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Uber, D.C.
Searles, W.L.

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D.C. Uber and W.L. Searles

January 1994
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Adaptation of a Commercial Robot for Genome Library Replication

Donald C. Uber and William L. Searles
Human Genome Center and Engineering Division
Lawrence Berkeley Laboratory
University of California, Berkeley, CA 94720

January 1994

This work was supported by the Director, Office of Energy Research, Office of Health and Environmental Research, Human Genome Program, of the U.S. Department of Energy under Contract No. DE-AC03-76SF00098.
Adaptation of a Commercial Robot for Genome Library Replication

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Abstract

This report describes tools and fixtures developed at the Human Genome Center at Lawrence Berkeley Laboratory for the Hewlett-Packard ORCA™ (Optimized Robot for Chemical Analysis) to replicate large genome libraries. Photographs and engineering drawings of the various custom-designed components are included.

Introduction

The Human Genome Program is a fifteen year project, funded by the U.S. Department of Energy and National Institutes of Health, to map and sequence the human genome. Similar programs are underway to map and sequence the DNA of other plant and animal species. Current sequencing technology requires that the DNA of the target organism be cut into fragments of a few hundred base pairs. To facilitate its manipulation, each fragment is introduced into a bacteria or yeast cell, which replicates this foreign DNA as well as its own when it divides. The DNA of a single human may consist of as many as two hundred thousand such colonies arrayed in microtiter plates, which are plastic dishes with grids of wells in standard formats of 96 or 384 wells each. Such a collection of plates is known as a genome library.

It is frequently necessary to make copies of a library so that several researchers may collaborate on the mapping and sequencing of the same organism. The original material, which took much effort to produce, can then be safely kept in cold storage. While the copies may be made with a hand replicating tool, it is a very tedious job for a library of several hundred plates. Fortunately, the task is automatable on a general purpose robot such as the ORCA.

The ORCA is a benchtop machine designed by Hewlett-Packard primarily for preparing samples and transporting them among analytical laboratory instruments (1). It has a rail-mounted arm with six degrees of freedom, giving it a great deal of dexterity. Its open hardware and software architecture permit it to be adapted to a wide variety of tasks. We chose library replication as the first task to implement on an ORCA at the LBL Human Genome Center.

Custom Hardware

Hewlett-Packard supplies the ORCA with a flexible software development system, and expects third party developers and technically sophisticated end users to develop the necessary hardware and programs for specific applications. Consequently, all the plate replication tools, fixtures, and software were developed at LBL. However, we were able to take advantage of our experience in customizing an earlier model Hewlett-Packard Microassay System robot for the same job (2), and refined those ideas for the ORCA.

We now describe each of the various custom hardware components in detail. Figure 1 shows the layout of the components on the ORCA table. Engineering drawings are found in the Appendixes.
**Gripper Fingers**

The stainless steel gripper fingers (Fig. 2) enable the ORCA to pick up microtiter plates, move them around the workspace, and remove their lids. They mate to the ORCA hand by means of standard adapters supplied by Hewlett-Packard that allow the robot to exchange tools during a procedure.

**Microplate Hotel**

The source microtiter plates during a replication run are stored in a Lucite "hotel" consisting of three columns of twelve shelves each, for a total of thirty-six plates. Cutouts at the rear of each shelf permit easy loading by hand. The robot can reach in with its gripper fingers and remove or replace the plates in any order. We use the hotel rather than a stacker because the source plates frequently come with sealing tape under the lids. Once the tape is removed by hand, the sticky residue prevents the robot from removing the lids, so the plates must be individually stored without lids on the shelves of the hotel. The library replication program has the option of removing source plate lids, so source plates without sealing tape may be stored in the hotel with their lids on.

The bottom level of the hotel has countersunk holes so that it may be screwed to the 25 mm grid of tapped holes on the ORCA table. The holes have minimal clearance so that the hotel is precisely located. This is also true for other fixtures such as the stackers, workstations, etc.

The front surfaces of the hotel are beveled to guide the plate into place when being replaced by the robot. We use this technique on all the fixtures where the robot must insert an object into a space with small clearance. This makes the system tolerant of small variations between similar workstations or of imprecisely taught motions, and prevents crashes that would occur if the robot tried to force an object against a blunt surface.

