238800-2-T (Vol. II)

Interim Design Review

# NASA GODDARD SPACE FLIGHT CENTER ROBOTIC PROCESSING SYSTEM PROGRAM AUTOMATION SYSTEMS



M.E. DOBBS

OCTOBER 1991

Prepared for:
NASA Goddard Space Flight Center
Space Technology Division
Greenbelt, MD 20771

Contract No. NAG 5-1517

SpARC
Space Automation
& Robotics Center

ERIM
P.O. Box 134001
Ann Arbor, MI 48113-4001

# Interim Design Review

## NASA Goddard Space Flight Center
## Robotic Material Processing System Program
## Automation Systems

18 October 1991

prepared by

Environmental Research Institute of Michigan
Space Automation and Robotics Center
P.O. Box 134001
Ann Arbor, Michigan 48113-4001

## RoMPS General Mission Requirements

- Rapid Thermal Annealing (RTA) in Microgravity
  - Microgravity material processing
  - High temperature annealing furnace
  - Automated RTA processing and sample change

- STS Hitchkiker Payload
  - GAS canister and HH avionics mounting plate
  - Class D payload classification
  - Serial command and telemetry

- Mission Characteristics
  - Operates during STS disturbance free "quiet" periods
  - Operational changes expected
    - reschedule operations to meet STS constraints
    - modification of RTA processing parameters

## Office of Commercial Programs Requirements

- Infrastructure - Enable Low Cost Space Manufacturing
  - new technology - patents, license, product sales
  - reduced cost-per-pound
    - reduce non-recurring engineering cost
    - use industrial practices and products
    - carrier independent systems
    - experiment independent systems
  - system architecture for manufacturing facility

- Closely Related OCP Infrastructure CCDS Flight Programs at SpARC
  - Autonomous Rendezvous & Docking
    - Autonomous Experiment Mangement System (AEMS)
  - Wake Shield Facility
    - Autonomous Experiment Mangement System (AEMS)
    - Robotic Substrate Servicing System
    - Satellite Servicing System
    - EPOP Control and Data System (AEMS)
  - LABS
    - Autonomous Experiment Mangement System (AEMS)
    - Material Handling Automation

