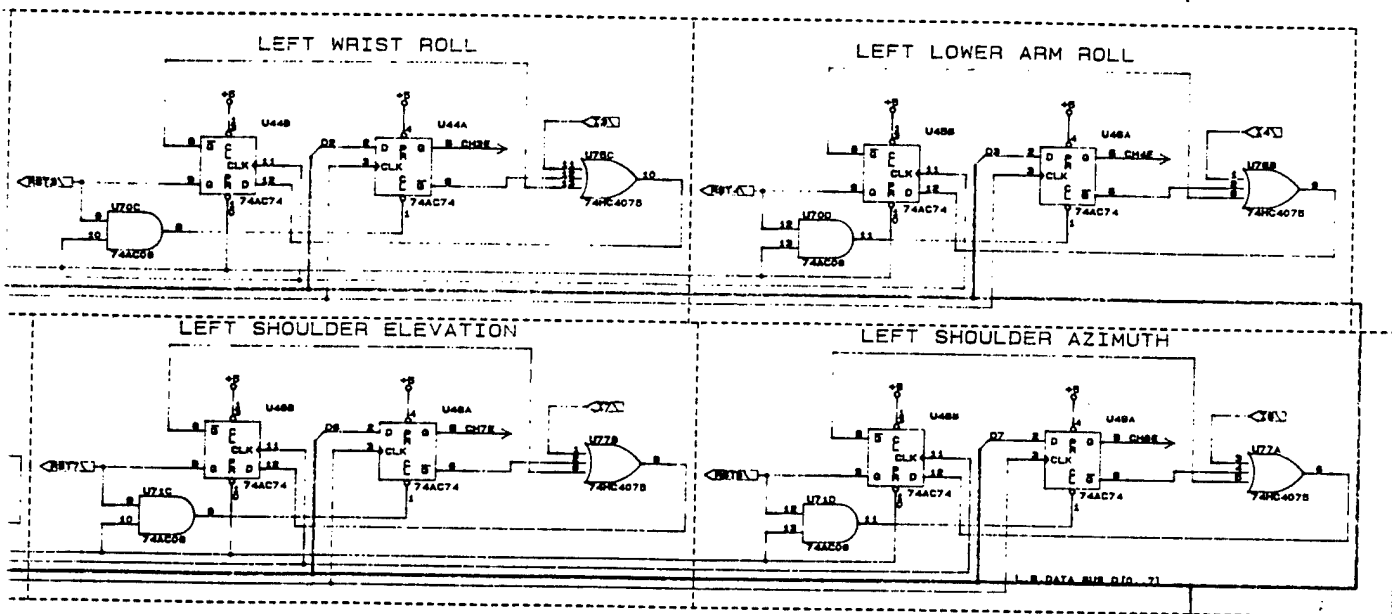


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DATE: DEC. 8, 1989		SHEET 1 OF 11	

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2





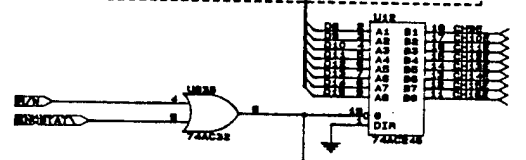
DECOUPLING CAPACITORS VCC TO VSS

PACKAGE

14
20

CAP VALUE

.02uF
.03uF



SYSTEMS RESEARCH LABS

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SIZE DOCUMENT NUMBER
D ROBOTICS TELEPRESENCE

DATE: MARCH 17, 1989

SHEET 2 OF 11

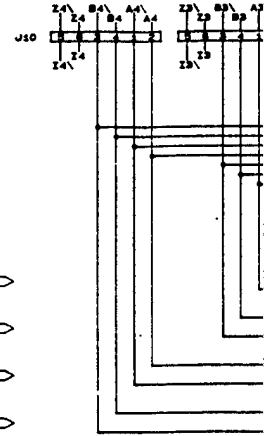
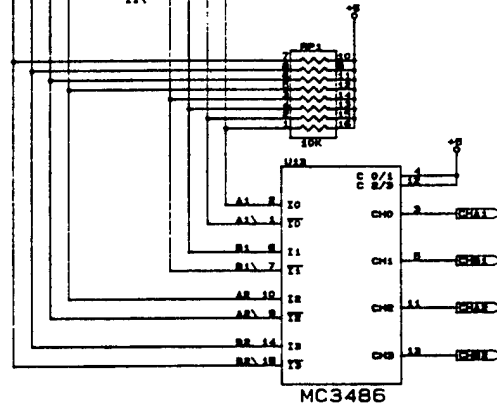
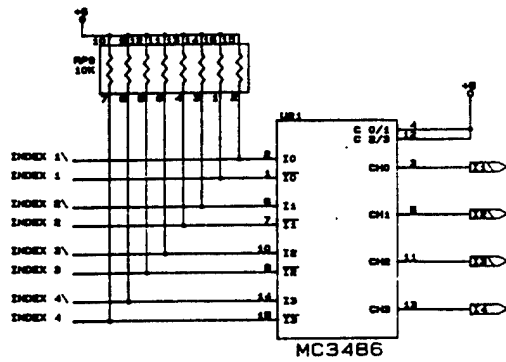
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WRIST FLEX

GRIP

LOWER ARM ROLL WRIST

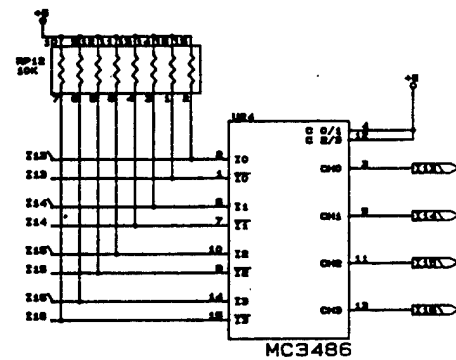
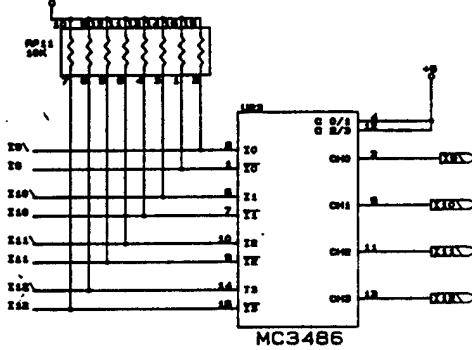
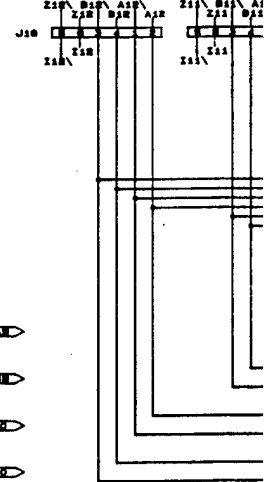
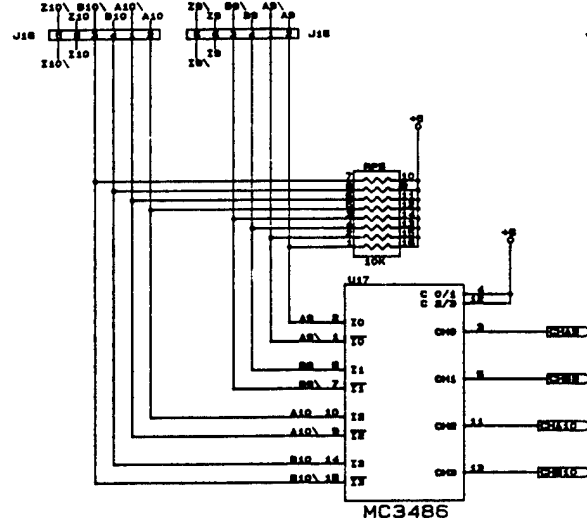
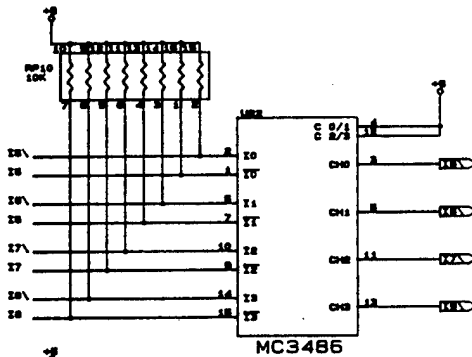


RIGHT ENCODERS

WRIST FLEX

GRIP

LOWER ARM ROLL WRIST



DECOUPLING CAPACITORS VCC TO VSS

PACKAGE

16

CAP VALUE

.03uF

16	U13	8
16	U14	8
16	U15	8
16	U16	8
16	U17	8
16	U18	8
16	U19	8
16	U20	8
16	U21	8
16	U22	8
16	U23	8
16	U24	8

J1
1
3
5
7
9
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1
3
5
7
9
11
13
15
17
19
2, 4

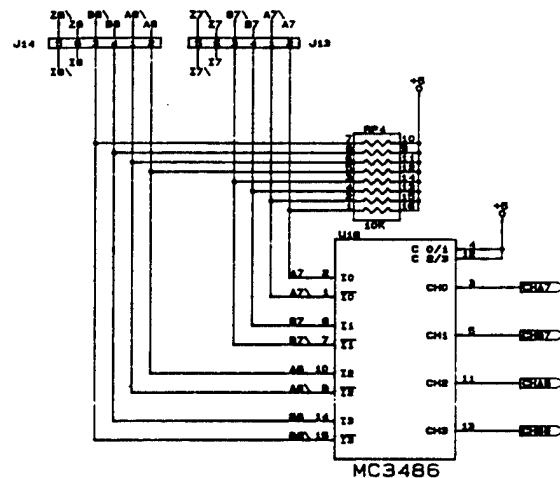
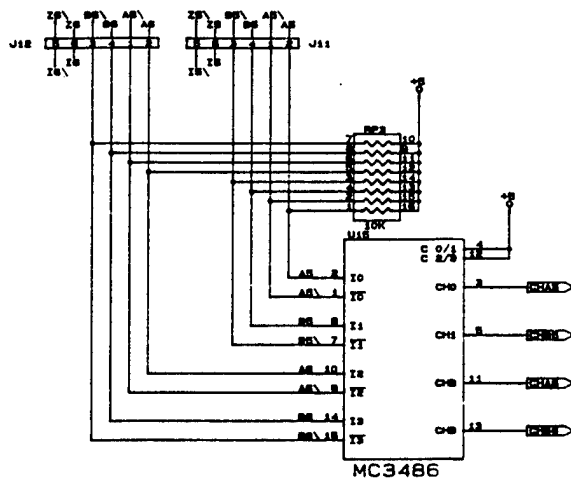
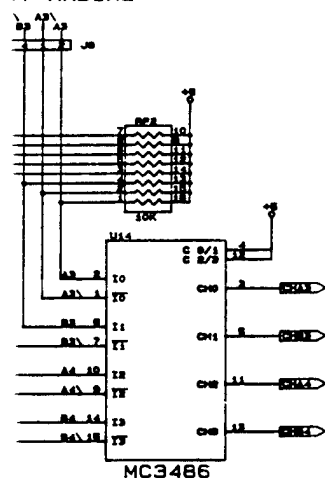
ST RADIAL

UPPER ARM ROLL

ELBOW

SHOULDER AZIMUTH

SHOULDER ELEVATION



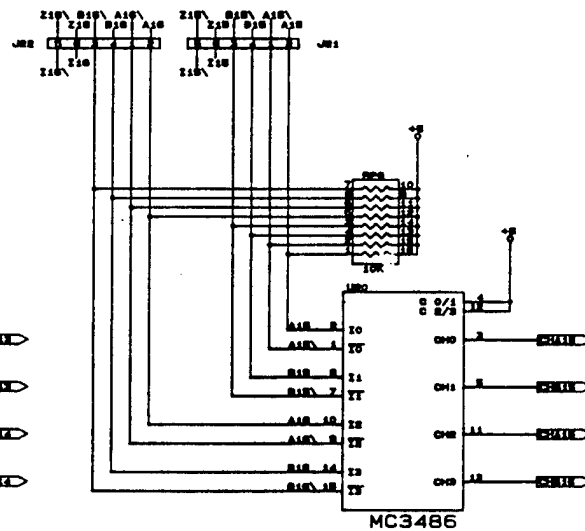
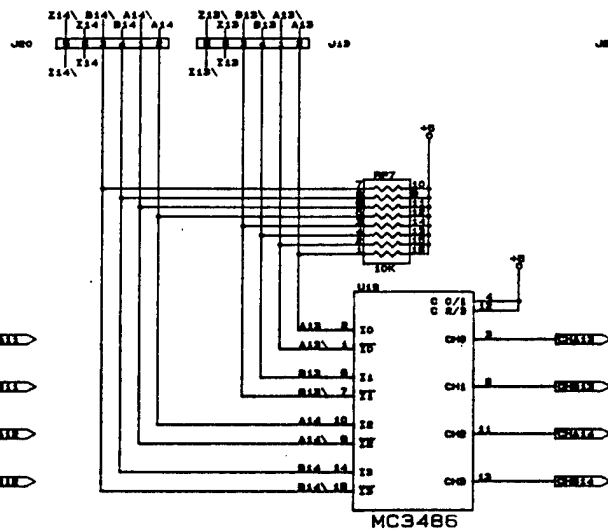
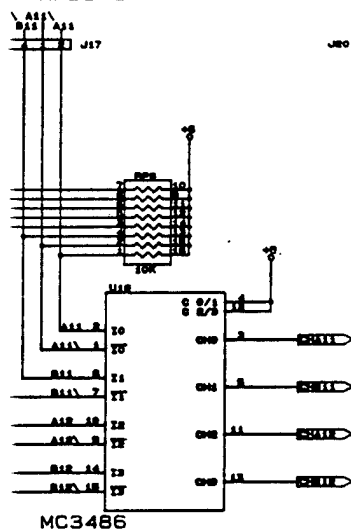
T RADIAL

UPPER ARM ROLL

ELBOW

SHOULDER AZIMUTH

SHOULDER ELEVATION



BOARD TO BOARD CONNECTIONS

1	SIGNAL NAME
1	D0
1	D1
1	D2
1	D3
1	D4
1	D5
3	D6
3	D7
7	N/C
3	N/C
4, 6...20 - SIGNAL GND	

J3	SIGNAL NAME
1	A1
3	A2
5	A3
7	A4
9	N.C.
11	N.C.
13	N.C.
15	N.C.
17	N.C.
19	N.C.
2, 4, 6...20 - SIGNAL GND	

2	SIGNAL NAME
1	12MHZ
1	R/W\
1	D5
1	N.C.
1	R/W
3	PH4\
3	RST\
3	ENCNT\
3	ENCSTAT\
3	GRIPLED\
4, 6...20 - SIGNAL GND	

J4	SIGNAL NAME
1	D8
3	D9
5	D10
7	D11
9	D12
11	D13
13	D14
15	D15
17	N.C.
19	N.C.
2, 4, 6...20 - SIGNAL GND	

SYSTEMS RESEARCH LABS

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SIZE D DOCUMENT NUMBER ROBOTICS TELEPRESENCE REV

DATE: MARCH 17, 1989 SHEET 3 OF 11

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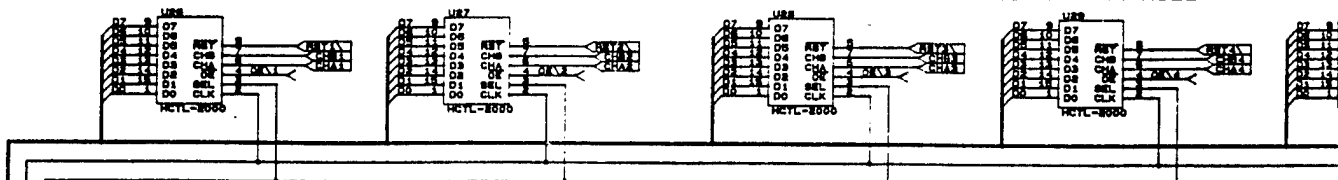
LEFT

GRIP

WRIST FLEX

WRIST RADIAL

LOWER ARM ROLL



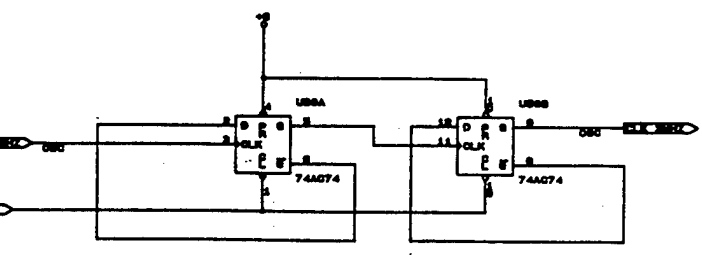
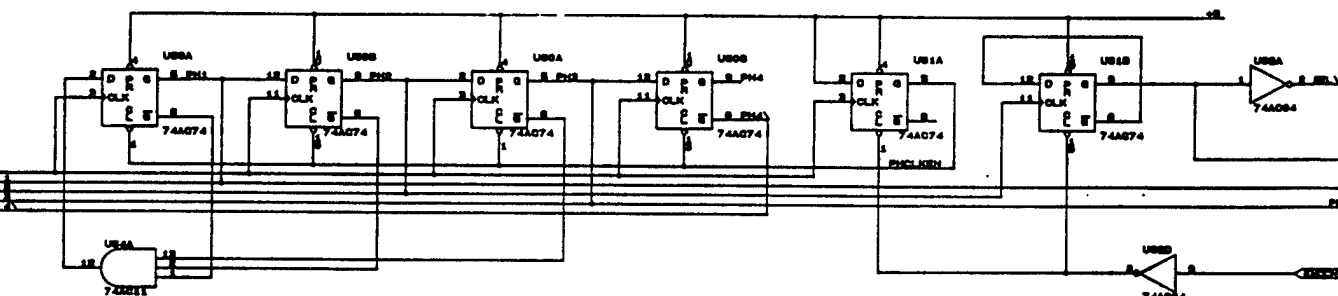
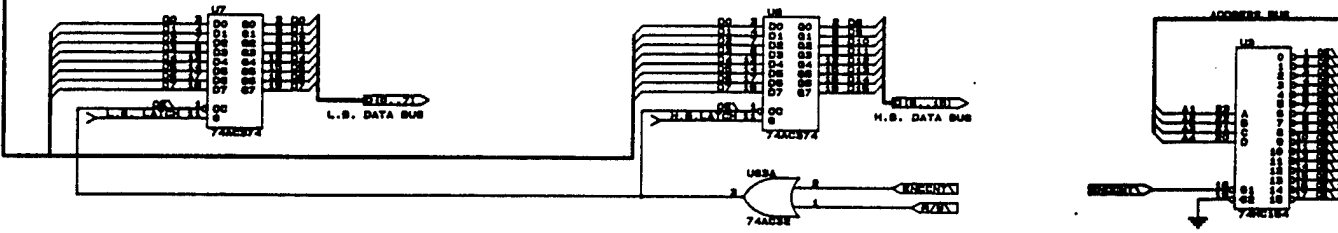
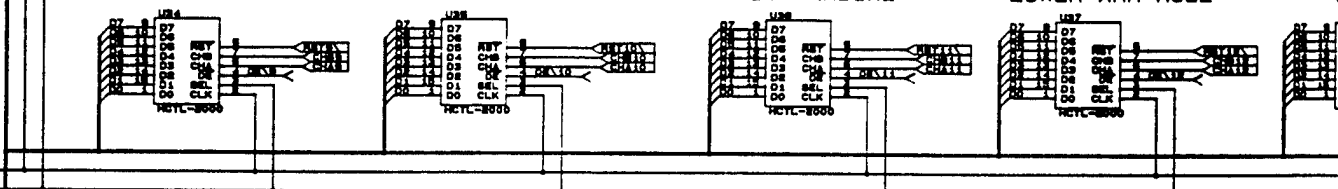
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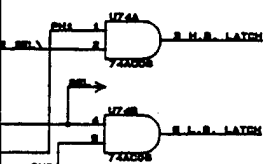
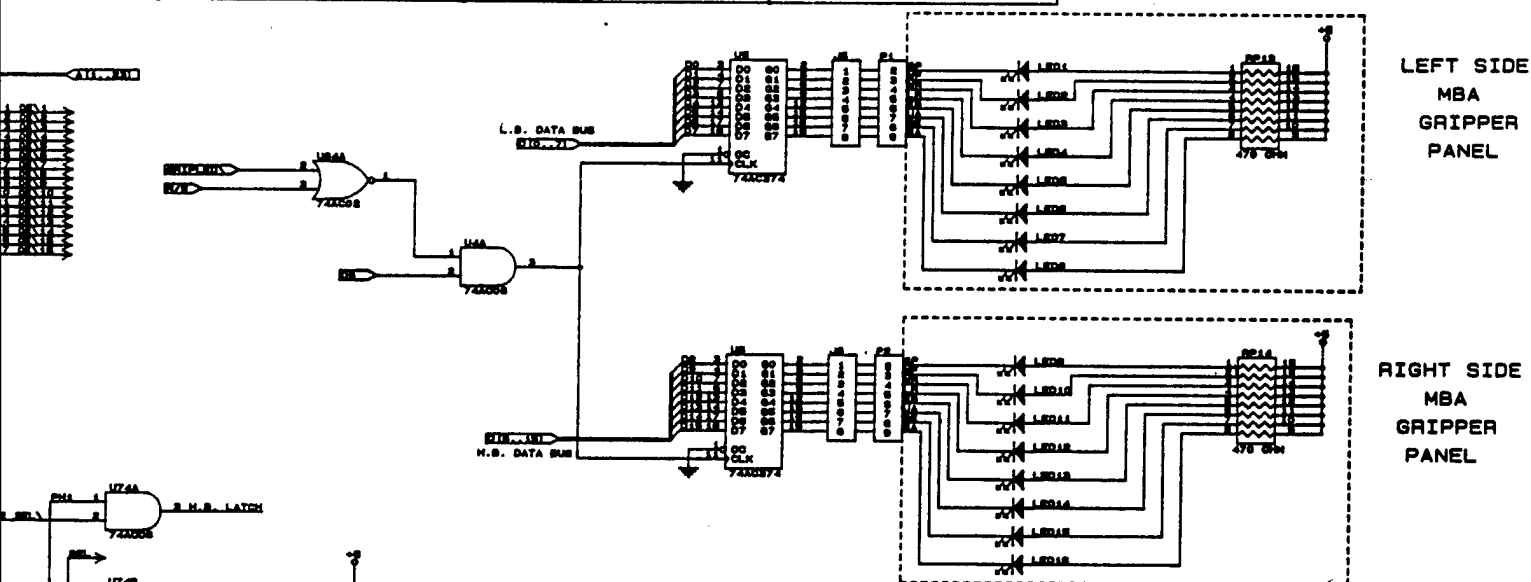
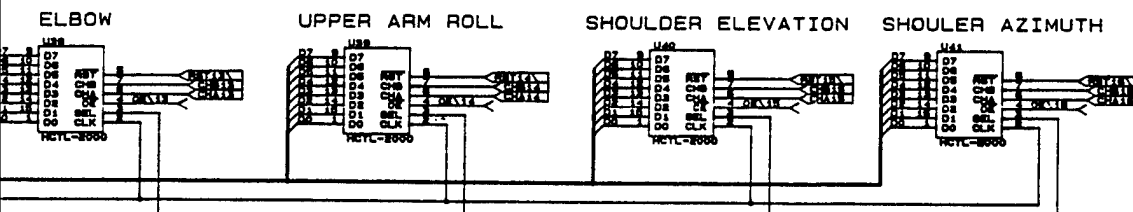
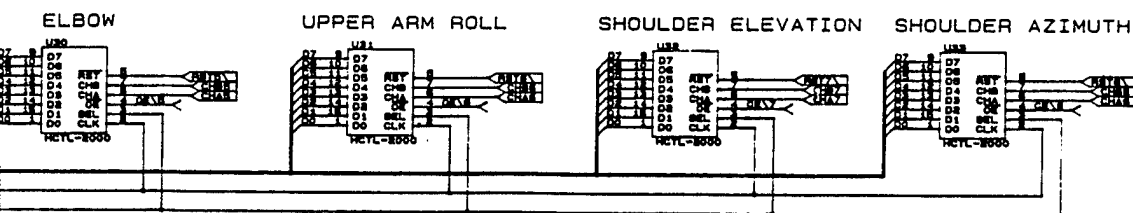
GRIP

WRIST FLEX

WRIST RADIAL

LOWER ARM ROLL





24	U3	12
20	U5	10
20	U6	10
20	U7	10
20	U8	10
16	U26	8
16	U27	8
16	U28	8
16	U29	8
16	U30	8
16	U31	8
16	U32	8
16	U33	8
16	U34	8
16	U35	8
16	U36	8
16	U37	8
16	U38	8
16	U39	8
16	U40	8
16	U41	8
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14	U61	7
14	U62	7
14	U64	7
14	U74	7

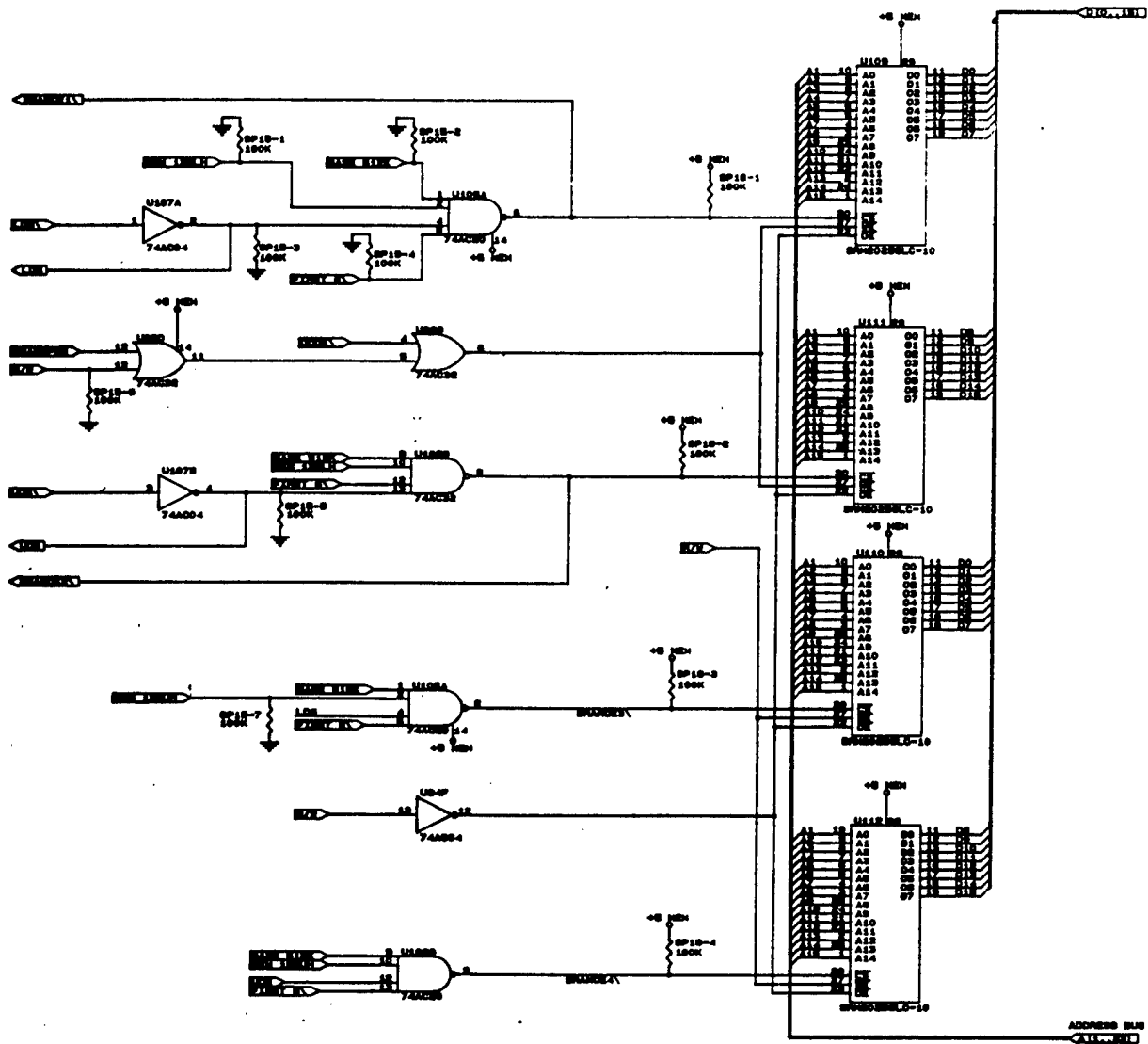
DECOUPLING CAPACITORS VCC TO VSS

PACKAGE	CAP VALUE
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20	.03
16	.03
14	.02

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DATE: MARCH 17, 1989	SHEET	4 OF 11

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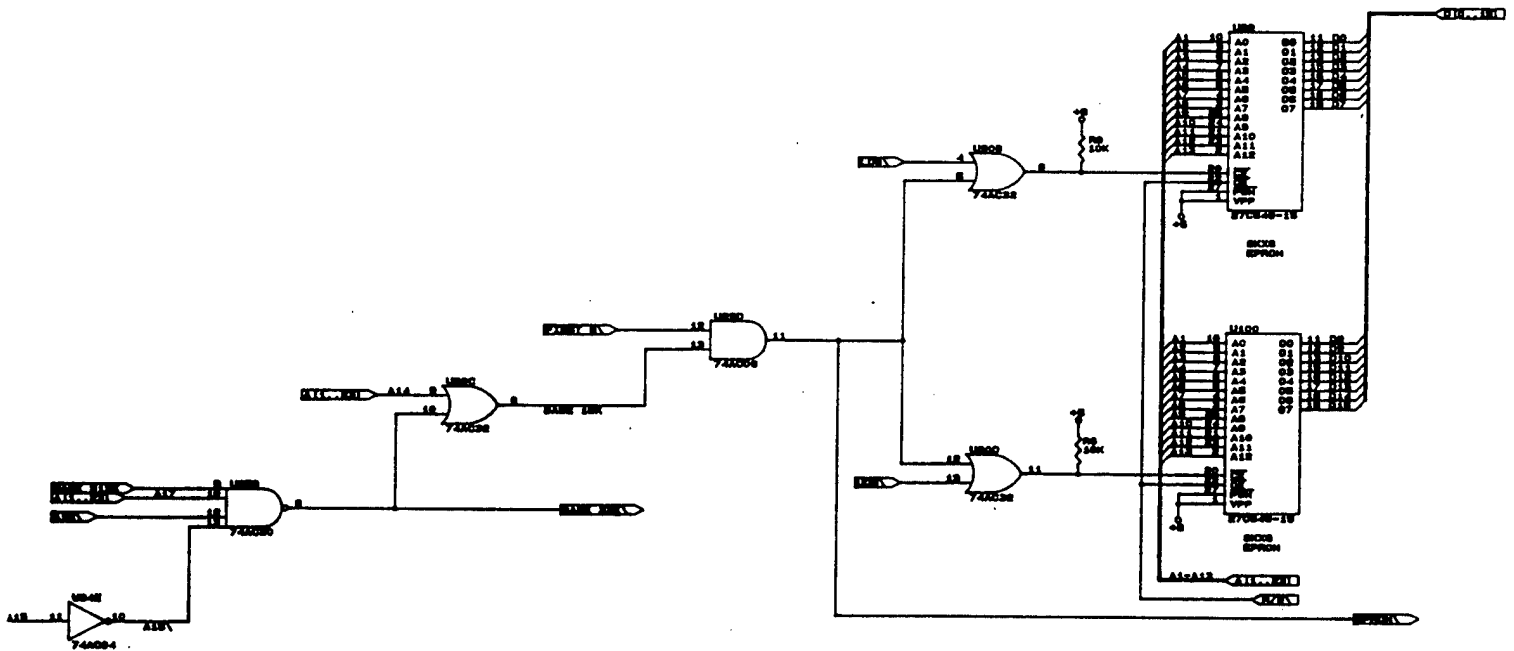
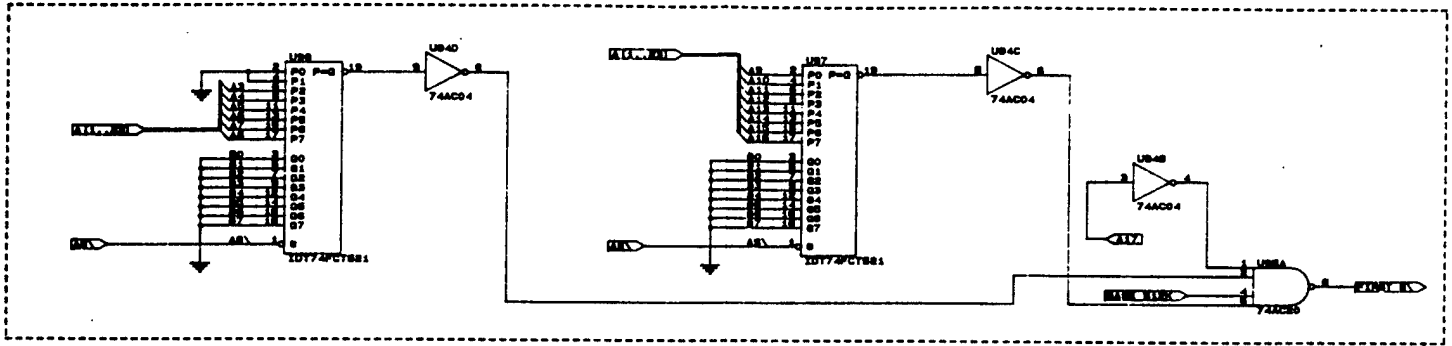


DECOUPLING CAPACITORS VCC TO VSS

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20	.03
14	.02

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14	U94	7
14	U95	7
20	U97	10
20	U98	10
28	U99	14
28	U100	14
14	U107	7
	SP15	10

FIRST EIGHT ADDRESS LOCATIONS DECODE

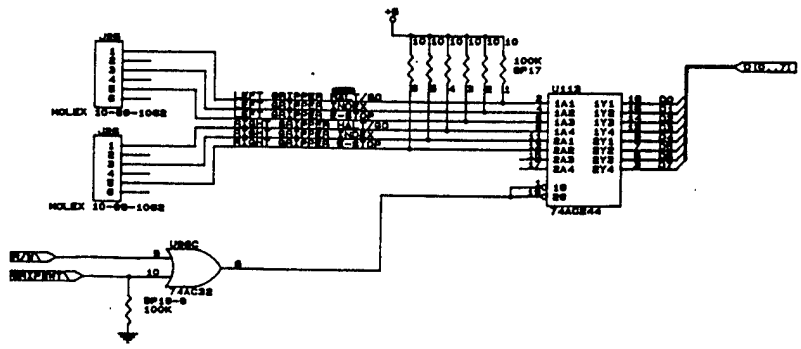
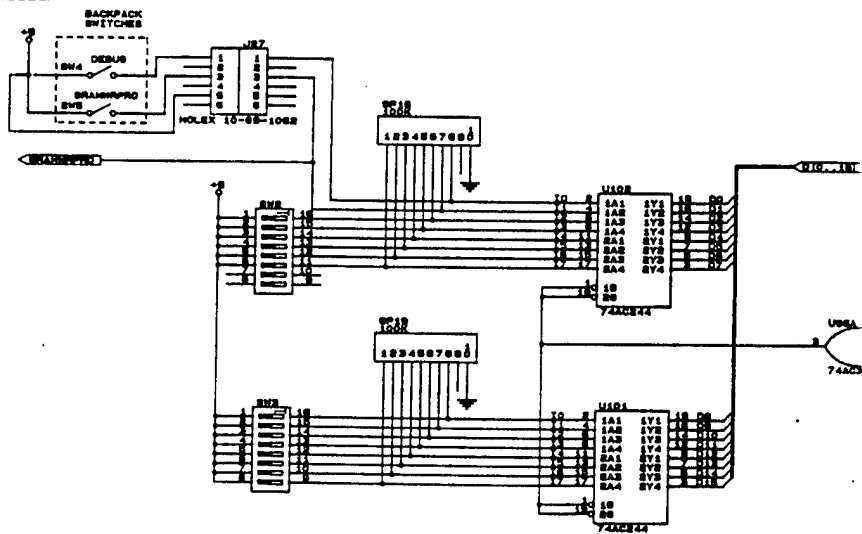
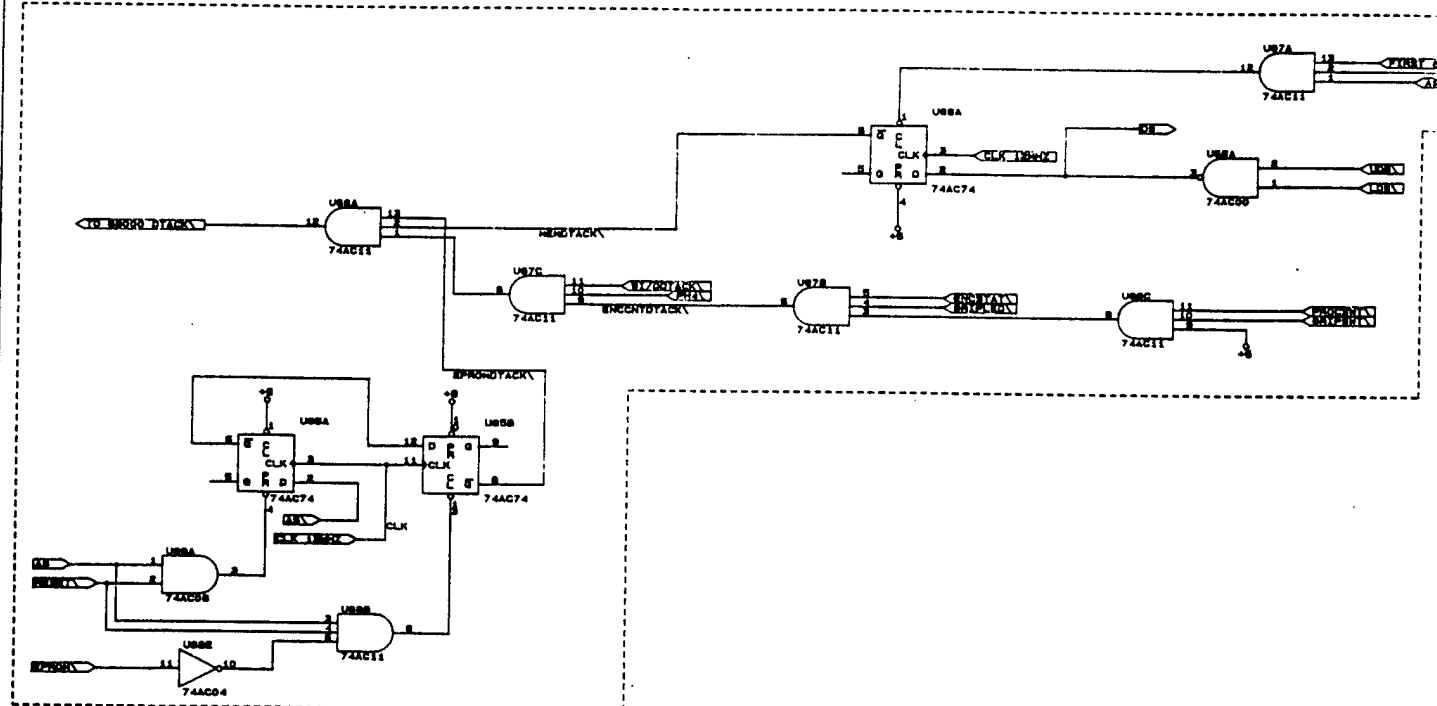


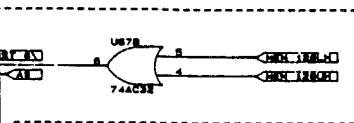
FROM	TO	OUT	IN
14	U96	7	
14	U105	7	
14	U106	7	
28	U109	14	
28	U110	14	
28	U111	14	
28	U112	14	
10	SP16		

SYSTEMS RESEARCH LABS			
TITLE MBA EXOSKELETON BACKPACK ELECTRONICS 128K SRAM AND 16K EPROM			
SIZE D	DOCUMENT NUMBER ROBOTICS TELEPRESENCE		REV A
DATE: MARCH 17, 1989		SHEET	5 OF 11

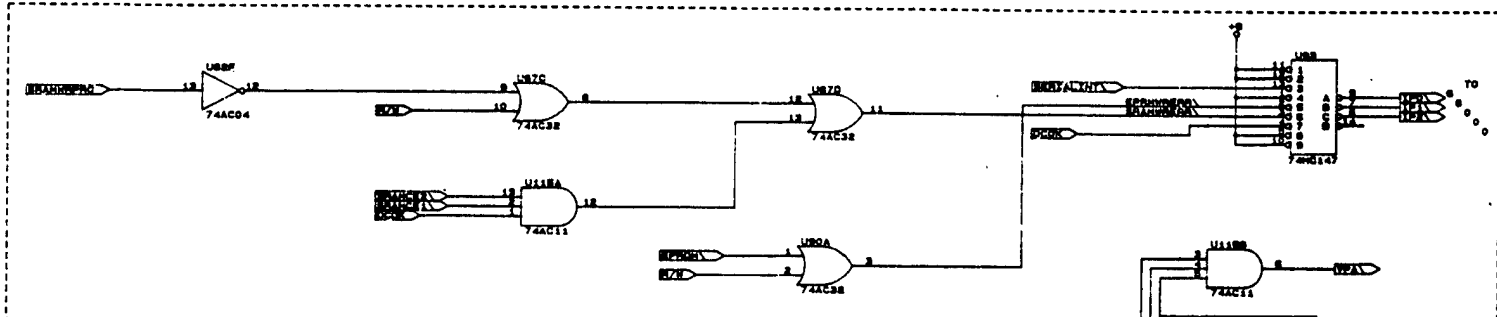
FILE "MBA4.04"

DTACK GENERATOR

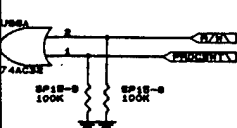
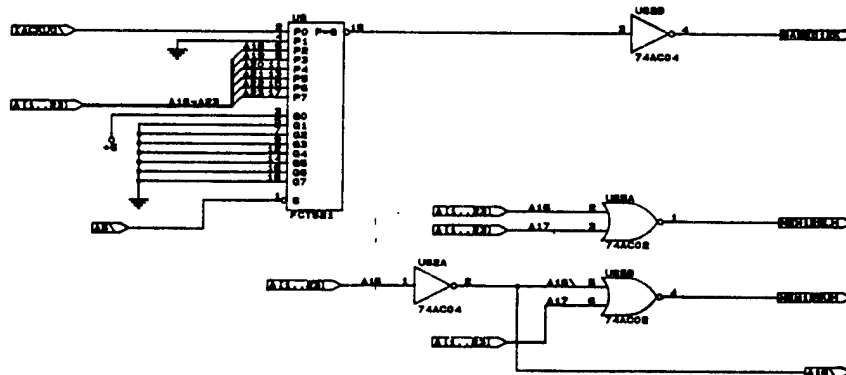
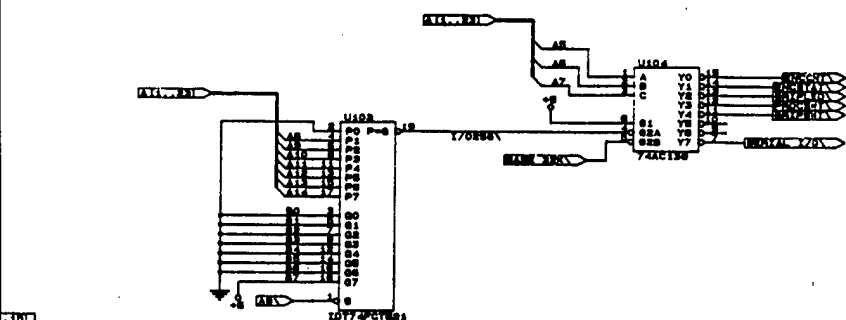




INTERRUPT HANDLER



A3	A2	A1	IP2\	IP1\	IP0\	LEVEL
1	1	1	0	0	0	7
1	1	0	0	0	1	6
1	0	1	0	1	0	5
1	0	0	0	1	1	4
0	1	1	1	0	0	3
0	1	0	1	0	1	2
0	0	1	1	1	0	1
0	0	0	1	1	1	0



20	U9	10
14	U65	7
14	U66	7
14	U67	7
14	U68	7
14	U85	7
14	U86	7
14	U87	7
14	U88	7
14	U89	7
14	U90	7
16	U93	8
14	U96	7
20	U101	10
20	U102	10
20	U103	10
16	U104	8
20	U113	10
16	U114	8
	SP18	10
	SP19	10

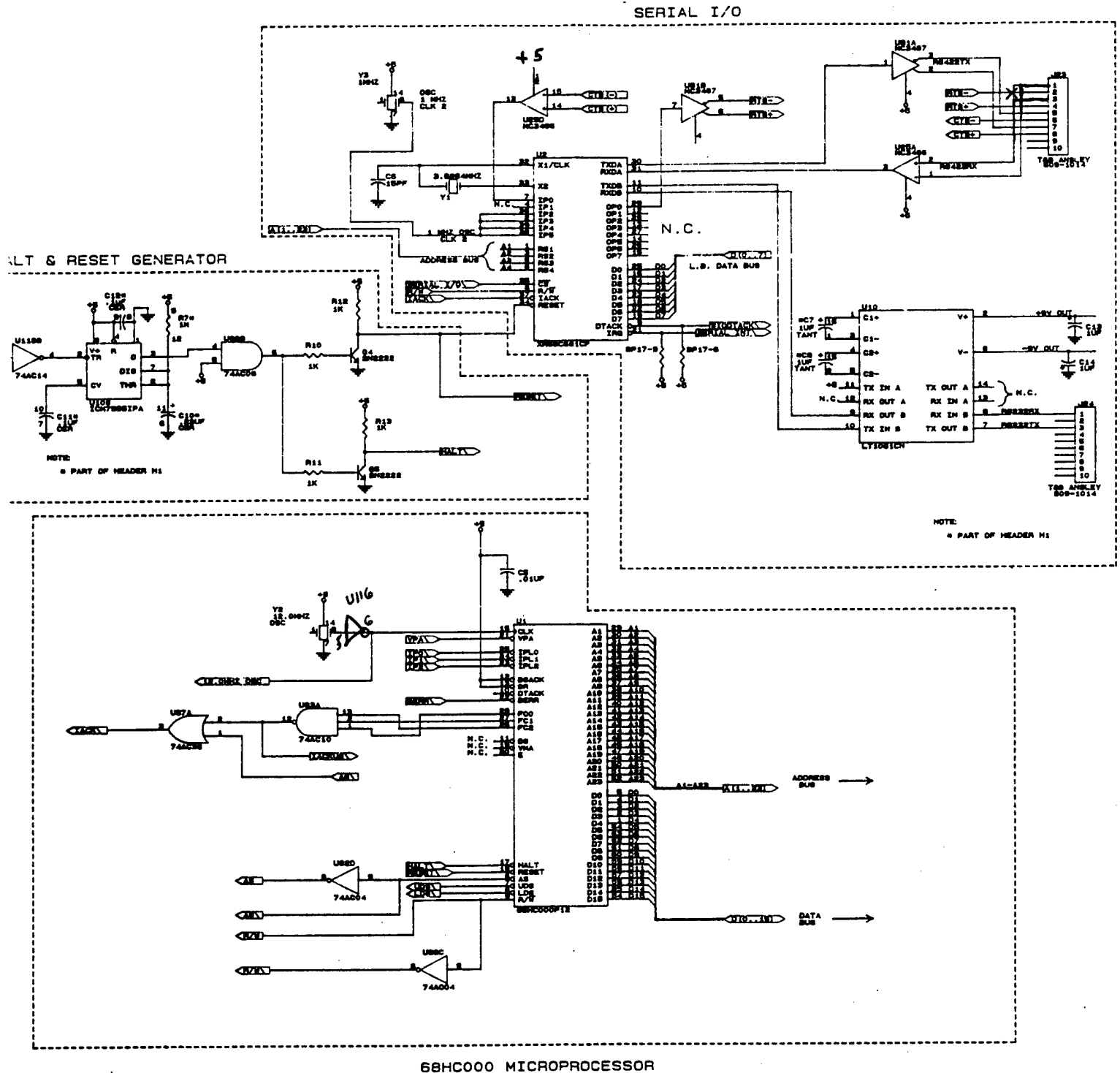
The circuit diagram shows a 100ns delay circuit. It consists of two 74AC181 chips, several 74AC00 inverters and NAND gates, and a 74AC04 hex inverters. The circuit is powered by a 5V supply and a 100k resistor. The output of the circuit is a square wave pulse, labeled "PULSE".