**Microplate Stacker**

The blank copy microtiter plates for a replication run are stored with lids in Lucite stackers (Fig. 2) that ORCA accesses sequentially. While the stackers can store up to twenty-five plates each, the robot arm can only reach twenty at the distance from the rail we mount the stackers. Lines are scribed on the back of the stackers to indicate stack heights for both standard 96-well and LLNL 384-well plates, which are slightly taller.

To optimize use of the workspace, stackers may be placed 10 cm apart. This spacing allows just enough room for the gripper fingers between adjacent stacks.

**Microplate Workstation**

The Lucite workstations (Fig. 2) provide temporary storage for microtiter plates and their lids during actual replication. They have the same 10 cm by 15 cm footprint as the stackers, so that they can be packed tightly together on the table.

**Multipin Replicating Tools**

The ORCA replicates plates with either a 96-pin or 384-pin tool (Fig. 3), depending on the type of plates being used. Replication from one plate size to the other is possible, as well as between like sizes. In addition, the tools may be used to make high density filters. Each tool contains stainless steel captive pins that can slide vertically in holes in a Delrin™ baseplate. An internal stripper plate pushes down on the heads of the pins, so that they do not get hung up in the holes. An aluminum heat shield on the bottom keeps the Delrin base from warping when the tool is heated in the sterilizing station.
Each tool has a polyethylene upper layer that supports two aluminum gripper bars (Fig. 4). Each bar has a centered square hole that mates with a pin on one of the gripper fingers. Both the pins and holes are beveled to assure positive mating. The pins are located on the support bar of the fingers, so that the multipin tool is very stably supported directly beneath the centerline of the ORCA hand.

Since the same gripper fingers are used to hold the multipin tools as well as to move microtiter plates, the robot does not have to waste time changing fingers.

**Multipin Tool Park**

Two simple Lucite parking stations hold the multipin tools between replication runs. These stations resemble raised microplate workstations with a large cutout so that the pins in the tools can hang freely.

**Multipin Tool Sterilizer**

The multipin tool in use must be cleaned between source plates, so that the organisms from one source plate do not contaminate the next. We have built a sterilizer (Fig. 4) that consists of two parts: a sonic bath and an electric heater. Under control of the library replication program, the ORCA places the multipin tool on top of the sonic bath, so that the pins are immersed in a sterilizing fluid, such as 70% ethanol, that is toxic to the organisms being replicated. The robot's control computer turns on a sonicator that agitates the fluid and helps knock contaminants off the pins. During this time the ORCA puts finished plates back into hotels and stackers. The computer turns off the sonicator after a programmed delay of several seconds. The ORCA then moves the tool to the electric heater, which the program switches on to evaporate the fluid from the pins. During the heating, the robot gets new plates ready for the next round of replication. The computer switches the heater off after it has been at operating temperature for several seconds.

The sonic bath is kept at a constant level by pumping fluid from an external reservoir. When the fluid in the bath reaches the top of an adjustable dam, the overflow returns the fluid to the reservoir. Level sensors in the bath and reservoir allow the computer to wait while the bath fills, and to alert the operator if insufficient liquid is present. At the end of a replication run, the computer turns off the pump, allowing the liquid to drain from the bath to the enclosed reservoir, to reduce evaporation.

The electric heater contains an electric heating element whose temperature is maintained by a commercial controller, using a thermocouple near the heating wire for feedback. The controller also tells the computer when the heater has reached operating temperature. An over-tem temp safety switch automatically shuts down the heater if the controller fails. Another safety switch prevents the heater from turning on unless the multipin tool is present, to reduce shock hazard. The computer monitors these switches and shuts down the system if a failure occurs.