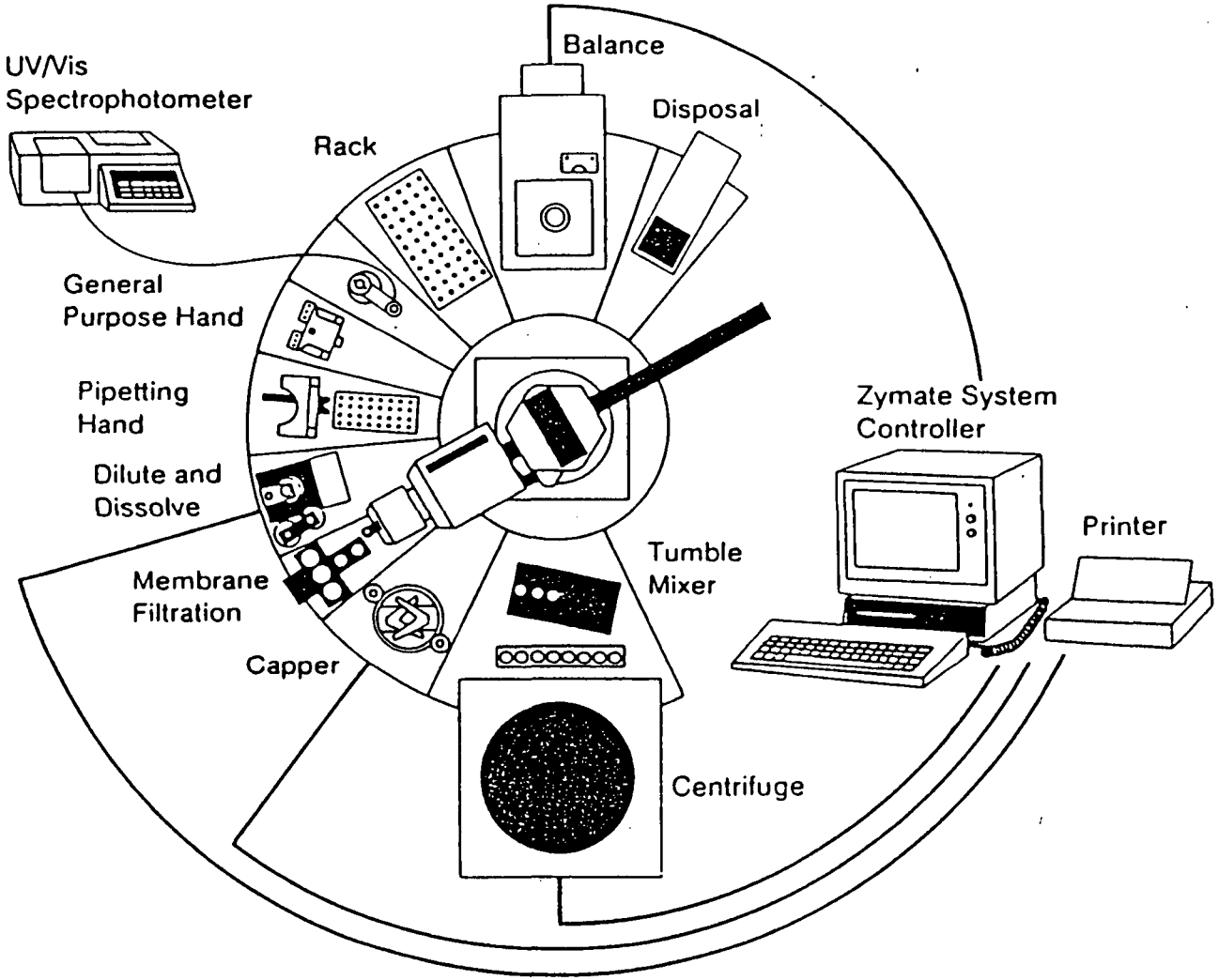
## Automation Management System

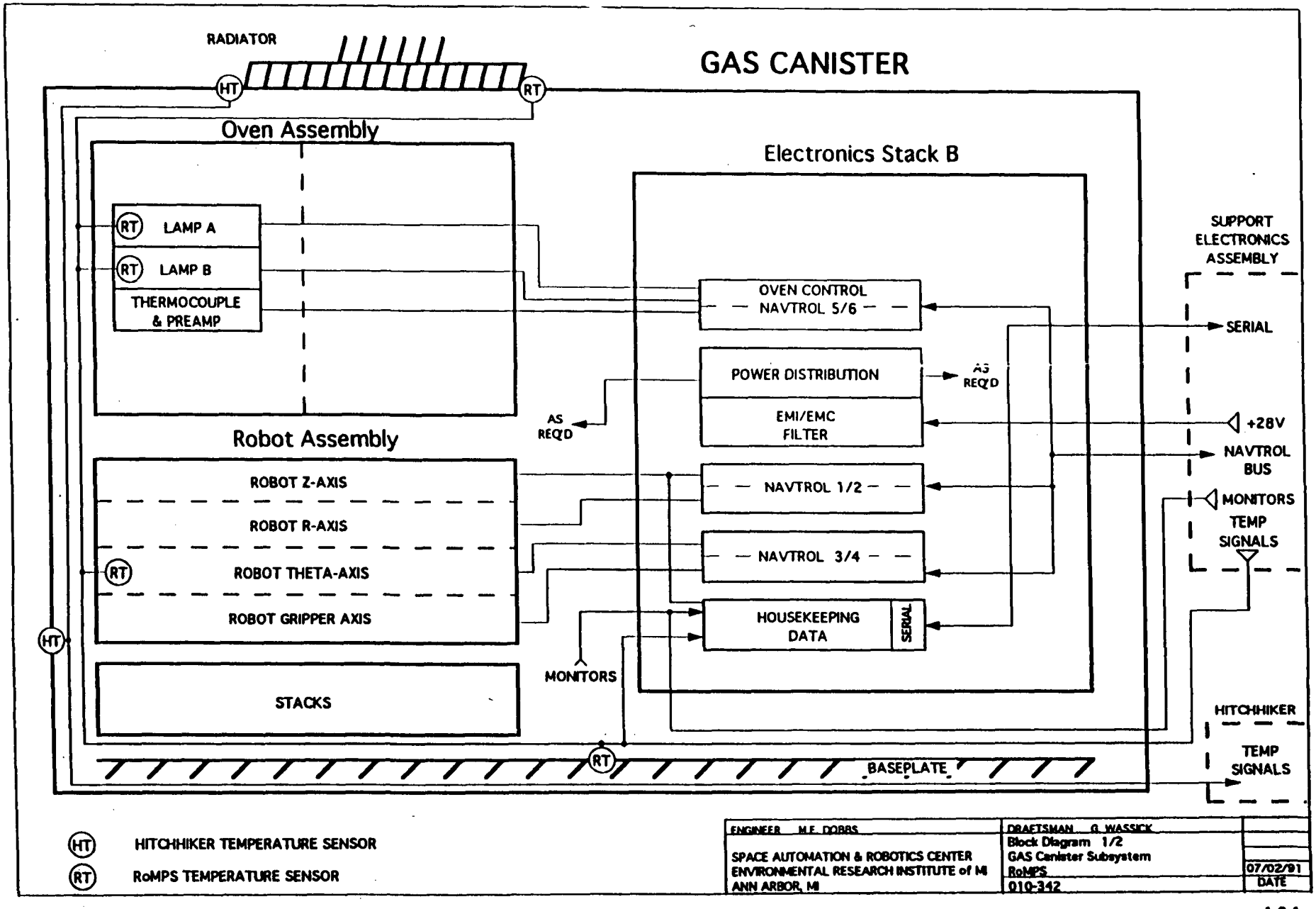
- Schedule Scripts
  - STS operational timeline changes
  - Investigator sample priority changes

- Processing Scripts
  - process methodology changes
  - process parameter changes

- High Level Language User Interface
  - industry proven
  - put PI in the drivers seat
  - attempt transparent environment from laboratory to flight

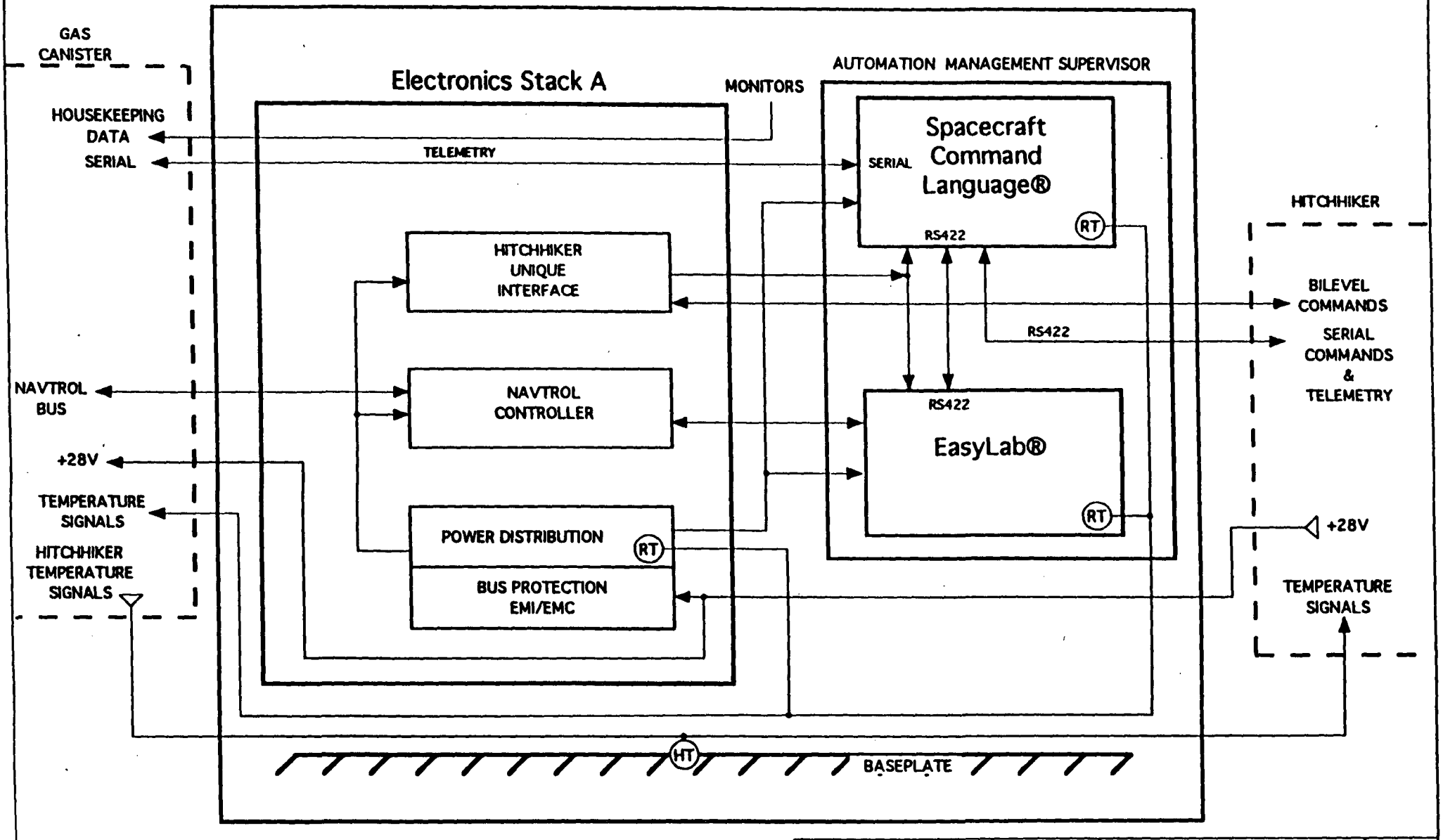
- Automatic Control
  - automatic sample change
  - automatic process control
  - rule based error detection and resolution