	(C1) YAT1 (ESU)	(C2) YAT2 (ESU)
14	49	16
40	U1	53
16	U2	20
14	U10	15
14	U63	7
14	U65	7
14	U66	7
14	U67	7
14	U82	7
16	U91	8
14	U94	7
14	U107	7
8	U108	1
14	Y2	7
14	Y3	7
16	U92	8
16	U25	8
16	U81	8
PIN 1	SP17	

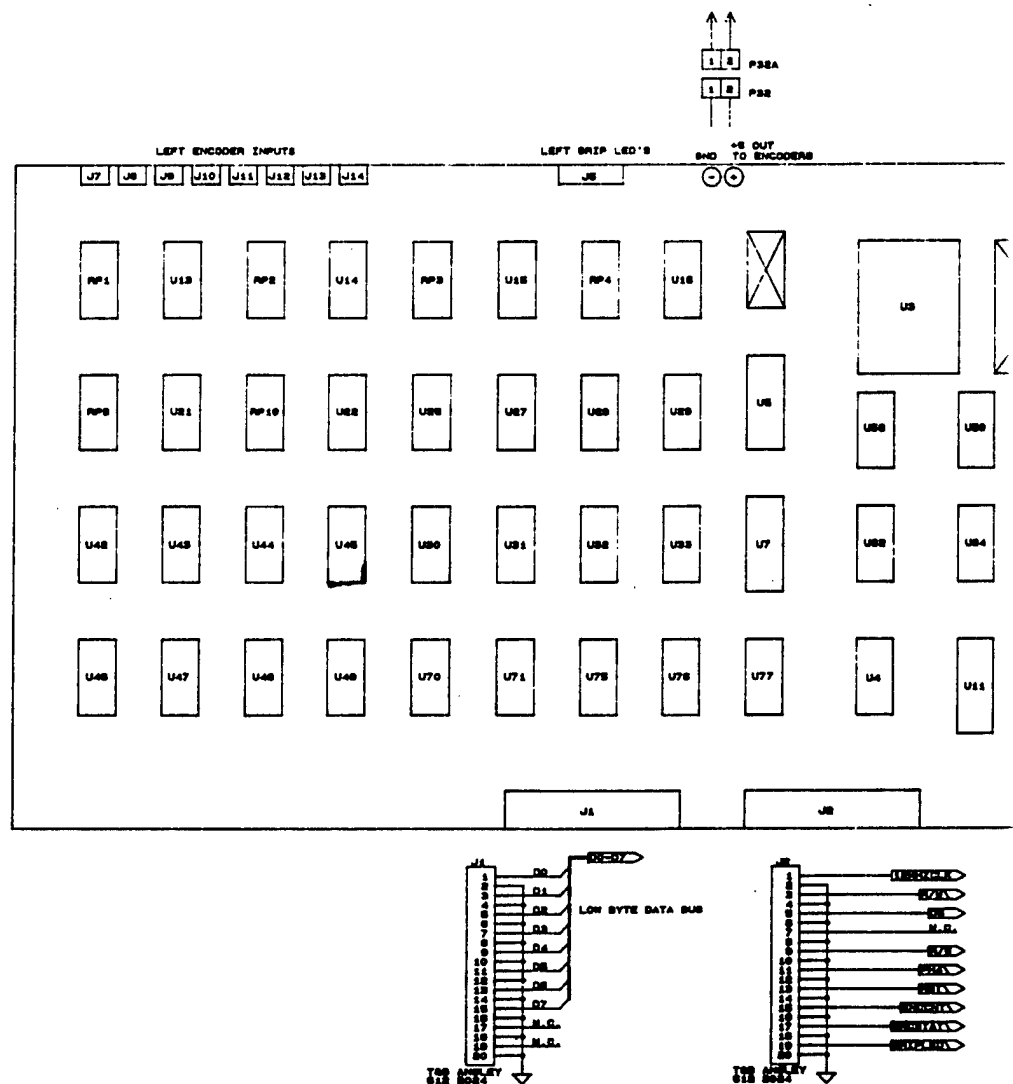
PACKAGE	VALUE
16	.03uF
14	.02uF
28	.07uF

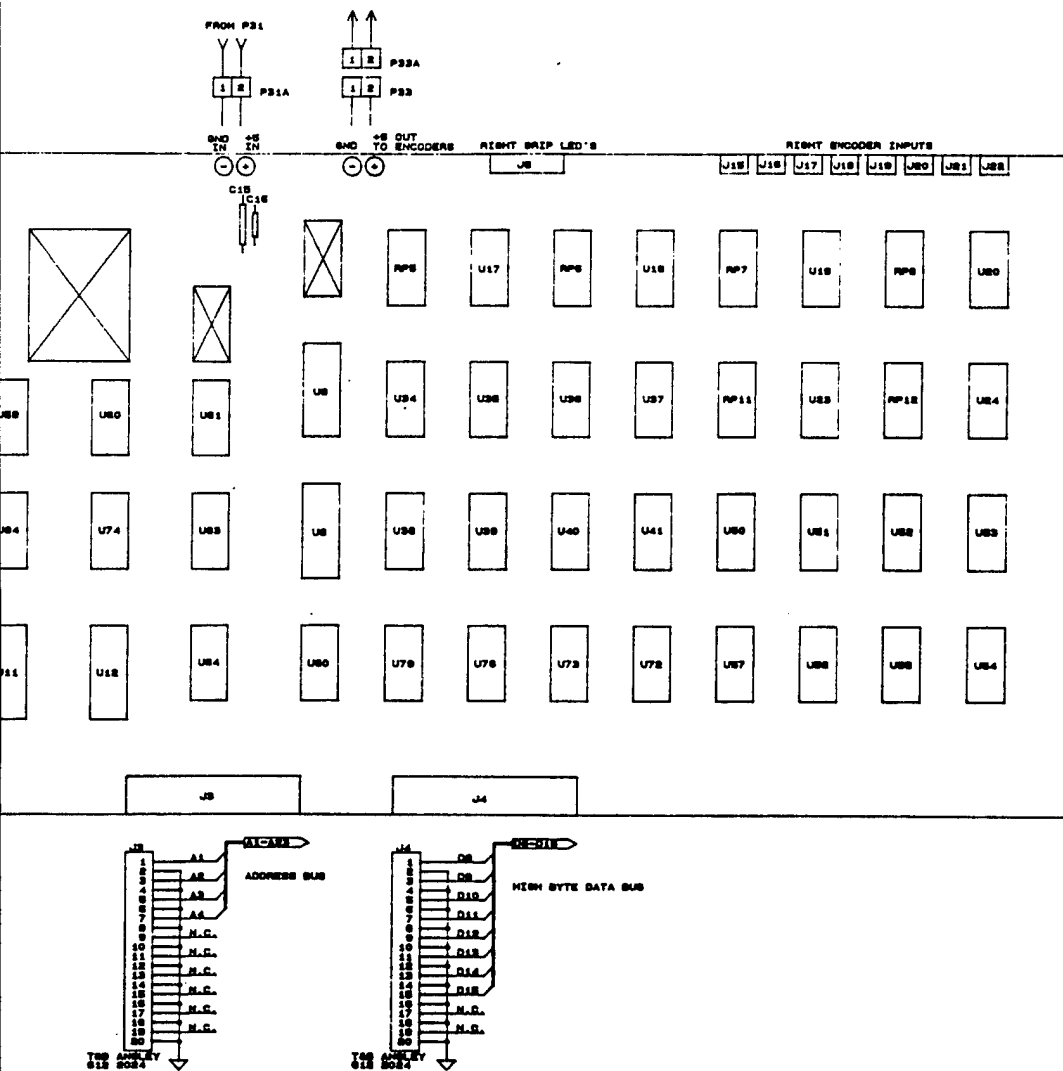
2N6109

A schematic diagram of a 2N6109 transistor. It shows a rectangular package with three pins extending from the bottom. The pins are labeled from left to right as 1, 2, and 3.



SYSTEMS RESEARCH LABS			
TITLE MBA EXOSKELETON BACKPACK ELECTRONICS (68HC000) (SERIAL I/O) (BERR) (BATT BACK-UP) (HALT/RESET)			
SIZE	DOCUMENT NUMBER	REV	
D	ROBOTICS TELEPRESENCE		
FILE "MBA6.04"	DATE: MARCH 17, 1989	SHEET	7 OF 11

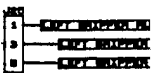
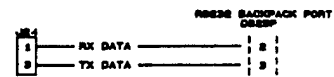
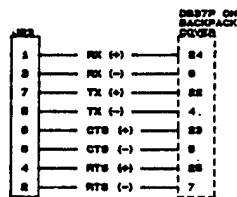
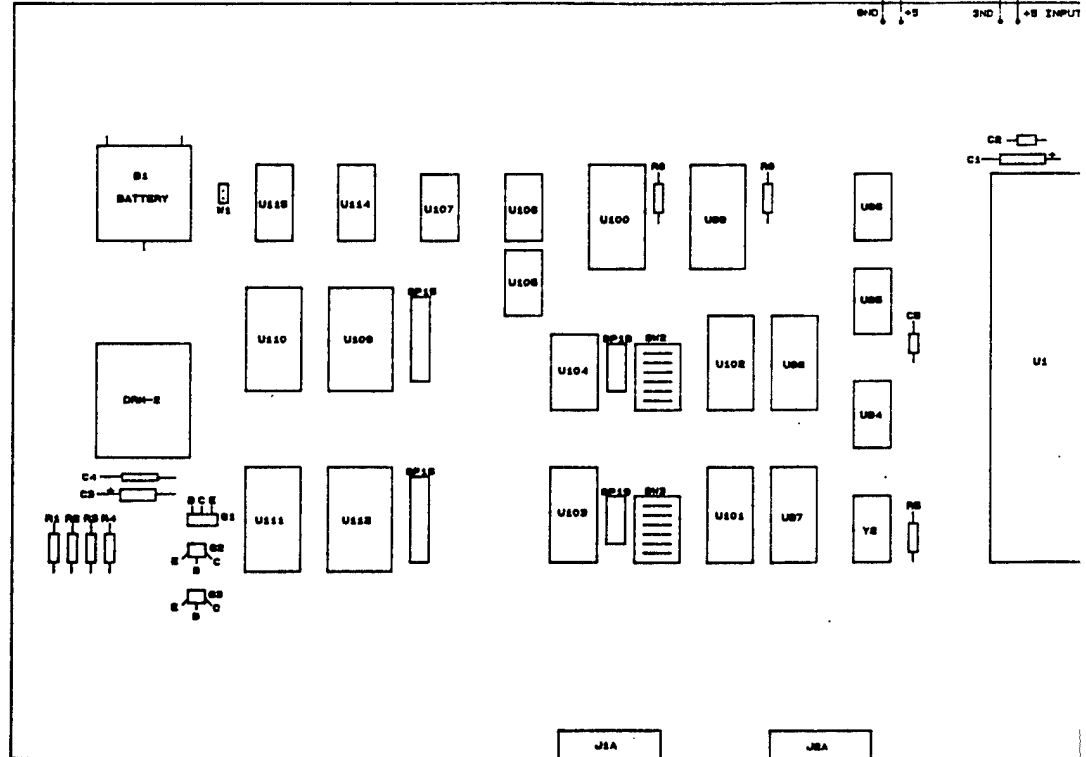
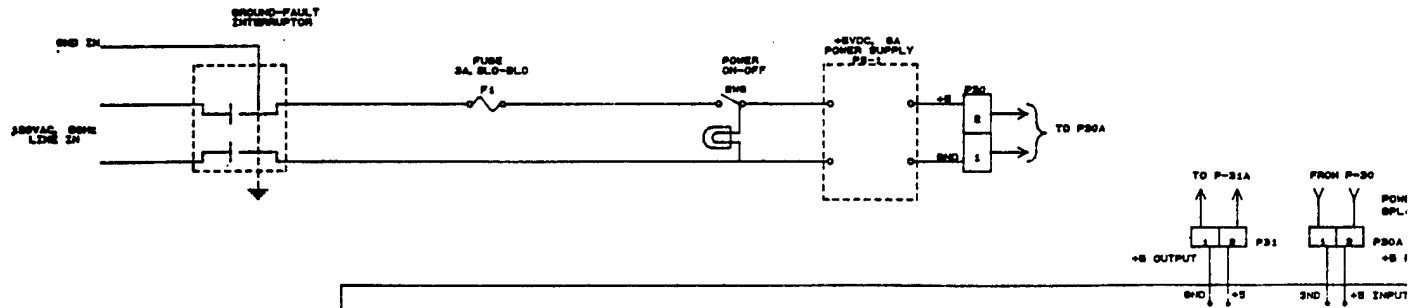


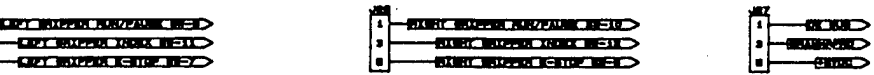
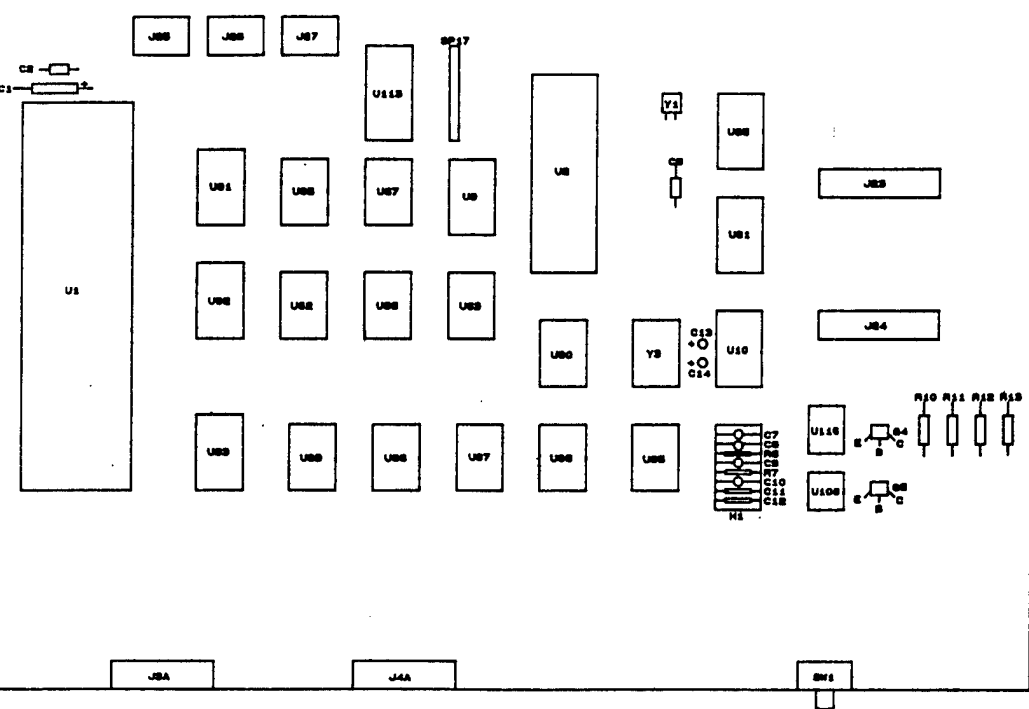
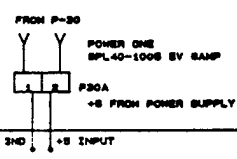


FILE "MBA7.04"

SYSTEMS RESEARCH LABS			
TITLE MBA EXOSKELETON BACKPACK ELECTRONICS BOARD LAYOUT			
SIZE	DOCUMENT NUMBER		REV
D	ROBOTICS TELEPRESENCE		
DATE:	MARCH 17, 1989	SHEET	8 OF 11

POWER INPUT CIRCUIT





2

FILE "MBA8.04"

SYSTEMS RESEARCH LABS			
TITLE MBA EXOSKELETON BACKPACK ELECTRONICS BOARD LAYOUT			
SIZE	DOCUMENT NUMBER		REV
D	ROBOTICS TELEPRESENCE		
DATE:	MARCH 17, 1989	SHEET	9 OF 11

MANUFACTURER	PART NUMBER	QUANTITY	DESCRIPTION
MOTOROLA	68HC000P12	1	16-/32-BIT MICROPROCESSOR
SIGNETICS	XR68C681CP	1	DUAL ASYNCHRONOUS RECEIVER/TRANSMIT
HEWLETT PACKARD	HCTL-2000	16	QUADRATURE DECODER/COUNTER INTERFAC
FAIRCHILD	74AC00	1	QUAD 2 INPUT NAND GATE / AVAILABLE
FAIRCHILD	74AC02	2	QUAD 2 INPUT NOR GATE / AVAILABLE G
FAIRCHILD	74AC04	4	HEX INVERTER / AVAILABLE GATES: U62
FAIRCHILD	74AC08	7	QUAD 2 INPUT AND GATE / AVAILABLE G
FAIRCHILD	74AC10	1	TRIPLE 3 INPUT NAND GATE / AVAILABL
FAIRCHILD	74AC11	4	TRIPLE 3 INPUT AND GATE / AVAILABLE
FAIRCHILD	74AC14	1	HEX SCHMIDT TRIGGER
FAIRCHILD	74AC20	3	DUAL 4 INPUT NAND
FAIRCHILD	74AC32	5	QUAD 2 INPUT OR GATE / AVAILABLE GA
FAIRCHILD	74AC74	22	DUAL D FLIP-FLOP / AVAILABLE FLIP-F
FAIRCHILD	74AC138	2	1 OF 8 DECODER/DEMULTIPLXER
MOTOROLA	74HC147	1	DECIMAL- TO - BCD ENCODER
MOTOROLA	74HC154	1	1 OF 16 DECODER/DEMULTIPLXER
FAIRCHILD	74AC191	2	UP/DOWN COUNTER
FAIRCHILD	74AC244	3	3-STATE OCTAL BUFFER/LINE DRIVER
FAIRCHILD	74AC245	2	OCTAL BIDIRECTIONAL TRANSCEIVER
FAIRCHILD	74AC374	4	OCTAL D-TYPE FLIP-FLOP
MOTOROLA	74HC4075	6	TRIPLE 3 INPUT OR GATE / AVAILABLE
MOTOROLA	MC3486	13	QUAD RS422 LINE RECEIVER / AVAILABL
MOTOROLA	MC3487	1	QUAD RS422 DRIVER / AVAILABLE PORTS:
LINEAR TECHNOLOGY	LT1081CN	1	RS232 DRIVER/RECEIVER
INTERSIL	ICM7555IPA	1	TIMER
IDT	IDT74FCT521	4	8-BIT IDENTITY COMPARATOR
SMOS SYSTEMS	SRM20256LC-10	4	256K BIT STATIC RAM
HITACHI	27C64G-15	2	8-BIT EPROM
CATALYST RESEARCH	B1000	1	2.8V LITHIUM IODINE BATTERY
CATALYST RESEARCH	DRM-2	1	BATTERY BACKUP MODULE
MOTOROLA	2N6109	1	PNP POWER TRANSISTOR
MOTOROLA	2N2222	4	PNP TRANSISTORS
POWER ONE	SPL40-1005	1	5 VOLT D.C., 8 AMP POWER SUPPLY (LOC
BOURNS	4116R-001-103	12	10K OHM 1%, RESISTOR PACKS
BOURNS	1-104G	4	100K SIP RESISTOR PACKS
BOURNS	4116R-001-471	2	470 OHM DIP RESISTOR PACKS (LOCATED
ALLEN BRADLEY	RCR07G4750JS	1	475 OHM RESISTOR, 1/4W 1%
ALLEN BRADLEY	RCR07G361JS	1	360 OHM RESISTOR, 1/4W 5%
ALLEN BRADLEY	RCR07G105JS	3	1M OHM RESISTOR 1/4W 1%
ALLEN BRADLEY	RCR07G104JS	3	100K RESISTORS, 1/4W 5%
ALLEN BRADLEY	RCR07G681JS	1	680 OHM RESISTOR, 1/4W 5%
ALLEN BRADLEY	RCR07G103JS	4	10K RESISTORS, 1/4W 5%
KEMET	T350E106K025AS	2	10uF CAPACITORS, 25V TANT.
KEMET	C320C104K5R5CA	5	.1uF CAPACITORS, 25V CERAMIC
KEMET	C330C103K1G5CA	1	.01uF CAPACITOR, 50V CERAMIC
SPRAGUE	30GAQ15	1	15pF CAPACITOR, 1KV CERAMIC
KEMET	T350A105K025AS	4	1uF CAPACITOR, 25V TANT.
SPRAGUE	1990224X9035AA2	2	.22uF CAPACITORS, 25V TANT.
B-D CRYSTAL	BD03686B	1	3.6864 MHZ CLOCK CRYSTAL
SARONIX	NCC060C-12	1	12.0 MHZ OSCILLATOR
M-TRON	MCO-T1-S3-1.0	1	1 MHZ OSCILLATOR
C&K	8125	1	SPST RESET SWITCH
GRAYHILL	8744	2	DIP SWITCHES
C&K	T101J12Q	1	DEBUG SWITCH
C&K	T101J12Q	1	SRAMWRPRO SWITCH
ARROW HART	1600R1E	1	LIGHTED ROCKER SWITCH (LOCATED ON BA
C&K	7101J12Q	2	LEFT GRIPPER, RIGHT GRIPPER E-STOP S
C&K	T101SH2Q	2	LEFT GRIPPER, RIGHT GRIPPER HALT-GO
C&K	T108SH2Q	2	LEFT GRIPPER, RIGHT GRIPPER IDX SWIT
BUSSMAN	HTB24I	1	FUSEHOLDER (LOCATED ON BACKPACK COVE
DIALIGHT	521-9501-002	16	T-1 3/4 HIGH EFFICIENCY RED LED'S (L
SAMTEC	CA-02-SJC-B	1	BATTERY JUMPER, 2 PIN
T&B ANSLEY	609-2004	8	RIGHT ANGLE PCB MALE HEADER (20 PIN)
MOLEX	22-04-1081	2	8 PIN HEADER
MOLEX	10-89-1062	16	DUAL ROW HEADER
T&B ANSLEY	609-2041CE	8	FEMALE SOCKET TRANSITION CONNECTOR (
MOLEX	10-89-1068	3	RIGHT ANGLE HEADERS
MOLEX	03-06-1023	4	2 PIN HOUSING
MOLEX	03-06-2023	4	2 PIN PLUG
BEI MOTION SYSTEMS	E113-1024-20	12	1024PPR OPTICAL ENCODER
BEI MOTION SYSTEMS	E113-120-20	4	120PPR OPTICAL ENCODER
AMLAN	CDS25L	1	25 PIN MALE D-SUBMINIATURE CONNECTOR
AMLAN	CDS37L	1	37 PIN MALE D-SUBMINIATURE CONNECTOR
MOLEX	03-06-2092	16	9 PIN PLUG
MOLEX	03-06-1092	16	9 PIN RECEPTACLE
MOLEX	02-06-2132	200	MALE CRIMP PINS
MOLEX	02-06-1132	200	FEMALE CRIMP PINS
MOLEX	16-02-0097	100	CRIMP TERMINALS
T&B ANSLEY	609-1014	2	RIGHT ANGLE PCB MALE HEADER (10 PIN)
T&B ANSLEY	609-1041CE	2	FEMALE SOCKET TRANSITION CONNECTOR (

/TRANSMITTER
 INTERFACE IC
 AVAILABLE GATES: U66-D
 AVAILABLE GATES: U65-D, U84-C&D
 GATES: U62-B, C, E, F
 AVAILABLE GATES: U80-A&C
 AVAILABLE GATES: U63-B&C
 AVAILABLE GATES: U64-B&C, U115 - C

AVAILABLE GATES: U83-C&D
 LE FLIP-FLOP: U86-B
 ER

KER

DRIVER
 DRIVER

AVAILABLE GATES: U80-A&C
 AVAILABLE PORTS: U25 - C&D
 BLE PORTS: U81 - C&D

APPLY (LOCATED ON BACKPACK COVER)

(LOCATED IN GRIPPER PANELS)

C
 C

TED ON BACKPACK COVER)
 E-STOP SWITCH (LOCATED IN GRIPPER PANELS)
 HALT-GO SWITCH (LOCATED IN GRIPPER PANELS)
 IDX SWITCH (LOCATED IN GRIPPER PANELS)
 PACK COVER)
 LED'S (LOCATED IN GRIPPER PANELS)
 (20 PIN)

INJECTOR (20 PIN)

ONNECTOR
 ONNECTOR

(10 PIN)
 INJECTOR (10 PIN)

REFERENCE

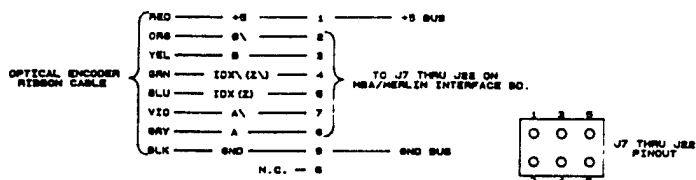
U1
 U2
 U26 THRU U41
 U66
 U65, 84
 U62, 82, 94, 107
 U4, 70, 71, 72, 73, 74, 89
 U63
 U64, 87, 88, 115
 U116
 U95, 105, 106
 U67, 83, 90, 96, 105
 U42 THRU U61, U85, U86
 U104, 114
 U93
 U3
 U91, 92
 U101, 102, 113
 U11, 12
 U5, 6, 7, 8
 U75, 76, 77, 78, 79, 80
 U13 THRU U25
 U81
 U10
 U108
 U8, 97, 98, 103
 U109, 110, 111, 112
 U99, 100
 B-1
 DRM-2
 Q1
 Q2, 3, 4, 5
 PS-1
 RP1 THRU RP12
 SP15, SP16, SP17, SP18
 RP13, RP14
 R1
 R2
 R3, R6*, R7*
 R4, R10, R11
 R5
 R8, R9, R12, R13
 C1, C3, C15
 C2, C4, C11*, C12*, C16
 C5
 C6
 *C7, *C8, C13, C14
 C9*, C10*
 Y1
 Y2
 Y3
 SW1
 SW2, SW3
 SW4
 SW5
 SW6
 SW7, SW8
 SW9, SW10
 SW11, SW12
 F1
 LED 1 THROUGH LED 16
 W1
 J1, J2, J3, J4, J1A, J2A, J3A, J4A
 J5, J6
 J7 THRU J22
 INTERCONNECT CABLE
 J25, J26, J27
 P30, P31, P32, P33
 P30A, P31A, P32A, P33A
 ENCODERS FOR SA, SE, EB, WF, WR, GP
 ENCODERS FOR UR, LR
 RS232 PORT
 RS422 PORT
 ENCODER CONNECTORS
 ENCODER CONNECTORS
 CONNECTOR PINS
 CONNECTOR PINS
 CONNECTOR PINS
 J23, J24
 INTERCONNECT CABLE

*CAPACITORS C7 THRU C12 LOCATED ON HEADER H1

SYSTEMS RESEARCH LABS			
TITLE MBA PARTS LIST			
SIZE	DOCUMENT NUMBER		REV
D	ROBOTICS TELEPRESENCE		
DATE: AUGUST 4, 1989		SHEET	10 OF 11

FILE "MBA9.04"

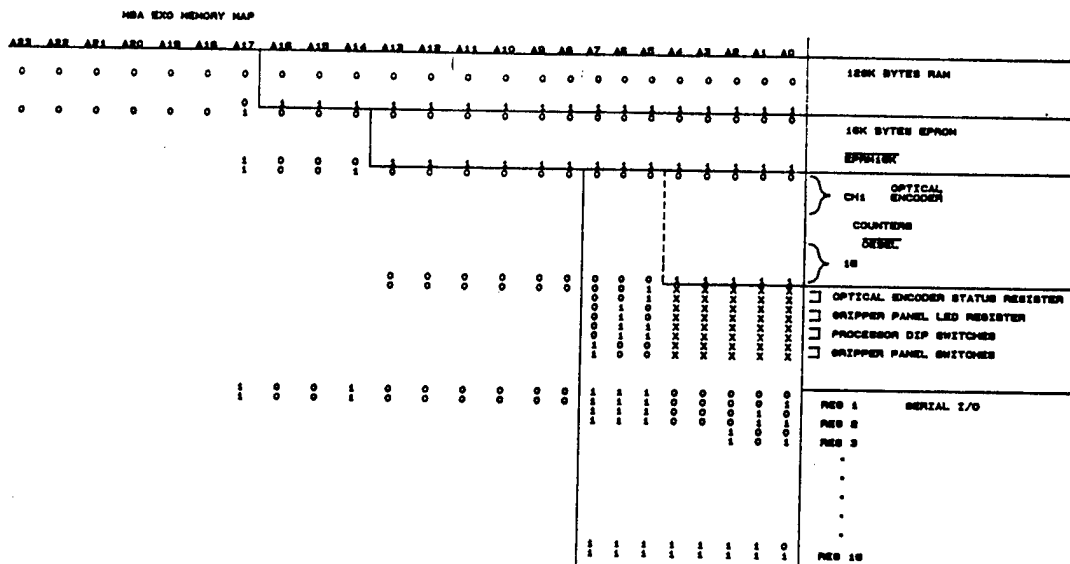
BEI MODEL 8118 ENCODER CONNECTIONS



LEFT SIDE ENCODER OUTPUTS

NSA/MERLIN INTERFACE SO.

ENCODER	DESCR	OUTPUTS	INPUT CONNECTOR	TO:
1	LEFT GRIP (BP)	A1\	J7 - 1	U12-1
		A2	2	U12-2
		B1\	3	U12-7
		B2	4	U12-8
		Z1\	5	U21-2
		Z2	6	U21-1
2	LEFT WRIST FLEX (WP)	A2\	J6 - 1	U13-9
		A3	2	U13-10
		B2\	3	U13-15
		B3	4	U13-14
		Z2\	5	U21-6
		Z3	6	U21-7
3	LEFT WRIST RADIAL (WR)	A2\	J6 - 1	U14-1
		A3	2	U14-2
		B2\	3	U14-7
		B3	4	U14-8
		Z2\	5	U21-10
		Z3	6	U21-9
4	LEFT LOWER ARM ROLL (LA)	A4\	J10 - 1	U14-9
		A4	2	U14-10
		B4\	3	U14-15
		B4	4	U14-14
		Z4\	5	U21-14
		Z4	6	U21-15
5	LEFT ELBOW (EB)	A5\	J11 - 1	U15-1
		A6	2	U15-2
		B5\	3	U15-7
		B6	4	U15-8
		Z5\	5	U22-2
		Z6	6	U22-1
6	LEFT UPPER ARM ROLL (UA)	A5\	J12 - 1	U15-9
		A6	2	U15-10
		B5\	3	U15-15
		B6	4	U15-14
		Z5\	5	U22-4
		Z6	6	U22-7
7	LEFT SHOULDER ELEVATION (SE)	A7\	J13 - 1	U15-1
		A7	2	U15-2
		B7\	3	U15-7
		B7	4	U15-8
		Z7\	5	U22-10
		Z7	6	U22-9
8	LEFT SHOULDER AZIMUTH (SA)	A8\	J14 - 1	U15-9
		A8	2	U15-10
		B8\	3	U15-15
		B8	4	U15-14
		Z8\	5	U22-14
		Z8	6	U22-15
9	RIGHT GRIP (BP)	A9\	J15 - 1	U17-1
		A9	2	U17-2
		B9\	3	U17-7
		B9	4	U17-8
		Z9\	5	U23-6
		Z9	6	U23-1
10	RIGHT WRIST FLEX (WP)	A10\	J16 - 1	U17-9
		A10	2	U17-10
		B10\	3	U17-15
		B10	4	U17-14
		Z10\	5	U23-8
		Z10	6	U23-7
11	RIGHT WRIST RADIAL (WR)	A11\	J17 - 1	U18-1
		A11	2	U18-2
		B11\	3	U18-7
		B11	4	U18-8
		Z11\	5	U23-10
		Z11	6	U23-9
12	RIGHT LOWER ARM ROLL (LA)	A12\	J18 - 1	U18-9
		A12	2	U18-10
		B12\	3	U18-15
		B12	4	U18-14
		Z12\	5	U23-14
		Z12	6	U23-15
13	RIGHT ELBOW (EB)	A13\	J19 - 1	U18-1
		A13	2	U18-2
		B13\	3	U18-7
		B13	4	U18-8
		Z13\	5	U24-2
		Z13	6	U24-1
14	RIGHT UPPER ARM ROLL (UA)	A14\	J20 - 1	U18-9
		A14	2	U18-10
		B14\	3	U18-15
		B14	4	U18-14
		Z14\	5	U24-6
		Z14	6	U24-7
15	RIGHT SHOULDER ELEVATION (SE)	A15\	J21 - 1	U20-1
		A15	2	U20-2
		B15\	3	U20-7
		B15	4	U20-8
		Z15\	5	U24-10
		Z15	6	U24-9
16	RIGHT SHOULDER AZIMUTH (SA)	A16\	J22 - 1	U20-9
		A16	2	U20-10
		B16\	3	U20-15
		B16	4	U20-14
		Z16\	5	U24-14
		Z16	6	U24-15



SYSTEMS RESEARCH LABS		
TITLE MBA BACKPACK ELECTRONICS ENCODER WIRING / MEMORY MAP		
SIZE D	DOCUMENT NUMBER ROBOTICS TELEPRESENCE	REV
DATE: AUGUST 4, 1989		SHEET 11 OF 11

FILE "MBA10.04"

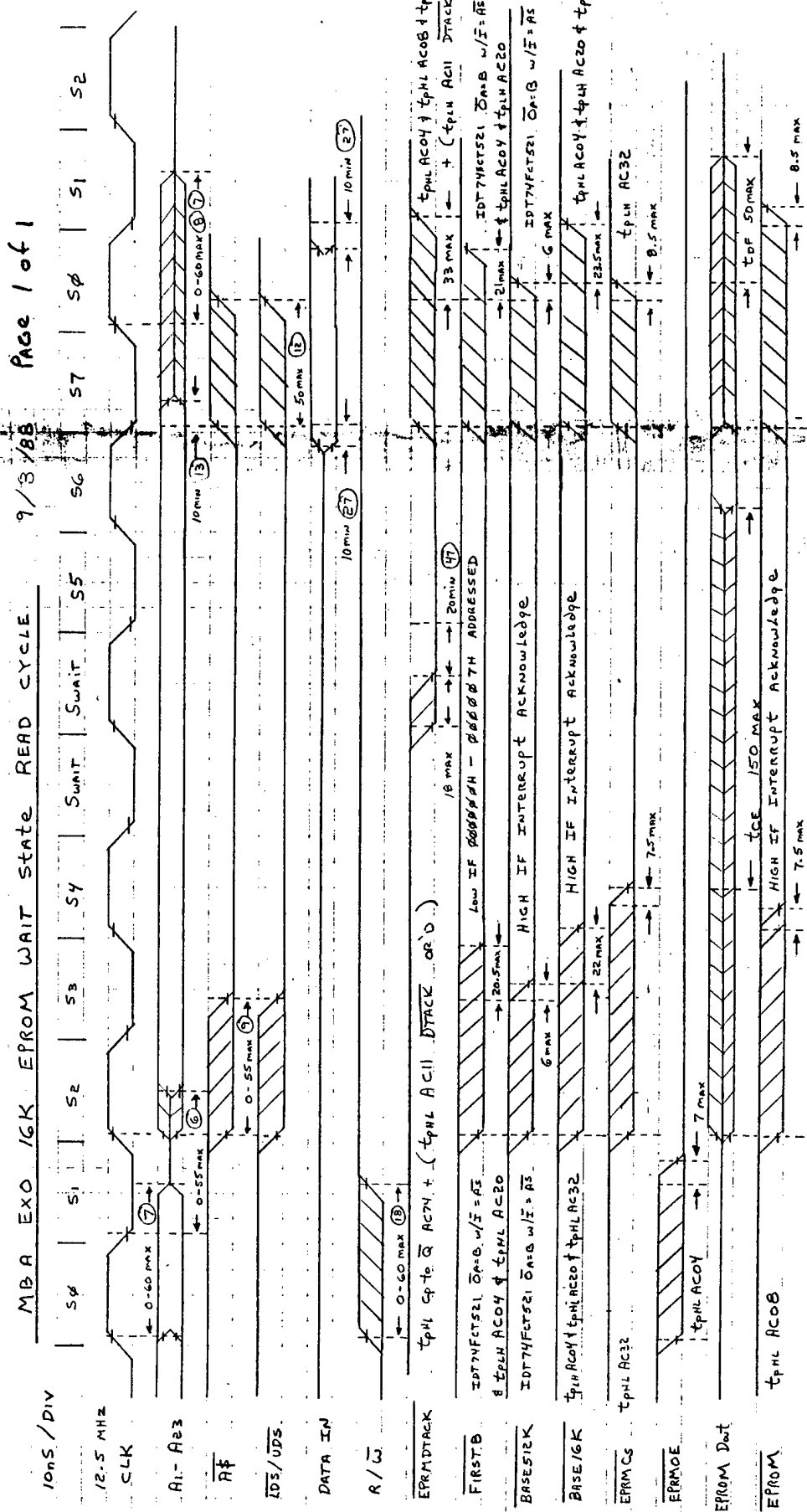
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9.0 Appendix A: MBAssociates Backpack