**Dispensing Station**

New copy plates may optionally be filled with growth medium during a replication run. For this purpose, we took Hewlett-Packard G1243A syringe pump drives from the older Microassay System, and interfaced them to a COM port on the ORCA control computer via an RS232 to RS485 converter. The dispensing station and 16-channel head were also taken from the Microassay System and mounted on the ORCA table with a simple Lucite adapter plate. A vacuum pump connected through a trap vessel suctions fluid from a catch basin underneath the dispense head when the dispenser system is being primed.
**Input/Output Control**

Digital control of external devices such as the vacuum pump and the sterilizer sonicator, temperature control, and reservoir pump, is accomplished by means of a Hewlett-Packard HP3488A Switch/Control Unit with a 44474A 16-bit digital i/o card. The 3488A is controlled by the ORCA computer via the IEEE 488 bus. Eight bits of the i/o card are connected to a control box of our own design that provides latched 115 vac outputs and allows the same eight bits to be used as inputs via tri-state gates. The control box also provides a 5 vdc supply for external circuitry such as the heater temperature control and sonicator level sensor.

**Performance**

The number of new copy plates that the system can generate per hour is shown in Fig. 5. The throughput increases as more copies of each source plate are made, because the overhead of fetching and storing the source plate and cleaning the replication tool is spread over all the copy plates. The 384-well plates are copied more slowly than 96-well simply because of the longer time needed to dispense growth medium into the larger number of wells. For comparison, the older Microassay System (polar arm) is also shown.

In terms of volume, the ORCA can generate up to 180 new copy plates (e.g., five copies of thirty-six source plates) in a single unattended run using the workspace on only one side of the rail. The Microassay System can generate a maximum of eighty new plates per run.

**Conclusions**

The custom hardware described above, together with appropriate software, provides a good example of how a commercially available, general purpose robot can be successfully adapted to replicate large genomic libraries. In developing such a system, we have found it essential to have access to a high quality machine shop that can provide rapid turnaround as new ideas are tried. Almost all the items described went through several iterations before reaching final form.

**Acknowledgments**

We thank Arnold Haus, Steven Rothway, and Donald Thewlis for expert machining and construction of the custom hardware, Joseph Katz and Michael Press for design and construction of the I/O control box, Davey Hudson for design and construction of the sonic bath level sensor, and Michael Osofsky and John Home for preparing CAD drawings.

This work was supported by the Director, Office of Energy Research, Office of Health and Environmental Research, Human Genome Program, of the U.S. Department of Energy under Contract No. DE-AC03-76SF00098.

Reference to a company or product name does not imply approval or recommendation of the product by the University of California or the U.S. Department of Energy to the exclusion of others that may be suitable.

**References**


Figure 1. Overview of automated library replication system. The ORCA arm and rail are at right. The ORCA is holding a multipin replicating tool over workstations containing microtiter plates and lids. Furthest from the rail, starting at lower left, are stackers with copy plates, the hotel with source plates, the dispensing station (partially hidden), the sterilizer heater, and sterilizer bath.
Figure 2. Close-up of gripper fingers lifting a microplate from a stacker. A 384-well plate sits on a workstation in the foreground.
Figure 3. The 96 and 384-pin replicating tools. The captive pins slide in holes in the black Delrin baseplate. An aluminum heat shield keeps the Delrin from warping in the sterilizer heater.
Figure 4. The sterilizing station. The ORCA gripper is holding a multipin tool above the sonic bath. The electric heater is at left; its temperature controller at right. The ethanol reservoir is out of sight beneath the table.
Library Replication Throughput

Figure 5. System throughput for the ORCA and Microassay System (polar) robots.
APPENDIXES

Engineering Drawings

Appendix A: Gripper Fingers

Appendix B: Microplate Hotel
   B(1): Assembly, Common Details, & Blanks
   B(2): Auxiliary Pieces
   B(3): Base I/Hotel 5/8 Blank 11.80 X 5.630
   B(4): Roof I/Hotel 1/4 Blank 11.800 X 5.630
   B(5): Floor II/Hotel 1/4 Blank 11.800 X 5.630