UV/Vis
Spectrophotometer
Balance
Disposal
Rack
General
Purpose Hand
Pipetting
Hand
Dilute and
Dissolve
Membrane
Filtration
Capper
Tumble
Mixer
Zymate System
Controller
Printer
Centrifuge


RADIATOR
GAS CANISTER
HT
RT
Oven Assembly
RT LAMP A
RT LAMP B
THERMOCOUPLE & PREAMP
Electronics Stack B
OVEN CONTROL NAVTROL 5/6
POWER DISTRIBUTION
EMI/EMC FILTER
NAVTROL 1/2
NAVTROL 3/4
HOUSEKEEPING DATA
SERIAL
AS REQ'D
AS REQ'D
Robot Assembly
ROBOT Z-AXIS
ROBOT R-AXIS
RT ROBOT THETA-AXIS
ROBOT GRIPPER AXIS
STACKS
MONITORS
SUPPORT ELECTRONICS ASSEMBLY
SERIAL
+28V
NAVTROL BUS
MONITORS
TEMP SIGNALS
HITCHHIKER
TEMP SIGNALS
HT
RT
BASEPLATE
HT HITCHHIKER TEMPERATURE SENSOR
RT RoMPS TEMPERATURE SENSOR
ENGINEER M.F. DOBBS
SPACE AUTOMATION & ROBOTICS CENTER
ENVIRONMENTAL RESEARCH INSTITUTE of MI
ANN ARBOR, MI
DRAFTSMAN G. WASSICK
Block Diagram 1/2
GAS Canister Subsystem
RoMPS
010-342
07/02/91
DATE

1.2.1

# HITCHHIKER AVIONICS PLATE




(HT) HITCHHIKER TEMPERATURE SENSOR

(RT) RoMPS TEMPERATURE SENSOR

| | | |
|---|---|---|
| ENGINEER M.F. DOBBS | DRAFTSMAN G. WASSICK | |
| | Block Diagram 2/2 | |
| SPACE AUTOMATION & ROBOTICS CENTER | SEA Subsystem | |
| ENVIRONMENTAL RESEARCH INSTITUTE of MI | RoMPS | 07/02/91 |
| ANN ARBOR, MI | 010-339 | DATE |

Experiment Spreadsheet

| | A | B | C | D | E | F | G | H | I |
|---|---|---|---|---|---|---|---|---|---|
| 1 | Run | Sample | Rack | Rack Index | Temperature 1 | Time 1 | Temperature 2 | Time 2 | Processed |
| 2 | 1 | 1 | 1 | 1 | 410 | 90 | 410 | 90 | N |
| 3 | 2 | 2 | 1 | 2 | 410 | 90 | 410 | 90 | N |
| 4 | 3 | 3 | 1 | 3 | 410 | 90 | 410 | 90 | N |
| 5 | 4 | 4 | 1 | 4 | 410 | 90 | 410 | 90 | N |
| 6 | 5 | 5 | 1 | 5 | 410 | 90 | 410 | 90 | N |
| 7 | 6 | 6 | 1 | 6 | 410 | 90 | 410 | 90 | N |
| 8 | 7 | 7 | 1 | 7 | 350 | 90 | 350 | 90 | N |
| 9 | | ... | ... | ... | ... | ... | ... | ... | ... |
| 10 | | ... | ... | ... | ... | ... | ... | ... | ... |
| 11 | | ... | ... | ... | ... | ... | ... | ... | ... |
| 12 | | ... | ... | ... | ... | ... | ... | ... | ... |
| 13 | 141 | 141 | 6 | 5 | 400 | 30 | 400 | 30 | N |
| 14 | 142 | 142 | 6 | 6 | 200 | 30 | 200 | 30 | N |
| 15 | 143 | 143 | 6 | 7 | 400 | 5 | 400 | 5 | N |
| 16 | 144 | 144 | 6 | 8 | 400 | 15 | 400 | 15 | N |

```
-- SCL Scenario Script
--
-- Function Defines processing scenario for do_processing
-- script.

script  experiment_scenario

run                         = 1
gSample[run]                = 1
gRack[run]                  = 1
gRack_Index[run]            = 1
gTemperature1[run]          = 410
gTime1[run]                 = 90
gTemperature2[run]          = 410
gTime2[run]                 = 90

run                         = 2
gSample[run]                = 2
gRack[run]                  = 1
gRack_Index[run]            = 2
gTemperature1[run]          = 410
gTime1[run]                 = 90
gTemperature2[run]          = 410
gTime2[run]                 = 90

     ...

     ...
run                         = 144
gSample[run]                = 144
gRack[run]                  = 6
gRack_Index[run]            = 8
gTemperature1[run]          = 200
gTime1[run]                 = 30
gTemperature2[run]          = 200
gTime2[run]                 = 30

end  experiment_scenario
```