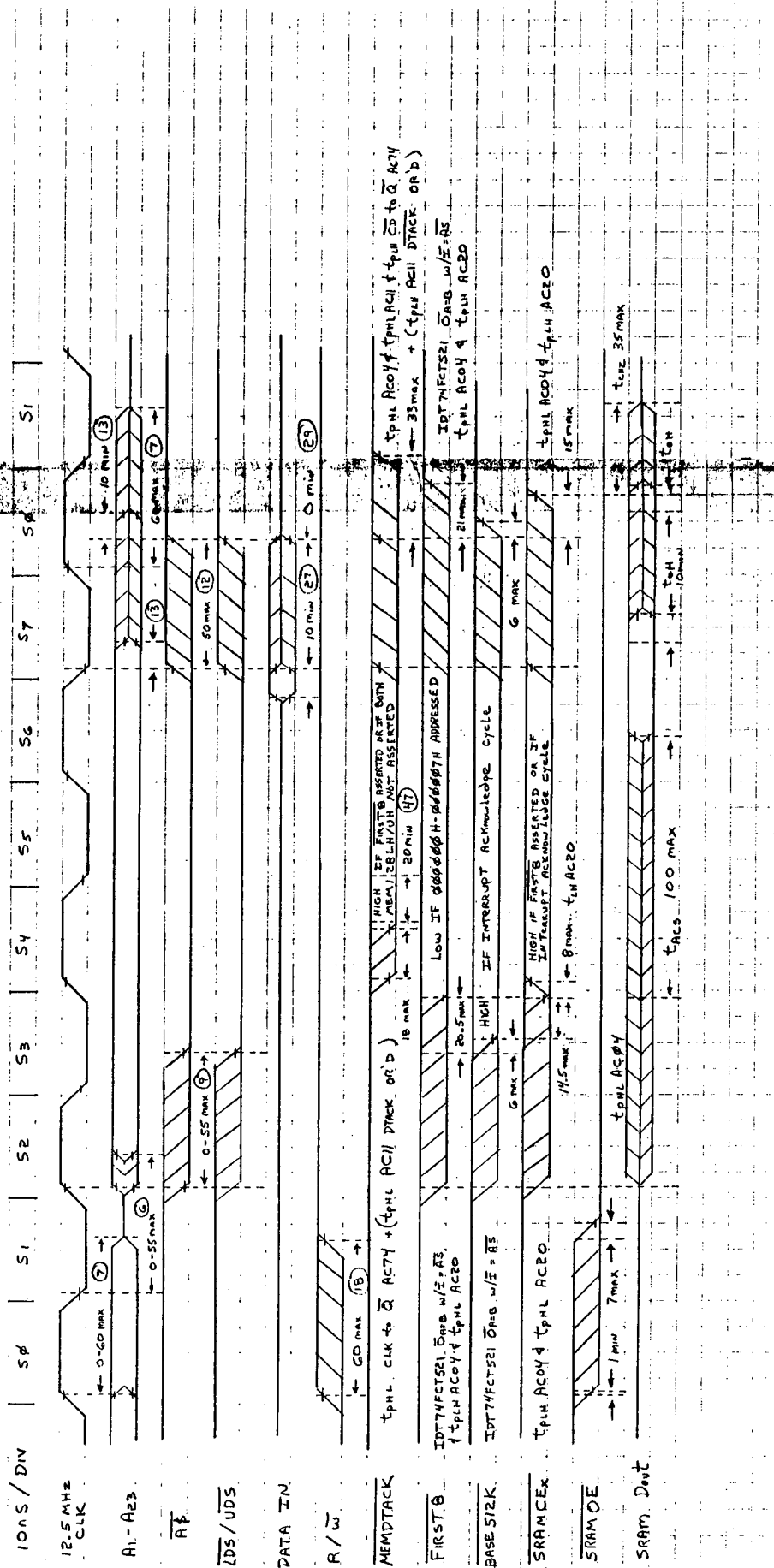
9.2 Timing Diagrams

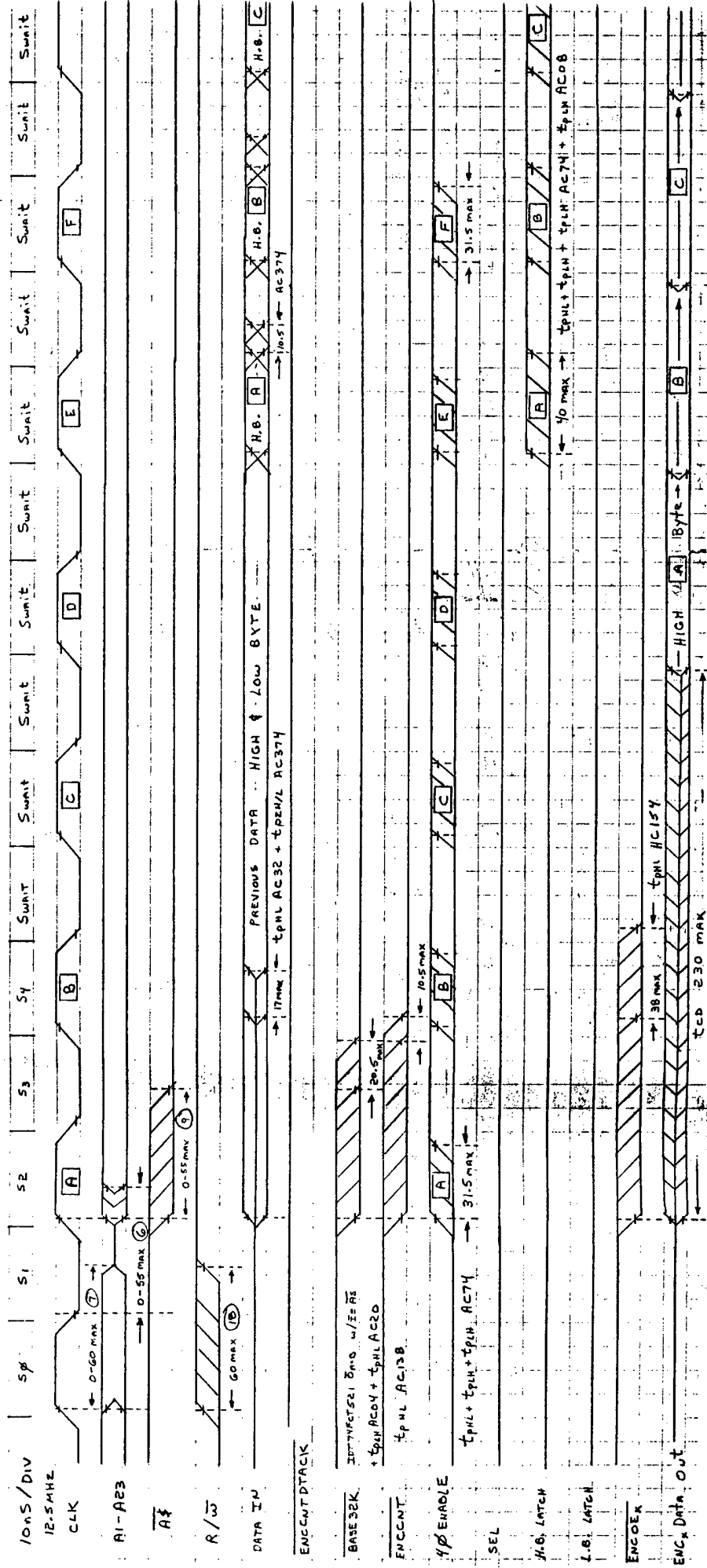
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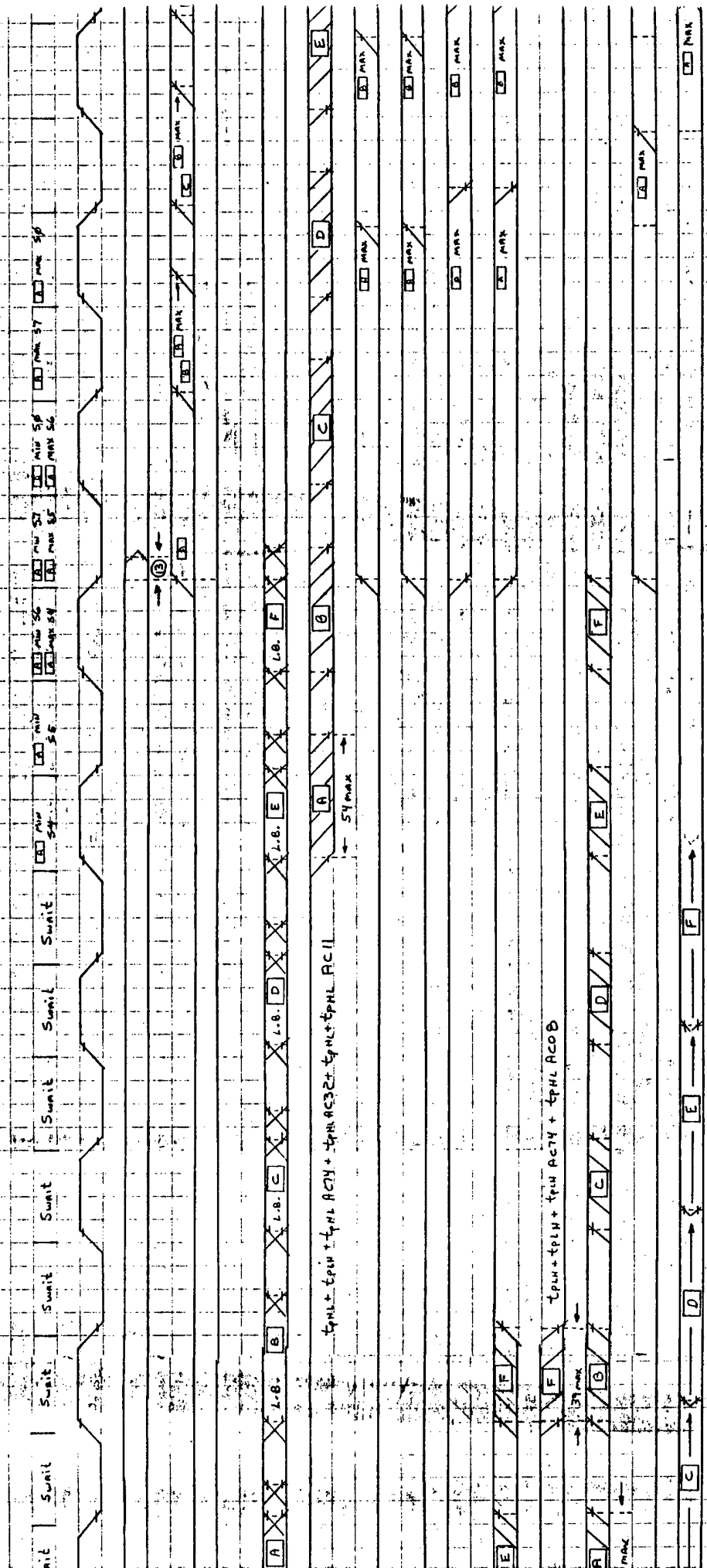


9/7/88

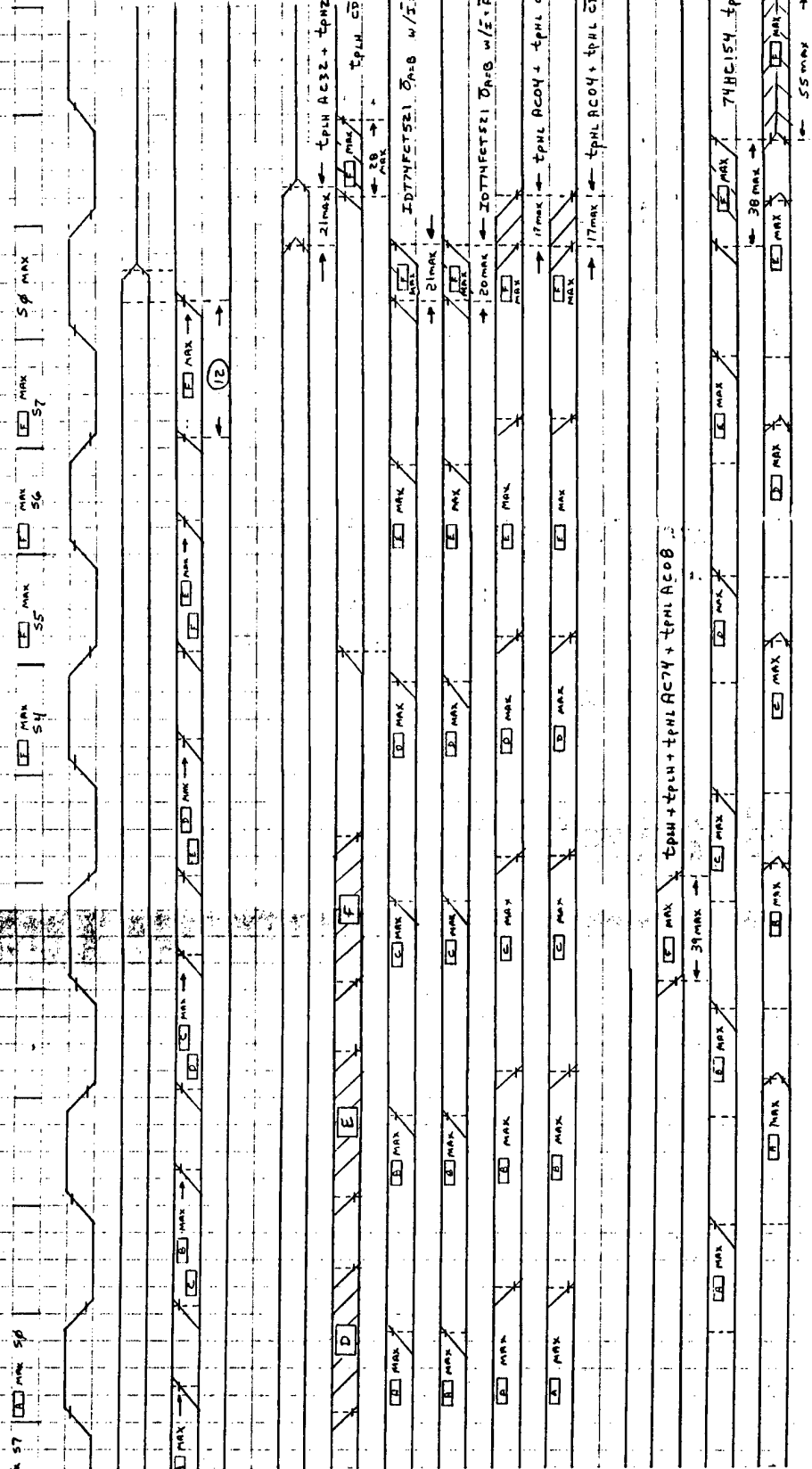
MBA EXO 128K SRAM READ CYCLE







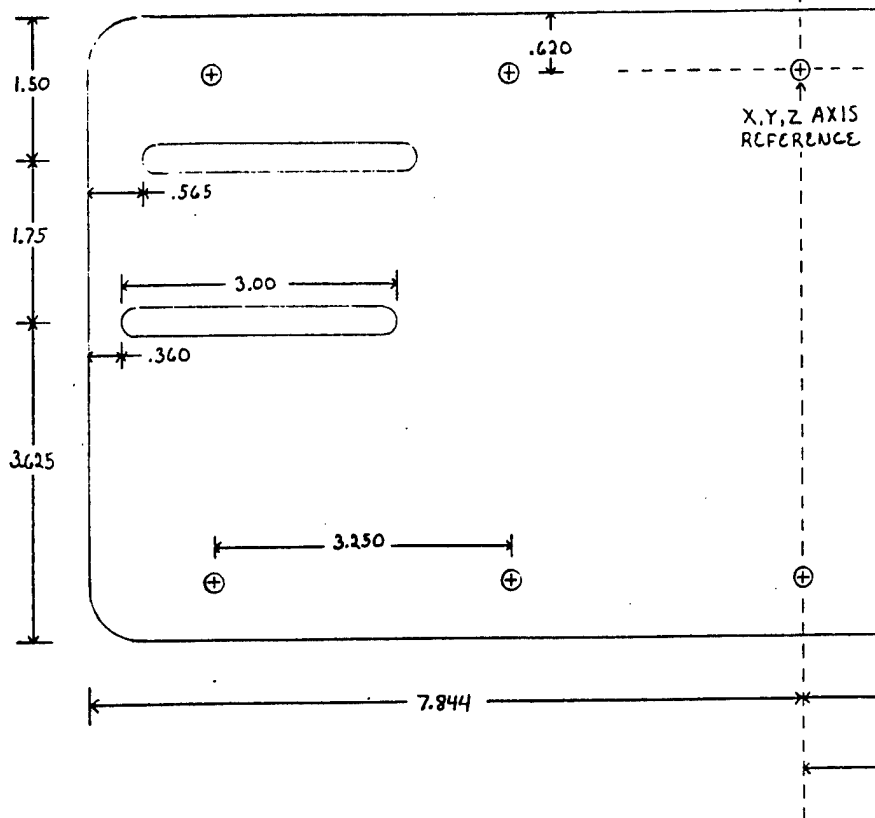
MBA EXOSKELETON ENCODER COUNTER READ Cycle 9 sept 88 Page 4 of 4



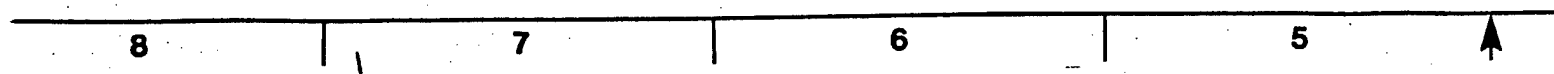
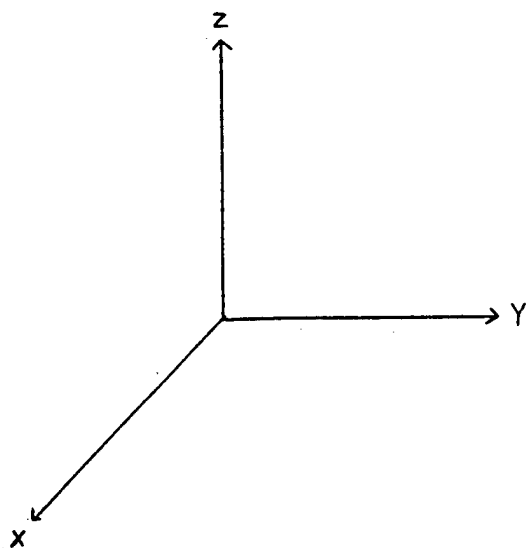
9.0 Appendix A: MBAssociates Backpack

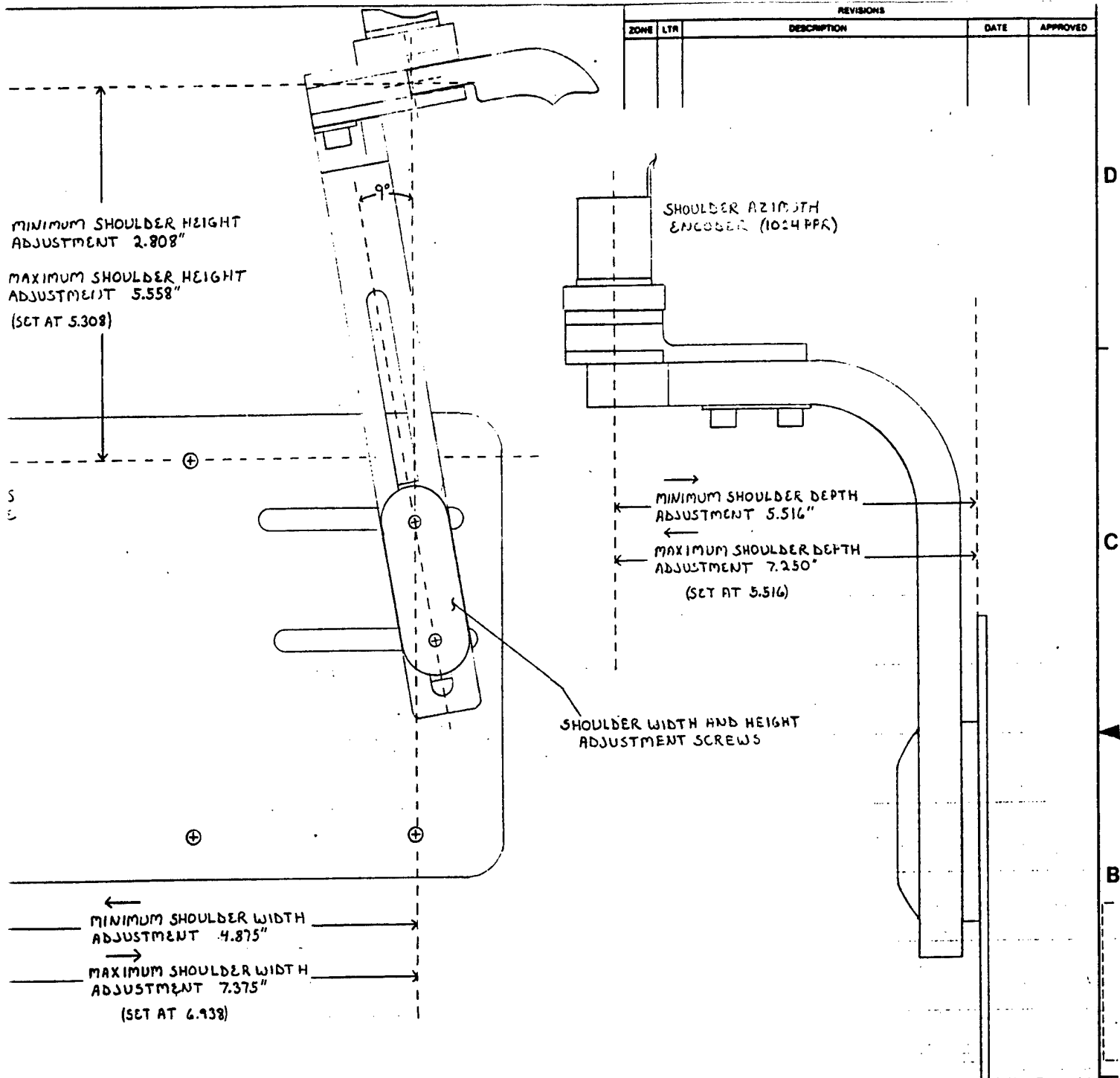
9.3 Mechanical Drawings

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$\downarrow M_{AB}$
 $\uparrow M_{AB}$
 (SC)





QTY REQD PER ASSY				PART OR IDENTIFYING NO.	CODE IDENT	NOMENCLATURE OR DESCRIPTION	MATERIAL OR MATERIAL CODE	DWG OR SPECIFICATION	ZONE	FIND NO.
				PARTS LIST						
				UNLESS OTHERWISE SPECIFIED DIMENSIONS ARE IN INCHES		CONTRACT NO.		SYSTEMS RESEARCH LABORATORIES, INC. 3800 INDIAN RIVULE ROAD, DAYTON, OHIO 45440		
				TOLERANCES:		DRAWN BY <i>J. Logan</i> DATE 1-30-90		MBA EXOSKELETON		
				XXI = ANGLES = ± 30°		CHECKED		MOUNTING PLATE TO SHOULDER AZIMUTH		
				XXX = FRACTIONS = ± 1/32		DESIGN		ENCODER / JOINT POSITIONS		
				XXXX = BASIC		PROJECT		SIZE CODE IDENT NO. DRAWING NO. REV		
				ALL SURFACES ✓		CUSTOMER		D 14590		
				MATERIAL		QUALITY ASSURANCE				
				FINISH		MANUFACTURING		SCALE RELEASE DATE SHEET 1 OF 6		
PART NO.	I/A	F/A	NEXT ASSY	USED ON						
QTY REQD	APPLICATION									



SHOULDER ELEVATION
ENCODER (1024 PPR)

Ⓐ

4.313"

4.063"

I.D. = 4.625

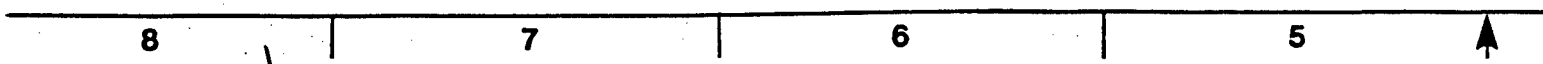
UPPER ARM
ROLL ENCODER
(120 PPR)

.750

ADJUST TO
.438"

.313"

Ⓑ₂
FROM LOWER
ARM ROLL



8

7

6

5

4

3

2

1

REVISIONS				
ZONE	LTR	DESCRIPTION	DATE	APPROVED

MINIMUM UPPER ARM LENGTH
ADJUSTMENT 10.141"

MAXIMUM UPPER ARM LENGTH
ADJUSTMENT 12.141"

(SET AT 12.141")

UPPER ARM LENGTH
ADJUSTMENT SCREWS

ELBOW ENCODER
(1024 PPR)

QTY REQD PER ASSY				PART OR IDENTIFYING NO.		CODE IDENT	NOMENCLATURE OR DESCRIPTION		MATERIAL OR MATERIAL CODE		DWG OR SPECIFICATION	ZONE	FINO NO
				UNLESS OTHERWISE SPECIFIED DIMENSIONS ARE IN INCHES		CONTRACT NO.		SYSTEMS RESEARCH LABORATORIES, INC. 2800 INDIAN RIPPLE ROAD, DAYTON, OHIO 45440					
				TOLERANCES:		DRAWN BY <i>J. Logan</i>		DATE 1-31-90					
				X.XX = ANGLES = ± 30°		CHECKED		MBA EXOSKELETON					
				X.XXX = FRACTIONS = ± 1/32		DESIGN		SHOULDER ELEVATION, UPPER ARM ROLL, ELBOW					
				X.XXXX = BASIC		PROJECT		ENCODER/JOINT POSITIONS					
				ALL SURFACES ✓		CUSTOMER		SIZE CODE IDENT NO. DRAWING NO. REV					
				MATERIAL		QUALITY ASSURANCE		D 14590					
				FINISH		MANUFACTURING		SCALE RELEASE DATE SHEET 3 OF 6					
PART NO.	N/A	P/A	NEXT ASSY	USED ON									
QTY REQD	APPLICATION												

4

3

2

1

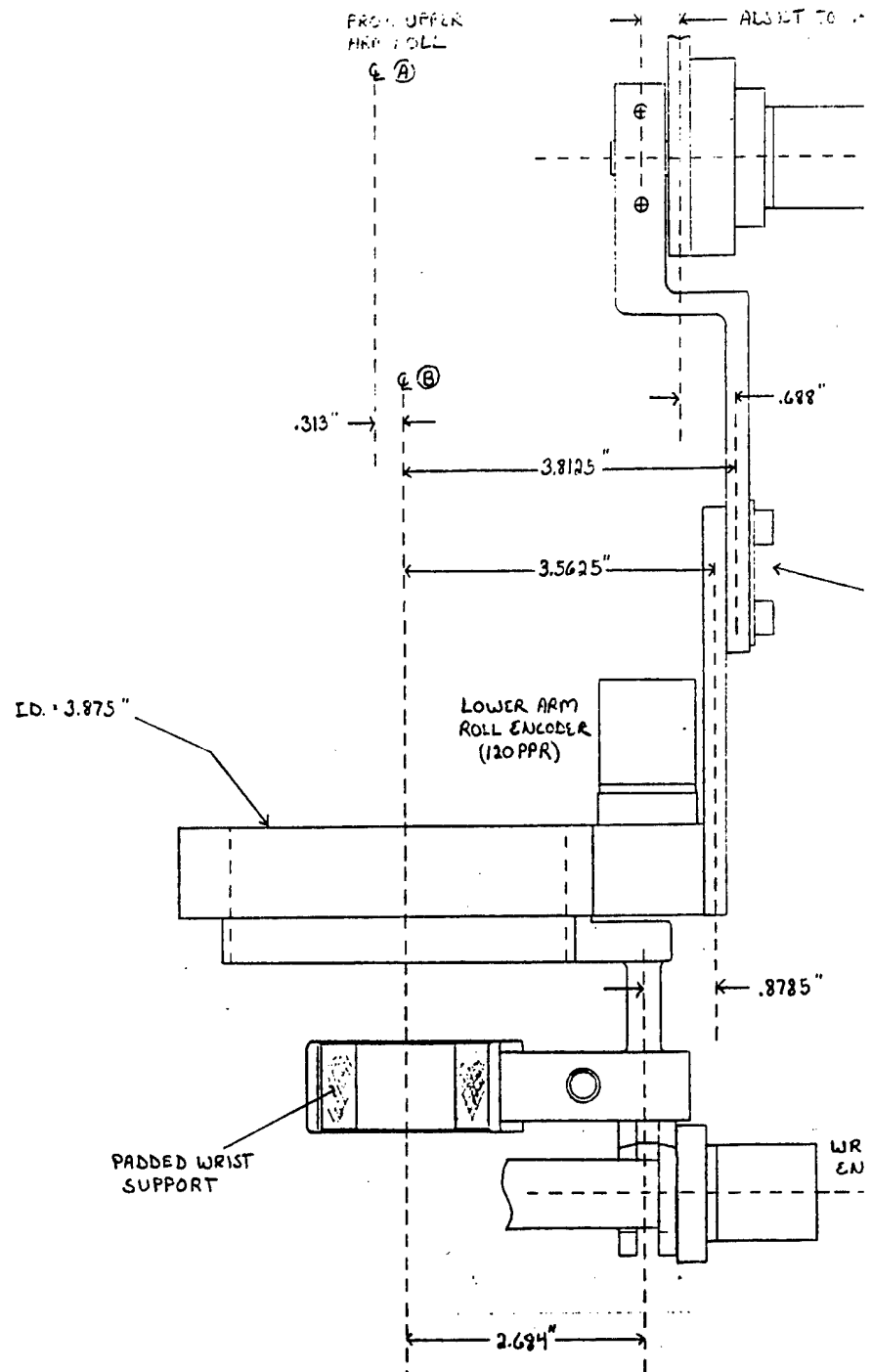
54

8

7

6

5

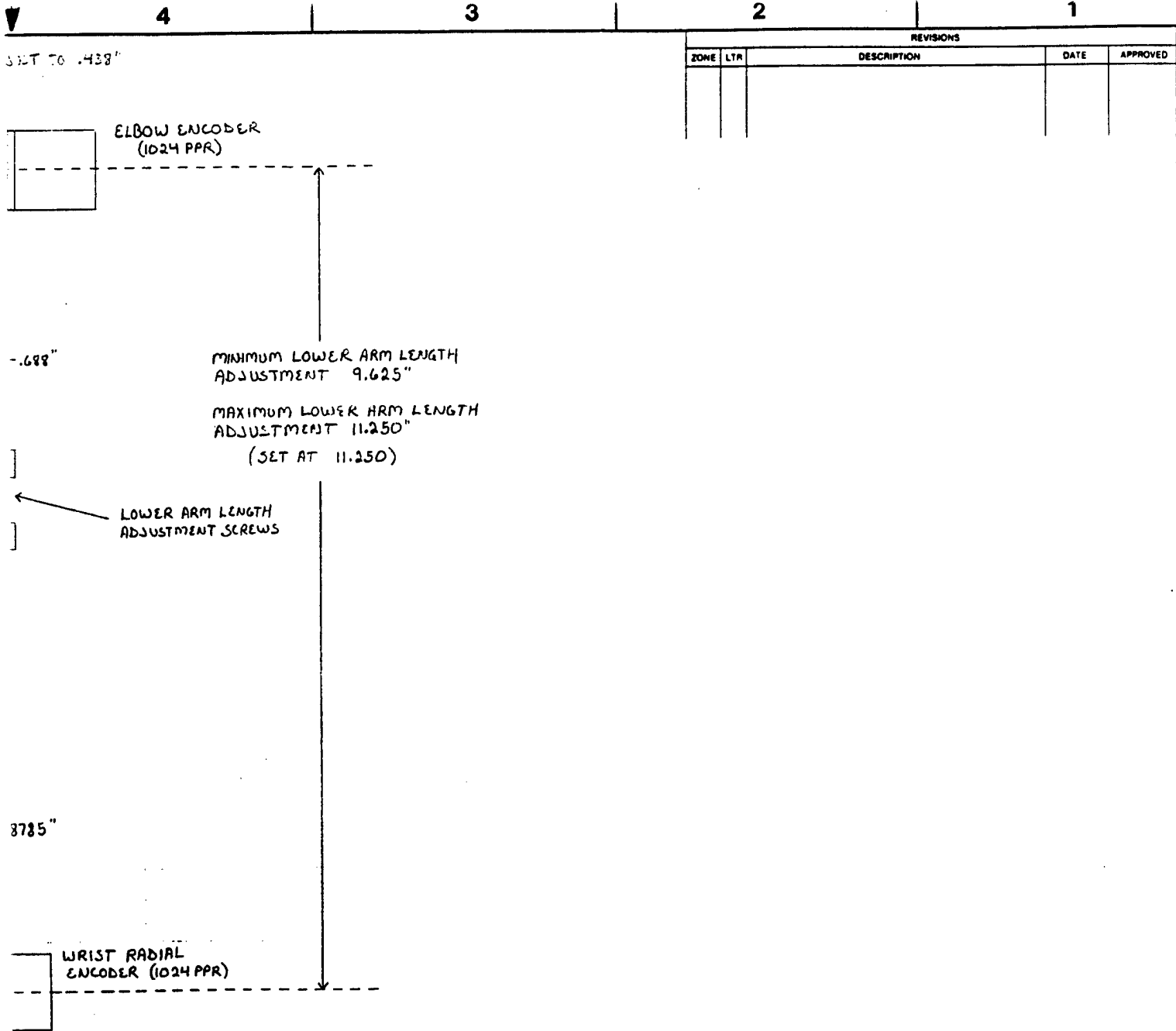


8

7

6

5



QTY REQD PER ASSY					PART OR IDENTIFYING NO.	CODE IDENT	NOMENCLATURE OR DESCRIPTION	MATERIAL OR MATERIAL CODE	DWG OR SPECIFICATION	ZONE	FIND NO.
					PARTS LIST						
					UNLESS OTHERWISE SPECIFIED DIMENSIONS ARE IN INCHES			CONTRACT NO.			
					TOLERANCES:			DRAWN BY <i>J. Logan</i> DATE 1-31-90			
					JXX = ANGLES = ± 30°			CHECKED			
					JXXX = FRACTIONS = ± 1/32			DESIGN			
					JXXXX = BASIC			PROJECT			
					ALL SURFACES ✓			CUSTOMER			
					MATERIAL			QUALITY ASSURANCE			
					FINISH			MANUFACTURING			
PART NO.	N/A	P/A	NEXT ASSY	USED ON				SYSTEMS RESEARCH LABORATORIES, INC. 2800 INDIAN RIFPLE ROAD, DAYTON, OHIO 45440			
								MBA EXOSKELETON ELBOW, LOWER ARM ROLL, WRIST RADIAL ENCODER / JOINT POSITIONS			
								SIZE CODE IDENT NO. DRAWING NO. REV			
								D 14590			
								SCALE RELEASE DATE SHEET 4 OF 6			

D

C

B

A

E B

FROM LOWER
ARM SECTIONWRIST RADIAL
ENCODER (1024PPR)

#1

2.228"

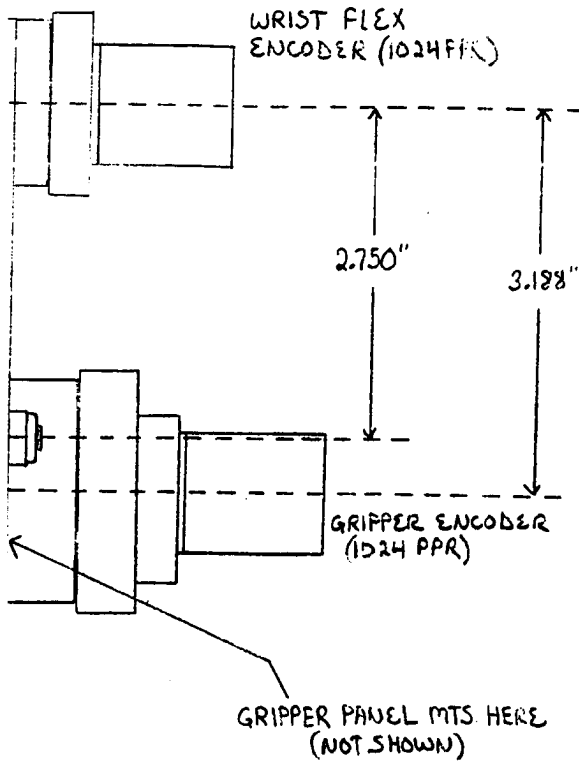
GRIPPER HANDLE

GRIPPER CONTROL
LEVER

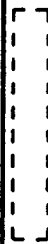
PART OR IDENTIFYING NO.					CODE IDENT
QTY REQD PER ASSY					UNLESS OTHERWISE SPECIFIED DIMENSIONS ARE IN INCHES TOLERANCES: XX = ANGLES = $\pm 30^\circ$ XXX = FRACTIONS = $\pm 1/32$ XXXX = BASIC ALL SURFACES ☒
PART NO.	N/A	F/A	NEXT ASSY	USED ON	MATERIAL
QTY REQD		APPLICATION			FINISH

REVISIONS				
ZONE	LTR	DESCRIPTION	DATE	APPROVED

D



C



B

NOTE (#1) WRIST RADIAL HAS $\approx 35^\circ$ OF FREE MOTION
IN DIRECTIONS SHOWN

ENT	NOMENCLATURE OR DESCRIPTION	MATERIAL OR MATERIAL CODE	DWG OR SPECIFICATION	ZONE	FIND NO.
PARTS LIST					
CONTRACT NO.		 SYSTEMS RESEARCH LABORATORIES, INC. 2800 INDIAN RIPPLE ROAD, DAYTON, OHIO 45440			
DRAWN BY	<i>J. Logan</i>	DATE	1-31-90		
CHECKED					
DESIGN					
PROJECT					
CUSTOMER					
QUALITY ASSURANCE					
MANUFACTURING					
		SIZE	CODE IDENT NO.	DRAWING NO.	REV
		C	14590		
		SCALE	RELEASE DATE	SHEET 5 OF 6	

A

3

A

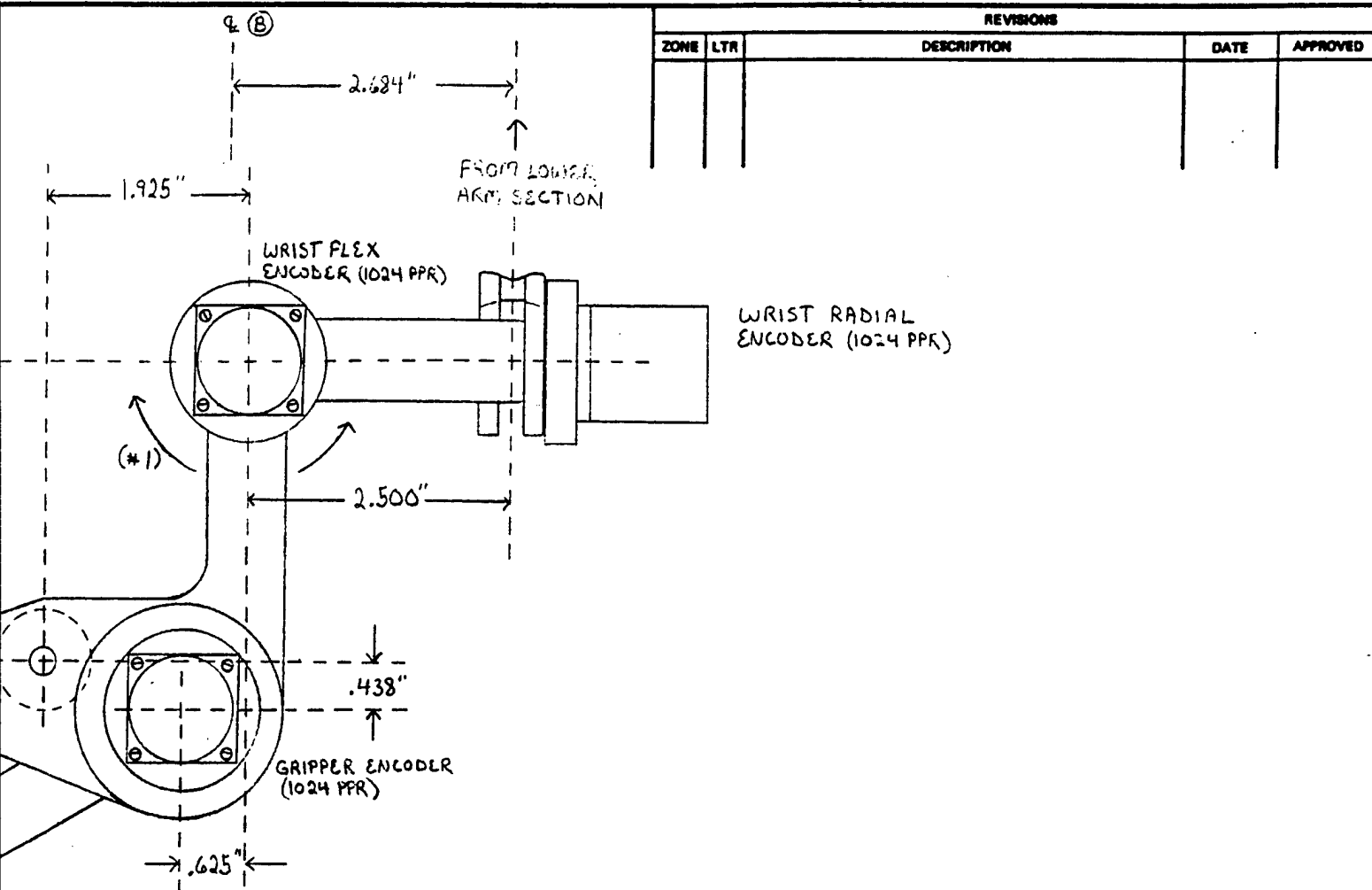
MRC 036303

2.750"

MOUNTING HOLES—
FOR GRIPPER PANEL
(NOT SHOWN)

GRIPPER CONTROL
LEVER

[illegible]



NOTE - (#1) WRIST FLEX HAS $\approx 90^\circ$ OF FREE MOTION
IN DIRECTION'S SHOWN

PART OR IDENTIFYING NO.	CODE IDENT	NOMENCLATURE OR DESCRIPTION	MATERIAL OR MATERIAL CODE	DWG OR SPECIFICATION	ZONE	FIND NO.
PARTS LIST						
UNLESS OTHERWISE SPECIFIED DIMENSIONS ARE IN INCHES TOLERANCES: XX = $\pm .01$ ANGLES = $\pm 30^\circ$ XXX = $\pm .005$ FRACTIONS = $\pm 1/32$ XXXX = BASIC ALL SURFACES ☒		CONTRACT NO. DRAWN BY <i>J. Leggett</i> DATE 1-31-90 CHECKED DESIGN PROJECT CUSTOMER QUALITY ASSURANCE MANUFACTURING		SYSTEMS RESEARCH LABORATORIES, INC. 2800 INDIAN RIPPLE ROAD, DAYTON, OHIO 45440 MBA EXOSKELETON (SIDE VIEW) WRIST RADIAL, WRIST FLEX, AND GRIPPER ENCODER / JOINT POSITIONS SIZE C CODE IDENT NO. 14590 DRAWING NO. SCALE RELEASE DATE SHEET 6 OF 6		
USED ON	MATERIAL	CUSTOMER	CODE IDENT NO.	DRAWING NO.	REV	
FINISH						

4

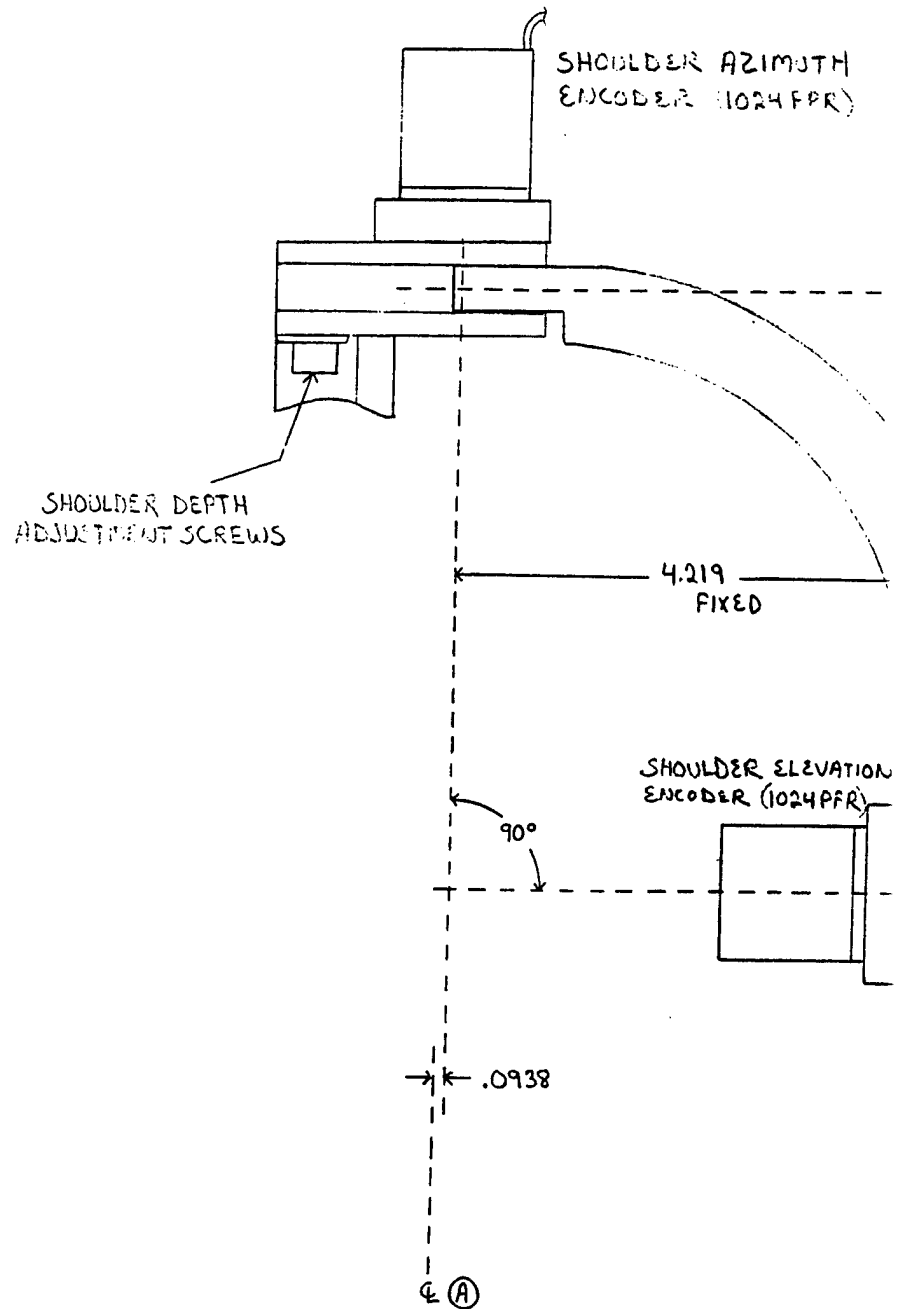
3

D

C

B

A



						PART OR IDENTIFYING NO.	CODE IDENT	NC
QTY REQD PER ASSY						UNLESS OTHERWISE SPECIFIED DIMENSIONS ARE IN INCHES TOLERANCES: XX = ANGLES = ± 30° XXX = FRACTIONS = ± 1/32 XXXX = BASIC ALL SURFACES ✓ MATERIAL FINISH		
PART NO.	N/A	F/A	NEXT ASSY	USED ON	CONTRACT			
	QTY REQD	APPLICATION				DRAWN BY		
						CHECKED		
						DESIGN		
						PROJECT		
						CUSTOMER		
						QUALITY ASSURANCE		
						MANUFACT.		