Appendix C: Microplate Stacker

Appendix D: Microplate Workstation

Appendix E: 96-Pin Replicating Tool

Appendix F: 384-Pin Replication Tool

Appendix G: Multipin Tool Parking Station

Appendix H: Multipin Tool Sterilizer Bath

Appendix I: Multipin Tool Sterilizer Bath Level Sensor

Appendix J: Multipin Tool Sterilizer Bath Sonicator Driver

Appendix K: Multipin Tool Sterilizer Reservoir

Appendix L: Multipin Tool Sterilizer Heater

Appendix M: Multipin Tool Sterilizer Heater Control

Appendix N: I/O Control Box (1 Of 8 Bits)
Appendix A: Gripper Fingers
SAW OK

6.000" 0.188"

MACHINE BOTH SIDES

0.125" STOCK STAINLESS STEEL PLATE

LAWRENCE BERKELEY LABORATORY ENGINEERING DIVISION HUMAN GENOME INSTRUMENTATION GROUP
TAP BOTH SIDES 0-80

0.200" →

0.125"

0.500" >

0.100"
Appendix B: Microplate Hotel
B(1): Assembly, Common Details, & Blanks
B(2): Auxillary Pieces
B(3): Base I/Hotel 5/8 Blank 11.80 X 5.630
B(4): Roof I/Hotel 1/4 Blank 11.800 X 5.630
B(5): Floor II/Hotel 1/4 Blank 11.800 X 5.630
Appendix B(1): Assembly, Common Details, & Blanks
1 ROOF/HOTEL 1/4 LUCITE
1 FLOOR/HOTEL 1/4 LUCITE
1 BASE/HOTEL 5/8 LUCITE
REAR END 3/HOTEL LUCITE

1/4

ABOUT 12" BY 15

REAR SPACER 3/HOTEL LUCITE

5/8 -> .535

ABOUT 12" BY 15

FRONT SPACER 2/HOTEL LUCITE

1/4

ABOUT 12" BY .535

STOPS 20/HOTEL LUCITE

1/4

ABOUT 12" BY .25

TIE ROD 2/HOTEL

36" STOCK

1/4-20 SS THREAD ROD
TOOL PATH 1/2 DIA END BILL
GROOVE .090 BELOW SURFACE
BASE AND FLOOR

X-AXIS
1 X 3.913 FIXED Y -.300 → 6.000
2 X 3.950 FIXED Y 6.000 → -.300
3 X 7.850 FIXED Y -.300 → 6.000
4 X 7.887 FIXED Y 6.000 → -.300
5 X -.300 → 12.100 Y -.027 FIXED
6 X 11.787 FIXED Y -.027 → 5.602
7 X 11.787 → .013 Y 5.602 FIXED
8 X .013 FIXED Y 5.602 → .300

Y-AXIS
11 ↓ 2
3 ↓ 4
5 → 6
8 ↑ 7
TOOL PATH 1/2 DIA END MILL
Appendix B(2): Auxiliary Pieces
Appendix B(3): Base I/Hotel 5/8 Blank 11.80 X 5.630
SCOT .090 DEEP

15/64 THRU 7/16 x .250 CNTBR 4 PLCS
Appendix B(4): Roof 1/Hotel 1/4 Blank 11.800 X 5.630
Appendix B(5):  Floor II/Hotel 1/4 Blank 11.800 X 5.630
SCOT .090 DEEP
FINISH 1/2 AND 1/4 PLATES
TO SIZE BUT ONLY
FINISH 1/4 PLATE

LAWRENCE BERKELEY LABORATORY
ENGINEERING DIVISION
HUMAN GENOME INSTRUMENTATION GROUP

DATE

MICHAEL J. OSOFSKY

WILLIAM SEARLES
Appendix C: Microplate Stacker
5.630" +.005

-0.005

0.500"
(STOCK)

3.925" +.005

-0.005

LAWRENCE BERKELEY LABORATORY
ENGINEERING DIVISION
HUMAN GENOME INSTRUMENTATION GROUP

PART OF
MICROPLATE WORKSTATION

COMPONENT NAME
BASE PLATE

REF. NO.
BLANK

ORIGINAL DATE
12-1-92

REV. DATE
4-21-93

MICHAEL J. OSOFSKY

WILLIAM SEARLES

ORCA WORKSTATION STS
DRILL 15/64
CNTBR 7/16x.250
DEEP
(END MILL OK)
6 PLCS.