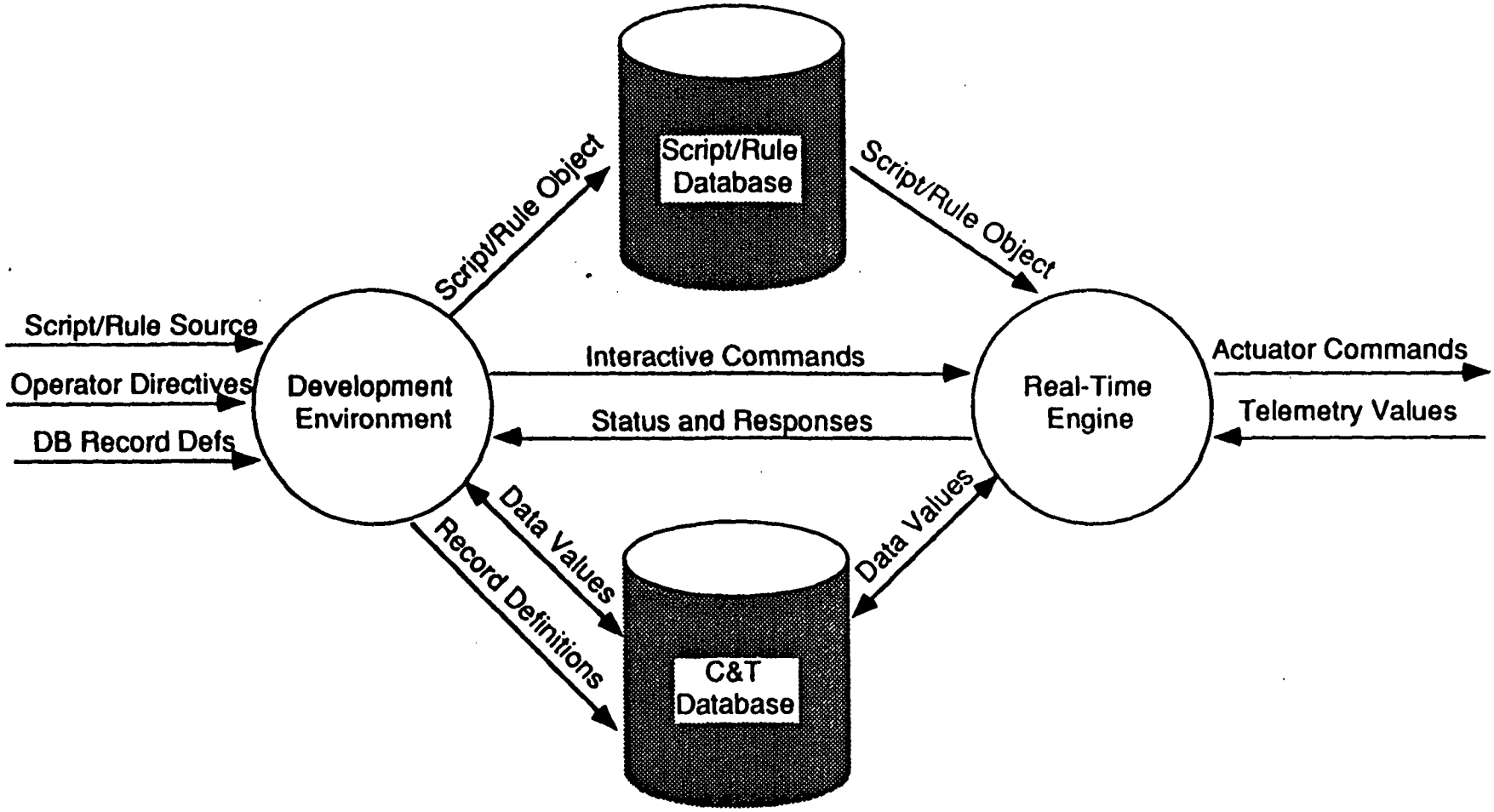
# SCL Scripts

- SCL scripts are similar to tasks or other stand alone programs.
- Scripts can be executed immediately by command directive.
- Scripts can also be scheduled for deferred execution. SCL supports:
  - Absolute execution times.
  - Relative execution times.
- Scripts can be scheduled for cyclic execution (repetitive execution).

# SCL Software Components

- The SCL software system is divided into 3 major components:
  - The Development Environment. The development environment provides tools for developing and maintaining scripts and rules and for controlling the operation of the system
  - The Real-Time Database. The database defines the SCL software's operating environment.
  - The Real-Time Engine (RTE). Executes the SCL scripts, rules, and command directives.

# SCL Software Data Flows



# SCL Real-Time Engine

- The Real-Time Engine (RTE) executes SCL scripts, rules and command directives.
- The RTE is portable:
  - Written in C and Ada
  - Application specific I/O and system service calls have been isolated and "abstracted" out the SCL software.
- The RTE is generic/reusable. SCL scripts and rules are used to tailor the system to a specific application.
- The RTE is dynamic. Scripts and rules can be added or deleted without changing the RTE and its underlying interface routines.

# RoMPS EasyLab Command &Variable Summary for Rack Stations

| | |
|---|---|
| **RACK.INDEX** | EasyLab variable used by RoMPS PyTechnology to determine the current sample for robot to manipulate. Initial Value is 1. |
| **GET.FROM.RACK** | Get sample RACK.INDEX from its home rack and slot. |
| **PUT.INTO.RACK** | Move the currently held sample into the home rack and slot of RACK.INDEX. |

# RoMPS EasyLab Command &Variable Summary for Annealer Module

| | |
|---|---|
| **ANNEALER.TEMPERATURE** | Output Command Variable used to set the target temperature for the next annealing initiated by ANNEALER.ON and ANNEALER.TIMED.RUN. Initial Value TBD. |
| **ANNEALER.TIME** | Output Command Variable used to set the annealing time for the next annealing initiated by ANNEALER.TIMED.RUN. Initial Value TBD. |
| **ANNEALER.RATE** | Output Command Variable used to set the heating rate for the next annealing initiated by ANNEALER.ON and ANNEALER.TIMED.RUN. Initial Value TBD. |
| **ANNEALER.ACTIVE.OVEN** | EasyLab variable used by the Annealer robot movent commands, to determine position to put and get samples. |
| **MOVE.UNDER.ANNEALER** | Move Robot Gripper Under Sample, Lined up to allow pallet to be inserted into annealer. |
| **PUT.INTO.ANNEALER** | Move sample up into Annealer After a MOVE.UNDER.ANNEALER command. |
| **ANNEALER.ON** | Initiate an untimed run of the Annealer. |
| **ANNEALER.OFF** | Terminate an untimed run of the Annealer. |
| **ANNEALER.TIMED.RUN** | Initiate a timed run of the Annealer. |