4

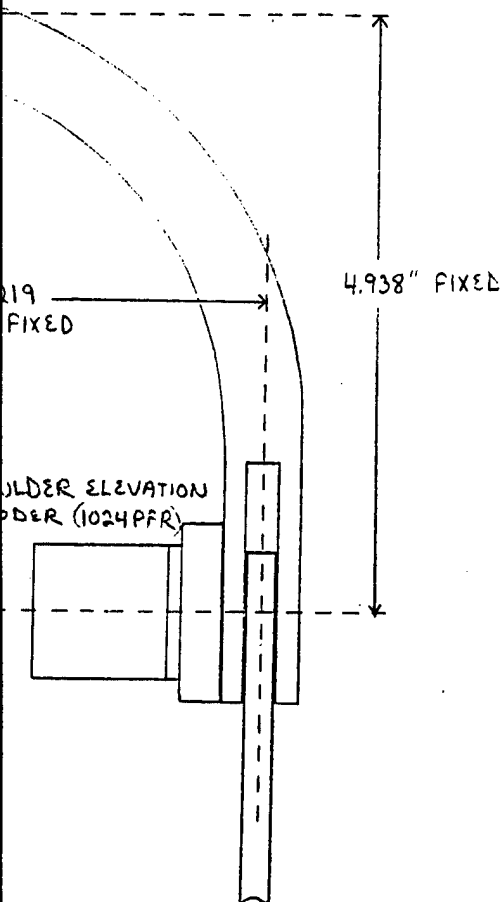
3

2

1

REVISIONS				
ZONE	LTR	DESCRIPTION	DATE	APPROVED

AZIMUTH
(1024 PPR)



NO.	CODE IDENT	NOMENCLATURE OR DESCRIPTION	MATERIAL OR MATERIAL CODE	DWG OR SPECIFICATION	ZONE	FIND NO.
PARTS LIST						

SPECIFIED IN INCHES ES: ANGLES = ± 30' TIONS = ± 1/32 ES ✓	CONTRACT NO.		 SYSTEMS RESEARCH LABORATORIES, INC. 2800 INDIAN RIPPLE ROAD, DAYTON, OHIO 45440				
	DRAWN BY	<i>J. Logan</i>					DATE
	CHECKED				MBA EXOSELETON SHOULDER AZIMUTH TO SHOULDER ELEVATION ENCODER/JOINT POSITIONS		
	DESIGN						
	PROJECT						
	CUSTOMER			SIZE	CODE IDENT NO.	DRAWING NO.	REV
	QUALITY ASSURANCE			C	14590		
MANUFACTURING			SCALE	RELEASE DATE	SHEET 2 OF 6		

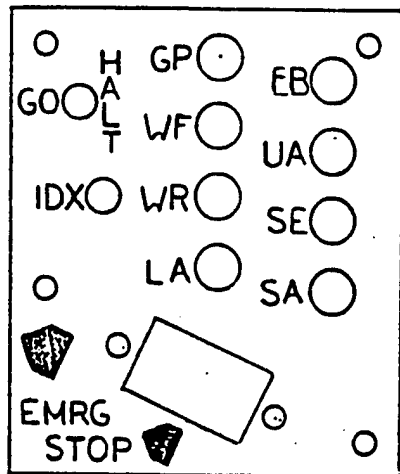
2

2

1

1

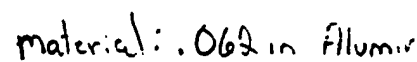
50



NOTE: Left Panel Shown, Right Panel
Is Mirror Image

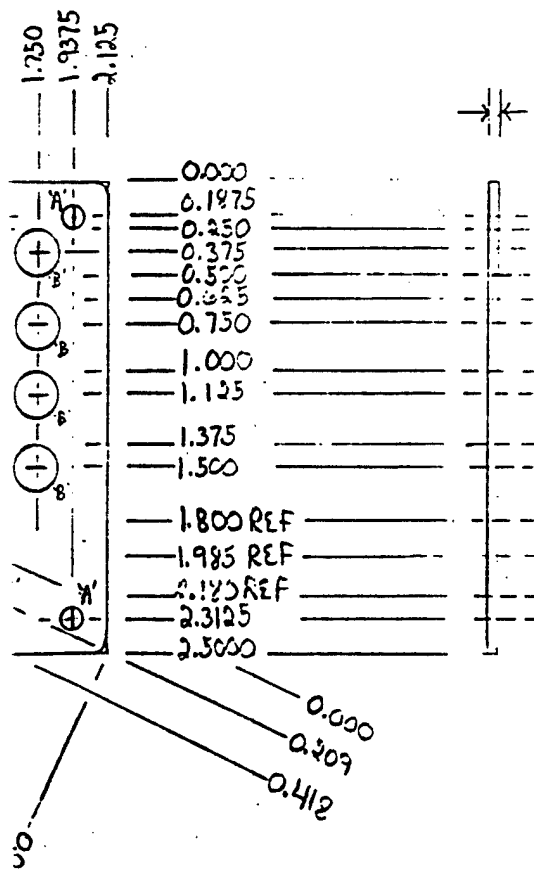
MBA EXOSKELETON GRIPPER PANEL LABELING

→ ← .02



GRIPPER

RT = LT Control Panel
 * (rt panel is brown, Lt panel is Mirror Image)



material: .062 in Aluminum

MBA EXOSKELETON
 GRIPPER PANEL COVER

DRILL THRU for #4 Clearance
4 Places marked A

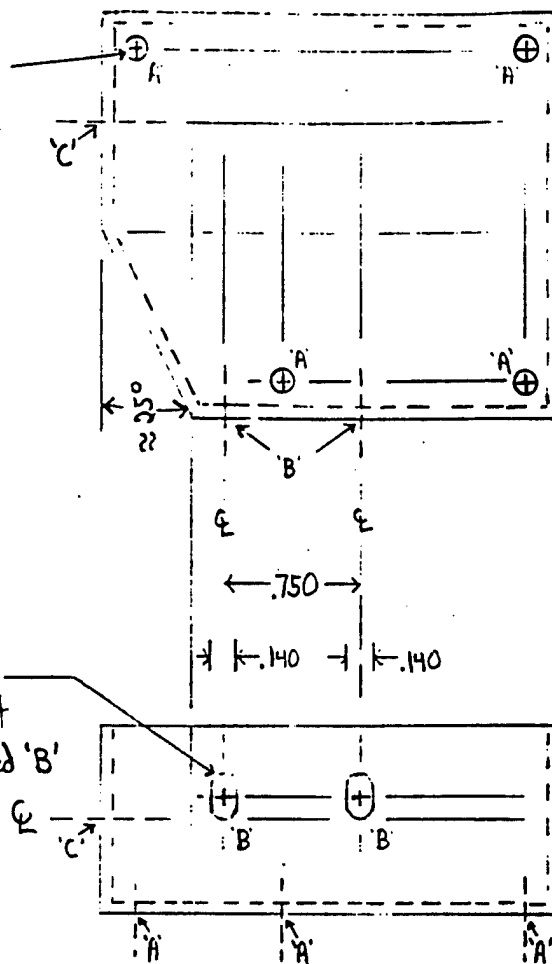
TOP

0.000
0.1875
0.5625
1.125
1.4375
2.3125
2.500

0.000
0.1875
0.5625
1.125
1.9375
2.125

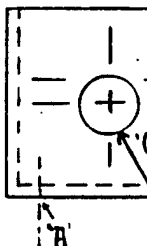
DRILL THRU for #6
Clearance x .250 Slot
length, 2 Places marked 'B'

FRONT



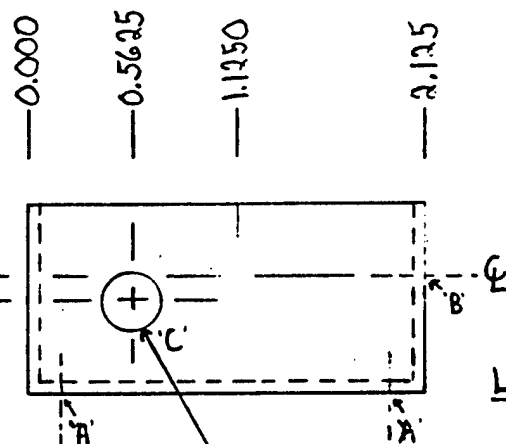
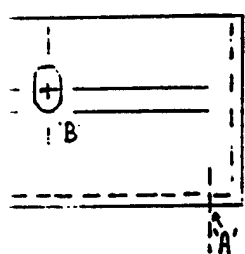
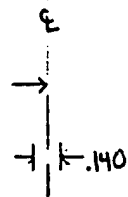
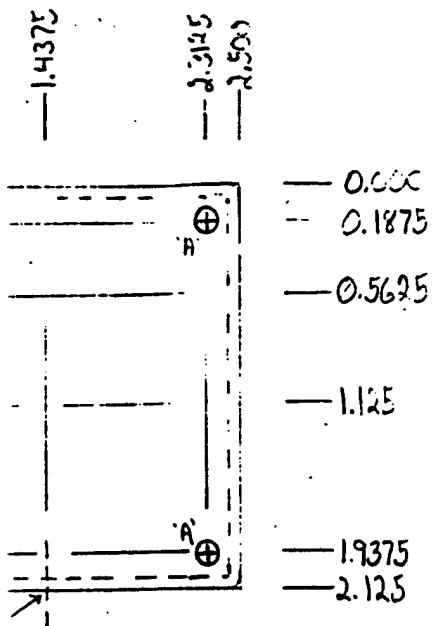
0.000
0.5625

0.000
0.250
0.375
0.500
1.000



MATERIAL: .062" Aluminum

ME
GR
(L

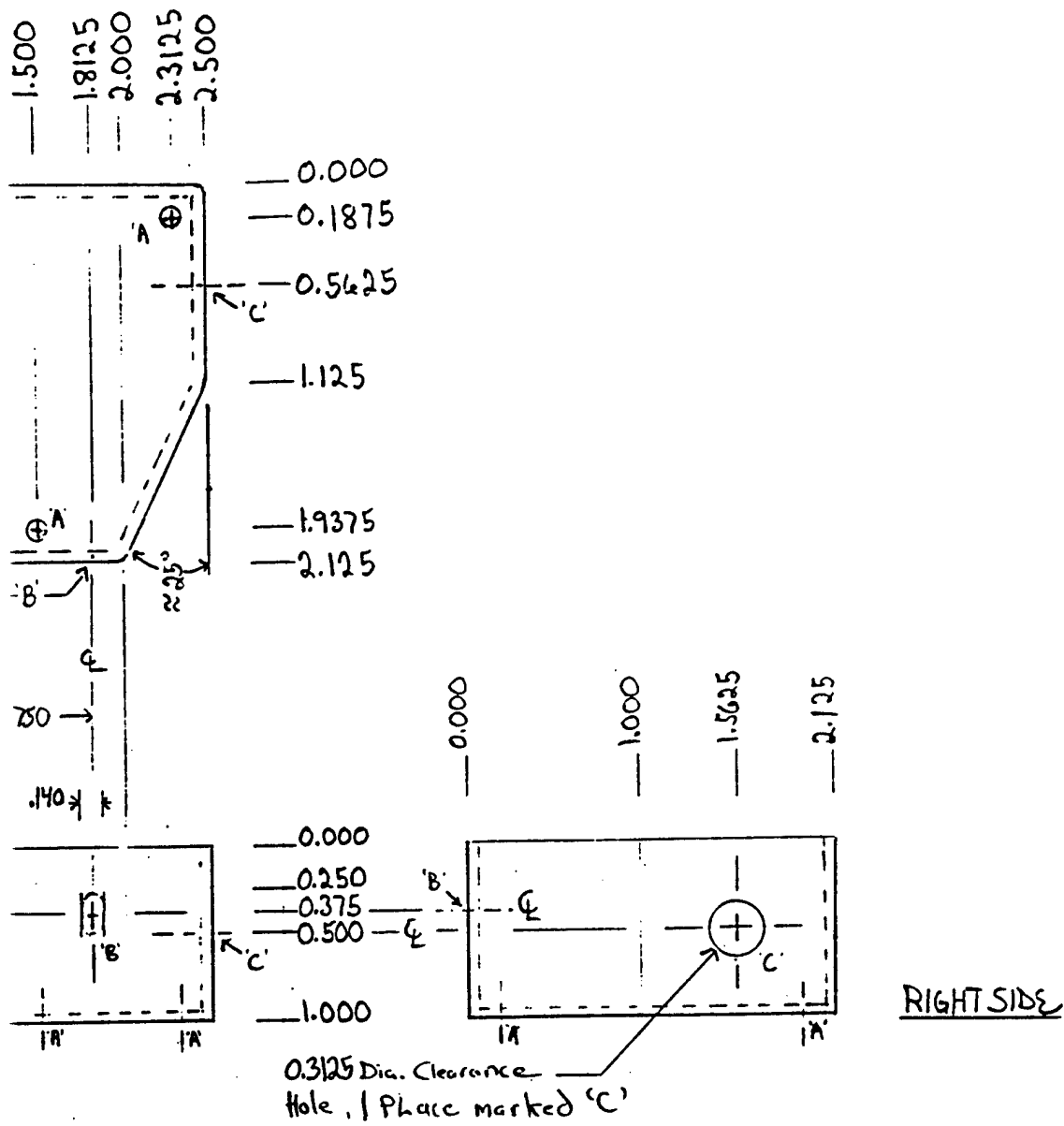


LEFT SIDE

0.3125 Dia Clearance Hole, 1 Place Marked 'C'

62" Aluminum

MBA EXOSKELETON
GRIPPER PANEL ENCLOSURE
(LEFT)



IAL: 062" Aluminum

MBA EXOSKELETON
GRIPPER PANEL ENCLOSURE
(Right)

4

3



D

C



B

A

MRC

4

3



				PART OR IDENTIFYING NO.	CODE IDENT
QTY REQD PER ASSY					
				UNLESS OTHERWISE SPECIFIED DIMENSIONS ARE IN INCHES TOLERANCES: XX = ANGLES = $\pm 30'$ XXX = FRACTIONS = $\pm 1/32$ XXXX = BASIC ALL SURFACES ☒	CONTR
					DRAWN
					CHECKE
					DESIGN
					PROJEC
				MATERIAL	CUSTOM
				303 Stainless	QUALITY
PART NO.	N/A	F/A	NEXT ASSY	USED ON	ASSURAN
	QTY REQD	APPLICATION			MANUFAC



2

1

1

REVISIONS				
ZONE	LTR	DESCRIPTION	DATE	APPROVED

		PART OR IDENTIFYING NO.	CODE IDENT	NOMENCLATURE OR DESCRIPTION	MATERIAL OR MATERIAL CODE	DWG OR SPECIFICATION	ZONE	FIND NO.
PARTS LIST								
UNLESS OTHERWISE SPECIFIED DIMENSIONS ARE IN INCHES		CONTRACT NO.			 SYSTEMS RESEARCH LABORATORIES, INC. 2800 INDIAN RIPPLE ROAD, DAYTON, OHIO 45440			
TOLERANCES:		DRAWN BY	DATE		MBA EXOSKELETON VANE ACTUATOR ADAPTOR SHAFT			
JXX = ANGLES = ± 30°		CHECKED	12-28-87					
JXXX = FRACTIONS = ± 1/32		DESIGN						
JXXX = BASIC		PROJECT						
ALL SURFACES ✓		CUSTOMER			SIZE	CODE IDENT NO.	DRAWING NO.	REV
USED ON	MATERIAL	QUALITY ASSURANCE			C	14590		
FINISH	303 Stainless	MANUFACTURING			SCALE * X2	RELEASE DATE	SHEET 1 OF	



2

1

1

4

1

3

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D

C

→

B

A

MRC

2.125

1.675

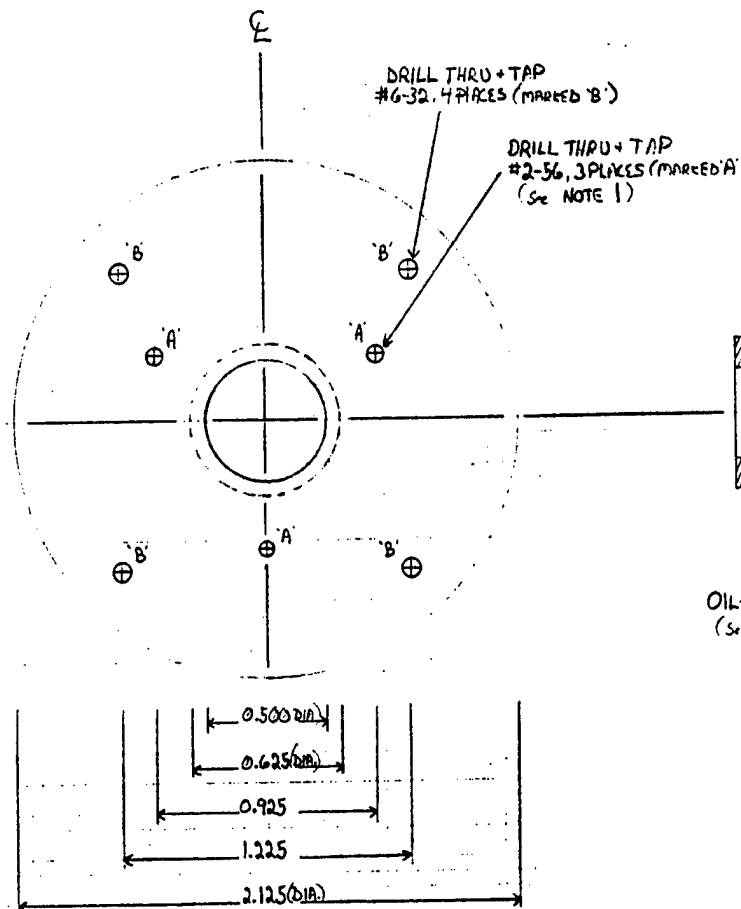
1.330

1.0625

0.5315

0.450

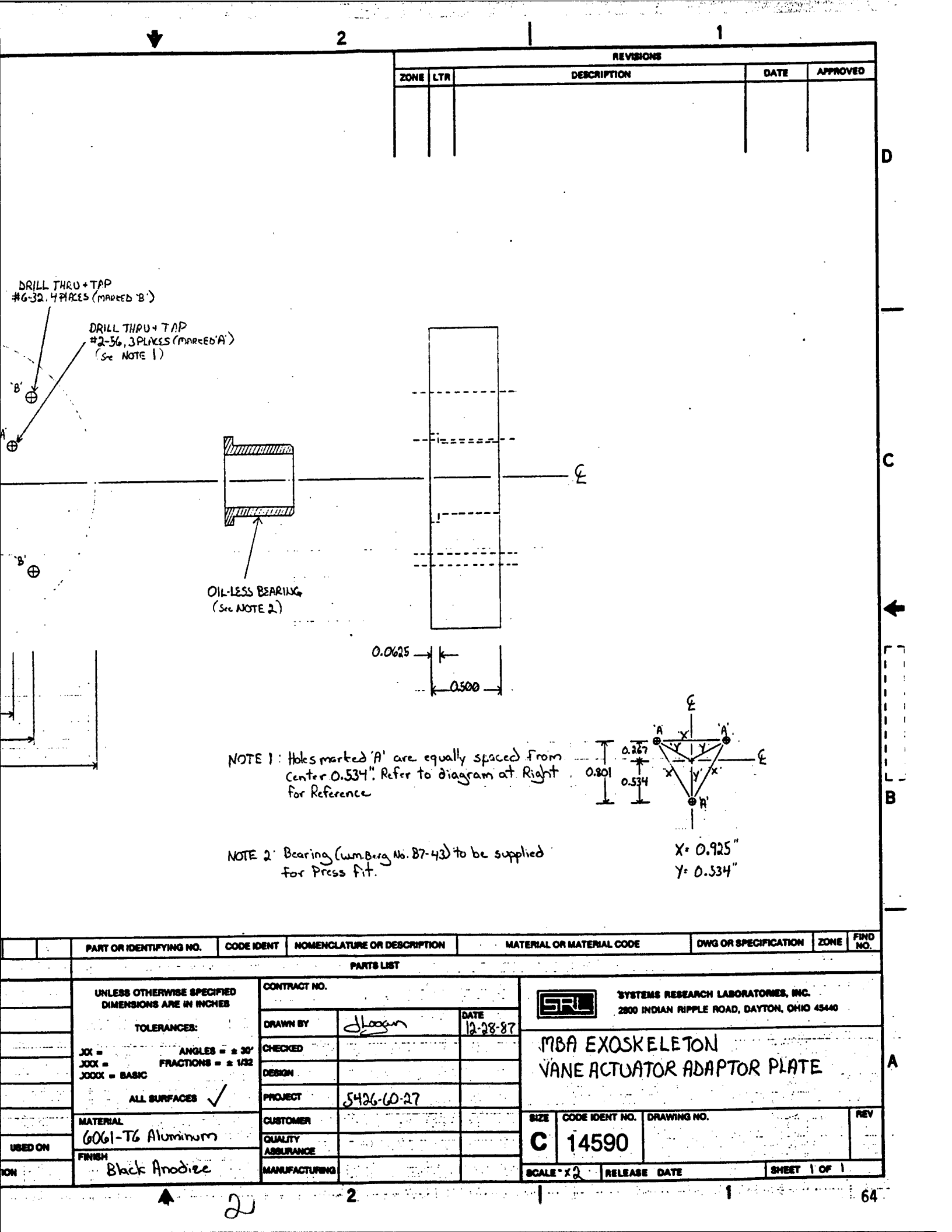
0.000



PART OR IDENTIFYING NO.					C
QTY REQD PER ASSY					
UNLESS OTHERWISE SPECIFIED DIMENSIONS ARE IN INCHES					
TOLERANCES:					
JXX = ANGLES =					
JXXX = FRACTIONS = ±					
JXXXX = BASIC					
ALL SURFACES ✓					
MATERIAL					
6061-T6 Aluminum					
FINISH					
Black Anodize					
PART NO.	N/A	F/A	NEXT ASSY.	USED ON	
QTY REQD		APPLICATION			

3

↑



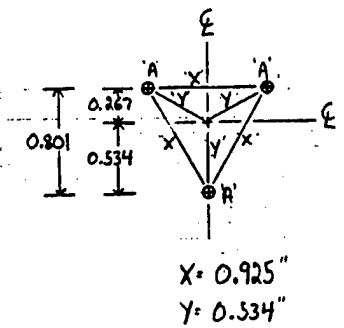
DRILL THRU + TAP
#6-32, 4 PLACES (MARKED 'B')

DRILL THRU + TAP
#2-56, 3 PLACES (MARKED 'A')
(See NOTE 1)

OIL-LESS BEARING
(See NOTE 2)

NOTE 1: Holes marked 'A' are equally spaced from center 0.534". Refer to diagram at Right for Reference

NOTE 2: Bearing (Linn. Berg No. 87-43) to be supplied for Press fit.

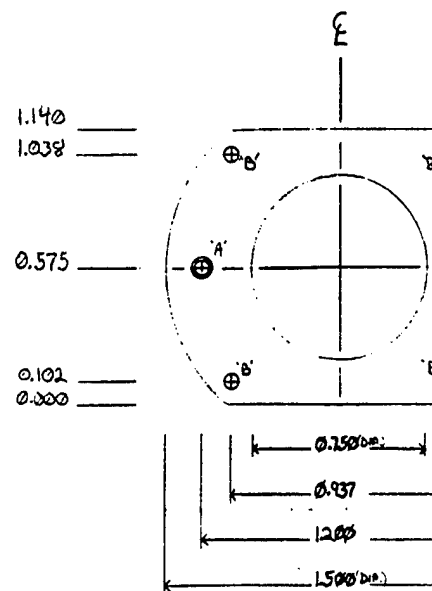


PART OR IDENTIFYING NO.		CODE IDENT	NOMENCLATURE OR DESCRIPTION		MATERIAL OR MATERIAL CODE	DWG OR SPECIFICATION	ZONE	FIND NO.
PARTS LIST								
UNLESS OTHERWISE SPECIFIED DIMENSIONS ARE IN INCHES			CONTRACT NO.			 SYSTEMS RESEARCH LABORATORIES, INC. 2800 INDIAN RIPPLE ROAD, DAYTON, OHIO 45440		
			DRAWN BY	<i>Glaxon</i>	DATE			
TOLERANCES: JXX = ANGLES = ± 30' JXXX = FRACTIONS = ± 1/32 JXXXX = BASIC ALL SURFACES ✓			CHECKED		MBA EXOSKELETON VANE ACTUATOR ADAPTOR PLATE			
			DESIGN					
MATERIAL 6061-T6 Aluminum			PROJECT	5426-60-27	SIZE CODE IDENT NO. DRAWING NO. REV			
			CUSTOMER					
FINISH Black Anodize			QUALITY ASSURANCE		C 14590			
			MANUFACTURING					
USED ON			SCALE: X2			RELEASE DATE		SHEET 1 OF 1

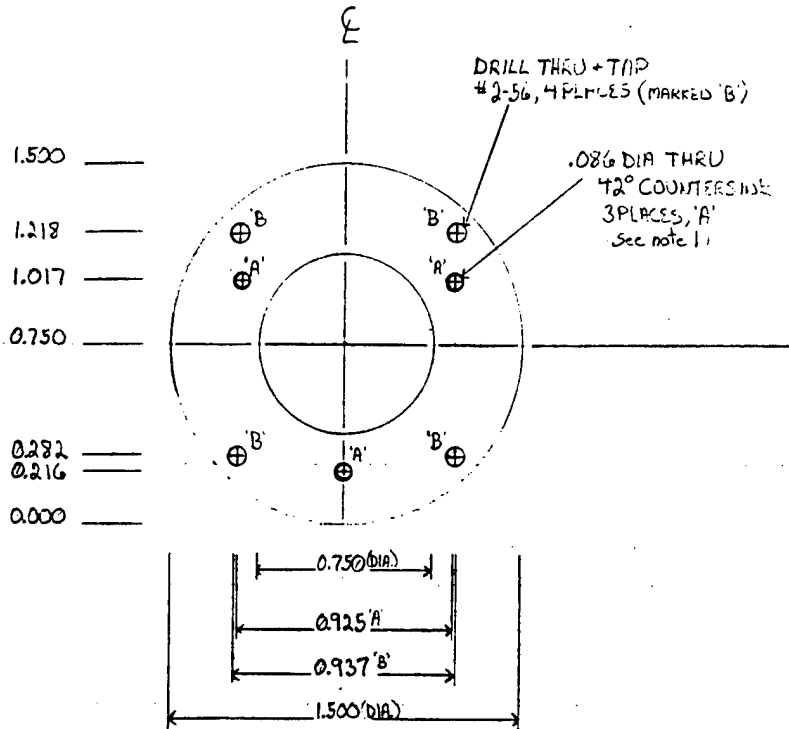
3

A

MRC



QTY REQD PER ASSY										
PART NO.	N/A	F/A	NEXT ASSY				USED ON			
	QTY REQD		APPLICATION							



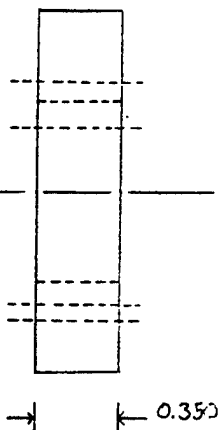
NOTE

PART OR IDENTIFYING NO.					CODE IDENT	NOMENCL
QTY REQD PER ASSY					CONTRACT NO.	
					UNLESS OTHERWISE SPECIFIED DIMENSIONS ARE IN INCHES TOLERANCES: JXX = ANGLES = ± 30' JXXX = FRACTIONS = ± 1/32 JXXXX = BASIC ALL SURFACES ✓	
					MATERIAL 6061-T6 Aluminum	
					FINISH Black Anodize	
PART NO.	N/A	F/A	NEXT ASSY	USED ON	CUSTOMER	
					QUALITY ASSURANCE	
					MANUFACTURING	

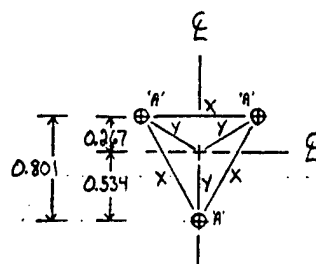
REVISIONS				
ZONE	LTR	DESCRIPTION	DATE	APPROVED

D
(MARKED 'B')

IN THRU
COUNTERSINK
HOLES, 'A'
c. note 1



NOTE 1 Holes marked 'A' are equally spaced from center 0.534 in. Refer to diagram at right.



X = 0.925"
Y = 0.534"

CODE IDENT	NOMENCLATURE OR DESCRIPTION	MATERIAL OR MATERIAL CODE	DWG OR SPECIFICATION	ZONE	FIND NO.
------------	-----------------------------	---------------------------	----------------------	------	----------

PARTS LIST

SPECIFIED DIMENSIONS LES = ± 30' VS = ± 1/32 ✓ 2c	CONTRACT NO.		 SYSTEMS RESEARCH LABORATORIES, INC. 2800 INDIAN RIPPLE ROAD, DAYTON, OHIO 45440			
	DRAWN BY	DATE				
	CHECKED		ENCODER MOUNTING BRACKET, STANDARD JOINTS (A,S,R,F,E,G)			
	DESIGN					
	PROJECT	5426-60-27				
	CUSTOMER		SIZE	CODE IDENT NO.	DRAWING NO.	REV
	QUALITY ASSURANCE		C	14590		
	MANUFACTURING		SCALE X 2 RELEASE DATE SHEET OF			

D

C



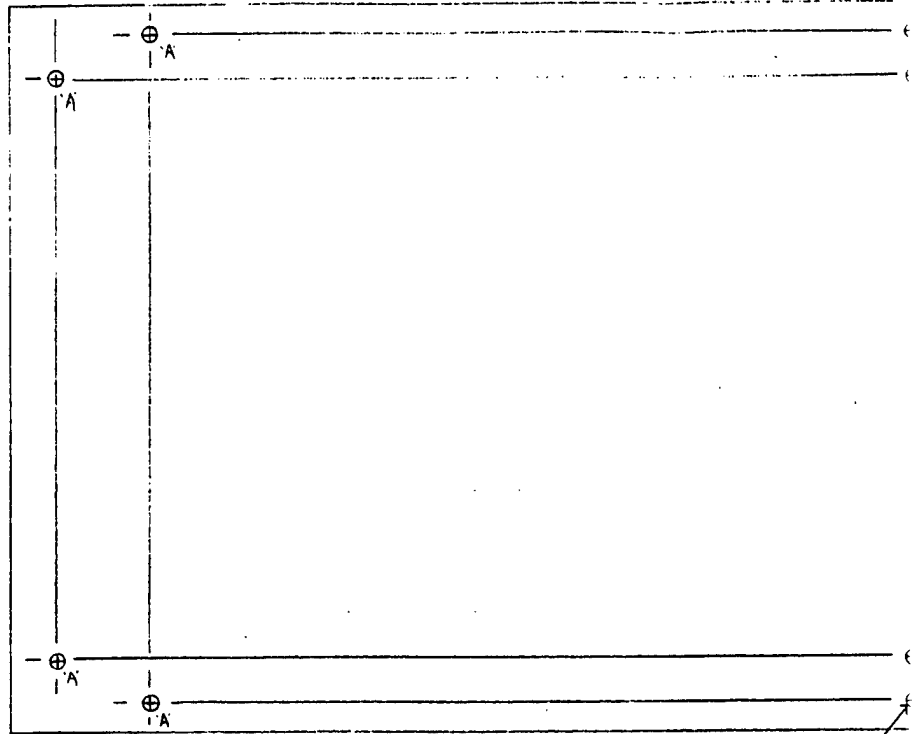
B

A

MRC

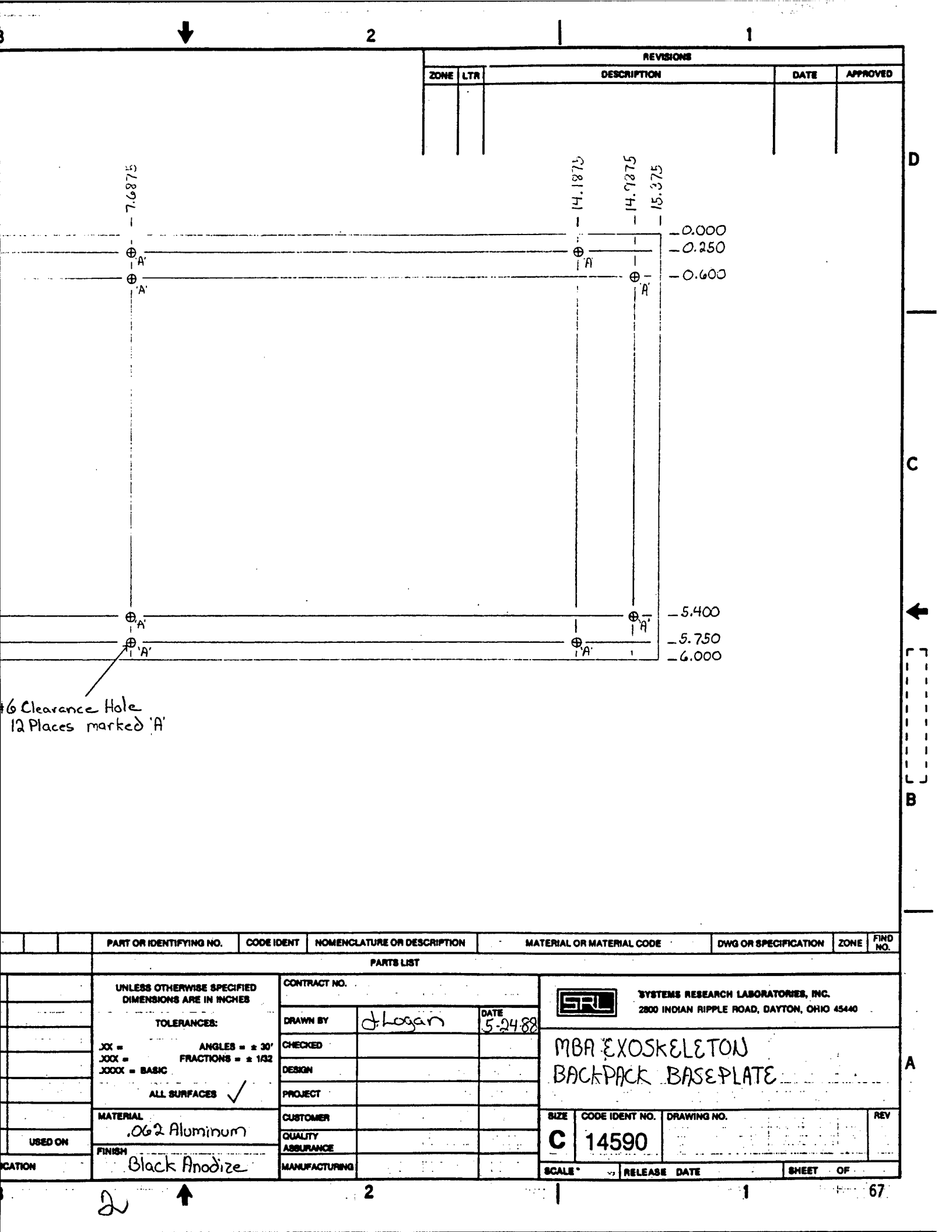
0.000
0.3875

1.1875



#6 Clearance Hol
12 Places mark

QTY REQD PER ASSY					PART
					UN.
					D.
					JXX =
					JXXX =
					JXXXX
					MATER
PART NO.	N/A	F/A	NEXT ASSY	USED ON	FINISH
	QTY REQD		APPLICATION		



4

3

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.188 Dia Thru
Hole 5 Places
marked 'B'

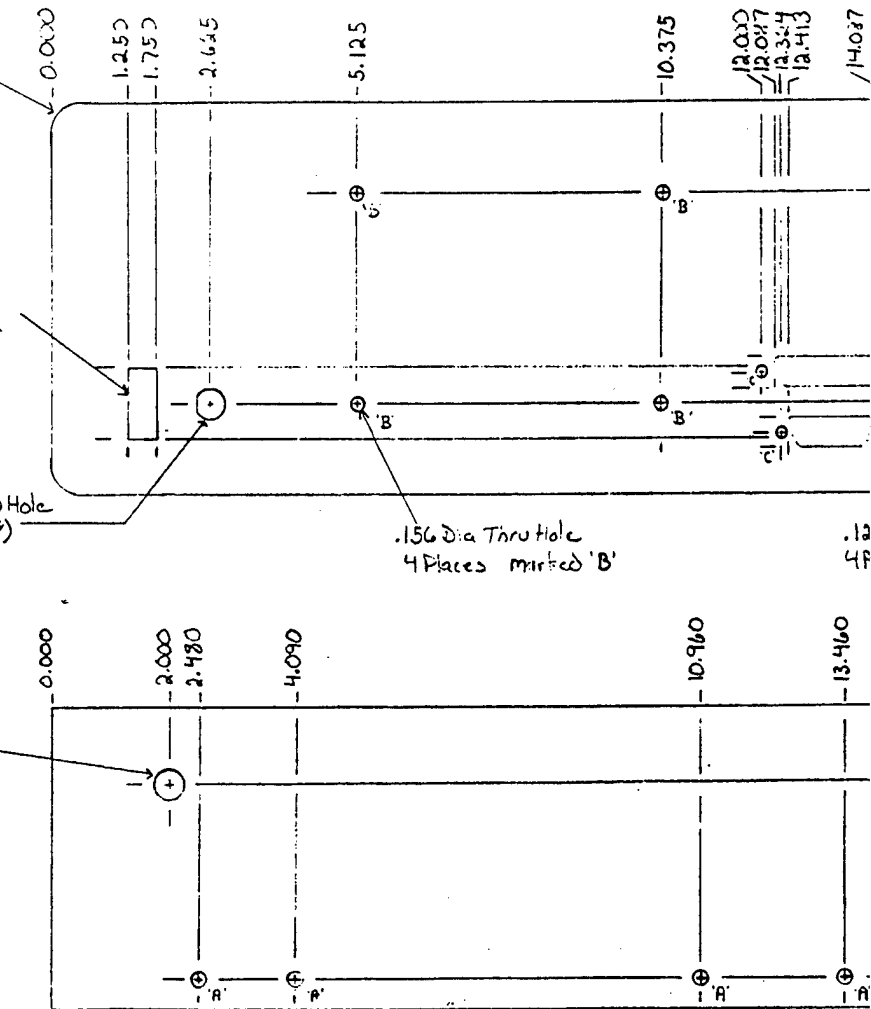
* NOTE 1

.500" x 1.150"
PANEL CUTOUT

.506" Dia. D Hole
(.506" x .473")

.156 Dia Thru Hole
4 Places marked 'B'

.515" Dia Thru
1 Place

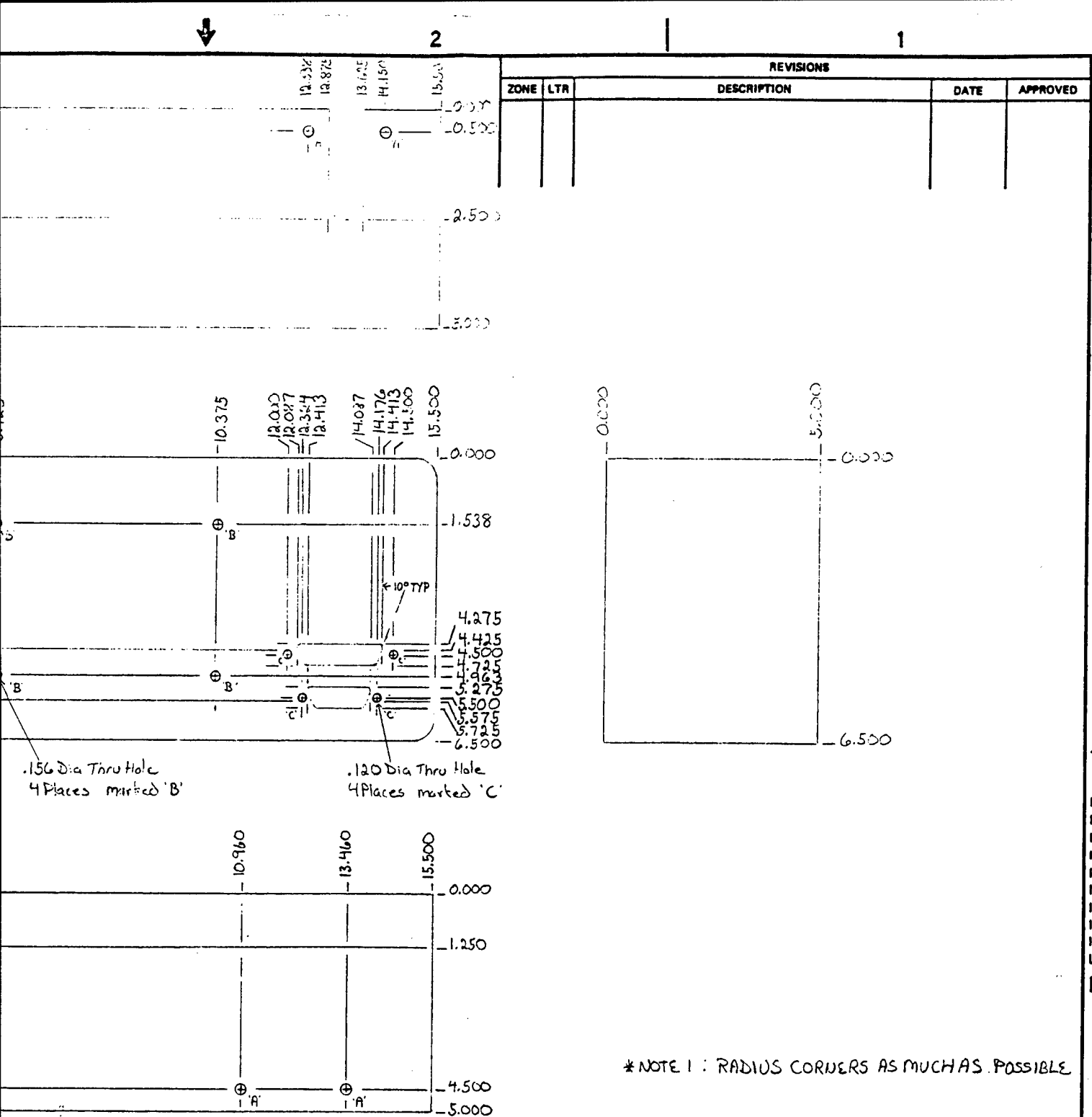


						PART OR IDENTIFYING NO.		CODE IDENT		
QTY REQD PER ASSY						UNLESS OTHERWISE SPECIFIED DIMENSIONS ARE IN INCHES TOLERANCES: XX = ANGLES = ± 30° XXX = FRACTIONS = ± 1/32 XXXX = BASIC ALL SURFACES ✓ MATERIAL .062 Aluminum FINISH BLACK Anodize				
PART NO.	N/A	F/A	NEXT ASSY	USED ON						
	QTY REQD		APPLICATION							

4

3

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PART OR IDENTIFYING NO.	CODE IDENT	NOMENCLATURE OR DESCRIPTION	MATERIAL OR MATERIAL CODE	DWG OR SPECIFICATION	ZONE	FIND NO.
PARTS LIST						
UNLESS OTHERWISE SPECIFIED DIMENSIONS ARE IN INCHES TOLERANCES: XX = ANGLES = ± 30' XXX = FRACTIONS = ± 1/32 XXXX = BASIC ALL SURFACES ✓		CONTRACT NO.		SYSTEMS RESEARCH LABORATORIES, INC. 2800 INDIAN RIPPLE ROAD, DAYTON, OHIO 45440		
		DRAWN BY <u>J. Logan</u> DATE <u>5-24-88</u> CHECKED <u> </u> DESIGN <u> </u> PROJECT <u> </u> CUSTOMER <u> </u> QUALITY ASSURANCE <u> </u> MANUFACTURING <u> </u>				
MATERIAL <u>.062 Aluminum</u> FINISH <u>BLACK Anodize</u>		SIZE <u>C</u> CODE IDENT NO. <u>14590</u> DRAWING NO. <u> </u> REV <u> </u>		SCALE * <u> </u> RELEASE DATE <u> </u> SHEET OF <u> </u>		

9.0 Appendix A: MBAssociates Backpack

9.4 Software Source Listing

mba.c68

/*****

FILE mba.c68

FUNCTION main

AUTHOR Todd Mosher

DATE 5-6-91

GENERAL DESCRIPTION

This program runs in the mba back pack.
This routine will wait for the user to
move the joints through their indexes and
then it will return the position of the encoders
with respect to their index position.