OPTIONAL HOLE

LAWRENCE BERKELEY LABORATORY
ENGINEERING DIVISION
HUMAN GENOME INSTRUMENTATION GROUP

MICROPLATE WORKSTATION
BASE PLATE HOLES

DATE 4-29-93

MICHAEL J. OSOFSKY

WILLIAM SEARLES ORCWORKSTATBSPLAT2
1.965"  

TIGHT 5/32  

2.815"  0.815"

2.415"  3.215"

--1  

DRILL #17 CNTBR 5/16 x .156 DEEP

SLOT OPTIONAL

ZYMARK MTG OPTION

LAWRENCE BERKELEY LABORATORY
ENGINEERING DIVISION
HUMAN GENOME INSTRUMENTATION GROUP

PART OF
MICROPLATE WORKSTATION

COMPLETED
BASE PLATE & OPTIONAL TAPE SLOT

DATE 12-1-92
REV. DATE 4-21-93

MICHAEL J. OSOFSKY
WILLIAM SEARLES
#3 CENTER DRILL

30°

1.000"

0.250"

< 0.250"
Appendix D: Microplate Workstation
Base Plate Holes

- Optional hole:
  - Drill 15/64
  - Cntbr 7/16 x .250 deep
  - (End mill OK)
  - 6 Plcs.

- Reference dimensions:
  - 0.980" up
  - 2.949
  - 0.125" up

- Part CF Microplate Workstation

- Lawrence Berkeley Laboratory
  Engineering Division
  Human Genome Instrumentation Group

- Michael J. Ososky
  William Searles
  Orca Workstat Baseplate
DRILL #17 CNTBR 5/16x.156 DEEP

SLOT OPTIONAL

ZYMARK MTG OPTION

MICHAEL J. OSOFSKY
WILLIAM SEARLES

LAWRENCE BERKELEY LABORATORY
ENGINEERING DIVISION
HUMAN GENOME INSTRUMENTATION GROUP

PART OF MICROPLATE WORKSTATION

BASE PLATE & OPTIONAL TAPE SLOT

DETAIL
ORIGINAL DATE: 12-1-92
REV. DATE: 4-21-93

DRAWN BY: MICHAEL J. OSOFSKY
CHECKED BY: WILLIAM SEARLES

ORCA\WORKSTAT\WKSTB55

D.6.
Appendix E: 96-Pin Replicating Tool
TAP 4-40 TYP 4 PLCS

USE 1/4" DIA END MILL

SEE REQUIRED PIN HOLE DWG

DELrin BASE

MILL

MICHAEL J. OSOFSKY

WILLIAM SEARLES
<table>
<thead>
<tr>
<th>Hole Diameter (in)</th>
<th>Number of Holes</th>
</tr>
</thead>
<tbody>
<tr>
<td>.447</td>
<td>96</td>
</tr>
<tr>
<td>.802</td>
<td>96</td>
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<td>1.156</td>
<td>96</td>
</tr>
<tr>
<td>1.510</td>
<td>96</td>
</tr>
<tr>
<td>1.865</td>
<td>96</td>
</tr>
<tr>
<td>2.219</td>
<td>96</td>
</tr>
<tr>
<td>2.573</td>
<td>96</td>
</tr>
<tr>
<td>2.928</td>
<td>96</td>
</tr>
</tbody>
</table>

HOLE SPACING 9.0 mm
USE 1/4" DIA END MILL

TYP 4 CORNERS--DRILL #32

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ENGINEERING DIVISION
HUMAN GENOME INSTRUMENTATION GROUP

POLYETHYLENE LAYER

MICHAEL J. OSOFSKY
WILLIAM SEARLES
NOM 1/32

STAINLESS STEEL

1/8 RADIUS & SAND ALL EDGES SMOOTH & ROUND

PART CF
MULTIPIN TOOL
STRIッPER PLATE

LAWRENCE BERKELEY LABORATORY
ENGINEERING DIVISION
HUMAN GENOME INSTRUMENTATION GROUP

DAN. TYPE DETAIL
ORIGINAL DATE 12-1-92
REV. DATE

BY: MICHAEL J. OSOFSKY
BY: WILLIAM SEARLES
.030 MIRROR ALUM SHEET

5.035"