## Automation Management System

- Architecture Demonstrated at SpARC on 4 October 1991

  SC4 #1 with SCL implements
  - generic - scheduler
  - specific - carrier i/o

  SC4 #2 with EASYLAB implements
  - generic - sample handling, processing
  - specific - robot geometry

  Electronics
  - generic - servos, housekeeping
  - specific - interfaces

- Status
  - MOU's in place
  - License agreements outlined
  - DFD's prepared
  - Elements to be designed have models to work from

- Long Term Architecture
  - Multiple robot and process space manufacturing facility

- Minimize Lifecycle Costs
  - Industrial development, support, maintenance and documentation

## RoMPS Electronics Assemblies

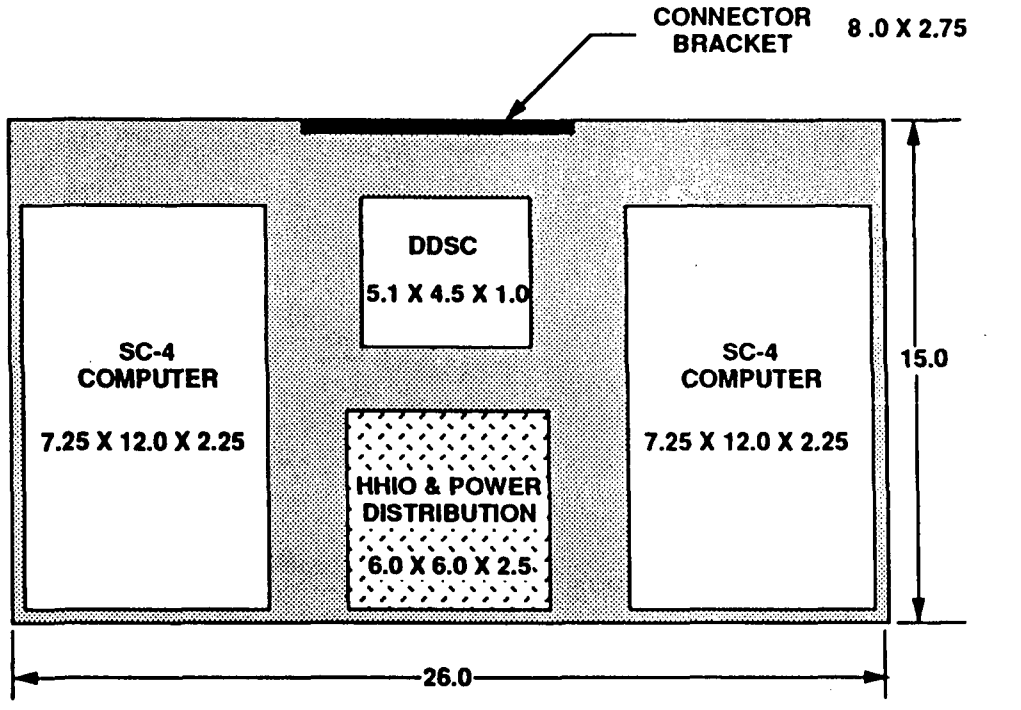
- Support Electronics Assembly

  Mounted to Hitchhiker Adapter Plate
  Integrated assembly with common support plate and cover
    - Connector Bracket
    - Power Distribution
    - SwRI SC4 Computer #1
    - SwRI SC4 Computer #2
    - Navtrol DDSC Master

- GAS Electronics Assembly

  Mounted inside 5" GAS Extension
  Integrated assembly with common support plate
    - Connector Brackets
    - Power Distribution
    - Navtrol DDSC Slave #1
    - Navtrol DDSC Slave #2
    - Navtrol DDSC Slave #3
    - Thermocouple Signal Conditioning
    - Data Acquisition