*****/

#include <stdio.h68>

#include <ctype.h68>

#define ESTOP 0x0024

#define GOHALT 0x0009

#define chr_in() ((iostat[0]) & 0x01) /* check char avail status */

#define get_byt() (ioport[0]) /* look at the incoming char */

int *optenc; /* pointer to optical encoder values */

int *optsta; /* pointer to optical encoder status */

char *ioport;

char *iostat;

int *swt;

int *lights;

int glob_pos[16]; /* position from index mark */

int last_pos[16]; /* last encoder val read */

int reqpnd;

int send();

int init_oe();

int position();

main()

{

int comcnt = 0;

int i,j;

int tog = 0;

int off = 0xffff;

int on = 0xfefe;

int lit_mask;

/* only gripper light on */

for (i=0;i < 16;i++)

{

mba.c68

```

    glob_pos[i] = 0;
    last_pos[i] = 0;
}
optsta = 0x24020;
ioport = 0x240e7;
iostat = 0x240e3;
swt = 0x24080;
lights = 0x24040; /* point to lights */
optenc = 0x24000; /* point to optical encoders */

reqpnd = 0;
init_oe(); /* initialize optical encoders */
lit_mask = on;
*lights = lit_mask;
while (1) /* do forever */
{
    if (chr_in() || reqpnd) /* if char in the serial io port */
    {
        if (comcnt++ == 100) /* show comm with blinking lights */ lit_mask = lit_mask &
            0xefef;
        if (comcnt == 200)
        {
            lit_mask = on;
            comcnt = 0;
        }
        tog = ~tog;
        if (tog)
            lit_mask = lit_mask & 0x7f7f;
        else
            lit_mask = lit_mask | 0x8080;
        *lights = lit_mask;

        if (!reqpnd) /* if a request was pending */
            i = get_byt();
        else
            i = reqpnd;

        if (i == 'H' || i == 'B' || i == 'L' ||
            i == 'R' || reqpnd) /* pc requesting data */
        {
            reqpnd = 0;
            if ((swt[0] & GOHALT) != GOHALT) /* z for sleep/halt */ send("Z",1);
            else if ((swt[0] & 0x0012) == 0x0012) /* no index swt pressed */ send("H",1);
            else if ((swt[0] & 0x0012) == 0) /* both indexes pressed */
                send("R",1); /* reset indexes */
            else
                send("I",1); /* indexing mode */

            if (i == 'H' || reqpnd == 'H')

```

mba.c68

```

        for (i=0;i<16;i++) /* send out all data */
        {
            send(&glob_pos[i],2); /* return an error code */
            position(); /* get new encoder positions */
        }
    else if (i == 'L' || reqpnd == 'L')
        for (i=0;i<8;i++) /* send out all data */
        {
            send(&glob_pos[i],2); /* return an error code */
            position(); /* get new encoder positions */
        }
    else if (i == 'R' || reqpnd == 'R')
        for (i=8;i<16;i++) /* send out all data */
        {
            send(&glob_pos[i],2); /* return an error code */
            position(); /* get new encoder positions */
        }
    }
    else if (i == 'S') /* pc requesting status */
        send("S",1);

        position(); /* get new encoder positions */
}
/* if ((swt[0] & ESTOP) != ESTOP) /* allow user to get out on */
/* exit(0); /* emergency stop */

/* while ((swt[0] & GOHALT) != GOHALT) /* send nothing for gohalt */
/* position(); /* keep track of position */
/* }
/* i = 1;
/* if (!i)
/* printf(" "); /* this is because of a bug in the libs */
}

int position()
{
    int cur_pos;
    int i;

    for (i=0;i<16;i++) /* for all encoders, calc their positions */
    {
        cur_pos = optenc[i];
        if (cur_pos >= last_pos[i]) /* clock wise or else ccw past index */
            if ((last_pos[i] + 2046) > cur_pos) /* cw motion */
                glob_pos[i] += cur_pos - last_pos[i];
            else
                glob_pos[i] -= last_pos[i] + 4096 - cur_pos; /* ccw past index */
        else /* ccw or else clock wise past index */
            if ((cur_pos + 2046) >= last_pos[i]) /* ccw motion */
                glob_pos[i] -= last_pos[i] - cur_pos;
            else

```

mba.c68

```

        glob_pos[i] += cur_pos + 4096 - last_pos[i]; /* cw through index */ last_pos[i] = cur_pos;
    }
int init_oe() /* initialize the optical encoders */
{
    /* set bits to 1 which will cause the */
    int list[16]; /* hw to reset counters when the index is */
    int tmp; /* crossed */
    int i;
    int j;

    for (i=0;i<16;i++)
        list[i] = 0;

    *lights = 0; /* turn all lights on */
    *optsta = -1; /* set all bits to 1 to allow the hardware */
    tmp = optsta[0]; /* to reset the counters when the index is passed */
    /* while(optsta[0]) /* while not all indexs crossed */
    while(optsta[0] & 0xff00) /* while not all indexs crossed */
    {
        *lights = ~(*optsta); /* lights reflect the status to users */
        if ((swt[0] & 0x0012) != 0x0012) /* index switch aborts */
        {
            /* this is incase of broken encoder */
            optsta[0] = 0;
            for (i=0;i<16000;i++); /* delay for swt release */
            break;
        }
        if (tmp != *optsta) /* 1 or more indexs crossed */
        {
            j = 1;
            for (i=0;i<16;i++) /* which ones were crossed */
            {
                if ((*optsta & j == 0) && !list[i]) /* new index crossed */
                {
                    list[i]++; /* note that index crossed */
                    glob_pos[i] = optenc[i]; /* set global position info */ last_pos[i] = glob_pos[i];
                }
                j = j << 1;
            }
            position();
        }
    }
    if (chr_in()) /* if there is a char in the serial io port */
    {
        i = get_byt();
        if (i == 'H' || i == 'B' ||
            i == 'L' || i == 'R') /* pc requesting data */
            reqpnd = i; /* note the pending request */
        else if (i == 'S') /* pc requesting status */
            send("S",1);
    }
}

```

mba.c68

```
    }  
}  
int send(byt,cnt)      /* send cnt bytes out the serial io port */  
char *byt;            /* if cnt is 0 then an ascii string is being */  
int cnt;              /* sent */  
{  
    int i;  
    long j;  
  
    if (!cnt)          /* sending a text string */  
        cnt = strlen(byt);  
    for (i=0;i<cnt;i++) /* send out all bytes */  
    {  
        for (j=0;j<64000l;j++) /* wait for tx free */  
            if ((iostat[0] & 0x04) == 0x04) /* tx ready */  
                break;  
        if (j < 64000l) /* max wait for tx ready */  
            ioport[0] = byt[i];  
        else  
            return(1); /* return error */  
    }  
    return(0);  
}
```

makcur.bat

c68 +fi -o mba.r68 mba.c68
ln68 +c 1000 -t -o mba.e68 mba.r68 -lc68s

setenv.bat

```
set INCL68=c:\aztec_c\include  
set CLIB68=c:\aztec_c
```

exomon.c

"C"
 "68000"
 #EXTENSIONS ON\$
 #FULL LIST ON\$
 #ENTRY OFF\$
 #LIST_CODE ON\$

```

/*****
/*
/*      DESIGNED BY : TODD MOSHER / MONTY CRABILL      */
/*
/*      CODED BY : TODD MOSHER                        */
/*
/*      DATE : JAN-16-1991                            */
/*
/*      REVISION NUMBER: ORIGINAL                      */
/*
/*****
/*
/*      REVISIONS LOG:                                */
/*      NUMBER  DATE      DESCRIPTION                */
/*      -----  -----  -----                    */
/*
/*              RL C MBA                            */
/*****
/*
/*      THIS PROGRAM IS FOR THE MBA BACKPACK.  IT IS A MONITOR  */
/*      WHICH WILL INITIALIZE THE ENCODERS AND THEN WAIT FOR A  */
/*      FILE TO BE UPLOADED OVER THE SERIAL PORT.  DURING      */
/*      INITIALIZATION OF THE ENCODERS, ALL LEDS WILL BE LIT.   */
/*      AT THIS POINT, ALL JOINTS MUST BE ROTATED THROUGH THEIR */
/*      RANGE OF MOTION SO THAT THE LEDS WILL GO OFF.          */
/*      THEN THE LEDS WILL CONTINUE TO FLASH UNTIL A FILE STARTS */
/*      UPLOADING.  WHILE THE FILE IS LOADING, THE LIGHTS WILL DO */
/*      A COUNTING PATTERN, AND FINALLY THEY WILL BE TURNED OFF */
/*      WHEN THE UPLOADED PROGRAM BEGINS EXECUTION.            */
/*      ERROR CODES WILL BE DISPLAYED ON THE LEFT HAND        */
/*      ERROR CODES:                                          */
/*      LIGHT      ERROR                                     */
/*      GP      "PGM" PREFACE TO FILE TX MISSING            */
/*      WF      STARTING ADDR OF CODE MISSING              */
/*      WR      CODE SIZE MISSING                          */
/*      LR      STARTING ADDR OF DATA MISSING             */
/*      EB      DATA SIZE MISSING                         */
/*      UA      NOT ENOUGH CODE SENT UP                    */
/*      SE      NOT ENOUGH DATA SENT UP                   */
/*      SA      CHECK SUM ERROR                            */
/*
/*      SEE UPLOAD FUNCTION HEADER FOR EXPECTED INFO FOR FILE TX
/*
/*****

```

exomon.c

```

#define DUART_A 0x0240E7
#define DUART_B 0x0240F7
#define TXR_MASK 0x04
#define SND_MASK 0x01
/*char *jstack = 0x20000; /* FOR EPROM 0-3 MUST BE STACK POINTER */ int main();
/*char *jaddr = main; /* FOR EPROM... 4-7 MUST BE PGM PC ADDR */
/* MUST BE 20100 IN EPROM BITS 4-7 */
/*char *jaddr = 0x30228; /* FOR EMULATION */
extern int STRT();
#$ORG 0x24080$
int switches; /* gripper switches bit 0 - left halt/go */
/* bit 1 - left indx */
/* bit 2 - left E stop */
/* bit 3 - right halt/go */
/* bit 4 - right indx */
/* bit 5 - right E stop */
/* note debug is bit 0 @ 0x24060 */
#$END ORG$
#$ORG 0x240E3$
short txr_stat_ptr;
#$END ORG$
#$ORG 0x24020H$
int oe_sta;

#$END ORG$
short *dev_ptr;
char tarr[4];
char (*usrpgm)(); /* pointer to user program */
int glberr; /* general purpose error indicator */
int *grp_led; /* addr of griper leds */
int grpdsp;
char *cadr;
char sndstr[100]; /* string to send from function send */
int wait(); /* waits for tx ready */
int send();
int getbyt(); /* byte from serial port, -1 = time out */
/* int init_oe(); /* optical encoder initialization */
int upload(); /* attempts to upload and execute the usr pgm */

main()
{
    short z;
    short j;
    int k;
    short *oe_ptr,i;
    short *c_r_ts;
    grp_led = (int *)0x24040;
    grpdsp = 0;
    c_r_ts = (short *)0x240E1; /* setup pointers */
    dev_ptr = (short *)DUART_A;

```

exomon.c

```

STRT();          /* CALL STRT TO INITIALIZE SERIAL PORT */
glberr = 0;

*c_r_ts = 0x13;
*c_r_ts = 0x1F;

k = 0;
while(1)         /* wait for a program to be uploaded */
{
    if ((switches & 0x0012) != 0x0012) /* index clears the err flag */ glberr = 0;

    if (!glberr)
        k++;
    if (k == 20000 && !glberr) /* if no error, flash leds */
    {
        if (grpdsp)
            grpdsp = 0;
        else
            grpdsp = 0xffff;
        *grp_led = grpdsp;
        k = 0;
    }

    j = (short)(txr_stat_ptr & SND_MASK); /* get rs422 status */
    if (j == 1) /* char rx from PC */
    {
        *grp_led = 0xffff; /* turn lights off */
        if (upload() != 1) /* upload and exec user program */
            send("ER"); /* on error, send error msg */
    }
}
}

```

exomon.c

```

/*****
/*
/* THIS ROUTINE WILL CONTROL THE UPLOADING OF A PROGRAM */
/* THIS ROUTINE EXPECTS */
/*   BYTES 0-2  PGM */
/*   BYTES 3-6  CODE START ADDR */
/*   BYTES 7-10 BYTES OF CODE */
/*   BYTES 11-14 DATA START ADDR */
/*   BYTES 15-18 BYTES OF DATA */
/*   CODE DATA */
/*   DATA DATA */
/*   1 BYTE CHECK SUM */
/*
/* THE PC UPLOAD PROGRAM ALWAYS SENDS OUT AN 'S' BEFORE */
/* STARTING THE UPLOAD. THIS IS TO STOP ANY PROGRAMS WHICH */
/* MAY ALREADY BE RUNNING IN THE BACK PACK */
/*
/* AFTER EACH THING LISTED ABOVE, AN 'OK' OR 'ER' WILL */
/* BE SENT TO THE SENDING DEVICE, ON 'ER', THIS ROUTINE */
/* WILL RETURN TO MONITOR MODE */
/*
*****/
int upload()
{
    long i,j;
    char chksum = 0;
/*   char *cadr = 0l;      /* code address */
    long csiz = 0;          /* size of code in bytes */
    char *dadr = 0l;        /* data address */
    long dsiz = 0;          /* data size */
    long tlong;
    long tmp;
    int err = 0;

    i = getbyt();
    if (i == 'S')
        return(1);          /* ignore initial S's */

    if (i != 'P' ||
        getbyt() != 'G' ||
        getbyt() != 'M')
        return(glberr = (*grp_led = 0xfffe)); /* return error */
    send("OK");
    cadr = 0l;
    tlong = 0l;
    for (i=3;i>=0;i--)      /* get code start address */
        if ((tarr[i] = getbyt()) == -1) /* -1 = no data available */
            /* return(glberr = (*grp_led = 0xfffd)); */
        else
            tlong = tlong * 256 + tarr[i]; /* build code address */
    cadr = (char *)tlong;

```

exomon.c

```

send("OK");

for (i=3;i>=0;i--) /* get code size in bytes */
    if ((tmp = getbyt()) == -1) /* -1 = no data available */ return(glberr = (*grp_led =
        0xfffb));
    else
        csiz = csiz | (tmp << (8 * i)); /* build code size */

send("OK");

for (i=3;i>=0;i--) /* get data start address */
    if ((tmp = getbyt()) == -1) /* -1 = no data available */ return(glberr = (*grp_led =
        0xff7));
    else
        tlong = tlong | (tmp << (8 * i)); /* build data address */ dadr = (char *)tlong;

send("OK");

for (i=3;i>=0;i--) /* get data size in bytes */
    if ((tmp = getbyt()) == -1) /* -1 = no data available */ return(glberr = (*grp_led =
        0xffef));
    else
        dsiz = dsiz | (tmp << (8 * i)); /* build data size */

send("OK");

for (i=0;i<csiz;i++) /* load in all code */
    if ((tmp = getbyt()) == -1)
        return(glberr = (*grp_led = 0xffdf));
    else /* no error so continue */
    {
        if (grpdsp++ > 32760)
            grpdsp = 0;
        *grp_led = grpdsp;
        chksum += tmp;
        cadr[i] = tmp;
    }
send("OK");
for (i=0;i<dsiz;i++) /* load in all data */
    if ((tmp = getbyt()) == -1)
        return(glberr = (*grp_led = 0xffbf));
    else /* no error so continue */
    {
        if (grpdsp++ > 32760)
            grpdsp = 0;
        *grp_led = grpdsp;
        chksum += tmp;
        dadr[i] = tmp;
    }
send("OK");

```

exomon.c

```

if (chksum == getbyt()) /* verify check sums of code&data */
{
    send("OK");
    *grp_led = 0xffff; /* turn leds off */
/* while ((switches & 0x0012) == 0x0012); DEBUG ONLY */
    usrpgm = cadr; /* set up jump to user program */
    usrpgm(); /* go execute user program */
}
else
    return(glberr = (*grp_led = 0xff7f));
return(1); /* all done, go back to monitor */
}

/*****
/*
/* THIS ROUTINE WILL SEND OUT THE REQUESTED DATA FROM THE */
/* BUFFER. (LATER ON THIS SHOULD BE CONVERTED INTO AN */
/* INTERRUPT DRIVEN ROUTINE) */
*****/
int send(str)
char *str;
{
    int i;

    for (i=0;str[i] != 0;i++) /* for all data points */
    {
        wait(); /* wait for tx ok status */
        *dev_ptr = str[i]; /* send the data byte */
    }
}

/*****
/*
/* THIS ROUTINE WILL WAIT FOR AN INCOMING CHARACTER FROM */
/* THE SERIAL PORT. THIS SENDS BACK THE CHAR BEING RX AND */
/* WILL SEND BACK A -1 ON TIME OUT. THE TIMEOUT CHOSEN IS */
/* SOMEWHAT A RANDOM CHOICE WHICH HAS BEEN PROPERLY ADJUSTED */
/* DURING TESTING. */
*****/
int getbyt()
{
    int i,j,ch_in;
    int status;
    for (i=0;i<12000;i++)
    {
        for (j=0;j<50;j++)
            if ((txr_stat_ptr & SND_MASK) == 1) /* char rx */
                break;
    }
}

```

exomon.c

```

        break;
    }
    if (i < 12000)
        return(*dev_ptr & 0x00ff);
    return(-1);
}

/* yes char rx */
/* yes char rx */
/* return char */
/* else no char rx */

/*****
 *
 * THE ROUTINE WAIT POLLS THE XMIT BUFFER STATUS WAITING FOR
 * A FREE TRANSMIT BUFFER.
 *
 *****/
int wait()
{
    while(txr_stat_ptr & TXR_MASK != 4);
}

/*****
 *
 * THE ROUTINE INIT OE MAPS THE OPTICAL ENCODERS IN THE
 * MEMORY. THE ROUTINE THEN WAITS FOR EACH OF THE OPTICAL
 * ENCODERS TO BE MOVED THROUGH THEIR ZERO POINTS. UPON
 * COMPLETION OF THIS INITIALIZATION PROCEDURE CONTROLL IS
 * RETURNED TO THE CALLING ROUTINE.
 *
 * ----- not used any more - this taken care of by uploaded */
 *
 * program -----
 *****/
int init_oe()
{
    #ORG 24000H$
    int lgp_cnt;
    int lwf_cnt;
    int lwr_cnt;
    int llr_cnt;
    int leb_cnt;
    int lua_cnt;
    int lse_cnt;
    int lsa_cnt;
    int rgp_cnt;
    int rwf_cnt;
    int rwr_cnt;
    int rlr_cnt;
    int reb_cnt;
    int rua_cnt;
    int rse_cnt;
    int rsa_cnt;
}

```

exomon.c

```
*grp_led = 0;
oe_sta = -1;
do
{
    *grp_led = ~oe_sta;
    if ((switches & 0x0012) != 0x0012) /* user may abort - indx sw */ break;
}
while (oe_sta);
*grp_led = -1;
}
```

10.0 Appendix B: MBA/Merlin Control Software Listing

merlin.prj

merlin
testsys
getjr3
prockey
utime
keycont
movearm
calibmer
mercmd
window
forkin
sinvkin
merinit
merlmat
utils
enctorad
fullsys
transp
wristang
merlmat
jointang
mbainit
rexotmat
calib
getmba
ttyopen
ttylir.obj
tmwinl.lib
lwin.lib

merlin.c

/*

*/

FILENAME: Merlin.C

PROGRAM: (main)

AUTHOR: TW Mosher ML Crabill

DATE: 4 April 91

DESCRIPTION:

*/

```
#include <stdio.h>
#include <conio.h>
#include <math.h>
#include "merlin.def"
```

```
extern int forkin(); /* forward kinematic function */
int cbreak() /* control the ctrlc vector */
{
```

```
    wn_exit();
    tty_close();
    exit printf("User aborting program\n");
}
```

```
main()
{
```

```
    long tst[6] = {0};
    int j,i,k,l;
```

```
    window_init(); /* bit 3 window init */
    wn_init(); /* graphics screen init */
    mer_init(); /* variable initialization */
    clrscr();
    ctrlbrk(cbreak); /* setup ctrl c vector */
    mer_init_servo(); /* init servo values - gain ... */
```

```
    while(1)
    {
```

```
        /* fill in main menu */
        fill_menu(25,5," HSHI ", "
        "CALIBRATE
        "DIAG FORWD KIN ",
        "INVERSE KIN ",
        "MOVE TO ZERO POS ",
        "FULL SYSTEM ",
        "TEST SYSTEM ",
        "ZZZ - do not use ",
        "EXIT & ZERO POS ",
        "TERM HSHI & EXIT ",
        "QUIT ",
```

merlin.c

```

        NULL); /* must end with null */

switch(menu()) /* display menu and get option selected */
{
case 0: /* calibrate */
    calib_mer();
    break;
case 1: /* do fdw din */
    mer_init_serv(); /* set 0 deg here */
    j = status(1,11," FORWARD KINEMATICS INFO ",75,12);
    key_control(forkin,&j);
    close_status();
    break;
case 2: /* do merlin inverse kinematics */
    mer_init_serv(); /* set 0 deg here */
    j = status(1,8," INVERSE KINEMATICS INFO ",75,12);
    while(1)
    {
        fill_form(1,1,"X POSITION ", " ",-1,-1,'D',6,&x_pos);
        fill_form(1,3,"Y POSITION ", " ",-1,-1,'D',6,&y_pos);
        fill_form(1,5,"Z POSITION ", " ",-1,-1,'D',6,&z_pos);
        form_disp(" TOOL TIP POSITION ", " ",1,1,
                    25,3,25,8); /* display initial form */
        form_exe(&i,0); /* get user input for xyz */
        form_close();
        /* invkin(j,x_pos,y_pos,z_pos); */
        sinvkin(j,x_pos,y_pos,z_pos);
        i = wind(20,5,"DO MORE?", 'V', 'Y', "Enter more points (y)",NULL)
        if (i != 'Y')
            break;
    }
    close_status();
    break;
case 3: /* move joints to zero position */
    mer_close(); /* sets joints to 0 position */
    break;
case 4: /* full exo master to merlin slave system */
    mer_init_serv(); /* set 0 deg here */
    full_system(); /* full up control */
    mer_close();
    break;
case 5: /* full test system */
    mer_init_serv(); /* set 0 deg here */
    test_system(); /* full up control */
    mer_close();
    break;
case 6: /* test code */
    mer_init_serv(); /* set 0 deg here */
    i = 0;
    j = 0;
    k = 0;

```

merlin.c

```

while (1)
{
    fill_form(1,1,"option ","",-1,-1,'I',1,&k);
    fill_form(1,3,"deg ","",-1,-1,'I',3,&j);
    form_disp(" max joint tst ","",1,1,
              25,3,25,8); /* display initial form */
    form_exe(&i,0); /* get user input for xyz */
    form_close();
    if (k > 1)
        break;
    if (k == 0) /* option move to deg */
    {
        for (i=0;i<3;i++)
            tst[i] = j * 276;
        movearm(tst,'E');
    }
    else /* move a deg each time */
    {
        for (i=0;i<3;i++)
            tst[i] = 0;
        for (i=0;i<j;i++)
            for (l=0;l<3;l++)
            {
                tst[l] += 276;
                movearm(tst,'E');
            }
        }
        wind(2,2,"pause",'E',' ', " ",NULL);
        for (i=0;i<3;i++)
            tst[i] = 0;
        movearm(tst,'E');
    }
    break;
case 7:
    mer_close(); /* sets joints to 0 position */
    wn_exit(); /* close window stuff */
    exit(0);
case 8:
    mer_close(); /* sets joints to 0 position */
    mer_hshi_exit(); /* terminates the hshi pgm */
    wn_exit(); /* close window stuff */
    exit(0);
default:
    wn_exit();
    exit(0);
    break;
}
}
}

```

testsys.c

/******

FILENAME: fullsys.c

FUNCTION NAME: full_system

AUTHOR: Todd Mosher & Monty Crabill

DATE: April 23 1991

DESCRIPTION:

This program will allow a user to control the merlin robot
using the mba exo-skeleton.

*****/

```
#include <stdio.h>
#include <conio.h>
#include <math.h>
```

```
#include "merlin.ref"
extern int stop_print; /* this is a var in the tmwin.lib */
```

```
/* used to stop screen prints */ unsigned int utime();
extern float data[3][2000];
extern int datcnt;
extern int trigr;
```

```
float flimit(val)
float val;
{
    if (val > 1)
        return(1);
    if (val < -1)
        return(-1);
    return(val);
}
```

```
int test_system()
{
    long tm;
    char str[100];
    unsigned int ptime,ctime;
    int i,j,k,wptr;
    double x = 15;
    double y = 18; /* y = 0 causes sqrt error --- fix for normal operation */
    double z = 7;
    double usedx = 0;
    double zforce;
```

testsys.c

```

double lastx,lasty,lastz;
long waste[6];
double opinp[4];
double resmat[4];
FILE *fp[3];
unsigned int cnts;
double Ferror = 0;
float Fdesired = 0;
double Fscale = 0;
double xd = 0;
double prevx,prevy,prevz;
float vel = 85;
float Ftol = .01;
float gain = 27;

mba_rqst = 'L';
j = 0;
datcnt = 0;
trigr = 0;
clrscr();
/* printf("\n\n      Loading Exo Program\n");
/* system("upload mba.e68"); /* load exo pgm */
/* if ((fp[0] = fopen("upload.sta","r")) == NULL)
/* {
/*     printf("Disk error or upload version error\n");
/*     printf("Press return to continue, ctrl c to abort\n");
/*     getchar();
/* }
/* fscanf(fp[0],"%d",&i); /* get result of upload to mba */
/* fclose(fp[0]);
/* if (i > 0) /* upload problem */
/*     return(wind(8,8,"COMM ERR",'E',' ','Can not communicate with MBA',NULL));
/*
/* tty_open(2,10,8,1,0); /* setup the serial port for mba */
/*
/* tty_out(2,mba_rqst); /* start handshaking with EXO */
/*
/* if (i == 0) /* Exo program newly loaded */
/* {
/*     wind(8,8,"INITIALIZE",'E',' ','Move all joints through their",
/*         "Full range of motion",NULL);
/*     calib_mba(); /* Calibrate system */
/* }
*/
clrscr();
fill_menu(25,8,"WRIST", /* setup the menu */
          "LOCK WRIST ON ", /* turn prints on/off for speed */
          "LOCK WRIST OFF ",
          NULL);

```

testsys.c

```

lock_wrist = !menu();
fill_form(1,1,"Desired force ","",-1,-1,'F',6,&Fdesired);
fill_form(1,3,"Desired Vel in/sec ","",-1,-1,'F',6,&vel);
fill_form(1,5,"Force tolerance ","",-1,-1,'F',6,&Ftol);
fill_form(1,7,"Gain (1-100)","",-1,-1,'F',6,&gain);
form_disp(" Force control params ","",1,1,
          25,3,30,12); /* display initial form */
          form_exe(&i,0); /* get user input for xyz */
          form_close();
          xd = vel / 250.0; /* 4 ms loop time = 250 */
          if (gain == 0)
            gain = 1;
          Fscale = 100.0 / gain;

/* stop_print = 1; */
/* while (!kbhit()) /* debug only */
/* {
/*   outputb(0x300 + 4,0x00);
/*   outputb(0x300 + 4,0x02);
/* }
/* getchar();
*/

mba_init(); /* init vars etc */

for (i=0;i<4;i++) /* make sure hshi shows proper motor positions */
  mer_r_mpos(waste);

tty_open(1,8,8,1,0); /* setup the serial port for jr3 */

tty_outs(1,"DP S\r"); /* do a clear buffer */
tty_outs(1,"RO\r"); /* zero offsets */
tm = time(NULL) + 2;
while (time(NULL) < tm);
while (tty_in(1) > 0);

tty_outs(1,"EA = FZ\r"); /* use only z this also starts hand shaking*/
get_jr3_info(str,9);
cnts = 7(1.0/133.0) / .8380966e-6 * 2;
wptr = status(1,1," INVERSE KINEMATICS INFO ",75,20);
done = 0;
sprintf(str,"xd = %6.3lf Fd = %6.2f",xd,Fdesired);
prints(0,str,1,5,0);
while(!done) /* until user aborts */
{
outputb(0x304,00); /* testing only!!! */
  prockey();
  prevx = x;
  prevy = y;
}

```

testsys.c

```

    prevz = z;
    lastx = mt6_0[0][3]; /* save prev xyz for indexing */
    lasty = mt6_0[1][3]; /* save prev xyz for indexing */
    lastz = mt6_0[2][3]; /* save prev xyz for indexing */

/*    joint_ang(wptr);      /* get joint angles from the mba */

/*    exot_mat();           /* Computes all required matrix */

/* elements */
outportb(0x304,02); /* testing only !!! */
/*    if (indexing)        /* set new indexing */
/*    {
/*        x_offset += lastx - mt6_0[0][3];
/*        y_offset += lasty - mt6_0[1][3];
/*        z_offset += lastz - mt6_0[2][3];
/*    }
/*    else                  /* calc new indexing position */
/*    {
/*        x = mt6_0[0][3] + x_offset; /* get x,y,and z -shift workspace */
/*        y = mt6_0[1][3] + y_offset;
/*        z = mt6_0[2][3] + z_offset;
/*    }
*/

    if (trigr)
    {
        if (datcnt == 0)
        {
            ptime = utime();
            data[0][datcnt] = x;
            data[1][datcnt] = y;
            data[2][datcnt] = z;
            datcnt++;
            if (datcnt == 2000)
            {
                trigr = 0;
                j = 0;
                while(1) /* wait proper interval before collecting */
                {
                    j++;
                    ctime = utime();
                    if (ptime - ctime >= cnts) /* done waiting */
                        break; /* go collect the data */
                }
                if (j < 3) /* just not fast enough for the task */
                    exit(sprintf("could not sample fast enough\n"
                                "ptime %u ctime %u\n",ptime,ctime));
                ptime = ctime;
            }
        }
    }

    get_jr3_info(str,21);

```

testsys.c

```

for (i=0;i<20;i++)
    if (str[0] != 'F')
        strcpy(str,&str[1]);
    else
        break;
    if (i < 20) /* f found */
        sscanf(&str[2], "%lf",&zforce); /* get force from sensor */

prints(0,str,50,1,0);
sprintf(str, "%lf",zforce);
prints(0,str,50,2,0);
/*****
force control loop
*****/

Error = Fdesired + zforce;
if ((Error < 0 && Error > -Ftol) ||
    (Error > 0 && Error < Ftol))
    Error = 0;

x += flimit((float)(Error/Fscale)) * xd;

sprintf(str,"x = %6.3lf Fscale = %6.2lf limit %6.2lf err %6.2lf",
        x,Fscale,(double)(flimit((float)(Error/Fscale))),
        Error);
prints(0,str,1,6,0);
if (x < 12) /* check mins and maxs */
    x = 12;
else if (x > 35.44)
    x = 35.44;

/* if (z < -23) /* do not allow crashing into floor */
/* z = -23;
*/
if (z < -28) /* do not allow crashing into floor */
    z = -28;

/* perform inverse kinematics for MERLIN */
if (sinvkin(&wptr,x,y,z,wrist_roll,wrist_flex,tool_roll) != 8)
{
    x = prevx;
    y = prevy;
    z = prevz;
}
}

if (datent)
{
    fp[0] = fopen("xvout.dat","w");
    fp[1] = fopen("yvout.dat","w");
    fp[2] = fopen("zvout.dat","w");

```

testsys.c

```

for (i=0;i<3;i++)
    fprintf(fp[i], "%c%s\nTime\nvel in/sec\n133\n", 'X'+i, "vout");

for (i=0;i<datcnt-1;i++)
    for(j=0;j<3;j++)
        data[j][i] = (data[j][i] - data[j][i+1]) / 7.5187699e-3;

for (i=0;i<datcnt-1;i++)
{
    fprintf(fp[0], "%f\n", data[0][i]);
    fprintf(fp[1], "%f\n", data[1][i]);
    fprintf(fp[2], "%f\n", data[2][i]);
}
fclose(fp[0]);
fclose(fp[1]);
fclose(fp[2]);
}

close_status();
tty_flush(1);
tty_flush(2);
tty_close(2);
tty_close(1);
if (done == 2)
    wind(8,8,"TIMEOUT", 'E', ' ', "Timeout waiting for MBA joint angles",
        NULL);
    else if (done == 3)
        wind(8,8,"TIMEOUT", 'E', ' ', "Timeout waiting for JR3 data",
            NULL);
}

```

getjr3.c

/******

FILENAME: getjr3.c

FUNCTION NAME: get_jr3_info()

AUTHOR: Todd Mosher

DATE: 07-15-91

DESCRIPTION:

 This routine will get the force and moment information
 from the jr3 force torque sensor

*****/

```
#include <stdio.h>
#include <conio.h>
#include <time.h>
#include "merlin.ref"
```

```
static char todd1[100] = {0};
```

```
int get_jr3_info(str,amt)
char *str;
```

```
{
    char tbuff[32];   /* temp input buffer */
    char byt;
    int j,i;
    char pstr[100];
    long tm;
```

```
tm = time(NULL) + 2;           /* time out for data */ while(tty_cnt(JR3_PORT) < amt) /*
wait for all data to return from jr3 */
```

```
if (time(NULL) >= tm)       /* timeout so getout */
```

```
{
    if (kbhit() && getch() == 27)
```

```
{
    done = 2;
    return;
```

```
}
tty_open(JR3_PORT,8,8,1,0);   /* setup the serial port for jr3 */
```

```
sprintf(pstr,"%d Missing JR3 data",++badcnt);
```

```
prints(0,pstr,25,1,0);
```

```
while (tty_cnt(JR3_PORT)) /* clear the port */
```

```
  tty_in(JR3_PORT);
```

```
tm = time(NULL) + 2;       /* setup time for new request */
```

```
  tty_outs(JR3_PORT,"DP S\r"); /* send new request for data */
```

```
}
```

getjr3.c

```
for(j=0;j<amt;j++) /* get the data */
    str[j] = tty_in(JR3_PORT);
    str[j] = NULL;

if (tty_cnt(JR3_PORT)) /* bad condition - should not be any leftover */
{
    /* charactors */
    for (;tty_cnt(JR3_PORT)>0;j++)
        str[j] = tty_in(JR3_PORT);
        str[j] = NULL;
        prints(0,str,10,10,0);
        prints(0,todd1,10,11,0);
    }
    strcpy(todd1,str);

tty_outs(JR3_PORT,"DP S\r"); /* give next request to jr3 */ }
```

prockey.c

/*****

FILENAME: prockey.c

FUNCTION NAME: prockey

AUTHOR: Todd Mosher

DATE: 7-30-91

DESCRIPTION:

This will handle any operator input.

*****/

```
#include <stdio.h>
#include <conio.h>
#include <time.h>
#include <math.h>
```

```
#include "merlin.ref"
extern int trigr, datcnt;
```

```
int prockey()
{
```

```
    int i;
    char str[100];
    long tm;
```

```
    if (!kbhit()) /* nothing to process */
        return;
```

```
    i = toupper(getch()); /* esc aborts this program */
```

```
    if (i == 27)
        done = 1;
    else if (i == 'S') /* stops system until a q is pressed */ while(toupper(getch()) != 'Q');
    else if (i == 'T') /* trigger to save data */
```

```
    {
        trigr = 1;
        datcnt = 0;
    }
```

```
    else if (i == 'R')
```

```
    {
        wind(8,8,"RELEASING LATCH",'I',' ','Releasing latch to engage motors", NULL);
        tty_outs(1,"RL\r"); /* release latch */
        tm = time(NULL) + 2;
        while (time(NULL) < tm);
        while (tty_in(1) > 0);
        close_info();
    }
```

prockey.c

```
tty_outs(1,"DP S\r");    /* restart data request */
    }
    else if (i == 'C')
    {
        wind(8,8,"CLR BUF",'I',' ','Clearing jr3 serial buffers",
            NULL);
        tm = time(NULL) + 2;
        while (time(NULL) < tm);
        while (tty_in(1) > 0);
        close_info();
        tty_outs(1,"DP S\r");    /* restart data request */
    }
    else if (i == 0)
        i = getch();
}
```

utime.c

```
/******
```

This will return the number of counter
tics in the 5253 counter timer.
Each tic is approx .8380966us and the
counter is reset every 53ms.
This is a down counter.

```
*****/
```

```
#include <stdio.h>
#include <conio.h>
#include <ctype.h>
```

```
unsigned int utime()
{
    char arr[5];
    unsigned int *ptr;

    ptr = (unsigned int *)arr;

    outportb(0x43,0x00); /* latch current count */
    arr[0] = inportb(0x40); /* get data from counter */ arr[1] = inportb(0x40);
    return(ptr[0]);
}
```

keycont.c

/*

*/

FILENAME: keycont.c

ROUTINE: key_control

AUTHOR: TW Mosher

DATE: 3-25-91

DESCRIPTION:

This routine will allow the user to set any joint to any position. When done, this will be calibrated to the new zero position area.

*/

```
#include <stdio.h>
#include <conio.h>
#include <math.h>
#include "merlin.ref"
```

```
int key_control(usrfun,ufparam)
int (*usrfun); /* pass in desired function */
int *ufparam; /* parameter for user function */
{
```

```
    char jnt[6][40] = { "base - left/right",
                        "shoulder - up/down",
                        "elbow - up/down",
                        "wrist roll - left/right",
                        "wrist flex - up/down",
                        "hand roll - left/right "
                      };
```

```
    char str[100];
    int i,joint = 0;
    int k;
    int wid;
    float speed = .05; /* slow */
    double deg[6] = {0};
```

```
/* mer init serv(); /* init servo values - gain ... */
wind(23,0," ARROW CONTROL ',' 'I' ',' '1-6 To select joint",
      "F/S for fast/slow",
      "Use arrows to move ",
      "Press ESC when done",
      NULL);
wid = status(5,6," INFORMATION ",60,3); /* put up a status
window */ prints(wid,"Control speed is slow",31,1,0);
prints(wid,jnt[joint],1,1,0); /* print to status window */
while (1) /* allow user to control the robot */
{
    if (usrfun) /* if user function passed in, use it */
```

keycont.c

```
usrfun(ufparam); /* call user function */
if (kbhit())
{
    k = toupper(getch()); /* get the key */
    switch(k) /* process the key */
    {
        case '1':
        case '2':
        case '3': /* joint selections */
        case '4':
        case '5':
        case '6':
            joint = k - '1'; /* convert to joint 0-5 */
            prints(wid,jnt[joint],1,1,0); /* print to status window */ break;
        case 'F':
            prints(wid,"Control speed is fast",31,1,0);
            speed = 4;
            break;
        case 'S':
            prints(wid,"Control speed is slow",31,1,0);
            speed = .05;
            break;
        case 75: /* left arrow */
            if (joint == 0 || joint == 3 || joint == 5)
                deg[joint] -= speed;
            break;
        case 77: /* right arrow */
            if (joint == 0 || joint == 3 || joint == 5)
                deg[joint] += speed;
            break;
        case 72: /* up arrow */
            if (joint == 2 || joint == 4)
                deg[joint] -= speed;
            else if (joint == 1)
                deg[joint] += speed;
            break;
        case 80: /* down arrow */
            if (joint == 2 || joint == 4)
                deg[joint] += speed;
            else if (joint == 1)
                deg[joint] -= speed;
            break;
        case 27: /* esc */
            close_info();
            close_status();
            return;
        default:
            break;
    }
}
```

keycont.c

```
if (deg[joint] > degmax[joint])
    deg[joint] = degmax[joint];
else if (deg[joint] < degmin[joint])
    deg[joint] = degmin[joint];
movearm(deg, 'D'); /* move to new encoder position */
}
```

calibmer.c

/******

FILENAME: calibmer.c

ROUTINE: calib_mer

AUTHOR: TW Mosher

DATE: 3-25-91

DESCRIPTION:

This routine will allow the user to set any joint to any position. When done, this will be calibrated to the new zero position area.

*****/

```
#include <stdio.h>
#include <conio.h>
#include <math.h>
#include "merlin.ref"
```

```
int calib_mer()
{
    char str[100];

    mer_init_serv(); /* init servo values - gain ... */ key_control(NULL,NULL);
    mer_init_serv();
}
```

movearm.c

/*

*/

FILENAME: movearm.c

PROGRAM: movearm

AUTHOR: TW Mosher

DATE: 3-21-91

DESCRIPTION:

This will command the motors to the proper position which was passed in. The passed in vals can be radians, degrees, or encoder counts.

Parameters

pointer to an array of 6 rad or deg (double) or encoder (long)
char r for rad, d for deg, e for encoder

note - no range checking done here.