4.835"

3.375"

2.975"

0.400"

0.200"

PRESS DIMPLE FOR 4-40 FH DRILL #33
DRILL CNTSK 82° FOR #4 FLAT HEAD

0.200”  5.035”

0.088”

2.229”  0.577”

0.375”

0.500”

2.353”  0.330”

MULTIPIN TOOL
GRIPPER BAR

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PART OF
MULTIPIN Tool
GRIPPER BAR

MANUFACTURED BY
ORCA/TPOOL/GRIPOBAR

DRAWN AND CHECKED:
MICHAEL J. OSOFSKY
WILLIAM SEARLES

DATE: 12-1-92

E 8.
Appendix F: 384-Pin Replication Tool
SEE REQUIRED PIN HOLE DWG

TAP 4-40 TYP 4 PLCS

USE 1/4" DIA END MILL

0.250" X .075 DEEP

ORIGINAL DATE: 12-1-92
REV. DATE: 0

MICHAEL J. OSOFSKY
WILLIAM SEARLES
HOLE SPACING 4.5 mm

SHIELD: DRILL #49
DELRIN: DRILL #55
TYP 4 CORNERS--DRILL #32

USE 1/4" DIA END MILL
1/8 RADIUS & SAND ALL EDGES SMOOTH & ROUND

STAINLESS STEEL

4.200"

2.800"

NOM 1/32
.030 MIRROR ALUM SHEET

5.035"  4.835"

PRESS DIMPLE FOR 4-40 FH DRILL #33

3.375"  2.975"  0.400"  0.200"

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PART CF MULTIPIN TOOL
COMPONENT NAME HEAT SHIELD

DATE 4-23-92 REV. DATE

BY MICHAEL J. OSOFSKY
SK WILLIAM SEARLES ORCA\MP TOOL\HEAT SHLD
DRILL CNTSK 82° FOR #4 FLAT HEAD

0.200°  5.035°
0.375°  4.835°

2.229°  0.577°

0.125°  0.330°

2.353°
Appendix G: Multipin Tool Parking Station
DRILL THRU 15/64 CNTBR 7/16x.250 DEEP 4 PLCS OK END MILL

DRILL THRU #33 CNTBR 3/16x.250 DEEP 4 PLCS OK END MILL
NOTE OPPOSITE SIDES FOR CNTBR
USE 1/4 D END MILL

DRILL #43 TAP

4-40 4 PLCS
0.250" -> 3/8 STOCK

DRILL #31

MAKE 4/UNIT
#3 CENTER DRILL

\[ 30^\circ 
\]

\[ 1.000'' \]

\[ 0.250'' \]
Appendix H: Multipin Tool Sterilizer Bath
DRILL #29 THRU COUNTERBORE 5/16" 0.100" DEEP

30 DEG. CHAMFER

TAP 10-32

USE MODIFIED CENTER DRILL

LAWRENCE BERKELEY LABORATORY ENGINEERING DIVISION HUMAN GENOME INSTRUMENTATION GROUP

PART NO: STERILIZER LOCATOR

SPEC: MECHANICAL 6/23/93 REV: DATE

DRAWN BY J. HOME III CHECKED BY W. SEARLES R&I SEARLES@BERKELEY.EDU

0.370"

0.490"

0.250"

0.250"

0.125"

2.062"

3.385"

1.250" (TYP.)

0.125"
DRILL 5/32" 8 PLCS.

1/32" THICK SOLVENT-RESISTANT GASKET MATERIAL (2 REQ'D.)

(ALL HOLE DIMENSIONS TYPICAL)

LAWRENCE BERKELEY LABORATORY
ENGINEERING DIVISION
HUMAN GENOME INSTRUMENTATION GROUP

STERILE BATH

GASKET

MECH. 7/13/93

BY J. HOME III

BY W. SEARLES

H. 4.
EXACT LOCATION NOT CRITICAL

OVER FLOW

0.500" (TYP.)