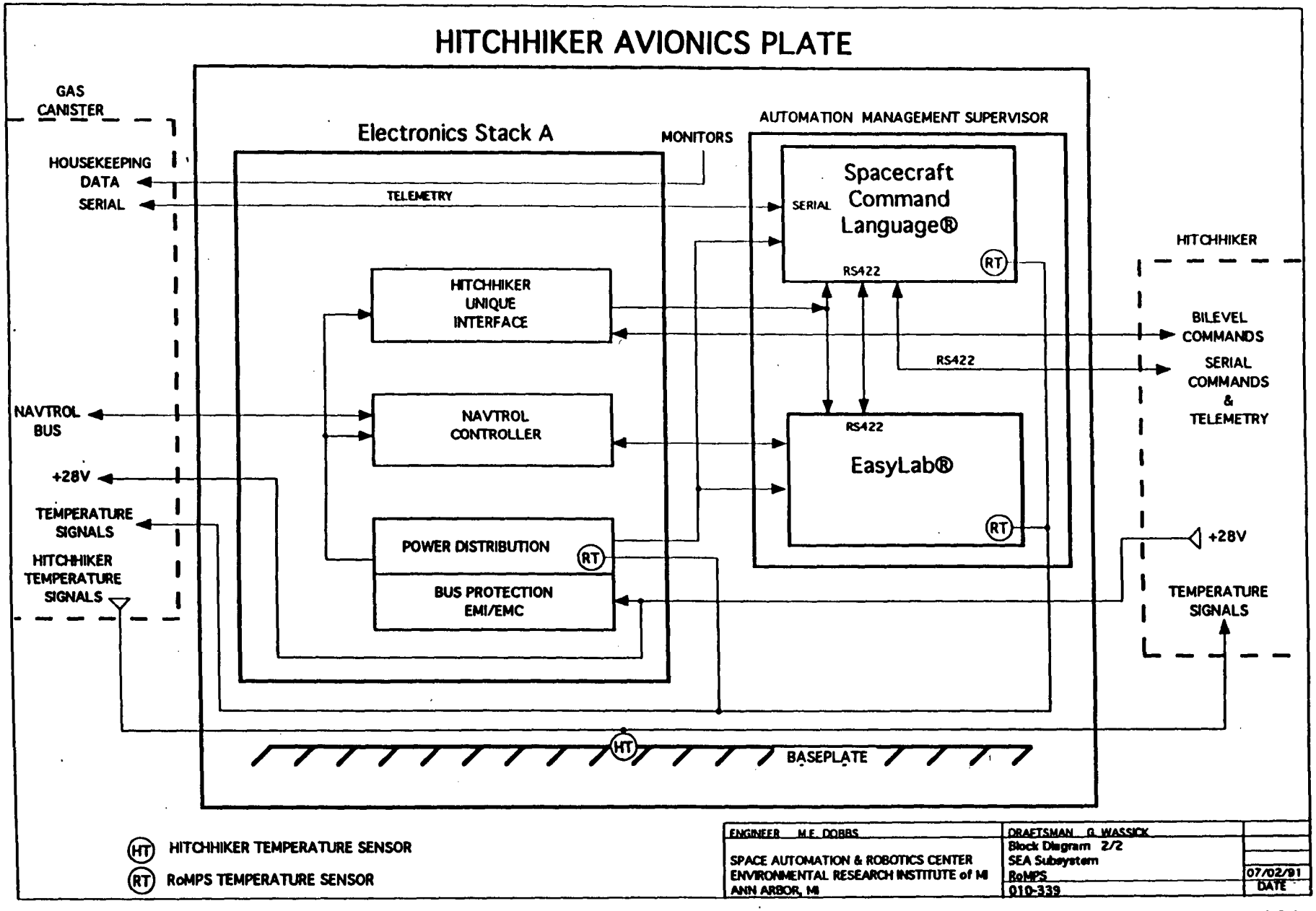
# SUPPORT ELECTRONICS ASSEMBLY




| | | |
|---|---|---|
| ENGINEER R.E. QUADA | DRAFTSMAN S.J. CARR | |
| SPACE AUTOMATION & ROBOTICS CENTER<br>ENVIRONMENTAL RESEARCH INSTITUTE of MI<br>ANN ARBOR, MI | LAYOUT<br>SUPPORT ELECTRONICS ASSEMBLY<br>ROMPR | 10/09/91<br>DATE |

RoMPS Elec Weight & Power

| | A | B | C | D | E | F | G | H |
|---|---|---|---|---|---|---|---|---|
| 1 | RoMPS Weight & Power | | | | | | | |
| 2 | Assembly | Subassembly | Mfgr | Size LWH in | Mass lbs | Avg Pwr | Peak Pwr | Comments |
| 3 | | | | | | | | |
| 4 | Support Elect | mount plate | GSFC | | tbd | | | |
| 5 | Assembly | emi cover | GSFC | | tbd | | | |
| 6 | | SC-4 | SwRI | 7.25x12.25x2 | 3.7 | 5 | 5 | |
| 7 | | SC-4 | SwRI | 7.25x12.25x2 | 3.7 | 5 | 5 | |
| 8 | | HH I/O | ERIM | 7 x 7 x 0.75 | 1.1 | 1 | 1 | |
| 9 | | HH PWR | ERIM | 7 x 7 x 1.25 | 1.1 | 0 | 0 | |
| 10 | | DDSC Master | Navtrol | 4.5x5.1x1 | 2 | 3.7 | 3.7 | |
| 11 | | connec. brack | ERIM | | tbd | | | |
| 12 | | harness | ERIM | | tbd | | | |
| 13 | | hardware | | | tbd | | | |
| 14 | | | | | | | | |
| 15 | | SUBTOTAL | | | 11.6 | 14.7 | | |
| 16 | | | | | | | | |
| 17 | GAS Eectroni | mount plate | GSFC | 17.5 dia | tbd | | | |
| 18 | Assembly | DDSC | Navtrol | 4.5x5.1x1 | 2 | 3.7 | 269 | 9.6a worst ca |
| 19 | | DDSC | Navtrol | 4.5x5.1x1 | 2 | 3.7 | | one axis only |
| 20 | | DDSC | Navtrol | 4.5x5.1x1 | 2 | 3.7 | | one axis only |
| 21 | | Housekeeping | ERIM | 7x7x0.75 | 1.1 | 3 | 5 | logic |
| 22 | | Housekeeping | ERIM | 7x7x0.75 | 1.1 | 2 | 5 | analog |
| 23 | | Power Dist | ERIM | 7x7x1.25 | 2.2 | 2 | 2 | converter los |
| 24 | | connec.bracke | ERIM | | tbd | | | |
| 25 | | harness | ERIM | | tbd | | | |
| 26 | | hardware | | | tbd | | | |
| 27 | | | | | | | | |
| 28 | | SUBTOTAL | | | 10.4 | 18.1 | | |
| 29 | | | | | | | | |
| 30 | | TOTAL | | | 22 | 32.8 | | |