Returns 0 on success, else non 0 = error

-1 = invalid data type passed in

-2 = can not get control from hshi

*/

```
#include <stdio.h>
#include <conio.h>
#include <stdlib.h>
#include <math.h>
#include "merlin.ref"
```

```
static long lastpos[6];
```

```
int movearm(data,typ)
```

```
double *data;
```

```
char typ;
```

```
{
```

```
    int i;
```

```
    long *ldata;
```

```
    double dtmp;
```

```
    long encod[6] = {0};
```

```
    char str[100];
```

```
    char str1[100];
```

```
    int maxmov;
```

```
    ldata = (long *)data; /* make either type the correct addr */
```

```
    typ = toupper(typ); /* ensure no typo problem */
```

```
    if (typ == 'D') /* degrees to encoders */
```

```
{
```

```
    encod[0] = data[0] * dtoe[0]; /* convert joint 0 */
```

```
    encod[1] = data[1] * dtoe[1]; /* convert joint 1 */
```

```
    encod[2] = (data[2] - data[1]) * dtoe[2]; /* convert joint 2 */
```

```
    encod[3] = data[3] * dtoe[3]; /* convert joint 3 */
```

movearm.c

```

/* joints 3,4,&5 are coupled together */
dtmp = data[4] * DTORAD * 1.2; /* 1.2 is ratio hshi manual */
encod[4] = (data[3] * DTORAD - dtmp) * 7639.437;
/* 7639.437 is */
/* ticks / rad hshi manual */
encod[5] = (((data[3] - data[5]) * DTORAD) + dtmp) * 7639.437;
}
else if (typ == 'R')
{
    encod[0] = data[0] * rtoe[0]; /* convert joint 0 */
    encod[1] = data[1] * rtoe[1]; /* convert joint 1 */
    encod[2] = (data[2] - data[1]) * rtoe[2];
    /* convert joint 2 */
    encod[3] = data[3] * rtoe[3]; /* convert joint 3 */
    /* joints 3,4,&5 are coupled together */
    dtmp = data[4] * 1.2; /* 1.2 is ratio from hshi manual */
    encod[4] = (data[3] - dtmp) * 7639.437; /* 7639.437 is */
    /* ticks / rad from hshi manual */
    encod[5] = (data[3] - data[5] + dtmp) * 7639.437;
}
else if (typ == 'E')
    for (i=0;i<6;i++)
        encod[i] = ldata[i];
    else
        return(-1); /* bad type passed in */

/* the motors can attempt a 30 deg increment */
/* when the motors are on, but can only attempt */
/* a 1 degree increment when the motors are off */

maxmov = 100; /* assume motors off - can not move - .5 deg max */
for (i=0;i<6;i++) /* save prev val */
    if (lastpos[i] != hr_mpos->axis[i]) /* has moved - motors ok */
    {
        maxmov = 8000; /* while tracking - 30 deg max increments */
        break;
    }

for (i=0;i<6;i++) /* save prev motor position */
    lastpos[i] = hr_mpos->axis[i];
for (i=0;i<6;i++) /* max motion per frame = 30 deg */
{
    if (encod[i] > hr_mpos->axis[i] + maxmov)
        encod[i] = hr_mpos->axis[i] + maxmov; /* limit max motion */
    else if (encod[i] < hr_mpos->axis[i] - maxmov)
        encod[i] = hr_mpos->axis[i] - maxmov;
}

mer_get_ctrl(); /* do not update window until we are in control */
str[0] = NULL;
str1[0] = NULL;

```

movearm.c

```
for (i=0;i<6;i++) /* update merlin joint areas */
{
    hc_mpos->axis[i] = encod[i];
    sprintf(&str[strlen(str)], " %6ld", encod[i]);
    sprintf(&str1[strlen(str1)], " %6ld", hr_mpos->axis[i]);
}
prints(0,str,1,10,0);
prints(0,str1,1,11,0);
mer_mov();          /* move merlin to new position */
}
```

mercmds.c

/******

FILENAME: mercmds.c

ROUTINE: several low level cmds to control the merlin

AUTHOR: TW Mosher

DATE: 3-25-91

DESCRIPTION:

mer_init_serv - does a set servo parameters command - this both
 sets the servo stuff and resets the joint computers
mer_mov - sets the merlin command to move. - joint values
 assumed to be correct at this time
mer_cmd - does actual handshaking with the merlin when setting commands.
mer_r_mpos - reads motor position encoders from window
mer_close - resets joints to 0 position
mer_hshi_exit - exits hshi pgm

*****/

```
#include <stdio.h>
#include <conio.h>
#include <time.h>
#include <math.h>
#include "merlin.ref"
```

```
int mer_init_serv()
{
    int i;

    for (i=0;i<6;i++) /* set all servo parameters */
    {
        hc_srv->servo_param[i].max_acc = max_srv_acc[i]; hc_srv->servo_param[i].max_vel =
        max_srv_vel[i]; hc_srv->servo_param[i].gain = gain[i];
    }
    mer_cmd(CMD_SET_PARAMS); /* have merlin do command */
}
```

```
int mer_r_mpos(mp_encoders)
long *mp_encoders;
{
    int i;
    mer_cmd(CMD_RD_M_STAT); /* this forces a status update */
    for (i=0;i<6;i++) /* read all motor position encoders */ mp_encoders[i] =
        hr_mpos->axis[i];
}
```

mercmds.c

```

int mer_r_jpos(mp_rad)
double *mp_rad;
{
    int i;
    mer_cmd(CMD_RD_J_STAT); /* this forces a status update */
    mer_cmd(CMD_RD_J_STAT); /* this forces a status update */
    for (i=0; i<6; i++) /* read all joint angles */
        mp_rad[i] = hr_jpos->axis[i];
}

int mer_mov() /* simple move command -- all joints */
/* have already been set */ mer_cmd(CMD_M_POS);
}

int mer_get_ctrl()
{
    long tm;

    tm = time(NULL) + 2; /* max wait for merlin robot */ while(hc_buf->buf_stat !=
    BUF_HOST) /* wait to gain control */
        if (time(NULL) > tm) /* only occasionally check for keystroke */ {
            if (kbhit() && getch() == 27) /* of hshi -- allow user abort */ break;
            tm = time(NULL) + 2;
            printf("Merlin is not Powered up properly\n");
        }
}

int mer_cmd(cmd)
int cmd;
{
    mer_get_ctrl(); /* make sure we are in control of buffer */
    hc_buf->command = cmd; /* set the command word */
    hc_buf->buf_stat = BUF_HSHI; /* give merlin control */
}

int mer_close() /* set robot to zero position */
{
    int i;
    int j;
    double ang[6];

    mer_r_jpos(ang); /* get current position */
    for (i=0; i<6; i++)
    {
        hc_srv->servo_param[i].max_acc = 1; /* set all servos to min */ hc_srv-
        >servo_param[i].max_vel = 1;
        hc_srv->servo_param[i].gain = 2;
    }
}

```

mercmds.c

```
mer_cmd(CMD_SET_PARAMS); /* set servos - this inits joint position */ for (i=0;i<6;i++)
    hc_jpos->axis[i] = -angs[i]; /* move from new 0 to prev angles */
mer_cmd(CMD_J_POS); /* have merlin move slow */ wind(8,8,"WAIT",'E','
',"Press return when MERLIN",
        "Has returned to its origin",
        NULL);
}

int mer_hshi_exit()
{
    mer_cmd(CMD_EXIT);
}
```

window.c

/****** NAME OF

ROUTINE: window_init
NAME OF FILE: window
CREATION DATE: 05/22/89
AUTHOR: T. Mosher

DESCRIPTION:
This will initialize the 32k dual port ram that
is in the VME chasis.

REVISIONS		
REV#	DESCRIPTION	INITIALS DATE
---	-----	-----

***** */

```
/*#define MEM_OFFSET 0x0d0000000 */  
#include "merlin.ref"  
#define ATCMD 0x0200
```

```
int window_init()  
{  
    int i;  
    int at_cmd = ATCMD;  
    int at_stat = ATCMD + 2;  
    int vme_stat = ATCMD + 8;  
    int vme_am = ATCMD + 13;  
    int stat;  
  
    inportb(at_stat);  
    inportb(vme_stat);  
    stat = inportb(at_stat); /* b added by steve */  
    if (stat & 1)  
    {  
        printf("Power is off or cable is disconnected.\n");  
        return(0);  
    }  
    outportb(at_cmd,128);  
    outportb(vme_am,61);  
    stat = inportb(at_stat); /* b added by steve */  
    if (stat & 197)  
    {  
        printf("Setup status error:\n");  
        if (stat & 128)  
            printf("interface parity error\n");  
        if (stat & 64)  
            printf("vme bus error\n");  
        if (stat & 4)  
            printf("interface timeout\n");  
        if (stat & 1)
```

window.c

```
        printf("power is off or cable is disconnected\n");
        return(0);
    }
    hc_buf->buf_stat = BUF_HOST; /* gain control of window from merlin */ return(1);
}
```

forkin.c

/*

FILENAME: forkin.c

FUNCTION NAME: forkin()

AUTHOR: Mosher & Crabill

DATE: 22 March 91

MODIFIED: 3 April 91

DESCRIPTION: This program will allow checkout of the Merlin
left arm forward kinematics.

*/

```
#include <stdio.h>
#include <conio.h>
#include <math.h>
```

```
#include "merlin.ref"
```

```
int forkin(wid)
```

```
int *wid;
```

```
{
```

```
    int i;
```

```
    int wp;
```

```
    double resmat[4];
```

```
    long motor_encoder[6];
```

```
    char str[100];
```

```
    wp = *wid;    /* get window id */
```

```
    mer_r_mpos(motor_encoder);    /* read motor position encoders */
```

```
    prints(wp,"Motor encoder values",14,0,1);
```

```
    str[0] = 0;
```

```
    for(i=0;i<6;i++)
```

```
        sprintf(&str[strlen(str)],"%6ld ",motor_encoder[i]);
```

```
        prints(wp,str,1,1,0);
```

```
        enc to rad(motor_encoder,in_merlin_joint,"MERLIN");
```

```
    /*  
*****
```

```
    in_merlin_joint[2] -= 1.5707963; /* -90 deg correction for elbow */
```

```
    /*  
*****
```

```
    merltmat();    /* Merlin's tool roll/global reference */
```

```
    /* transformation matrix elements */
```

```
    prints(wp,"Joint angles",18,2,1);
```

forkin.c

```
str[0] = 0;
for (i=0;i<6;i++)
    sprintf(&str[strlen(str)], "%6.2lf ", in_merlin_joint[i] * 57.29578); /* display degrees */
prints(wp, str, 1, 3, 0);

matmilt(st6_0, gripper_tip, resmat, wp);
/* multiply tool roll/ global ref */
/* transformation matrix by gripper */
/* tip position matrix */
/* }
*/
}
```

sinvkin.c

/******

FILENAME: sinvkin.c smart inverse kinematics

FUNCTION NAME: sinvkin()

AUTHOR: Mosher & Crabill

DATE: 09 March 91

MODIFIED:

DESCRIPTION:

This program will take an xyz position and use the 3 main axis of motion to move the wrist to the position. This then calls the procedure to determine the wrist angles and then finally does the actual moving of the robot to the correct place.

*****/

```
#include <stdio.h>
#include <conio.h>
#include <math.h>
```

```
#include "merlin.ref"
```

```
/******
```

```
*
*   Calculate the k and g function values
*
```

```
*****/
```

```
double skgfun(indx,typ)
```

```
int indx;
```

```
char typ;   /* g or k */
```

```
{
```

```
    double f[4],k[5],g[5];
    double ct3,ca2;
```

```
    typ = toupper(typ);
```

```
    ct3 = cos(theta[3]);
```

```
    ca2 = cos(alpha[2]);
```

```
    f[1] = a[3] * ct3 + d[4] * sin(alpha[3]) * sin(theta[3]) + a[2];
```

```
    f[2] = a[3] * sin(theta[3]) * ca2 -
          d[4] * sin(alpha[3]) * ct3 * ca2 -
          d[4] * cos(alpha[3]) * sin(alpha[2]) -
          sin(alpha[2]) * d[3];
```

```
    f[3] = a[3] * sin(theta[3]) * sin(alpha[2]) -
          d[4] * sin(alpha[3]) * ct3 * sin(alpha[2]) +
          d[4] * cos(alpha[3]) * ca2 +
          ca2 * d[3];
```

```
    if (typ != 'G')   /* must be a k function request */
```

sinvkin.c

```

{
    k[1] = f[1];
    k[2] = -f[2];
    k[3] = sqrt(f[1]) + sqrt(f[2]) + sqrt(f[3]) + sqrt(a[1]) + sqrt(d[2]) +
        2 * d[2] * f[3];
    k[4] = f[3] * cos(alpha[1]) + d[2] * cos(alpha[1]);
    return(k[indx]);
}
else
{
    g[1] = f[1] * cos(theta[2]) - f[2] * sin(theta[2]) + a[1];
    g[2] = f[1] * sin(theta[2]) * cos(alpha[1]) +
        f[2] * cos(theta[2]) * cos(alpha[1]) - f[3] * sin(alpha[1]) - sin(alpha[1]) * d[2];
    return(g[indx]);
}
}

/*****
*
*   Limit some motions
*
*****/
double limit(val)    /* only for ranges from -pi/2 to pi/2 */
double val;
{
    if (val <= -1.5 * PI)
        return(2 * PI + val);
    if (val >= 1.5 * PI)
        return(-2 * PI + val);
    return(val);
}

int sinvkin(wid,x,y,z,wrist_roll,wrist_flex,tool_roll)
int *wid;
double x,y,z,wrist_roll,wrist_flex,tool_roll;
{
    double r,f[4],k[5],g[5];
    char str[100];
    double thetat[2];    /* temp theta */
    int i;
    int wptr;

    wptr = *wid;

    /* sprintf(str,"x,y,z = %lf %lf %lf",x,y,z);
    /* prints(0,str,0,0,0);
    /* getchar();
    */

```

sinvkin.c

```

r = sqrt(x) + sqrt(y) + sqrt(z);
if (sqrt(r) < 18.5)
    return(prints(wptr, "TOO CLOSE", 0, 0, 1));
else if (sqrt(r) > 36)
    return(prints(wptr, "TOO FAR ", 0, 0, 1));
/* prints(wptr, " ", 0, 0, 0); */
h[1] = r + h1_partial;
/****** theta 3 *****/
thetat[0] = 2 * atan2((double)(2 * h[3] +
    sqrt((double)(4 * sqrt(h[3]) - 4 * (sqrt(h[1]) - sqrt(h[2]))))), (double)(2 * (h[1] +
    h[2])));
thetat[1] = 2 * atan2((double)(2 * h[3] -
    sqrt((double)(4 * sqrt(h[3]) - 4 * (sqrt(h[1]) - sqrt(h[2]))))), (double)(2 * (h[1]
    + h[2])));

if (thetat[1] <= -PI/2.0) /* elbow up */
    theta[3] = thetat[1];
else
    theta[3] = thetat[0];
/* sprintf(str, "theta 3 %8.2lf", (double)(theta[3]*57.295)); */
/****** theta 2 *****/
for (i=1; i<5; i++)
    k[i] = skgfun(i, 'K'); /* get k value */
thetat[0] = 2 * atan2((double)(-sin(alpha[1]) * k[1] +
    sqrt((double)(sqrt(sin(alpha[1])) * sqrt(k[1]) -
    (sqrt(z) + 2 * z * k[4] - sqrt(sin(alpha[1])) *
    sqrt(k[2]) + sqrt(k[4]))))),
    (double)(z + k[4] + sin(alpha[1]) * k[2]));

thetat[1] = 2 * atan2((double)(-sin(alpha[1]) * k[1] - sqrt((double)(sqrt(sin(alpha[1])) * sqrt(k[1]) -
    (sqrt(z) + 2 * z * k[4] - sqrt(sin(alpha[1])) * sqrt(k[2]) + sqrt(k[4]))))),
    (double)(z + k[4] + sin(alpha[1]) * k[2]));

thetat[0] = limit(thetat[0]);
if (thetat[0] >= PI / 2.0 && thetat[0] <= -PI / 2.0)
    theta[2] = thetat[0];
else
    theta[2] = limit(thetat[1]);

/* sprintf(str, "theta 2 %8.2lf", (double)(theta[2]*57.295)); */
/****** theta 1 *****/
for (i=1; i<3; i++)
    g[i] = skgfun(i, 'G');
thetat[0] = 2 * atan2((double)(-(x * g[1] - y * g[2]) + sqrt((double)((sqrt(x) + sqrt(y)) *
    (sqrt(g[1]) + sqrt(g[2]))))), (double)(-(y * g[1] + x * g[2])));

thetat[1] = 2 * atan2((double)(-(x * g[1] - y * g[2]) - sqrt((double)((sqrt(x) + sqrt(y)) * (sqrt(g[1])
    +

```

sinvkin.c

```

                sqr(g[2])))), (double)(-(y * g[1] + x * g[2])));

thetat[0] = limit(thetat[0]);

if (thetat[0] <= PI / 2.0 && thetat[0] >= -PI / 2.0)
    theta[1] = thetat[0];
else
    theta[1] = limit(thetat[1]);

/*    sprintf(str,"theta 1 %8.2lf",(double)(theta[1]*57.295)); */

wrist_angles();      /* calculate euler angles for MERLIN wrist */

theta[3] += PI / 2.0;    /* correct 90 deg for lo level drivers */

for (i=0;i<3;i++)      /* correct for indexing */
    theta[i] = theta[i+1];

if (wrist_flex > 1.4835) /* limit wrist_flex to 85 deg */
    wrist_flex = 1.4835;
else if (wrist_flex < -1.4835)
    wrist_flex = -1.4835;
theta[3] = wrist_roll;
theta[4] = wrist_flex;
theta[5] = tool_roll;

movearm(theta,'R');      /* move the robot to the desired positions */ return(8);
}

```

merinit.c

/*****

FILENAME: merinit.c

FUNCTION NAME: merinit

AUTHOR: TW Mosher ML Crabill

DATE: 4/9/91

MODIFIED:

DESCRIPTION:

Assorted initializations for variables.

*****/

```
#include <stdio.h>
#include <conio.h>
#include <math.h>
```

```
#include "merlin.ref"
```

```
int merinit()
{
```

```
    /*****
```

```
    *
```

```
    *   init section for inverse kin vars
```

```
    *
```

```
    *****/
```

```
h1_partial = -sqr(a[3]) - sqr(a[2]) - sqr(a[1]) - sqr(d[4]) -sqr(d[3]) -sqr(d[2]) - 2 * d[4] * d[3] *
              cos(alpha[3]) -
              2 * d[2] * (d[4] * cos(alpha[3]) * cos(alpha[2]) + cos(alpha[2]) * d[3]);
h[2] = 2 * a[2] * a[3] - 2 * d[2] * d[4] * sin(alpha[3]) * sin(alpha[2]); h[3] = 2 * a[2] * d[4] *
sin(alpha[3]) + 2 * d[2] * a[3] * sin(alpha[3]); }
```

merltmat.c

/******

FILENAME: merltmat.c

FUNCTION NAME: merltmat()

AUTHOR: Mosher & Crabill

DATE: 03/22/91

MODIFIED: 04/02/91
11:00 am

DESCRIPTION: Forward kinematic transformation matrices
for Merlin left armed robot.

*****/

```
#include <stdio.h>
#include <conio.h>
#include <math.h>
#include "merlin.ref"
```

```
merltmat()
{
double ct1,nct1,st1,nst1,ct2,nct2,st2,nst2,ct3,nct3,st3,nst3,
      ct4,nct4,st4,nst4,ct5,nct5,st5,nst5,ct6,nct6,st6,nst6;
```

```
/* Merlin Left Arm Robot Matrix[1] to transform from coordinate system at Waist/Shoulder
Intersect back to Reference. */
```

```
ct1 = cos(in_merlin_joint[0]);
nct1 = -ct1;
st1 = sin(in_merlin_joint[0]);
nst1 = -st1;
```

```
st1_0[0][0] = ct1;
st1_0[0][1] = nst1;
st1_0[0][2] = 0;
st1_0[0][3] = 0;
st1_0[1][0] = nst1;
st1_0[1][1] = nct1;
st1_0[1][2] = 0;
st1_0[1][3] = 0;
st1_0[2][0] = 0;
st1_0[2][1] = 0;
st1_0[2][2] = -1;
st1_0[2][3] = 0;
```

```
/* Merlin Left Arm Robot Matrix[2] to transform from coordinate system at Shoulder back to
Reference. */
```

```
ct2 = cos(in_merlin_joint[1]);
```

merltmat.c

```
nct2 = -ct2;
st2 = sin(in_merlin_joint[1]);
nst2 = -st2;
```

```
st2_0[0][0] = st1_0[0][0] * ct2;
st2_0[0][1] = st1_0[0][0] * nst2;
st2_0[0][2] = st1_0[0][1];
st2_0[0][3] = st1_0[0][1] * -12.00;
st2_0[1][0] = st1_0[1][0] * ct2;
st2_0[1][1] = st1_0[1][0] * nst2;
st2_0[1][2] = st1_0[1][1];
st2_0[1][3] = st1_0[1][1] * -12.00;
st2_0[2][0] = st1_0[2][2] * nst2;
st2_0[2][1] = st1_0[2][2] * nct2;
st2_0[2][2] = 0.0;
st2_0[2][3] = 0.0;
```

/* Merlin Left Arm Robot Matrix[3] to transform from coordinate system at Elbow/Wrist Roll intersect back to Reference. */

```
ct3 = cos(in_merlin_joint[2]);
nct3 = -ct3;
st3 = sin(in_merlin_joint[2]);
nst3 = -st3;
```

```
st3_0[0][0] = st2_0[0][0] * ct3 + st2_0[0][1] * nst3;
st3_0[0][1] = st2_0[0][0] * nst3 + st2_0[0][1] * nct3;
st3_0[0][2] = -st2_0[0][2];
st3_0[0][3] = st2_0[0][0] * 17.3 + st2_0[0][3];
st3_0[1][0] = st2_0[1][0] * ct3 + st2_0[1][1] * nst3;
st3_0[1][1] = st2_0[1][0] * nst3 + st2_0[1][1] * nct3;
st3_0[1][2] = -st2_0[1][2];
st3_0[1][3] = st2_0[1][0] * 17.3 + st2_0[1][3];
st3_0[2][0] = st2_0[2][0] * ct3 + st2_0[2][1] * nst3;
st3_0[2][1] = st2_0[2][0] * nst3 + st2_0[2][1] * nct3;
st3_0[2][2] = -st2_0[2][2];
st3_0[2][3] = st2_0[2][0] * 17.3 + st2_0[2][3];
```

/* Merlin Left Arm Robot Matrix[4] to transform from coordinate system at Wrist Roll/Flex intersect back to Reference. */

```
ct4 = cos(in_merlin_joint[3]);
nct4 = -ct4;
st4 = sin(in_merlin_joint[3]);
nst4 = -st4;
```

```
st4_0[0][0] = st3_0[0][0] * ct4 + st3_0[0][2] * nst4;
st4_0[0][1] = st3_0[0][0] * nst4 + st3_0[0][2] * nct4;
st4_0[0][2] = st3_0[0][1];
st4_0[0][3] = st3_0[0][1] * 17.25 + st3_0[0][3];
st4_0[1][0] = st3_0[1][0] * ct4 + st3_0[1][2] * nst4;
```

merlmat.c

```

st4_0[1][1] = st3_0[1][0] * nst4 + st3_0[1][2] * nct4;
st4_0[1][2] = st3_0[1][1];
st4_0[1][3] = st3_0[1][1] * 17.25 + st3_0[1][3];
st4_0[2][0] = st3_0[2][0] * ct4 + st3_0[2][2] * nst4;
st4_0[2][1] = st3_0[2][0] * nst4 + st3_0[2][2] * nct4;
st4_0[2][2] = st3_0[2][1];
st4_0[2][3] = st3_0[2][1] * 17.25 + st3_0[2][3];

```

/* Merlin Left Arm Robot Matrix[5] to transform from coordinate system at Wrist Roll/Flex intersect back to Reference. */

```

ct5 = cos(in_merlin_joint[4]);
nct5 = -ct5;
st5 = sin(in_merlin_joint[4]);
nst5 = -st5;

```

```

st5_0[0][0] = st4_0[0][0] * ct5 + st4_0[0][2] * nst5;
st5_0[0][1] = st4_0[0][0] * nst5 + st4_0[0][2] * nct5;
st5_0[0][2] = st4_0[0][1];
st5_0[0][3] = st4_0[0][3];
st5_0[1][0] = st4_0[1][0] * ct5 + st4_0[1][2] * nst5;
st5_0[1][1] = st4_0[1][0] * nst5 + st4_0[1][2] * nct5;
st5_0[1][2] = st4_0[1][1];
st5_0[1][3] = st4_0[1][3];
st5_0[2][0] = st4_0[2][0] * ct5 + st4_0[2][2] * nst5;
st5_0[2][1] = st4_0[2][0] * nst5 + st4_0[2][2] * nct5;
st5_0[2][2] = st4_0[2][1];
st5_0[2][3] = st4_0[2][3];

```

/* Merlin Left Arm Robot Matrix[6] to transform from coordinate system at Wrist Flex/Tool Roll intersect back to Reference. */

```

ct6 = cos(in_merlin_joint[5]);
nct6 = -ct6;
st6 = sin(in_merlin_joint[5]);
nst6 = -st6;

```

```

st6_0[0][0] = st5_0[0][0] * ct6 + st5_0[0][2] * nst6;
st6_0[0][1] = st5_0[0][0] * nst6 + st5_0[0][2] * nct6;
st6_0[0][2] = st5_0[0][1];
st6_0[0][3] = st5_0[0][3];
st6_0[1][0] = st5_0[1][0] * ct6 + st5_0[1][2] * nst6;
st6_0[1][1] = st5_0[1][0] * nst6 + st5_0[1][2] * nct6;
st6_0[1][2] = st5_0[1][1];
st6_0[1][3] = st5_0[1][3];
st6_0[2][0] = st5_0[2][0] * ct6 + st5_0[2][2] * nst6;
st6_0[2][1] = st5_0[2][0] * nst6 + st5_0[2][2] * nct6;
st6_0[2][2] = st5_0[2][1];
st6_0[2][3] = st5_0[2][3];

```

}

utils.c

/******

FILENAME: util.c

FUNCTION NAME: several useful routines

AUTHOR: Todd Mosher

DATE: 12-27-90

DESCRIPTION:

*****/

```
#include <stdio.h>
#include <conio.h>
#include <math.h>
#include "merlin.ref"
```

```
int matmlt(tmat,inmat,resmat)
```

```
double tmat[4][4];
```

```
double *inmat;
```

```
double *resmat;
```

```
{
    register int i,j;
    char str[100];
```

```
/* prints("T MATRIX INFO",17,5,1);
```

```
str[0] = 0;
```

```
for (i=0;i<4;i++)
```

```
{
```

```
    str[0] = 0;
```

```
    for(j=0;j<4;j++)
```

```
        sprintf(&str[strlen(str)],"%10.5lf ",tmat[i][j]); prints(str,1,6 + i,0);
```

```
    }
```

```
prints("GRIPPER TIP",51,5,1);
```

```
*/
```

```
for (i=0;i<4;i++)
```

```
{
```

```
    resmat[i] = 0;
```

```
    for(j=0;j<4;j++)
```

```
        resmat[i] += tmat[i][j] * inmat[j]; sprintf(str,"%10.5lf ",resmat[i]);
```

```
/* prints(wp,str,50,6+i,0);
```

```
*/
```

```
    }
```

```
}
```

```
int matmlt33(tmat,inmat,resmat)
```

utils.c

```
double tmat[4][4];
double inmat[4][4];
double resmat[4][4];
{
    register int i,j,k;
    for (i=0;i<3;i++)
    {
        for (j=0;j<3;j++)
            resmat[j][i] = 0;
        for (j=0;j<3;j++)
            for (k=0;k<3;k++)
                resmat[j][i] += tmat[j][k] * inmat[k][i];
    }
}

matdisp(wptra,basy,dispmat)
double dispmat[4][4];
int basy;
{
    register int i,j,k;
    char str[100];

    for (i=0;i<3;i++)
    {
        str[0] = NULL;
        for(j=0;j<4;j++)
            sprintf(&str[strlen(str)], "%7.2lf ",dispmat[i][j]); prints(wptra,str,1,i+basy,0);
    }
}
```

enctorad.c

/*

*/

FILENAME: enctorad.c

PROGRAM: enc_to_rad

AUTHOR: Monty Crabill

DATE: 4-3-91

DESCRIPTION:

Parameters

*/

```
#include <stdio.h>
#include <conio.h>
#include <stdlib.h>
#include <math.h>
#include "merlin.ref"
```

```
int enc_to_rad(enc_in,rad_out,dev)
```

```
long *enc_in;
```

```
double *rad_out;
```

```
char *dev; /* valid dev = MBA or MERLIN */
```

```
{
```

```
    double dtmp;
```

```
    if (toupper(dev[1]) == 'E')
```

```
    {
```

```
        rad_out[0] = enc_in[0] / rtoc[0]; /* convert joint 0 */
```

```
        rad_out[1] = enc_in[1] / rtoc[1]; /* convert joint 1 */
```

```
        rad_out[2] = enc_in[2] / rtoc[2] + rad_out[1]; /* convert joint 2 */
```

```
        rad_out[3] = enc_in[3] / rtoc[3]; /* convert joint 3 */
```

```
        /* joints 3,4,&5 are coupled together */
```

```
        dtmp = enc_in[4] / rtoc[4];
```

```
        rad_out[4] = (rad_out[3] - dtmp) * 0.8333;
```

```
        rad_out[5] = (2 * rad_out[3] - dtmp - (enc_in[5] / rtoc[5]));
```

```
    }
```

```
}
```

fullsys.c

/*

FILENAME: fullsys.c

FUNCTION NAME: full_system

AUTHOR: Todd Mosher & Monsy Crabill

DATE: April 23 1991

DESCRIPTION:

This program will allow a user to control the merlin robot
using the mba exo-skeleton.

```
#include <stdio.h>
#include <conio.h>
#include <math.h>
```

```
#include "merlin.ref"
extern int stop_print; /* this is a var in the tmwin.lib */
```

```
/* used to stop screen prints */ unsigned int utime();
float data[3][2000];
int datcnt = 0;
int trigr = 0;
```

```
full_system()
{
```

```
    long tm;
    char str[100];
    unsigned int ptime,ctime;
    int i,j,k,wptr;
    double x = 28;
    double y = 18; /* y = 0 causes sqrt error --- fix for normal operation */
    double z = 7;
    double zforce;
    double lastx,lasty,lastz;
    long waste[6];
    unsigned int cnts;
    double opinp[4];
    double resmat[4];
    FILE *fp[3];
```

```
    badcnt = 0; /* count of bad comm packets */
    fill_menu(25,8,"ARM?", /* setup menu for selecting arm to use */
              "Right arm ",
              "Left arm ",
              NULL);
```

```

if (!menu()) /* right arm selected */
    mba_rqst = 'R';
else /* left arm selected */
    mba_rqst = 'L';

j = 0;
clrscr();
printf("\n\n Loading Exo Program\n");
system("upload mba.e68"); /* load exo pgm */

if ((fp[0] = fopen("upload.sta","r")) == NULL)
{
    printf("Disk error or upload version error\n");
    printf("Press return to continue, ctrl c to abort\n");
    getchar();
}
fscanf(fp[0],"%d",&i); /* get result of upload to mba */
fclose(fp[0]);
if (i > 0) /* upload problem */
    return(wind(8,8,"COMM ERR",'E',' ','Can not communicate with MBA",NULL));

tty_open(MBA_PORT,10,8,1,0); /* setup the serial port for mba */
tty_out(MBA_PORT,mba_rqst); /* start handshaking with EXO */

clrscr();
wptr = status(1,1," INVERSE KINEMATICS INFO ",75,20);

if (i == 0) /* Exo program newly loaded */
{
    wind(8,8,"INITIALIZE",'E',' ','Move all joints through their",
        "Full range of motion",NULL);
    calib_mba(); /* Calibrate system */
}

fill_menu(25,8,"WRIST", /* setup the menu */
    "LOCK WRIST ON ", /* turn prints on/off for speed */
    "LOCK WRIST OFF ",
    NULL);
lock_wrist = !menu();

/* stop_print = 1; */
/* while (!kbhit()) /* debug only */
/* {
/*     outportb(0x300 + 4,0x00);
/*     outportb(0x300 + 4,0x02);
/* }
/* getchar(); */

```

fullsys.c

```

mba_init();    /* init vars etc */

for (i=0;i<4;i++) /* make sure hshi shows proper motor positions */
    mer_r_mpos(waste);

tty_open(JR3_PORT,8,8,1,0);    /* setup the serial port for jr3 */

tty_outs(JR3_PORT,"DP S\r");    /* do a clear buffer */
tty_outs(JR3_PORT,"RO\r");    /* zero offsets */
tm = time(NULL) + 2;
while (time(NULL) < tm);    /* wait for 2 seconds */
while (tty_in(JR3_PORT) > 0);    /* now clear the buffers */

tty_outs(JR3_PORT,"EA = FZ\r"); /* use only z this starts hand shaking*/
get_jr3_info(str,9);
cnts = ((1.0/133.0) / .8380966e-6) * 2;
done = 0;

while(!done)    /* until user aborts */
{
    outportb(0x304,00);    /* testing only!!! */
    prockey();    /* processes s (stop) q(continue) t(trigger) esc(exit) */

    lastx = mt6_0[0][3];    /* save prev xyz for indexing */
    lasty = mt6_0[1][3];    /* save prev xyz for indexing */
    lastz = mt6_0[2][3];    /* save prev xyz for indexing */

    joint_ang(wptr);    /* get joint angles from the mba */

    r_exo_tmat();    /* Computes all required matrix */
                    /* elements */
    matdisp(0,1,mt6_0);
    outportb(0x304,02);    /* testing only !!! */
    if (indexing)    /* set new indexing */
    {
        x_offset += lastx - mt6_0[0][3];
        y_offset += lasty - mt6_0[1][3];
        z_offset += lastz - mt6_0[2][3];
    }
    else    /* calc new indexing position */
    {
        x = mt6_0[0][3] + x_offset; /* get x,y,and z - shift workspace */
        y = mt6_0[1][3] + y_offset;
        z = mt6_0[2][3] + z_offset;
    }
    sprintf(str,"xyz = %7.2lf %7.2lf %7.2lf",x,y,z);
}

```

fullsys.c

```

prints(0,str,45,3,0);

if (trigr) /* set by prockey - used to store xyz info into a file */
{
    /* press t to start the trigger */
    if (datcnt == 0)
    {
        ptime = utime();
        data[0][datcnt] = x;
        data[1][datcnt] = y;
        data[2][datcnt] = z;
        datcnt++;
        if (datcnt == 2000) /* collect only 2000 samples */
            trigr = 0;
        j = 0;
        while(1) /* wait proper interval before collecting */
        {
            j++;
            ctime = utime();
            if (ptime - ctime >= cnts) /* done waiting */
                break; /* go collect the data */
        }
        if (j < 3) /* just not fast enough for the task */
            exit(sprintf("could not sample fast enough \n"
                "ptime %u ctime %u\n",ptime,ctime));
        ptime = ctime;
    }

    get_jr3_info(str,21);
    for (i=0;i<20;i++)
        if (str[0] != 'F')
            strcpy(str,&str[1]);
        else
            break;
    if (i < 20) /* f found */
        sscanf(&str[2],"%lf",&zforce); /* get force from sensor */

    prints(0,str,50,1,0);
    sprintf(str,"%lf",zforce);
    prints(0,str,50,2,0);

    if (x < 12) /* check mins and maxs */
        x = 12;
    else if (x > 35.44)
        x = 35.44;

    if (z < -23) /* do not allow crashing into floor */
        z = -23;

    /* perform inverse kinematics for MERLIN */

```

fullsys.c

```

sinvkin(&wptr,x,y,z,wrist_roll,wrist_flex,tool_roll);
}

if (datcnt)
{
    fp[0] = fopen("xvout.dat","w");
    fp[1] = fopen("yvout.dat","w");
    fp[2] = fopen("zvout.dat","w");
    for (i=0;i<3;i++)
        fprintf(fp[i],"%c%s\nTime\nvel in/sec\n133\n",'X'+i,"vout");

    for (i=0;i<datcnt-1;i++)
        for(j=0;j<3;j++)
            /* calc velocity at 133 samples per sec */
            data[j][i] = (data[j][i] - data[j][i+1]) / 7.5187699e-3;

    for (i=0;i<datcnt-1;i++)
    {
        fprintf(fp[0],"%f\n",data[0][i]);
        fprintf(fp[1],"%f\n",data[1][i]);
        fprintf(fp[2],"%f\n",data[2][i]);
    }
    fclose(fp[0]);
    fclose(fp[1]);
    fclose(fp[2]);
}

close status();
tty_flush(1);
tty_flush(2);
tty_close(2);
tty_close(1);
if (done == 2)
    wind(8,8,"TIMEOUT",'E',' ','Timeout waiting for MBA joint angles",
        NULL);
    else if (done == 3)
        wind(8,8,"TIMEOUT",'E',' ','Timeout waiting for JR3 data",
            NULL);
}

```

transp.c

FILENAME: transp.c

FUNCTION NAME: transpose.c

AUTHOR: Todd Mosher

DATE: 4-26-91

DESCRIPTION:

*****/

```
#include <stdio.h>
#include <conio.h>
#include <math.h>
#include "merlin.ref"
```

```
int transpose(inmat,outmat)
double inmat[4][4];
double outmat[4][4];
{
    register int i,j;
    for (i=0;i<4;i++)
        for (j=0;j<4;j++)
            outmat[i][j] = inmat[j][i];
}
```

wristang.c

FILENAME: wristang.c

FUNCTION NAME: wrist_angles

AUTHOR: TW Mosher and ML Crabill

DATE: 4/26/91

DESCRIPTION:

*****/

```
#include <stdio.h>
#include <conio.h>
#include <math.h>
```

```
#include "merlin.ref"
```

```
int wrist_angles()
{
```

```
    double mt0_5[4][4];
    double mata_5[4][4] = {0};
    double mat5_a[4][4] = {0};
    double mat9_a[4][4] = {0};
    char str[100];
```

```
    /* first calculate the merlins 3 to 0 rotation matrix */
    merlrmatrix();
```

```
    /* calc a matrix to transform the MBA elbow to the merlin elbow */
    if (lock_wrist)
```

```
    {
        mt5_0[0][0] = -1;
        mt5_0[0][1] = 0;
        mt5_0[0][2] = 0;
        mt5_0[1][0] = 0;
        mt5_0[1][1] = 0;
        mt5_0[1][2] = -1;
        mt5_0[2][0] = 0;
        mt5_0[2][1] = -1;
        mt5_0[2][2] = 0;
```

```
    /* for straight out */
```

```
        mr9_5[0][0] = 0;
        mr9_5[0][1] = -1;
        mr9_5[0][2] = 0;
        mr9_5[1][0] = 0;
```

wristang.c

```

mr9_5[1][1] = 0;
mr9_5[1][2] = 1;
mr9_5[2][0] = 0;
mr9_5[2][1] = 0;
mr9_5[2][2] = -1;

/* for straight down
mr9_5[0][0] = -1;
mr9_5[0][1] = 0;
mr9_5[0][2] = 0;
mr9_5[1][0] = 0;
mr9_5[1][1] = 1;
mr9_5[1][2] = 0;
mr9_5[2][0] = 0;
mr9_5[2][1] = 0;
mr9_5[2][2] = -1;
*/

}
transpose(mt5_0,mt0_5);          /* transpose MBA elbow matrix */

matmlt33(mt0_5,sr3_0,mata_5); /* mult MERLIN elbow rotation */

/* matrix to the MBAs inverted */
/*matdisp(0,0,mata_5);          /* elbow rotation matrix */
transpose(mata_5,mat5_a);

/* now calc the MBAs 9 to 5 matrix */

matmlt33(mat5_a,mr9_5,mat9_a);
/*matdisp(0,5,mat9_a);*/

wrist_flex = atan2(mat9_a[1][1],
-sqrt((double)(sqr(mat9_a[0][1]) + sqr(mat9_a[2][1]))));
wrist_flex = atan2(-sqrt((double)(sqr(mat9_a[0][1]) + sqr(mat9_a[2][1]))),
mat9_a[1][1]);
wrist_roll = atan2((double)(mat9_a[2][1] / sin(wrist_flex)),
(double)(-mat9_a[0][1] / sin(wrist_flex)));
tool_roll = atan2((double)(mat9_a[1][2] / sin(wrist_flex)),
(double)(mat9_a[1][0] / sin(wrist_flex)));
/* printf(str,"wr %7.2lf", (double)(wrist_roll*180.0/3.14159));
/* printf(str,"wf %7.2lf", (double)(wrist_flex *180.0/3.14159));
/* printf(str,"tr %7.2lf", (double)(tool_roll*180.0/3.14158));
/* printf(str,"tr %7.2lf", (double)(tool_roll*180.0/3.14158));
*/

```

wristang.c

```
wrist_flex = atan2(mat9_a[1][1],
                  sqrt((double)(sqr(mat9_a[0][1]) + sqr(mat9_a[2][1]))));
wrist_flex = atan2(sqrt((double)(sqr(mat9_a[0][1]) + sqr(mat9_a[2][1]))),
                  mat9_a[1][1]);
wrist_roll = atan2((double)(mat9_a[2][1] / sin(wrist_flex)),
                  (double)(-mat9_a[0][1] / sin(wrist_flex)));

tool_roll = atan2((double)(mat9_a[1][2] / sin(wrist_flex)),
                  (double)(mat9_a[1][0] / sin(wrist_flex)));
/*  sprintf(str,"wr %7.2lf", (double)(wrist_roll*180.0/3.14159));
/*  prints(0,str,1,10,0);
/*  sprintf(str,"wf %7.2lf", (double)(wrist_flex *180.0/3.14159));
/*  prints(0,str,20,10,0);
/*  sprintf(str,"tr %7.2lf", (double)(tool_roll*180.0/3.14158));
/*  prints(0,str,40,10,0);
*/
}
```

merlrm.c

/*

FILENAME: merlrm.c

FUNCTION NAME: merlrm()

AUTHOR: Mosher & Crabill

DATE: 04/26/91

/

```
#include <stdio.h>
#include <conio.h>
#include <math.h>
#include "merlin.ref"
```

merlrm()

```
{
double ct1,nct1,st1,nst1,ct2,nct2,st2,nst2,ct3,nct3,st3,nst3;
```

```
ct1 = cos(theta[1]);
nct1 = -ct1;
st1 = sin(theta[1]);
nst1 = -st1;
```

```
sr1_0[0][0] = ct1;
sr1_0[0][1] = nst1;
sr1_0[1][0] = nst1;
sr1_0[1][1] = nct1;
sr1_0[2][2] = -1;
```

/* Merlin Left Arm Robot Matrix[2] to transform from coordinate system at Shoulder back to Reference. */

```
ct2 = cos(theta[2]);
nct2 = -ct2;
st2 = sin(theta[2]);
nst2 = -st2;
```

```
sr2_0[0][0] = sr1_0[0][0] * ct2;
sr2_0[0][1] = sr1_0[0][0] * nst2;
sr2_0[0][2] = sr1_0[0][1];
sr2_0[1][0] = sr1_0[1][0] * ct2;
sr2_0[1][1] = sr1_0[1][0] * nst2;
sr2_0[1][2] = sr1_0[1][1];
sr2_0[2][0] = sr1_0[2][2] * nst2;
sr2_0[2][1] = sr1_0[2][2] * nct2;
sr2_0[2][2] = 0.0;
```

merlrm.c

/* Merlin Left Arm Robot Matrix[3] to transform from coordinate system at Elbow/Wrist Roll intersect back to Reference. */

```
ct3 = cos(theta[3]);
nct3 = -ct3;
st3 = sin(theta[3]);
nst3 = -st3;
```

```
sr3_0[0][0] = sr2_0[0][0] * ct3 + sr2_0[0][1] * nst3;
sr3_0[0][1] = sr2_0[0][0] * nst3 + sr2_0[0][1] * ct3;
sr3_0[0][2] = -sr2_0[0][2];
sr3_0[1][0] = sr2_0[1][0] * ct3 + sr2_0[1][1] * nst3;
sr3_0[1][1] = sr2_0[1][0] * nst3 + sr2_0[1][1] * ct3;
sr3_0[1][2] = -sr2_0[1][2];
sr3_0[2][0] = sr2_0[2][0] * ct3 + sr2_0[2][1] * nst3;
sr3_0[2][1] = sr2_0[2][0] * nst3 + sr2_0[2][1] * ct3;
sr3_0[2][2] = 0;
```

```
}
```

jointang.c

FILENAME: jointang.c

FUNCTION NAME: joint_ang

AUTHOR: Todd Mosher

DATE: 12-27-90

MODIFIED: 23 Jan 91 by Montrose Crabbelly

DESCRIPTION:

This routine will get optical encoder information from the mba and then convert it to joint angles.

*****/

```
#include <stdio.h>
#include <conio.h>
#include "merlin.ref"
```

```
int joint_ang(wptr)
int wptr;
{
```

```
    int i;
    int lft_oe[8],rig_oe[8];
    char str[150];
    int itmp;
    double exo_hs_rad;
```

```
    get_mba_info(lft_oe,rig_oe,mba_rqst); /* get encoder information */
    for (i=0;i<7;i++) /* calc angles of all joints */
```

```
        if (mba_rqst == 'L')
            exo_l_arm[i] = exo_l_hs_rad[i] + (lft_oe[i] - arm_hs_oe[i])
                        * oe_to_rad[i];
```

```
        else
            /* exo_r_arm[i] = exo_r_hs_rad[i] + (arm_hs_oe[i] - rig_oe[i])
            /* * oe_to_rad[i];
            */
```

```
            exo_r_arm[i] = exo_r_hs_rad[i] + (rig_oe[i] - arm_hs_oe[i])
                        * oe_to_rad[i];
```

```
/* dist from hard stop times the */
/* conversion factor for encoder to deg */
/* plus the hardstop position */
```

```
prints(wptr,"Joint / Encoder / Angle / Encoder to rad / Hardstop(rad)"
        " / Hardstop(cnts)",1,12,0);
```

jointang.c

```
for (i=0;i<7;i++)
{
    if (mba_rqst == 'L') /* get proper display information */
    {
        itmp = lft_oe[i];
        exo_hs_rad = exo_l_hs_rad[i];
    }
    else
    {
        itmp = rig_oe[i];
        exo_hs_rad = exo_r_hs_rad[i];
    }

    sprintf(str,"enc %2d val %4d %7.2lf %7.3lf      %7.2lf
               %4d ", i,itmp,exo_r_arm[i] * 57.3, oe_to_rad[i],
               exo_hs_rad, arm_hs_oe[i]);
    prints(wptr,str,1,13+i,0);
}
}
```

mbainit.c

/*****

FILENAME: mbainit.c

FUNCTION NAME: mba_init()

AUTHOR: Todd Mosher

DATE: 12-31-90

MODIFIED: 18 January 91 by Montrose Crabbelly

DESCRIPTION:

This routine will initialize any necessary variables.