FLAT ON TOP

3/8" O.D.
S.S. TUBE

CLOSE TO BOTTOM

6.938"

4.875"

2.500"
COUNTERBORE 3/8" DIA. X 0.250 DEEP 4 PLACES

DRILL 5/32" 4 PLACES

DRILL 15/64 (STOCK)
0.150" deep on both sides
1/4" end mill
(weight reduction slot)

File break corners
0.030" x 45 deg.
4 places

0.075"

Section AA

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STERILIZER
COVER
MECH 7/15/93 8/7/93
ENG. J. HOM III
SM. W. SEARLES
SM. W. SEARLES/DHCOVER
STERILE PATH COVER FLOW

TAP 2-56 2 PLCS.

0.438" 0.500" 0.313"

2.500" 1.500"

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HUMAN GENOME INSTRUMENTATION GROUP

PART OF: STERILE PATH
COMPONENT NAME: COVER FLOW

SDS TYPE: PLCS.
ORIGINAL DATE: 7/28/93
REVISION DATE: 11/11/93

ENG. BY: J. HOM II
DRAWN BY: W. SEARLES
REVIEWED BY: SEARLES/BHOVERFL
Appendix I: Multipin Tool Sterilizer Bath Level Sensor
A circuit diagram showing a level sensor in a sterilizer bath. The diagram includes a metal container, a probe, and a liquid level indicator. The output is indicated as 'LOW = PROBE COVERED'.

- **Component Labels**:
  - 0.005 µF (capacitor)
  - 10 kΩ (resistor)
  - LM311 (operational amplifier)
  - 5V LED

- **Legend**:
  - PROBE LIQUID
  - METAL CONTAINER

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  - GROUP: HUMAN GENOME INSTRUMENTATION
  - FILE NAME: SEARLES/CIRCUIT
  - DATE: 1/28/93

- **Specifications**:
  - RES: 10 kΩ
  - CAP: 0.005 µF

- **References**:
  - J. HOME III
  - W. SEARLES
Appendix J: Multipin Tool Sterilizer Bath
Sonicator Driver
SONICATOR POWER SUPPLY

NOTE (1)
PARTS REMOVED FROM:
BRANSON MOD. 1200
VWR# 21812-119

NOTE (1)
CT40450
BLATEK, INC.
STATE COLLEGE, PA

Title
SONICATOR POWER SUPPLY

Drawn
Date

Checked
Date

Approved
Date

Engineer

Size

Document Number

File Name

Date: October 18, 1993

REV

A

Sheet of

J. 1.
Appendix K: Multipin Tool Sterilizer Reservoir
Appendix L: Multipin Tool Sterilizer Heater
DRILL #29 THRU COUNTERBORE 5/16” 0.100” DEEP

0.490”
30 DEG. CHAMFER
TAP 10-32

2.062”
0.250”

3.385”

0.370”

0.125”

0.125”

USE MODIFIED CENTER DRILL

(TYP.)

0.250”

0.250”

LAWRENCE BERKELEY LABORATORY
ENGINEERING DIVISION
HUMAN GENOME INSTRUMENTATION GROUP

PART OF
STERILIZER
LOCATOR

MATERIAL MECHANICAL 7/13/93
REV. DATE 8/25/93

D.M. BY:  J. HOME III

W. SEARLES SEARLES\DLLOGATR

W. SEARLES SEARLES\DLLOGATR
SAFETY SWITCH
ACTUATOR-μSWITCH
UNDER (HEAT SHIELD
NOT SHOWN)

MACHINABLE
CERAMIC HEATER
WIRE GUIDE

OVER TEMPERATURE
SAFETY SWITCH
UNDERNEATH

TYPICAL 40"
#28 NICHROME
HEATER WIRE
SECTION AA
Appendix M: Multipin Tool Sterilizer Heater Control
Appendix N: I/O Control Box (1 Of 8 Bits)
ORCA I/O CONTROL BOX
1 of 8 bits

From H-P 3488A
4474A Card

To External Device

DATA I/O
*WR STROBE

+5
10K

74HC175

*RD STROBE

74HC244 TRI-STATE

115 VAC

TTL IN

+5
10K

Solid State Relay

SWITCHED 115 VAC OUT

74HC244 TRI-STATE

TTL OUT