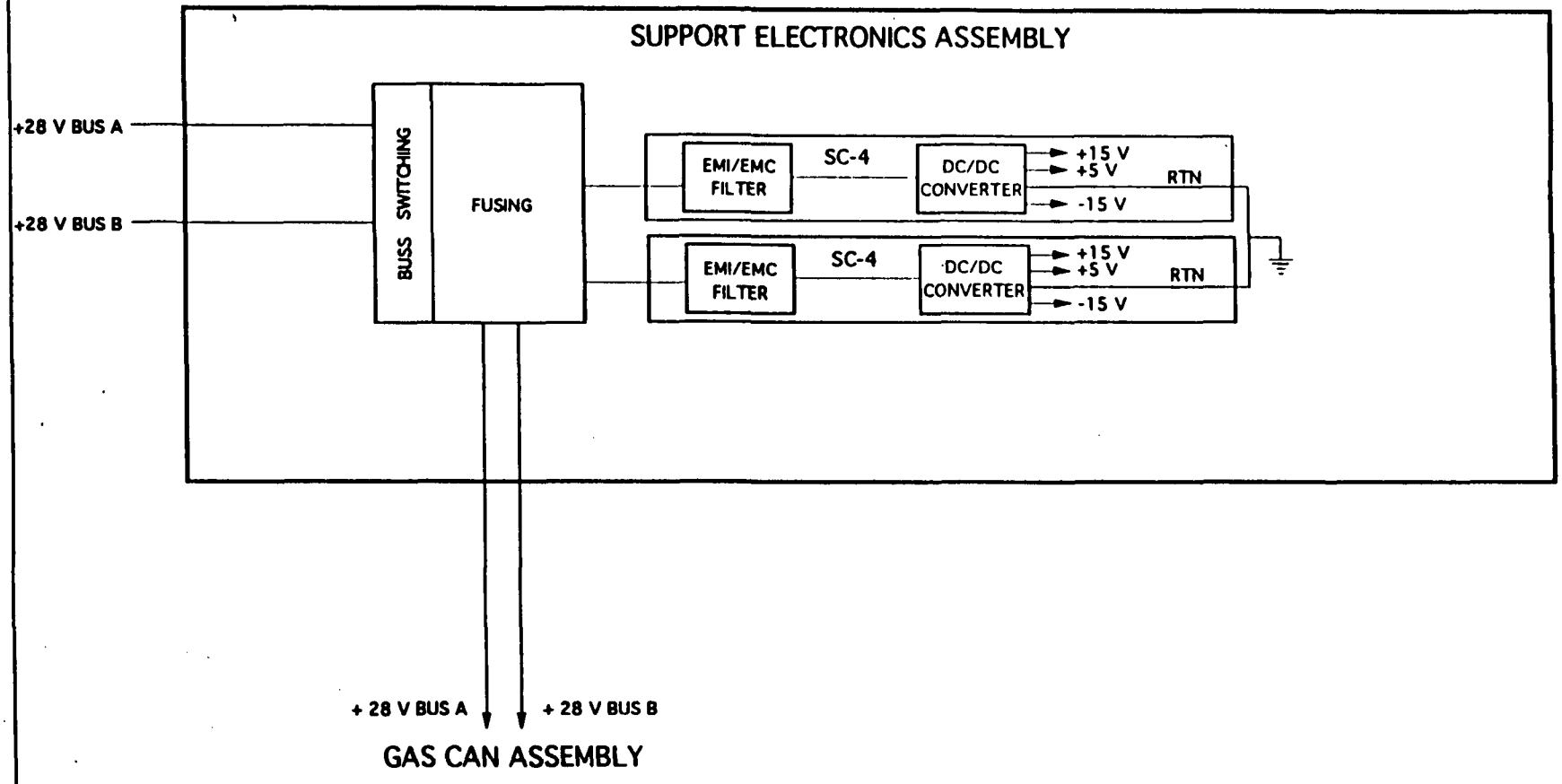

HITCHHIKER AVIONICS PLATE
GAS CANISTER
HOUSEKEEPING DATA SERIAL
NAVTROL BUS
+28V
TEMPERATURE SIGNALS
HITCHHIKER TEMPERATURE SIGNALS
Electronics Stack A
MONITORS
TELEMETRY
HITCHHIKER UNIQUE INTERFACE
NAVTROL CONTROLLER
POWER DISTRIBUTION
RT
BUS PROTECTION EMI/EMC
AUTOMATION MANAGEMENT SUPERVISOR
SERIAL
Spacecraft Command Language®
RS422
RT
RS422
RS422
EasyLab®
RT
HITCHHIKER
BILEVEL COMMANDS
SERIAL COMMANDS & TELEMETRY
+28V
TEMPERATURE SIGNALS
HT
BASEPLATE
HT HITCHHIKER TEMPERATURE SENSOR
RT RoMPS TEMPERATURE SENSOR
ENGINEER M.F. DOBBS
SPACE AUTOMATION & ROBOTICS CENTER
ENVIRONMENTAL RESEARCH INSTITUTE of MI
ANN ARBOR, MI
DRAFTSMAN G. WASSICK
Block Diagram 2/2
SEA Subsystem
RoMPS
010-339
07/02/91
DATE