*****/

```
#include <stdio.h>
#include <conio.h>
#include "merlin.ref"
```

```
int mba_init()
{
```

```
    FILE *fp;
    int i;
```

```
    if ((fp = fopen("mba.cfg", "r")) == NULL)
    {
```

```
        tty_close(MBA_PORT);
```

```
        wn_exit();
```

```
        exit(wind(9,9,"FILE NOT FOUND",'E',' ',
                    "MBA configuration file missing", "Calibration should create this file",
                    "Press return!",
                    NULL));
    }
```

```
    else
```

```
        for (i=0;i<8;i++)
```

```
            fscanf(fp,"%d",&arm_hs_oe[i]);
```

```
        fclose(fp);
```

```
        mt2_0[0][2] = 0;
```

```
        mt2_0[0][3] = 13;
```

```
        mt2_0[1][2] = -.1564;
```

```
        mt2_0[1][3] = -(11 + 14 * .1564);
```

```
        mt2_0[2][2] = -.9877;
```

```
        mt2_0[2][3] = -6.315 * (11 + 14 * .1564)
                        + (11 + 12 * .1584) / .1584;
```

```
        x_offset = initx_offset;
```

```
        y_offset = inity_offset;
```

```
        z_offset = initz_offset;
```

```
    }
```

rexotmat.c

/* **** */

FILENAME: rexotmat.c

FUNCTION NAME: r_exo_tmat()

AUTHOR: Monty Crabill

DATE: 06/18/92

MODIFIED:

DESCRIPTION:

Using MERLIN joint angle information, this creates the T matrix for the wrist xyz position and the rotation matrix for the gripper with respect to the elbow. The following method for calculating a final tmatrix is almost as fast as crunching the matrixs by hand and coming up with an equation (we know, we tested it). However, this method is far easier to modify, maintain, and read.

**** */

```
#include <stdio.h>
#include <conio.h>
#include <math.h>
#include "merlin.ref"
```

```
/* double ct2,st2,nst2,ct3,nct3,st3,nst3,ct4,nct4,st4,nst4,
    ct5,nct5,st5,nst5,ct6,nct6,st6,nst6,ct7,st7,nst7,
    ct8,nct8,st8,nst8;
    /* nct7 is not used */
    /* used in tmat() to allow computation of */
    /* cos(*tX) & sin(*tX) only once */
```

```
r_exo_tmat()
{
```

```
/* MBA Exo Right Matrix[2] to transform from coordinate system at */
/* Right Shoulder/Azimuth Elevation Intersect back to Reference. */
```

```
ct2 = cos(exo_r_arm[0]);
st2 = sin(exo_r_arm[0]);
nst2 = -st2;
```

```
mt2_0[0][0] = ct2;
mt2_0[0][1] = nst2;
```

```
/* mt2_0[0][2] = 0;
```

```
/* mt2_0[0][3] = 13;
```

```
mt2_0[1][1] = -.9877 * ct2;
```

```
computed once in mbainit.c */
" */ mt2_0[1][0] = -.9877 * st2;
```

rexotmat.c

```

/* mt2_0[1][2] = -.1564;          " */
/* mt2_0[1][3] = -(11 + 14 * .1564); " */ mt2_0[2][0] = .1564 * st2;
   mt2_0[2][1] = .1564 * ct2;
/* mt2_0[2][2] = -.9877;          " */
/* mt2_0[2][3] = -6.315 * (11 + 14 * .1564) "
   + (11 + 12 * .1584) / .1584; */

/* MBA Exo Right Matrix[3] to transform from coordinate system at Right Shoulder Elevation/
Upper Arm Roll Intersect back to Reference. */

ct3 = cos(exo_r_arm[1]);
nct3 = -ct3;
st3 = sin(exo_r_arm[1]);
nst3 = -st3;

mt3_0[0][0] = mt2_0[0][0] * ct3 + mt2_0[0][2] * st3;
mt3_0[0][1] = mt2_0[0][0] * nct3 + mt2_0[0][2] * ct3;
mt3_0[0][2] = -mt2_0[0][1];
mt3_0[0][3] = -mt2_0[0][1] * .032 + 13;
mt3_0[1][0] = mt2_0[1][0] * ct3 + mt2_0[1][2] * st3;
mt3_0[1][1] = mt2_0[1][0] * nct3 + mt2_0[1][2] * ct3;
mt3_0[1][2] = -mt2_0[1][1];
mt3_0[1][3] = -.032 * mt2_0[1][1] + mt2_0[1][3];
mt3_0[2][0] = mt2_0[2][0] * ct3 + mt2_0[2][2] * st3;
mt3_0[2][1] = mt2_0[2][0] * nct3 + mt2_0[2][2] * ct3;
mt3_0[2][2] = -mt2_0[2][1];
mt3_0[2][3] = -mt2_0[2][1] * .032 + mt2_0[2][3];

/* MBA Exo Right Matrix[4] to transform from coordinate system at Right Upper Arm Roll/ Elbow
Intersect back to Reference. */

ct4 = cos(exo_r_arm[2]);
nct4 = -ct4;
st4 = sin(exo_r_arm[2]);
nst4 = -st4;

mt4_0[0][0] = mt3_0[0][0] * ct4 + mt3_0[0][2] * nst4;
mt4_0[0][1] = mt3_0[0][0] * nst4 + mt3_0[0][2] * ct4;
mt4_0[0][2] = mt3_0[0][1];
mt4_0[0][3] = mt3_0[0][1] * 15 + mt3_0[0][3];
mt4_0[1][0] = mt3_0[1][0] * ct4 + mt3_0[1][2] * nst4;
mt4_0[1][1] = mt3_0[1][0] * nst4 + mt3_0[1][2] * ct4;
mt4_0[1][2] = mt3_0[1][1];
mt4_0[1][3] = mt3_0[1][1] * 15 + mt3_0[1][3];
mt4_0[2][0] = mt3_0[2][0] * ct4 + mt3_0[2][2] * nst4;
mt4_0[2][1] = mt3_0[2][0] * nst4 + mt3_0[2][2] * ct4;

```

rexotmat.c

```
mt4_0[2][2] = mt3_0[2][1];
mt4_0[2][3] = mt3_0[2][1] * l5 + mt3_0[2][3];
```

```
/* MBA Exo Right Matrix[5] to transform from coordinate system at Right Elbow and Lower
   Arm Roll Intersect back to Reference. */
```

```
ct5 = cos(exo_r_arm[3]);
nct5 = -ct5;
st5 = sin(exo_r_arm[3]);
nst5 = -st5;
```

```
mt5_0[0][0] = mt4_0[0][0] * ct5 + mt4_0[0][2] * st5;
mt5_0[0][1] = mt4_0[0][0] * nst5 + mt4_0[0][2] * ct5;
mt5_0[0][2] = -mt4_0[0][1];
mt5_0[0][3] = mt4_0[0][3];
mt5_0[1][0] = mt4_0[1][0] * ct5 + mt4_0[1][2] * st5;
mt5_0[1][1] = mt4_0[1][0] * nst5 + mt4_0[1][2] * ct5;
mt5_0[1][2] = -mt4_0[1][1];
mt5_0[1][3] = mt4_0[1][3];
mt5_0[2][0] = mt4_0[2][0] * ct5 + mt4_0[2][2] * st5;
mt5_0[2][1] = mt4_0[2][0] * nst5 + mt4_0[2][2] * ct5;
mt5_0[2][2] = -mt4_0[2][1];
mt5_0[2][3] = mt4_0[2][3];
```

```
/* MBA Exo Right Matrix[6] to transform from coordinate system at Right
   Lower Arm Roll & Wrist Radial Intersect back to Reference. */
```

```
/* ct6 = cos(exo_r_arm[4]);
/* nct6 = -ct6;
/* st6 = sin(exo_r_arm[4]);
/* nst6 = -st6;
```

```
/* some element calcs have been eliminated since */
/* only the position info from tmat 6 is used */
```

```
/* mt6_0[0][0] = mt5_0[0][0] * ct6 + mt5_0[0][2] * st6;
/* mt6_0[0][1] = mt5_0[0][0] * nst6 + mt5_0[0][2] * ct6;
/* mt6_0[0][2] = -mt5_0[0][1];
*/
mt6_0[0][3] = -mt5_0[0][1] * l6 + mt5_0[0][3];
/* mt6_0[1][0] = mt5_0[1][0] * ct6 + mt5_0[1][2] * st6;
/* mt6_0[1][1] = mt5_0[1][0] * nst6 + mt5_0[1][2] * ct6;
/* mt6_0[1][2] = -mt5_0[1][1];
*/
mt6_0[1][3] = -mt5_0[1][1] * l6 + mt5_0[1][3];
/* mt6_0[2][0] = mt5_0[2][0] * ct6 + mt5_0[2][2] * st6;
/* mt6_0[2][1] = mt5_0[2][0] * nst6 + mt5_0[2][2] * ct6;
/* mt6_0[2][2] = -mt5_0[2][1];
*/
```

rexotmat.c

```
mt6_0[2][3] = -mt5_0[2][1] * 16 + mt5_0[2][3];
```

```
/* MBA Exo Right Matrix[7] to transform from coordinate system at Right
   Wrist Radial & Wrist Flex Intersect back to Reference. */
/* no longer needed */
```

```
/* ct7 = cos(exo_r_arm[5]);
   nct7 = -ct7;
   st7 = sin(exo_r_arm[5]);
   nst7 = -st7;
```

```
/* mt7_0[0][0] = mt6_0[0][0] * ct7 + mt6_0[0][2] * nst7;
   mt7_0[0][1] = mt6_0[0][0] * nst7 + mt6_0[0][2] * nct7;
   mt7_0[0][2] = mt6_0[0][1];
   mt7_0[0][3] = -mt6_0[0][1] * .160 + mt6_0[0][3];
   mt7_0[1][0] = mt6_0[1][0] * ct7 + mt6_0[1][2] * nst7;
   mt7_0[1][1] = mt6_0[1][0] * nst7 + mt6_0[1][2] * nct7;
   mt7_0[1][2] = mt6_0[1][1];
   mt7_0[1][3] = -mt6_0[1][1] * .160 + mt6_0[1][3];
   mt7_0[2][0] = mt6_0[2][0] * ct7 + mt6_0[2][2] * nst7;
   mt7_0[2][1] = mt6_0[2][0] * nst7 + mt6_0[2][2] * nct7;
   mt7_0[2][2] = mt6_0[2][1];
   mt7_0[2][3] = -mt6_0[2][1] * .160 + mt6_0[2][3];
*/
```

```
/* MBA Exo Right Matrix[8] to transform from coordinate system at Right
   Wrist Radial & Wrist Flex Intersect back to Reference. */
/* no longer needed */
```

```
/* ct8 = cos(exo_r_arm[6]);
   nct8 = -ct8;
   st8 = sin(exo_r_arm[6]);
   nst8 = -st8;
```

```
/* mt8_0[0][0] = mt7_0[0][0] * ct8 + mt7_0[0][2] * nst8;
   mt8_0[0][1] = mt7_0[0][0] * nst8 + mt7_0[0][2] * nct8;
   mt8_0[0][2] = mt7_0[0][1];
   mt8_0[0][3] = mt7_0[0][3];
   mt8_0[1][0] = mt7_0[1][0] * ct8 + mt7_0[1][2] * nst8;
   mt8_0[1][1] = mt7_0[1][0] * nst8 + mt7_0[1][2] * nct8;
   mt8_0[1][2] = mt7_0[1][1];
   mt8_0[1][3] = mt7_0[1][3];
   mt8_0[2][0] = mt7_0[2][0] * ct8 + mt7_0[2][2] * nst8;
   mt8_0[2][1] = mt7_0[2][0] * nst8 + mt7_0[2][2] * nct8;
   mt8_0[2][2] = mt7_0[2][1];
   mt8_0[2][3] = mt7_0[2][3];
*/
```

rexotmat.c

```

/*****
*   rotation matrix from the wrist to the elbow
*
*****/

ct6 = cos(exo_r_arm[4]);
st6 = sin(exo_r_arm[4]);

/*   matrix to describe wrist roll to the elbow */

mr6_5[0][0] = ct6;
mr6_5[0][1] = -st6;
mr6_5[1][2] = 1;
mr6_5[2][0] = -st6;
mr6_5[2][1] = -ct6;

/*   matrix to describe wrist flex to the elbow */

ct7 = cos(exo_r_arm[5]);
st7 = sin(exo_r_arm[5]);

mr7_5[0][0] = mr6_5[0][0] * ct7;
mr7_5[0][1] = mr6_5[0][0] * -st7;
mr7_5[0][2] = mr6_5[0][1];
mr7_5[1][0] = st7;
mr7_5[1][1] = ct7;
mr7_5[1][2] = 0;
mr7_5[2][0] = mr6_5[2][0] * ct7;
mr7_5[2][1] = mr6_5[2][0] * -st7;
mr7_5[2][2] = mr6_5[2][1];

/*   matrix to describe tool roll to the elbow */

ct8 = cos(exo_r_arm[6]);
st8 = sin(exo_r_arm[6]);

mr8_5[0][0] = mr7_5[0][0] * ct8 + mr7_5[0][2] * -st8;
mr8_5[0][1] = mr7_5[0][0] * -st8 + mr7_5[0][2] * -ct8;
mr8_5[0][2] = mr7_5[0][1];
mr8_5[1][0] = mr7_5[1][0] * ct8;
mr8_5[1][1] = mr7_5[1][0] * -st8;
mr8_5[1][2] = mr7_5[1][1];
mr8_5[2][0] = mr7_5[2][0] * ct8 + mr7_5[2][2] * -st8;
mr8_5[2][1] = mr7_5[2][0] * -st8 + mr7_5[2][2] * -ct8;
mr8_5[2][2] = mr7_5[2][1];

/*   matrix to orient the frame 8 the same as the merlin gripper */

mr9_5[0][0] = mr8_5[0][2];

```

rexotmat

```
mr9_5[0][1] = -mr8_5[0][0];  
mr9_5[0][2] = -mr8_5[0][1];  
mr9_5[1][0] = mr8_5[1][2];  
mr9_5[1][1] = -mr8_5[1][0];  
mr9_5[1][2] = -mr8_5[1][1];  
mr9_5[2][0] = mr8_5[2][2];  
mr9_5[2][1] = -mr8_5[2][0];  
mr9_5[2][2] = -mr8_5[2][1];
```

}

calib.c

/**

FILENAME: calib.c

FUNCTION NAME: calib_mba()

AUTHOR: Todd Mosher

DATE: 12-31-90

DESCRIPTION:

This routine will instruct the user how to calibrate the mba.

*/

#include <stdio.h>

#include <conio.h>

#include "merlin.ref"

extern int tty_cnt;

char cal_txt[8][25] =
{ {"shoulder azimuth"},
{"shoulder elevation"},
{"upper arm roll"},
{"elbow flex"},
{"lower arm roll"},
{"wrist roll"},
{"wrist flex"},
{" "
};

int calib_mba()

{
FILE *fp;
int i,j;
char str[100];
char str2[100];
int lft[8],right[8];
int res[8];

wind(8,2,"INFORMATION",'I',' ',
"All rotations are clock wise. Look down the ",
"optical encoder shaft into the housing to ",
"determine the proper direction",NULL);

for (i=0;i<7;i++) /* for each joint */

{
printf(str,"Please rotate the %s",cal_txt[i]);

calib.c

```
if (mba_rqst == 'R')          /* display proper arm request */ sprintf(str2,"to the hardstop
    (right arm).");
    else
        sprintf(str2,"to the hardstop (left arm).");

wind(10,8,"INSTRUCTIONS",'E',' ',
str,
str2,
"Press enter when this is done.",
NULL);
get_mba_info(lft,right,mba_rqst); /* this gets data from old data request */
get_mba_info(lft,right,mba_rqst); /* this gets current data */

if (mba_rqst == 'L')          /* save proper results */
    res[i] = lft[i];          /* save result in res */
    else
        res[i] = right[i];    /* save result in res */
}
close_info();

fp = fopen("mba.cfg","w"); /* save the current info */
for (i=0;i<8;i++)
    fprintf(fp,"%d\n",res[i]);
fclose(fp);
}
```

getmba.c

FILENAME: getmba.c

FUNCTION NAME: get_mba_info()

AUTHOR: Todd Mosher

DATE: 12-31-90

DESCRIPTION:

This routine will get the optical encoder information from the mba

*****/

```
#include <stdio.h>
#include <conio.h>
#include <time.h>
#include "merlin.ref"
```

```
extern int trigr, datcnt;
```

```
int get_mba_info(lft_oe, rig_oe, typ)
int *lft_oe, *rig_oe;
int typ; /* Left Right or H/Both */
{
```

```
    char tbuff[32]; /* temp input buffer */
    char byt;
    int j, i;
    int bytecnt = 17;
    char str[100];
    unsigned int tm;
```

```
    typ = toupper(typ);
    if (typ == 'B' || typ == 'H')
        bytecnt = 33;
```

```
    tm = utime();
    while(tty_cnt(MBA_PORT) < bytecnt) /* wait for all data to return from mba */
    {
        if (tm - utime() >= 25000) /* timeout so getout */
        {
            if (kbhit() && getch() == 27)
            {
                done = 2;
                return;
            }
            tty_open(MBA_PORT, 10, 8, 1, 0); /* setup the serial port for mba */
            sprintf(str, "%d Missing MBA data", ++badcnt);
            prints(0, str, 25, 1, 0);
        }
    }
```

getmba.c

```

while (tty_cnt(MBA_PORT)) /* clear the port */
    tty_in(MBA_PORT);
    tty_out(MBA_PORT,typ); /* send out new request for data */
    tm = utime(); /* setup time for new request */
}
indexing = 0; /* turn off indexing */
byt = tty_in(MBA_PORT); /* get leading byte */
if (byt == 'R') /* index reset */
{
    x_offset = initx_offset;
    y_offset = inity_offset;
    z_offset = initz_offset;
}
else if (byt == 'I') /* turn on indexing */
    indexing = 1;
else if (byt != 'H' && byt != 'Z') /* h,i,r,z are valid header bytes */
/* z is halt button */
{
    while(tty_cnt(MBA_PORT)) /* clear the port */
        tty_in(MBA_PORT);
        sprintf(str,"%d Bad header found",++badcnt);
        prints(0,str,25,1,0);
}
}
if (typ == 'H' || typ == 'B')
    for (j=31;j>=0;j--) /* get the data */
        tbuff[j] = tty_in(MBA_PORT);
    else if (typ == 'L')
        for (j=31;j>=16;j--)
            tbuff[j] = tty_in(MBA_PORT);
    else if (typ == 'R')
        for (j=15;j>=0;j--)
            tbuff[j] = tty_in(MBA_PORT);
    tty_out(MBA_PORT,typ); /* give next request to mba */
    if (byt == 'Z') /* when in halt, do not update numbers */ return;
    if (typ == 'B' || typ == 'H' || typ == 'R')
        for (j=7;j>=0;j--) /* put highbyte,lowbyte together */
            rig_oe[j] = ((tbuff[2*j+1] < 8) & 0xFF00) | (tbuff[2*j] & 0x00FF);
    if (typ == 'B' || typ == 'H' || typ == 'L')
        for (j=15;j>=8;j--)
            lft_oe[j-8] = ((tbuff[2*j+1] < 8) & 0xFF00) | (tbuff[2*j] & 0x00FF);
/* gotoxy(1,3);
printf("%5d %5d %5d %5d\n",rig_oe[0],rig_oe[1],rig_oe[2],rig_oe[3]); printf("%5d %5d
%5d %5d\n",rig_oe[4],rig_oe[5],rig_oe[6],rig_oe[7]);
*/
}

```

ttyopen.c

```
/*
TTYOPEN.C
```

Task 25, Robotics

KL Johnston, SRL

Functions used by TTY68K to initialize and restore IBM-PC serial ports.
A serial input pattern matching function is also available.

```
*/
```

```
#include <bios.h>
#include <dos.h>
#include <stdio.h>
```

```
#define _1STOP      0x00
#define _2STOP      0x04
#define _7BITS      0x02
#define _8BITS      0x03
#define BASE1       0x3F8
#define BASE2       0x2E8
#define DLAB        0x80
#define DTR         0x01
#define IRQ1        0x10
#define IRQ2        0x20 /* 0x08 */
#define OUT1        0x04
#define OUT2        0x08
#define RTS         0x02
#define VECTOR1     0x0C
#define VECTOR2     0x0D /* 0x0B */
int port = 1;      /* com port ... default com1 */
int baud = 8;      /* index into baud table... default 9600 */
int dbits = 8;     /* data bits... default 8 */
int sbits = 1;     /* stop bits... default 1 */
int parity = 0;    /* parity.. default none */
int baud_table[12][3] = /* baud table for serial io stuff */
{
    { 50, 9, 0},
    {110, 4, 23},
    {150, 3, 0},
    {300, 1, 128},
    {600, 0, 192},
    {1200, 0, 96},
    {2400, 0, 48},
    {4800, 0, 24},
    {9600, 0, 12},
    {19200, 0, 6},
    {38400, 0, 3},
    {56000, 0, 2}
};
```

ttyopen.c

```

void interrupt tty1_isr(void);
void interrupt tty2_isr(void);
extern int tty1_base, tty1_error, tty1_qfull, tty1_cnt;
extern int tty2_base, tty2_error, tty2_qfull, tty2_cnt;

static int irq_level, vector;
static void interrupt (*old_isr)();

/*****
***** t t y _ o p e n *****/
/***** void
tty_open(int port,int baud,int dbits,int sbits,int parity)
*/
Initializes serial port and sets tty_isr (see TTYISR.ASM) as interrupt
service routine.
port   = 1 - 2 for COM1 or COM2 port.
baud   = 0 - 11, index into baud table array.
dbits  = 7 - 8, number of data bits/byte.
sbits  = 1 - 2, number of stop bits/byte.
parity = EVEN_PARITY, ODD_PARITY or NO_PARITY (see TTYOPEN.H).
This routine is not intended to be fool proof, it assumes valid arguments
and returns no status.
*/
{
    int w_len, n_stop;
    int tty_base;

    if (port == 1)
    {
        tty1_base = BASE1;
        tty_base = BASE1;
        vector = VECTOR1;
        irq_level = IRQ1;
    }
    else
    {
        tty2_base = BASE2;
        tty_base = BASE2;
        vector = VECTOR2;
        irq_level = IRQ2;
    }
    if (dbits == 7)
        w_len = _7BITS;
    else
        w_len = 8BITS;
    if (sbits == 1)

```

ttyopen.c

```

    n_stop = _1STOP;
else
    n_stop = _2STOP;
old_isr = getvect(vector);
if (port == 1)
    setvect(vector,tty1_isr); /* Establish 8259 handler for tty IRQ level */ else
    setvect(vector,tty2_isr); /* Establish 8259 handler for tty IRQ level */

disable();
outportb(tty_base+4,RTS | DTR); /* Disable any pending interrupts */
outportb(tty_base+1,0);
outportb(tty_base+3,DLAB | w_len | n_stop | parity);
outportb(tty_base,baud_table[baud][2]); outportb(tty_base+1,baud_table[baud][1]);
outportb(tty_base+3,w_len | n_stop | parity);
inportb(tty_base); /* Clear any pending 8250 receive */
inportb(tty_base+5); /* or status interrupts */
inportb(tty_base+6); /* or modem interrupts */
outportb(tty_base+1,0x07); /* Toggle enable bits to activate */ outportb(tty_base+1,0);
outportb(0x21,~irq_level & inportb(0x21)); /* Enable 8259 interrupts */
outportb(tty_base+4,OUT2 | RTS | DTR); /* OUT2 is wired as int enable */
outportb(tty_base+1,0x07); /* Enable rcv, xmit & status interrupts */ enable();
}

/*****
/***** t t y _ c l o s e *****/
/*****/ void
tty_close(port)
int port;
/*
Disables all interrupts from serial port previously initialized (tty_open). Restores original interrupt
service routine for serial port.
tty_open must have been previously called.
If program exits without calling this routine, the computer will likely
crash.
*/
{
    int tty_base;

    if (port == 1)
        tty_base = tty1_base;
    else

```

ttyopen.c

```
    tty_base = tty2_base;

    disable();
    outportb(0x21,irq_level | inportb(0x21));
    outportb(tty_base+4,RTS | DTR);
    outportb(tty_base+1,0);
    enable();
    tty_flush(port);
    setvect(vector,old_isr);
}
/*****
*
*   Support routines for selective port handling
*
*****/
int tty_cnt(port)
int port;
{
    if (port == 1)        /* return char from specified port */ return(tty1_cnt);
    return(tty2_cnt);
}
int tty_qfull(port)
int port;
{
    if (port == 1)        /* return char from specified port */ return(tty1_qfull);
    return(tty2_qfull);
}
int tty_error(port)
int port;
{
    if (port == 1)        /* return char from specified port */ return(tty1_error);
    return(tty2_error);
}
int tty_in(port)
int port;
{
    if (port == 1)        /* return char from specified port */ return(tty1_in());
    return(tty2_in());
}
int tty_out(port,byt)
int port,byt;
{
    if (port == 1)
        return(tty1_out(byt));
    return(tty2_out(byt));
}
int tty_outs(port,str)
```

ttyopen.c

```

int port;
char *str;
{
    if (port == 1)
        return(tty1_outs(str));
    return(tty2_outs(str));
}
int tty_outmem(port, str, cnt)
int port;
int *str;
int cnt;
{
    if (port == 1)
        return(tty1_outmem(str, cnt));
    return(tty2_outmem(str, cnt));
}
int tty_flush(port)
int port;
{
    if (port == 1)
        return(tty1_flush());
    return(tty2_flush());
}

/*****
***** t t y _ i n _ m a t c h *****/
/***** int
tty_in_match(char *pattern, int timeout_seconds)
*/
    Tries to match incoming tty character stream to a pattern string.
    When a mismatch is found the matching process is restarted.
    When a complete match is found, return value is true.
    If timeout expires before a match is found, return value is false.
*/
{
    int ch, i;
    long timeout;

    timeout = biostime(0,0) + 18 * timeout_seconds;
    i = 0;
    while (pattern[i] != 0)
    {
        if (tty_error || tty_qfull || biostime(0,0) > timeout)
            return(0);
        if ((ch = tty_in()) != EOF && ch != (pattern[i++] & 0xFF))
            i = 0;
    }
    return(1);
}

```

ttylir.asm

```
name    ttylir
large memory model

;
; ***** this version has no Xon Xoff stuff  todd
mosher
; TTYISR.ASM
;
; Task 25, Robotics
;
; KL Johnston, SRL
;
; Turbo C functions used by TTY68K. Interrupt service and input/output
; queue interface routines for serial (COM) port communications.
; Used along with functions in TTYOPEN.C.
;

EOF      = -1
EOI      = 20h
INQ_SIZE = 200h    ; was 256
NO_SERV  = 01h
OUTQ_SIZE = 2020h  ; Que size limits max array tty_outs & tty_outmem can handle.
RECV_SERV = 04h
XMIT_SERV = 02h
XOFF     = 13h
XON      = 11h

public  _tty1_base
public  _tty1_error
public  _tty1_flush
public  _tty1_in
public  _tty1_isr
public  _tty1_out
public  _tty1_outmem
public  _tty1_outs
public  _tty1_qfull
public  _tty1_cnt

public  _tty2_base
public  _tty2_error
public  _tty2_flush
public  _tty2_in
public  _tty2_isr
public  _tty2_out
public  _tty2_outmem
public  _tty2_outs
public  _tty2_qfull
public  _tty2_cnt

_data segment word public 'data'
in1_head    dw 0
in1_tail    dw 0
```

ttylir.asm

```

out1_head    dw 0
out1_tail    dw 0
xmit1_idle   dw 0
send1_xoff   dw 0
send1_xon    dw 0
recv1_pause  dw 0
_tty1_base   dw 0
_tty1_error  dw 0
_tty1_qfull  dw 0
_tty1_cnt    dw 0

in2_head     dw 0
in2_tail     dw 0
out2_head    dw 0
out2_tail    dw 0
xmit2_idle   dw 0
send2_xoff   dw 0
send2_xon    dw 0
recv2_pause  dw 0
_tty2_base   dw 0
_tty2_error  dw 0
_tty2_qfull  dw 0
_tty2_cnt    dw 0
_data ends

_bss segment word public 'bss'
inq1  db INQ_SIZE dup (?)
outq1  db OUTQ_SIZE dup (?)
inq2  db INQ_SIZE dup (?)
outq2  db OUTQ_SIZE dup (?)
_bss ends

_text segment byte public 'code'
dgroup group _data,_bss
        assume cs:_text,ds:dgroup,ss:dgroup

_tty1_isr    proc    near
;
; Serial port interrupt service routine. Never directly called from program.
;
        push    ax                ;Save a few registers to work with.
        push    bx
        push    dx
        push    ds
        mov     ax,dgroup         ;Set up ds to access Turbo C objects.
        mov     ds,ax
$20:
        mov     dx,_tty1_base     ;Read interrupt identification
register:
        add     dx,2

```

ttylstr.asm

```

        in     al,dx
        cmp    al,NO_SERV    ;Any service required?
        jne    $30           ;Yes.
        jmp    done          ;No.
$30:
        cmp    al,RCV_SERV    ;Service received data interrupt?
        jne    not1_recv      ;No.
        mov    dx,_tty1_base  ;Yes, read character.
        in     al,dx
        ;
        or     al,al          ;Null character?
        ;
        jz     $20            ;Yes, ignore it.
        ;
        cmp    al,XOFF        ;No, Xoff character?
        ;
        je     $20            ;Yes, ignore it.
        ;
        cmp    al,XON         ;No, Xon character?
        ;
        je     $20            ;Yes, ignore it.
        ;
        mov    bx,_tty1_cnt    ;increment the
        inc    bx             ;byte count
        mov    _tty1_cnt,bx    ;and save it
        mov    bx,in1_head     ;Advance input que head pointer.
        inc    bx
        cmp    bx,INQ_SIZE
        jl     $100
        xor    bx,bx
$100:
        cmp    bx,in1_tail     ;Input que full?
        je     $200            ;Yes.
        mov    in1_head,bx     ;No, save new que head pointer.
        mov    inqI[bx],al     ;Put received character on que.
        cmp    rcv1_pause,0    ;Receiver pause already flagged?
        jne    $20            ;Yes, don't bother checking again.
        mov    ax,in1_tail     ;Calculate free space remaining.
        sub    ax,bx
        dec    ax
        jge    $140
        add    ax,INQ_SIZE
$140:
        ;
        cmp    ax,INQ_SIZE/4   ;Input que 75 % full?
        ;
        jge    $20            ;No.
        ;
        mov    rcv1_pause,1    ;Yes, initiate receiver pause.
        ;
        mov    send1_xoff,1
        ;
        call   tickle1_xmit
        jmp    $20
$200:
        inc    _tty1_qfull     ;Count que full error.
        jmp    $20            ;Check for more servicing.
not1_recv:
        cmp    al,XMIT_SERV    ;Service transmit ready interrupt?
        jne    not1_xmit      ;No.
        cmp    send1_xoff,0    ;Yes, send Xoff?
        je     $250           ;No.
        mov    send1_xoff,0    ;Yes, reset flag.

```

ttylir.asm

```

        mov     al,XOFF
        jmp     $420
$250:
        cmp     send1_xon,0    ;Send Xon?
        je      $260           ;No.
        mov     send1_xon,0    ;Yes, reset flag.
        mov     al,XON
        jmp     $420
$260:
        cmp     recv1_pause,0  ;Receiver ISR paused?
        jne     $290           ;Yes, transmission must also pause.
        mov     bx,out1_tail   ;No, output que empty?
        cmp     bx,out1_head
        jne     $300           ;No.
$290:
        mov     xmit1_idle,1    ;Yes, flag output idle.
        jmp     $20            ;Check for more servicing.
$300:
        inc     bx              ;Advance que tail pointer.
        cmp     bx,OUTQ_SIZE
        jl      $400
        xor     bx,bx
$400:
        mov     out1_tail,bx    ;Save new que tail pointer.
        mov     al,outq1[bx]    ;Get character to be transmitted.
$420:
        mov     dx,tty1_base
        out     dx,al           ;Transmit character.
        jmp     $20            ;Check for more servicing.
not1_xmit:
        mov     dx,tty1_base    ;Assume status interrupt.
        add     dx,5
        in      al,dx           ;Access line status reg to clear
        error.
        inc     dx
        in      al,dx           ;Access modem status reg to clear
        error.
        inc     tty1_error      ;Count hardware error.
        jmp     $20            ;Check for more servicing.
done:
        mov     al,EOI          ;Non-specific EOI for 8259.
        out     20h,al
        pop     ds              ;Restore registers.
        pop     dx
        pop     bx
        pop     ax
        iret
_tty1_isr     endp
_tty1_in proc  far
;

```

ttylir.asm

```

; Returns next character on input que to caller as an integer.
; If input que is empty, returns EOF (-1).
;
    mov     ax,EOF           ;Assume que empty.
    mov     bx,in1_tail
    cmp     bx,in1_head     ;Input que empty?
    je      $1200           ;Yes.
    cli
    mov     bx,_tty1_cnt     ; decrement the
    dec     bx              ; byte count
    mov     _tty1_cnt,bx     ; and save it
    sti
    mov     bx,in1_tail
    inc     bx              ;No, advance input que tail pointer.
    cmp     bx,INQ_SIZE
    jl      $1100
    xor     bx,bx
$1100:
    mov     al,inq1[bx]     ;Return next character from input
que.
    xor     ah,ah
    mov     in1_tail,bx     ;Save new tail pointer.
$1200:
    push    ax              ;Save return value.
    cmp     rcv1_pause,0    ;Receiver paused?
    je      $1900           ;No.
    mov     ax,in1_head     ;Yes, calculate characters left in
que.
    sub     ax,bx
    jge     $1300
    add     ax,INQ_SIZE
$1300:
    cmp     ax,INQ_SIZE/4   ;Input que 75% free?
    jge     $1900           ;No.
    cli
    pause.                  ;Yes, no interrupts while changing
    mov     rcv1_pause,0    ;Clear receiver ISR pause.
    mov     send1_xon,1
    call    tickle1_xmit
    sti
$1900:
    pop     ax
    ret
_tty1_in    endp
_tty1_out   proc    far
;
; Adds a character (supplied by caller as an integer) to output que.
; If output que is full, character is not queued and function
; returns false (0), else function returns true (1).
;
    push    bp              ;Set up Turbo C call frame.

```

ttylir.asm

```

        mov     bp,sp
;       cmp     byte ptr [bp+6],XOFF ;Caller sending Xoff?
;       je      $2800                ;Yes, ignore it.
        mov     bx,out1_head        ;No, advance output que head pointer.
        inc     bx
        cmp     bx,OUTQ_SIZE
        jl      $2300
        xor     bx,bx
$2300:
        xor     ax,ax                ;Assume failure.
        cmp     bx,out1_tail        ;Output que full?
        je      $2900                ;Yes, return failure.
        mov     al,[bp+6]            ;No, get character passed by caller.
        mov     outq1[bx],al        ;Add character to output que.
        mov     out1_head,bx        ;Save new head pointer.
        cli
        call    tickle1_xmit
        sti
$2800:
        mov     ax,1                ;Return success.
$2900:
        pop     bp
        ret
_tty1_out     endp

_tty1_outs    proc    far
;
; Adds an entire null terminated string (supplied by caller) to output que.
; If string is longer than output que, false (0) is returned.
; If there is currently insufficient free space for the entire string to
; be placed on the output que, false (0) is returned.
; If string length is zero, true (1) is returned, but no action takes place.
; Else string is placed on output que and true (1) is returned.
;
        push    bp                    ;Set up Turbo C call frame.
        mov     bp,sp
        push    si                    ;Save callers index registers.
        push    di
        push    ds
        pop     es                    ;Pointer ES:DI to callers string.
        mov     di,[bp+6]
        mov     cx,OUTQ_SIZE+2        ;Max legal string length including
        null + 1.
        xor     ax,ax                ;0 = end of string.
        cld                          ;Make sure we increment DI.
        repnz   scasb                 ;String too long?
        jcxz    $3800                ;Yes.
        sub     cx,OUTQ_SIZE+1        ;No, calculate length of string.

```

ttylir.asm

```

        neg     cx
        je      $3700      ;Zero length string, all done.
$3000:
        mov     ax,out1_tail ;Calculate free space assuming tail >
head.
        sub     ax,out1_head
        dec     ax
        jge     $3100
        add     ax,OUTQ_SIZE ;Tail <= head, adjust for que wrap
around. $3100:
        cmp     ax,cx      ;Enough free space for entire string?
        jl      $3800      ;No.
        mov     si,[bp+6]  ;Yes, set up to xfer string to que.
        lea     di,outq1
        add     di,out1_head
        inc     di
$3200:
        cmp     di,offset dgroup:outq1+OUTQ_SIZE ;Need to wrap pointer
around?
        jl      $3300      ;No.
        lea     di,outq1   ;Yes.
$3300:
        movsb                    ;Transfer one byte to output que.
        loop    $3200
        dec     di
        sub     di,offset dgroup:outq1 ;Calculate new que head
pointer.
        mov     out1_head,di ;Save new que head.
        cli
        call    tickle1_xmit
        sti
$3700:
        mov     ax,1      ;Return success.
        jmp     $3900
$3800:
        xor     ax,ax      ;Return failure.
$3900:
        pop     di
        pop     si
        pop     bp
        ret
;
; Alternate entry for _tty_outs. Queues an array of bytes the size of
; which
; is specified by the caller.
;
_tty1_outmem:
        push    bp          ;Set up Turbo C call frame.
        mov     bp,sp
        push    si          ;Save callers index registers.
        push    di

```

ttylir.asm

```

push    ds
pop     es           ;Initialize ES = DS.
mov     cx,[bp+6]    ;Get callers byte count.
or      cx,cx        ;Byte count less than or equal zero?
jl      $3800        ;Yes, illegal.
je      $3700        ;Yes, all done.
cmp     cx,OUTQ_SIZE ;No, byte count too high?
jg      $3800        ;Yes.
jmp     $3000        ;No.
_tty1_outs    endp

_tty1_flush    proc    far
;
; Reset all input and output queue pointers (losing any characters
; currently in either queue). Also resets error counters.
; No arguments or return values.
;
xor     ax,ax
cli
mov     in1_head,ax  ;Reset input que.
mov     in1_tail,ax
mov     out1_head,ax ;Reset output que.
mov     out1_tail,ax
mov     tty1_cnt,ax  ;reset byte count
mov     xmit1_idle,1
mov     tty1_error,ax ;Reset error counts.
mov     tty1_qfull,ax
mov     send1_xoff,ax ;Reset Xon/Xoff flags.
mov     send1_xon,ax
mov     recv1_pause,ax
sti
ret
_tty1_flush    endp

tickle1_xmit    proc    near
cmp     xmit1_idle,0 ;Transmitter ISR idle?
je      $5800        ;No.
mov     dx,_tty1_base ;Yes, toggle xmit interrupt enable to
inc     dx            ;force xmit interrupt.
in      al,dx
mov     bl,al
and     al,0FDh
out     dx,al
mov     al,bl
out     dx,al
mov     xmit1_idle,0
$5800:
ret
tickle1_xmit    endp

```

ttylir.asm

```

***** routines for port 2 *****
;
; tty2_isr      proc    near
;
; Serial port interrupt service routine. Never directly called from program.
;
;      push     ax          ;Save a few registers to work with.
;      push     bx
;      push     dx
;      push     ds
;      mov     ax,dgroup    ;Set up ds to access Turbo C objects.
;      mov     ds,ax
$22:  mov     dx,_tty2_base  ;Read interrupt identification
register.
;      add     dx,2
;      in      al,dx
;      cmp     al,NO_SERV   ;Any service required?
;      jne     $32         ;Yes.
;      jmp     done2       ;No.
$32:  cmp     al,RECV_SERV  ;Service received data interrupt?
;      jne     not2_recv   ;No.
;      mov     dx,_tty2_base ;Yes, read character.
;      in      al,dx
;      or      al,al       ;Null character?
;      jz      $22         ;Yes, ignore it.
;      cmp     al,XOFF     ;No, Xoff character?
;      je      $22         ;Yes, ignore it.
;      cmp     al,XON      ;No, Xon character?
;      je      $22         ;Yes, ignore it.
;      mov     bx,_tty2_cnt ;increment the
;      inc     bx          ;byte count
;      mov     tty2_cnt,bx  ;and save it
;      mov     bx,in2_head  ;Advance input que head pointer.
;      inc     bx
;      cmp     bx,INQ_SIZE
;      jl      $102
;      xor     bx,bx
$102: cmp     bx,in2_tail   ;Input que full?
;      je      $202       ;Yes.
;      mov     in2_head,bx ;No, save new que head pointer.
;      mov     inq2[bx],al  ;Put received character on que.
;      cmp     rcv2_pause,0 ;Receiver pause already flagged?
;      jne     $22         ;Yes, don't bother checking again.
;      mov     ax,in2_tail  ;Calculate free space remaining.
;      sub     ax,bx
;      dec     ax
;      jge     $142
;      add     ax,INQ_SIZE
$142:

```

ttylir.asm

```

;      cmp     ax,INQ_SIZE/4 ;Input que 75 % full?
;      jge     $22           ;No.
;      mov     rcv2_pause,1  ;Yes, initiate receiver pause.
;      mov     send2_xoff,1
;      call    tickle2_xmit
;      jmp     $22
$202:  inc     tty2_qfull      ;Count que full error.
      jmp     $22           ;Check for more servicing.
not2_rcv:
      cmp     al,XMIT_SERV  ;Service transmit ready interrupt?
      jne     not2_xmit     ;No.
      cmp     send2_xoff,0  ;Yes, send Xoff?
      je      $252          ;No.
      mov     send2_xoff,0  ;Yes, reset flag.
      mov     al,XOFF
      jmp     $422
$252:  cmp     send2_xon,0   ;Send Xon?
      je      $262          ;No.
      mov     send2_xon,0   ;Yes, reset flag.
      mov     al,XON
      jmp     $422
$262:  cmp     rcv2_pause,0  ;Receiver ISR paused?
      jne     $292          ;Yes, transmission must also pause.
      mov     bx,out2_tail  ;No, output que empty?
      cmp     bx,out2_head
      jne     $302          ;No.
$292:  mov     xmit2_idle,1  ;Yes, flag outport idle.
      jmp     $22           ;Check for more servicing.
$302:  inc     bx            ;Advance que tail pointer.
      cmp     bx,OUTQ_SIZE
      jl      $402
      xor     bx,bx
$402:  mov     out2_tail,bx   ;Save new que tail pointer.
      mov     al,outq2[bx]   ;Get character to be transmitted.
$422:  mov     dx,tty2_base
      out     dx,al          ;Transmit character.
      jmp     $22           ;Check for more servicing.
not2_xmit:
      mov     dx,tty2_base  ;Assume status interrupt.
      add     dx,5
      in      al,dx          ;Access line status reg to clear
error.
      inc     dx
      in      al,dx          ;Access modem status reg to clear error.

```

ttylstr.asm

```

inc     _tty2_error    ;Count hardware error.
jmp     $22            ;Check for more servicing.
done2:
mov     al,EOI          ;Non-specific EOI for 8259.
out     20h,al
pop     ds              ;Restore registers.
pop     dx
pop     bx
pop     ax
iret
_tty2_isr    endp

_tty2_in proc    far
;
; Returns next character on input que to caller as an integer.
; If input que is empty, returns EOF (-1).
;
    mov     ax,EOF      ;Assume que empty.
    mov     bx,in2_tail
    cmp     bx,in2_head ;Input que empty?
    je      $1202       ;Yes.
    cli
    mov     bx,_tty2_cnt ; decrement the
    dec     bx           ; byte count
    mov     _tty2_cnt,bx ; and save it
    sti
    mov     bx,in2_tail
    inc     bx           ;No, advance input que tail pointer.
    cmp     bx,INQ_SIZE
    jl      $1102
    xor     bx,bx
$1102:
    mov     al,inq2[bx]  ;Return next character from input
que.
    xor     ah,ah
    mov     in2_tail,bx  ;Save new tail pointer.
$1202:
    push    ax           ;Save return value.
    cmp     rcv2_pause,0 ;Receiver paused?
    je      $1902        ;No.
    mov     ax,in2_head  ;Yes, calculate characters left in
que.
    sub     ax,bx
    jge     $1302
    add     ax,INQ_SIZE
$1302:
    cmp     ax,INQ_SIZE/4 ;Input que 75% free?
    jge     $1902        ;No.
    cli      ;Yes, no interrupts while changing
pause.
    mov     rcv2_pause,0 ;Clear receiver ISR pause.

```

ttylir.asm

```

        mov     send2_xon,1
        call    tickle2_xmit
        sti
$1902:
        pop     ax
        ret
_tty2_in     endp
_tty2_out    proc    far
;
; Adds a character (supplied by caller as an integer) to output que.
; If output que is full, character is not queued and function
; returns false (0), else function returns true (1).
;
        push    bp                ;Set up Turbo C call frame.
        mov     bp,sp
;        cmp     byte ptr [bp+6],XOFF ;Caller sending Xoff?
;        je      $2802             ;Yes, ignore it.
        mov     bx,out2_head      ;No, advance output que head pointer.
        inc     bx
        cmp     bx,OUTQ_SIZE
        jl      $2302
        xor     bx,bx
$2302:
        xor     ax,ax             ;Assume failure.
        cmp     bx,out2_tail      ;Output que full?
        je      $2902             ;Yes, return failure.
        mov     al,[bp+6]         ;No, get character passed by caller.
        mov     outq2[bx],al      ;Add character to output que.
        mov     out2_head,bx      ;Save new head pointer.
        cli
        call    tickle2_xmit
        sti
$2802:
        mov     ax,1             ;Return success.
$2902:
        pop     bp
        ret
_tty2_out     endp
_tty2_outs    proc    far
;
; Adds an entire null terminated string (supplied by caller) to output que.
; If string is longer than output que, false (0) is returned.
; If there is currently insufficient free space for the entire string to
; be placed on the output que, false (0) is returned.
; If string length is zero, true (1) is returned, but no action takes place.
; Else string is placed on output que and true (1) is returned.
;

```

ttylir.asm

```

push    bp           ;Set up Turbo C call frame.
mov     bp,sp
push    si           ;Save callers index registers.
push    di
push    ds
pop     es           ;Pointer ES:DI to callers string.
mov     di,[bp+6]
mov     cx,OUTQ_SIZE+2 ;Max legal string length including
null + 1.
xor     ax,ax        ;0 = end of string.
cld                     ;Make sure we increment DI.
repnz scasb          ;String too long?
jcxz    $3802         ;Yes.
sub     cx,OUTQ_SIZE+1 ;No, calculate length of string.
neg     cx
je      $3702         ;Zero length string, all done.
$3002:
mov     ax,out2_tail  ;Calculate free space assuming tail >
head.
sub     ax,out2_head
dec     ax
jge     $3102
add     ax,OUTQ_SIZE  ;Tail <= head, adjust for que wrap
around. $3102:
cmp     ax,cx         ;Enough free space for entire string?
jl      $3802         ;No.
mov     si,[bp+6]     ;Yes, set up to xfer string to que.
lea     di,outq2
add     di,out2_head
inc     di
$3202:
cmp     di,offset dgroup:outq1+OUTQ_SIZE ;Need to wrap pointer
around?
jl      $3302         ;No.
lea     di,outq2      ;Yes.
$3302:
movsb                    ;Transfer one byte to output que.
loop    $3202
dec     di
sub     di,offset dgroup:outq2 ;Calculate new que head
pointer.
mov     out2_head,di   ;Save new que head.
cli
call    tickle2_xmit
sti
$3702:
mov     ax,1          ;Return success.
jmp     $3902
$3802:
xor     ax,ax         ;Return failure.
$3902:

```

ttylir.asm

```

pop    di
pop    si
pop    bp
ret

```

; Alternate entry for tty_outs. Queues an array of bytes the size of which
; is specified by the caller.

```

;_tty2_outmem:
;_push    bp          ;Set up Turbo C call frame.
;mov     bp,sp
;push    si          ;Save callers index registers.
;push    di
;push    ds
;pop     es          ;Initialize ES = DS.
;mov     cx,[bp+6]   ;Get callers byte count.
;or      cx,cx       ;Byte count less than or equal zero?
;jl      $3802        ;Yes, illegal.
;je      $3702        ;Yes, all done.
;cmp     cx,OUTQ_SIZE ;No, byte count too high?
;jg      $3802        ;Yes.
;jmp     $3002        ;No.
;_tty2_outs    endp

```

```

;_tty2_flush    proc    far
;
;Reset all input and output queue pointers (losing any characters
;currently in either queue). Also resets error counters.
;No arguments or return values.
;

```

```

xor     ax,ax
cli
mov     in2_head,ax    ;Reset input que.
mov     in2_tail,ax
mov     out2_head,ax   ;Reset output que.
mov     out2_tail,ax
mov     tty2_cnt,ax    ;reset byte count
mov     xmit2_idle,1
mov     tty2_error,ax  ;Reset error counts.
mov     tty2_qfull,ax
mov     send2_xoff,ax  ;Reset Xon/Xoff flags.
mov     send2_xon,ax
mov     recv2_pause,ax
sti
ret

```

```

;_tty2_flush    endp

```

```

;_tickle2_xmit    proc    near
;_cmp     xmit2_idle,0    ;Transmitter ISR idle?
;_je      $5802          ;No.

```

ttylir.asm

```
mov    dx,_tty2_base    ;Yes, toggle xmit interrupt enable to
inc    dx                ;force xmit interrupt.
in     al,dx
mov    bl,al
and    al,0FDh
out    dx,al
mov    al,bl
out    dx,al
mov    xmit2_idle,0
$5802:
ret
tickle2_xmit    endp
_text    ends
end
```

merlin.def

```

/*****
*
*   merlin.def  global definition file
*
*****/

#include "merlin.typ"

/***** The following memory assignments simply map the */
/***** PC hshi control structures to the MERLIN structures */
/***** The assignments were copied out of the HSHI reference manual */
/***** pages 9 and 10. When used by the code, comments will */
/***** explain their use. For more info read the HSHI manual, */
/***** it is easy to follow and it is short! */

HC_BUF   huge *hc_buf   = (HC_BUF huge *) (0x00 + MEM_OFFSET);
HR_BUF   huge *hr_buf   = (HR_BUF huge *) (0x08 + MEM_OFFSET);
HR_RSP   huge *hr_rsp   = (HR_RSP huge *) (0x0e + MEM_OFFSET);

SRV_PAR   huge *hc_srv   = (SRV_PAR huge *) (0x10 + MEM_OFFSET);
SPNT      huge *hc_cpos   = (SPNT huge *) (0x60 + MEM_OFFSET);
float     huge *hc_cvel   = (float huge *) (0x80 + MEM_OFFSET);
JOINTS    huge *hc_jpos   = (JOINTS huge *) (0xa0 + MEM_OFFSET);
JOINTS    huge *hc_jvel   = (JOINTS huge *) (0xc0 + MEM_OFFSET);
LJOINTS    huge *hc_mpos   = (LJOINTS huge *) (0xe0 + MEM_OFFSET);
LJOINTS    huge *hc_mvel   = (LJOINTS huge *) (0x100 + MEM_OFFSET);

SPNT      huge *hr_cpos   = (SPNT huge *) (0x200 + MEM_OFFSET);
JOINTS    huge *hr_jpos   = (JOINTS huge *) (0x220 + MEM_OFFSET);
JOINTS    huge *hr_jvel   = (JOINTS huge *) (0x240 + MEM_OFFSET);
LJOINTS    huge *hr_mpos   = (LJOINTS huge *) (0x260 + MEM_OFFSET);
LJOINTS    huge *hr_mvel   = (LJOINTS huge *) (0x280 + MEM_OFFSET);
LJOINTS    huge *hr_mcy   = (LJOINTS huge *) (0x2a0 + MEM_OFFSET);

/***** conversions and limits for encoders */
double dtoc[6] = /* conversion for degrees to encoder cnts */
/* ranges are +- 48000 for j 1,2,3 */
/* +- 24000 for j 4,6 */
/* +- 12000 for j 5 */
/* take range / 180 (90 for j 5) for conv */
{266.66667,266.66667,266.66667,133.333,133.333,133.333};

double rtoc[6] = /* conversion for rads to encoder cnts */
/* ranges are +- 48000 for j 1,2,3 */
/* +- 24000 for j 4,6 */
/* +- 12000 for j 5 */
/* take range / pi (pi/2 for j 5) for conv */
{15278.8745,15278.8745,15278.8745,7639.437,7639.437,7639.437};

```

merlin.def

```

long encmin[6] = /* min encoder reading */
{-48000,-48000,-48000,-48000,-12000,-48000};
long encmax[6] = /* max encoder reading */
{48000,48000,48000,48000,12000,48000};
double degmin[6] = /* min degrees */
{-170,-170,-170,-360,-85,-360};
double degmax[6] = /* max degrees */
{170,170,170,360,85,360};
double radmin[6] = /* min rads */
{-2.967,-2.967,-2.967,-6.283,-1.4835,-6.283};
double radmax[6] = /* max rads */
{2.967,2.967,2.967,6.283,1.4835,6.283};

int max_srv_acc[6] = {12,12,12,12,12,20}; /* default servo accel 0..16*/
int max_srv_vel[6] = {8,8,8,8,8,12}; /* default servo veloc 0..32*/
int gain[6] = {4,4,4,4,4,6}; /* default servo gain 1..8*/
double x_pos; /* x end tip position */
double y_pos; /* y end tip position */
double z_pos; /* z end tip position */
double roll; /* gripper roll */
double pitch; /* gripper pitch */
double yaw; /* gripper yaw */
double a[5] = {0,0,17.3,0,0}; /* Denvait Hartenberg parameters */
double alpha[5] = {0,-1.5707,3.14159,-1.5707,-1.7507}; /* " -90,180,-90,-90 */
double d[5] = {0,0,-12,0,17.25}; /* " */
double h[4]; /* vars used by inverse kin */
double h1_partial;
double theta[6] = {0};

double in_merlin_joint[6];
double gripper_tip[4] = {0,0,-10.5,1}; /* gripper tip x,y,z coordinates */

/* defined w/respect to tool roll */ /* coordinate system */
double ct2,st2,nst2,ct3,nct3,st3,nst3,ct4,nct4,st4,nst4,
ct5,nct5,st5,nst5,ct6,nct6,st6,nst6,ct7,st7,nst7,
ct8,nct8,st8,nst8;
/* nct7 is not used */
/* used in tmat() to allow computation of */
/* cos(*tX) & sin(*tX) only once */

double st1_0[4][4] = {{ 0,0,0,0 },
{ 0,0,0,0 },
{ 0,0,0,0 },
{ 0,0,0,1 }};

```

merlin.def

```

double st2_0[4][4] = {{ 0,0,0,0 },
                      { 0,0,0,0 },
                      { 0,0,0,0 },
                      { 0,0,0,1 }};

double st3_0[4][4] = {{ 0,0,0,0 },
                      { 0,0,0,0 },
                      { 0,0,0,0 },
                      { 0,0,0,1 }};

double st4_0[4][4] = {{ 0,0,0,0 },
                      { 0,0,0,0 },
                      { 0,0,0,0 },
                      { 0,0,0,1 }};

double st5_0[4][4] = {{ 0,0,0,0 },
                      { 0,0,0,0 },
                      { 0,0,0,0 },
                      { 0,0,0,1 }};

double st6_0[4][4] = {{ 0,0,0,0 },
                      { 0,0,0,0 },
                      { 0,0,0,0 },
                      { 0,0,0,1 }};

double sr1_0[4][4] = {{ 0,0,0,0 },
                      { 0,0,0,0 },
                      { 0,0,0,0 },
                      { 0,0,0,1 }};

double sr2_0[4][4] = {{ 0,0,0,0 },
                      { 0,0,0,0 },
                      { 0,0,0,0 },
                      { 0,0,0,1 }};

double sr3_0[4][4] = {{ 0,0,0,0 },
                      { 0,0,0,0 },
                      { 0,0,0,0 },
                      { 0,0,0,1 }};

double wrist_roll;    /* slave wrist roll */
double wrist_flex;    /* slave wrist flex */
double tool_roll;     /* slave tool roll */
/* values for converting optical encoder vals */
/* to radians */
double oe_to_rad[8] = { ENC_RAD, ENC_RAD, UA_ENC_RAD, ENC_RAD,
                        LA_ENC_RAD, ENC_RAD, ENC_RAD, 0 };
/*double hs_lft_deg[8] = /* fixed, measured hardstop angles */
/* { 0,0,0,0,0,0,0,0 }; */

```

merlin.def

```
int arm_hs_oe[8];    /* hard stop values of the optical encoder */

double exo_l_hs_rad[8] =
    /* exo left arm joint encoder clockwise hardstop (rads) */
    { 1.57, /* shoulder azimuth */
      0.8098, /* shoulder elevation */
      -0.7662, /* upper arm roll */
      0.785, /* elbow flex */
      -2.12, /* lower arm roll */
      1.284, /* wrist radial */
      2.543, /* wrist flex */
      0.0 /* gripper */
    };

double exo_r_hs_rad[8] =
    /* exo right arm joint encoder clockwise hardstop (rads) */
    { 2.34, /* shoulder azimuth */
      0.0349, /* shoulder elevation */
      0.0, /* upper arm roll */
      0.8028, /* elbow flex */
      -1.6985, /* lower arm roll */
      1.284, /* wrist radial */
      -0.8264, /* wrist flex */
      0.0 /* gripper */
    };

double l1 = 6.9375;
double l2 = 5.3075;
double l3 = 5.5156;
double l4 = 4.9375;
double l5 = 12.141;
double l6 = 11.250;

double exo_r_arm[8];
double exo_l_arm[8];

double mt[4][4] = {{ 0,0,0,0 },
                  { 0,0,0,0 },
                  { 0,0,0,0 },
                  { 0,0,0,1 }};

double mt2_0[4][4] = {{ 0,0,0,0 },
                      { 0,0,0,0 },
                      { 0,0,0,0 },
                      { 0,0,0,1 }};
```

merlin.def

```
double mt3_0[4][4] = {{ 0,0,0,0 },
                      { 0,0,0,0 },
                      { 0,0,0,0 },
                      { 0,0,0,1 }};
double mt4_0[4][4] = {{ 0,0,0,0 },
                      { 0,0,0,0 },
                      { 0,0,0,0 },
                      { 0,0,0,1 }};
double mt5_0[4][4] = {{ 0,0,0,0 },
                      { 0,0,0,0 },
                      { 0,0,0,0 },
                      { 0,0,0,1 }};
double mt6_0[4][4] = {{ 0,0,0,0 },
                      { 0,0,0,0 },
                      { 0,0,0,0 },
                      { 0,0,0,1 }};
double mt7_0[4][4] = {{ 0,0,0,0 },
                      { 0,0,0,0 },
                      { 0,0,0,0 },
                      { 0,0,0,1 }};
double mt8_0[4][4] = {{ 0,0,0,0 },
                      { 0,0,0,0 },
                      { 0,0,0,0 },
                      { 0,0,0,1 }};

double mr6_5[4][4] = {{ 0,0,0,0 },
                      { 0,0,0,0 },
                      { 0,0,0,0 },
                      { 0,0,0,1 }};
double mr7_5[4][4] = {{ 0,0,0,0 },
                      { 0,0,0,0 },
                      { 0,0,0,0 },
                      { 0,0,0,1 }};
double mr8_5[4][4] = {{ 0,0,0,0 },
                      { 0,0,0,0 },
                      { 0,0,0,0 },
                      { 0,0,0,1 }};
double mr9_5[4][4] = {{ 0,0,0,0 },
                      { 0,0,0,0 },
                      { 0,0,0,0 },
                      { 0,0,0,1 }};

/*****
*
*   indexing vars
*
*****/
double x_offset;    /* indexing offsets */
double y_offset;    /* indexing offsets */
double z_offset;    /* indexing offsets */
int indexing = 0;
double initx_offset = 5; /* initial offsets for work space matching */
```

merlin.def

```
double inity_offset = 0;
double initz_offset = 15;
int lock_wrist = 0;      /* is wrist locked in cal position */
int mba_rqst = 'H';      /* requesting Left Right or H/Both */
int done = 0;            /* gen purpose done flag */
int badcnt = 0;          /* count of bad comm messages */
```

merlin.ref

```

/*****
*
*   merlin.def  global definition file
*
*****/

#include "merlin.typ"

/***** The following memory assignments simply map the */
/***** PC hshi control structures to the MERLIN structures */
/***** The assignments were copied out of the HSHI reference manual */
/***** pages 9 and 10. When used by the code, comments will */
/***** explain their use. For more info read the HSHI manual, */
/***** it is easy to follow and it is short! */

extern HC_BUF      huge *hc_buf;
extern HR_BUF      huge *hr_buf;
extern HR_RSP      huge *hr_rsp;

extern SRV_PAR     huge *hc_srv;
extern SPNT        huge *hc_cpos;
extern float       huge *hc_cvel;
extern JOINTS      huge *hc_jpos;
extern JOINTS      huge *hc_jvel;
extern LJOINTS     huge *hc_mpos;
extern LJOINTS     huge *hc_mvel;

extern SPNT        huge *hr_cpos;
extern JOINTS      huge *hr_jpos;
extern JOINTS      huge *hr_jvel;
extern LJOINTS     huge *hr_mpos;
extern LJOINTS     huge *hr_mvel;
extern LJOINTS     huge *hr_mcy;

/***** conversions and limits for encoders */
extern double dtoe[6]; /* conversion for degrees to encoder cnts */
/* ranges are +- 48000 for j 1,2,3 */
/* +- 24000 for j 4,6 */
/* +- 12000 for j 5 */
/* take range / 180 (90 for j 5) for conv */
extern double rtoe[6]; /* conversion for rads to encoder cnts */
/* ranges are +- 48000 for j 1,2,3 */
/* +- 24000 for j 4,6 */
/* +- 12000 for j 5 */
/* take range / pi (pi/2 for j 5) for conv */
extern long encmin[6]; /* min encoder reading */
extern long encmax[6]; /* max encoder reading */
```

merlin.ref

```

extern double degmin[6];    /* min degrees */
extern double degmax[6];    /* max degrees */
extern double radmin[6];    /* min rads */
extern double radmax[6];    /* max rads */
extern int max_srv_acc[6];  /* default servo accel 0..16*/
extern int max_srv_vel[6];  /* default servo veloc 0..32*/
extern int gain[6];         /* default servo gain 1..8*/
extern double x_pos;        /* x end tip position */
extern double y_pos;        /* y end tip position */
extern double z_pos;        /* z end tip position */
extern double roll;         /* gripper roll */
extern double pitch;        /* gripper pitch */
extern double yaw;          /* gripper yaw */
extern double a[5];         /* Denavit Hartenberg parameters */
extern double alpha[5];     /* " -90,180,-90,-90 */
extern double d[5];         /* " */
extern double h[4];         /* vars used by inverse kin */
extern double h1_partial;
extern double theta[6];

extern double in_merlin_joint[6];
extern double gripper_tip[4]; /* gripper tip x,y,z coordinates */

/* defined w/respect to tool roll */ /* coordinate system */
extern double ct2,st2,nst2,ct3,nct3,st3,nst3,ct4,nct4,st4,nst4,
             ct5,nct5,st5,nst5,ct6,nct6,st6,nst6,ct7,st7,nst7,
             ct8,nct8,st8,nst8;
/* nct7 is not used */
/* used in tmat() to allow computation of */
/* cos(*tX) & sin(*tX) only once */

extern double st1_0[4][4];
extern double st2_0[4][4];
extern double st3_0[4][4];
extern double st4_0[4][4];
extern double st5_0[4][4];
extern double st6_0[4][4];
extern double sr1_0[4][4];
extern double sr2_0[4][4];
extern double sr3_0[4][4];
extern double wrist_roll;    /* slave wrist roll */
extern double wrist_flex;    /* slave wrist flex */
extern double tool_roll;     /* slave tool roll */
/* values for converting optical encoder vals */
/* to radians */

extern double oe_to_rad[8];
/* extern double hs_arm_deg[8]; */
extern int arm_hs_oe[8];

/* clockwise hardstop values in radians */

```

merlin.ref

```
extern double exo_r_hs_rad[8];
/* most cw rotation of encoder */
extern double exo_l_hs_rad[8];
/* most cw rotation of encoder */

extern double l1;
extern double l2;
extern double l3;
extern double l4;
extern double l5;
extern double l6;

extern double exo_r_arm[8];
extern double exo_l_arm[8];
extern double mt[4][4];
extern double mt2_0[4][4];
extern double mt3_0[4][4];
extern double mt4_0[4][4];
extern double mt5_0[4][4];
extern double mt6_0[4][4];
extern double mt7_0[4][4];
extern double mt8_0[4][4];
extern double mr6_5[4][4];
extern double mr7_5[4][4];
extern double mr8_5[4][4];
extern double mr9_5[4][4];
/*****
*
*   indexing vars
*
*****/
extern double x_offset; /* indexing offsets */
extern double y_offset; /* indexing offsets */
extern double z_offset; /* indexing offsets */
extern int indexing;
extern double initx_offset; /* initial offsets for work space matching */
extern double inity_offset;
extern double initz_offset;
extern int lock_wrist; /* is wrist locked in cal position */
extern int mba_rqst; /* requesting Left Right or H/Both */
extern int done; /* gen purpose done flag */
extern int badcnt; /* count of bad comm messages */
```

merlin.typ

```

/*****
*
*   This is the type declaration file for Merlin
*
*****/

/*   This file declares the data types needed for shared memory */
/*   HSHI operations. This section is similar to that given */
/*   in the HSHI Reference Manual, pp. 9 - 10. */

#define MBA_PORT 2
#define JR3_PORT 1

#define FF1 59
#define FF2 60
#define FF3 61
#define FF4 62
#define FF5 63
#define FF6 64
#define LA 75
#define RA 77
#define UA 72
#define DA 80
#define FHOME 71
#define FEND 79
#define PI 3.14159
#define DTORAD .017453
typedef struct
{
    int cyc_clk;
    int cmd_no;
    char command; /* Switched from HSHI manual */
    char buf_stat; /* See page 9 */
    int cyc_no;
} HC_BUF;

#define NUM_AXES 6

#define BUF_HOST 0x55
#define BUF_HSHI 0xaa
#define sqr(x) (x) * (x)

#define CMD_SET_PARAMS 0x01
#define CMD_EXIT 0x12
#define CMD_RD_M_STAT 0x03
#define CMD_M_POS 0x08
#define CMD_M_VEL 0x09
#define CMD_RD_J_STAT 0x07
#define CMD_J_POS 0x05
#define CMD_J_VEL 0x06
#define CMD_RD_C_STAT 0x04
```

merlin.typ

```
#define CMD_C_POS      0x02
#define CMD_SET_C_VEL  0x0c
#define CMD_J_INTERP   0x0d
#define CMD_C_INTERP   0x0e

#define MEM_OFFSET     0xd0000000
```

```
typedef struct
{
    int ech_cmd;
    int ech_cyc;
    int end_cyc;
} HR_BUF ;
```

```
typedef struct
{
    int rsp_bits;
} HR_RSP ;
```

```
typedef struct
{
    long max_acc;
    long max_vel;
    long gain;
} SRVPAR ;
```

```
typedef struct
{
    SRVPAR servo_param[6] ;
} SRV_PAR ;
```

```
typedef struct
{
    float x;
    float y;
    float z;
    float roll;
    float pitch;
    float yaw;
} SPNT ;
```

```
typedef struct
{
    float axis[6];
} JOINTS ;
```

```
typedef struct
{
    long axis[6];
} LJOINTS ;
```

merlin.typ

```
#define ENC_RAD .001534    /* conversion encoder cnts to radians */
                          /* Encoder to Joint Gear Ratio 1:1
                          360 deg joint rev/ 4096 encoder cnts rev
                          = .0879 deg per encoder cnt
                          = .001534 rad per encoder cnt */
#define LA_ENC_RAD .0017858 /* conversion lower arm roll encoder to rad */ /* Encoder to Joint
                          Gear Ratio 7.33:1
                          360 deg joint rev/480 * 7.33 encoder cnts
                          = .10232 deg per encoder cnt
                          = .0017858 rad per encoder cnt */
/*#define UA_ENC_RAD .0015098 /* conversion upper arm roll encoder to rad */
                          /* Encoder to Joint Gear Ratio 8.67:1 */
                          /* 360 deg joint rev/480 * 8.67 encoder cnts */ /* =
                          .0865 deg per encoder cnt */
                          /* = .0015098 rad per encoder cnt */
#define UA_ENC_RAD .00126363 /* 480cnts/encrev * 10.3642encrev/armrev */ /*
                          /360deg/armrev = cnts/deg */
                          /* then convert to rad/cnts */
```

11.0 Appendix C: Bit3 PC-AT Adaptor Card Jumper Settings

PC-AT ADAPTOR CARD JUMPERS

MBA / MerLIN

Bit 3 PC/AT Adaptor

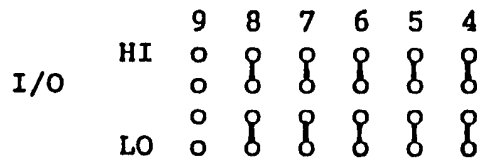
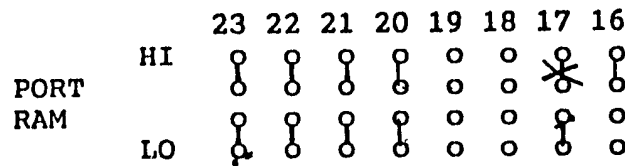
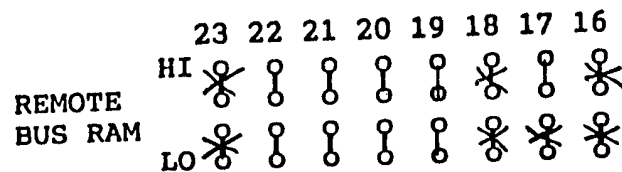
31 Dec 92

THE SYS JUMPERS (AT CARD)

Locate the SYS jumper block at location F2 on the AT board.

SYS

- o o 1 jumper if you want to select byte swap (1)
- o—o 2 jumper if you want to select word swap (1)
- o o 3 there should never be a jumper on these pins
- o o 4 jumper if you are using a IBM RT computer



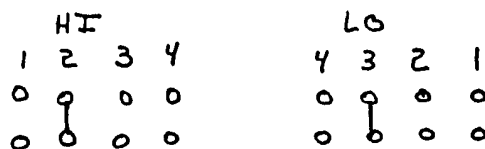
1 2 3 4 0
o o o o o

VMEbus INTERRUPTS (0 is
the status error interrupt)

o o o o o o o
15 12 11 10 5 4 3

PC-AT INTERRUPTS

Factory Presets
@ A5/6



12.0 Appendix D: Safety Light Fence Schematics

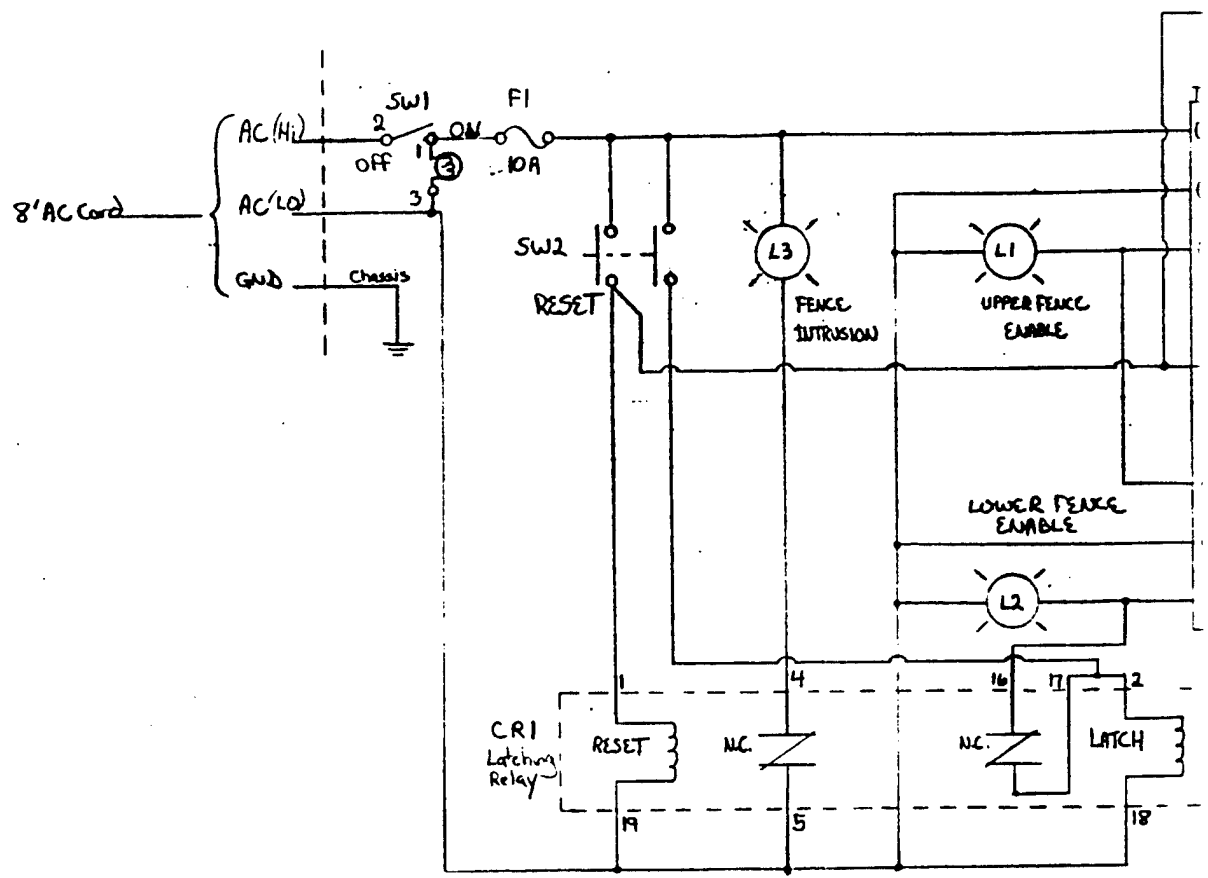
D

C

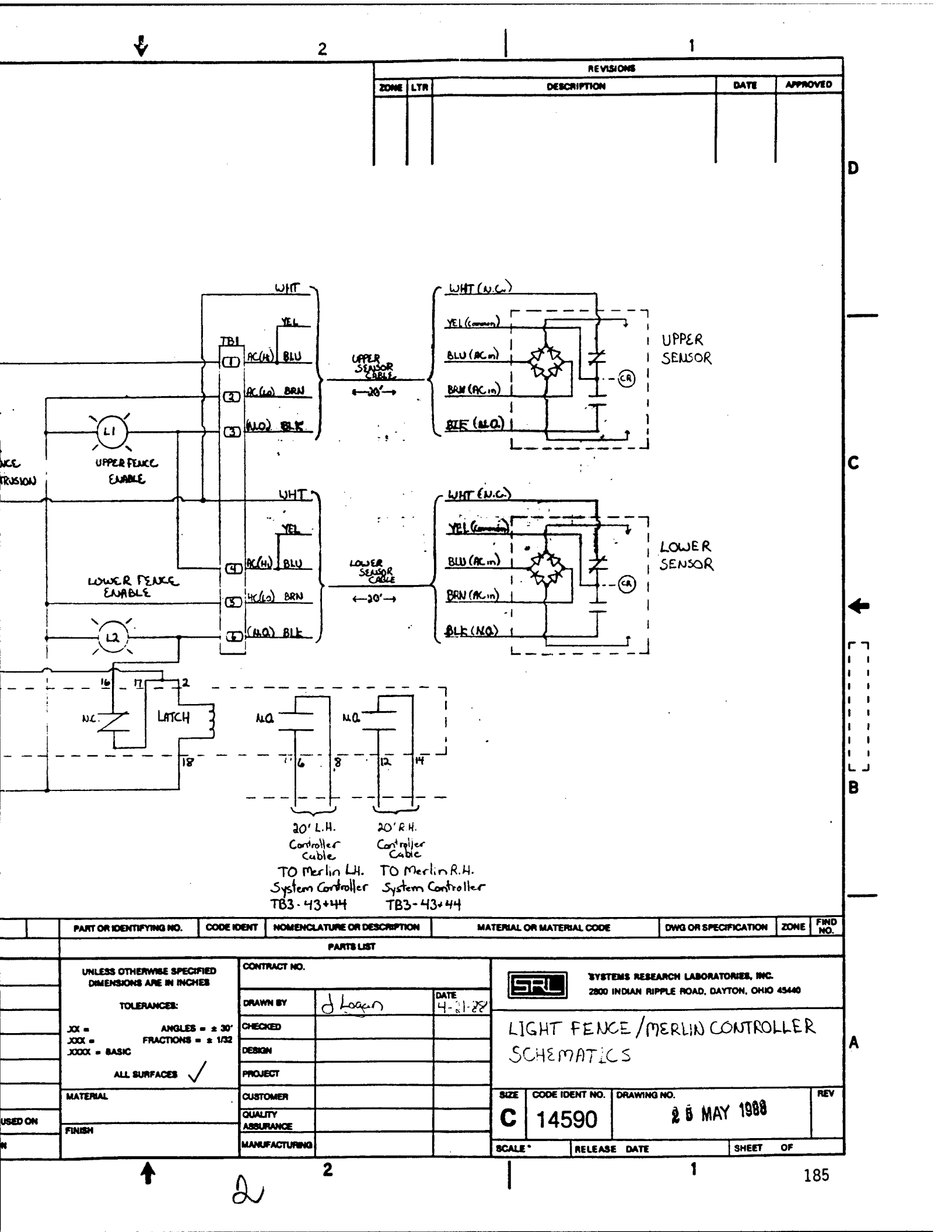
B

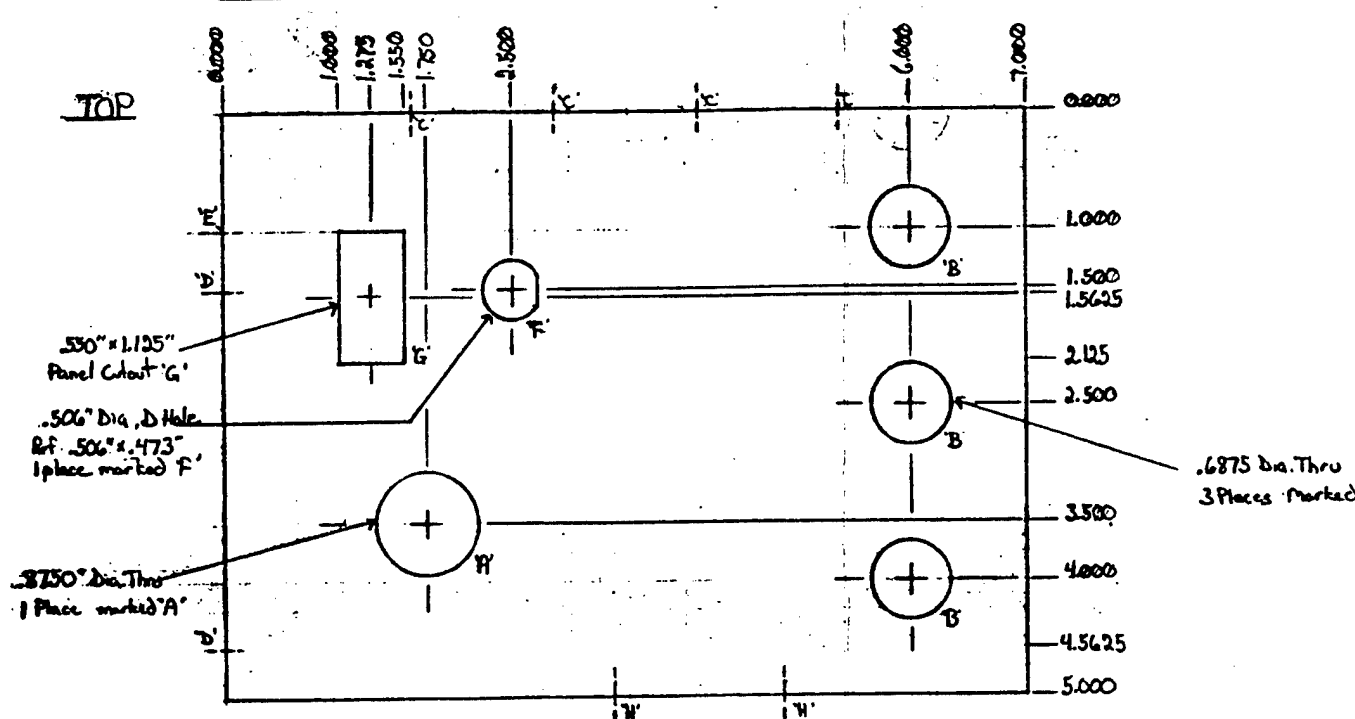
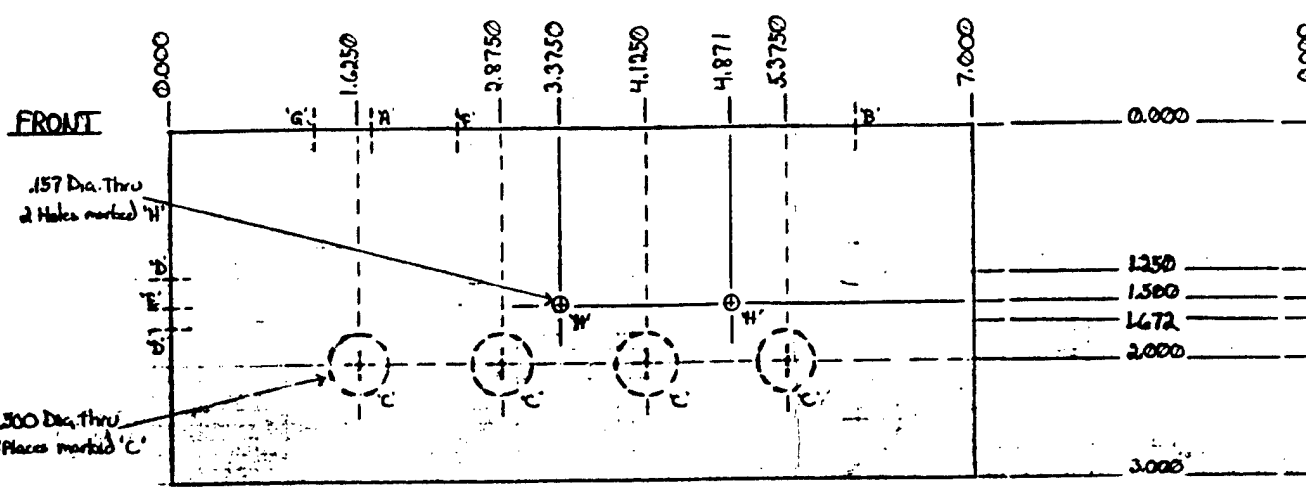
A

MRC

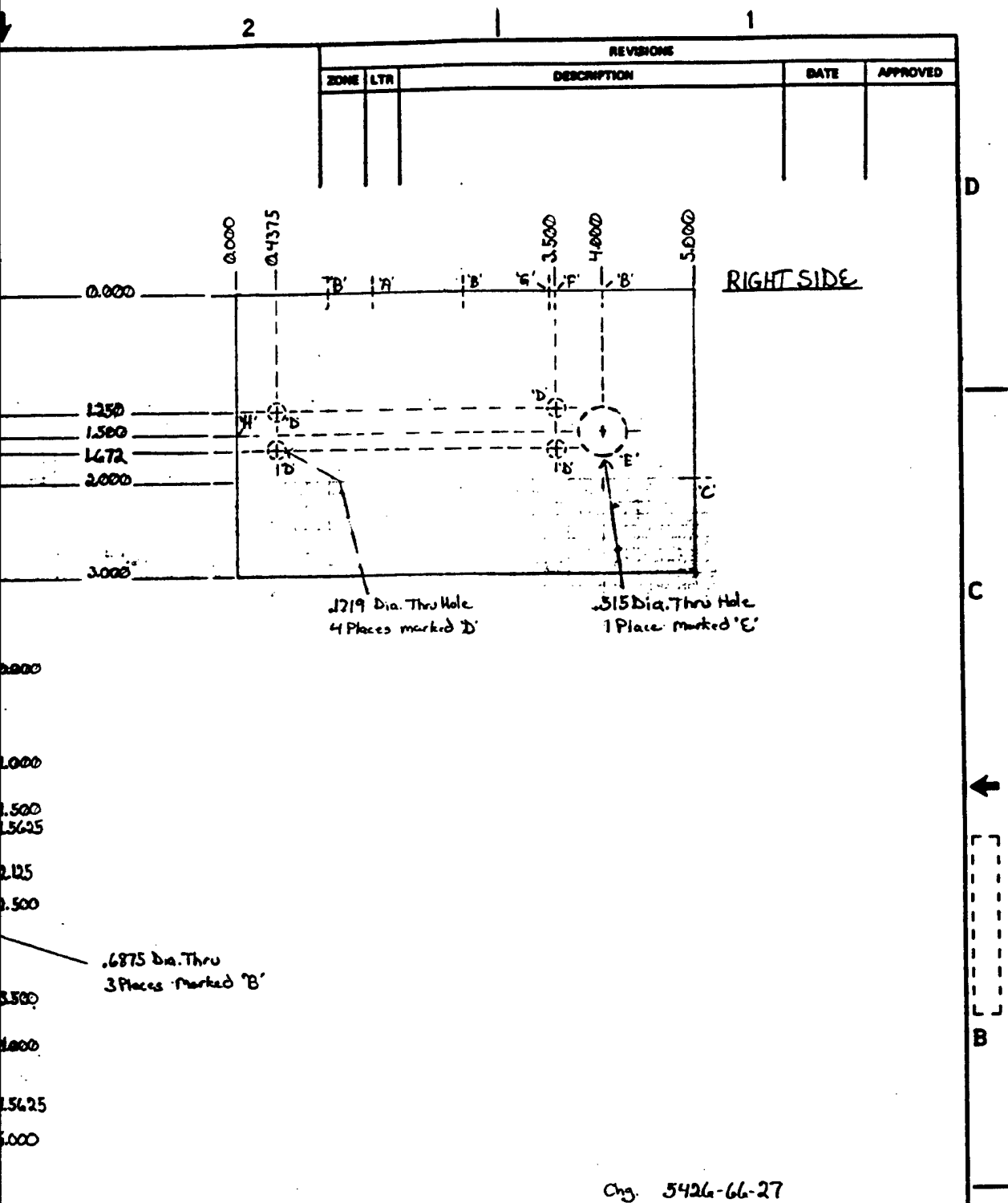


					PART OR IDENTIFYING NO.	COO
QTY REQD PER ASSY					UNLESS OTHERWISE SPECIFIED DIMENSIONS ARE IN INCHES TOLERANCES: .XX = ANGLES = ± 3 .XXX = FRACTIONS = ± 1C .XXXX = BASIC ALL SURFACES ✓	
PART NO.	N/A	F/A	NEXT ASSY	USED ON	MATERIAL	
	QTY REQD		APPLICATION		FINISH	





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