1.2.2

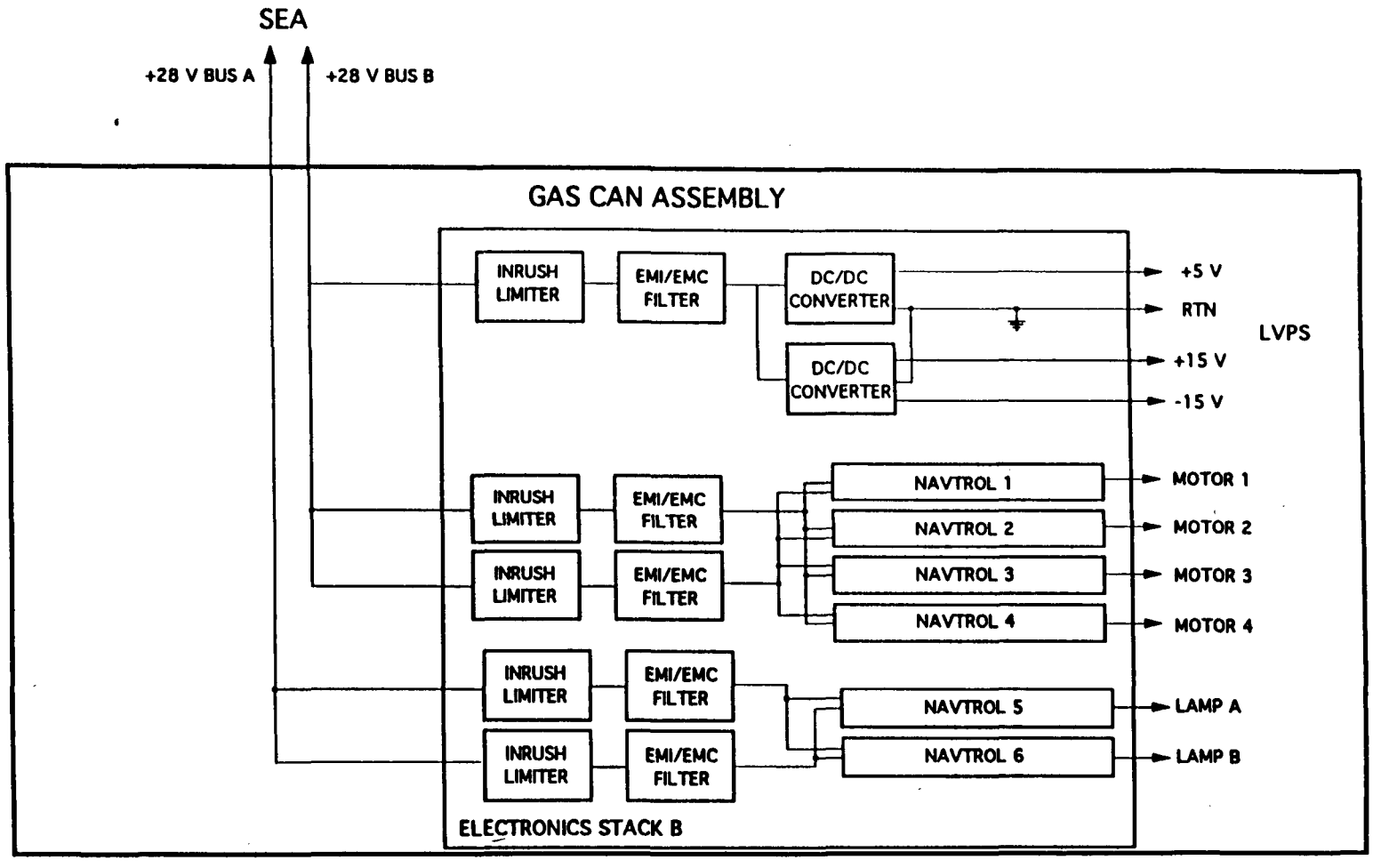
## Hitchhiker Interface Subsystem

- Flight Hardware
  - power switching and bus protection
  - serial interface receivers and drivers
  - HH command packet protocol processing
  - telemetry packet generation
  - health and safety monitors

- Ground Support Equipment & Operations Console
  - customer ground support equipment
    - command generation
      - script development
      - process development
    - telemetry processing
      - archiving
      - engineering unit conversion
      - parameter limit checking
  - investigator operations console



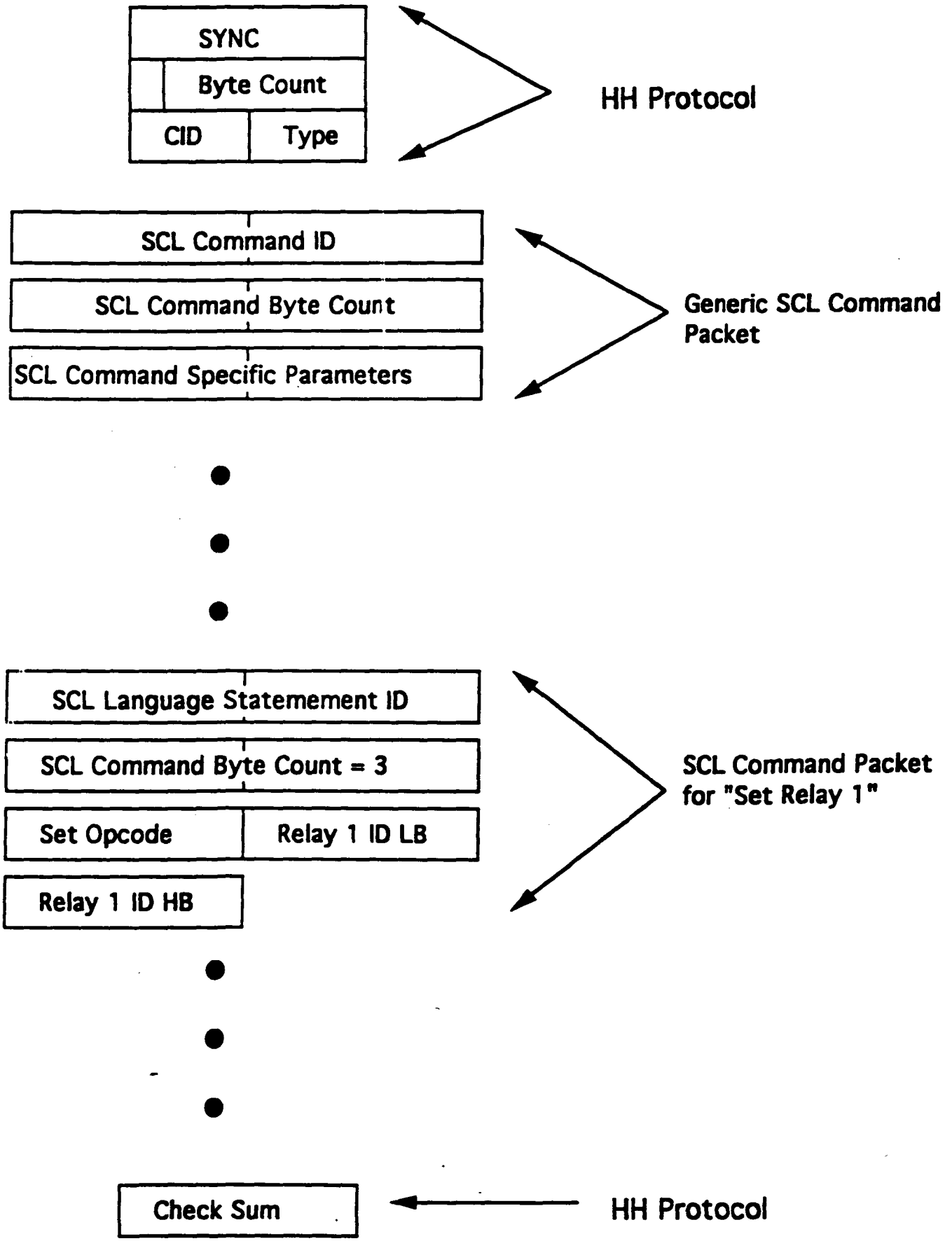

| | | |
|---|---|---|
| ENGINEER M. E. Dobbs | DRAFTSMAN | |
| | SEA | |
| SPACE AUTOMATION & ROBOTICS CENTER<br>ENVIRONMENTAL RESEARCH INSTITUTE of MI<br>ANN ARBOR, MI | Power Distribution Block Diagram<br>ROMPS<br>010-341 | 10/10/91<br>05/14/91<br>DATE |



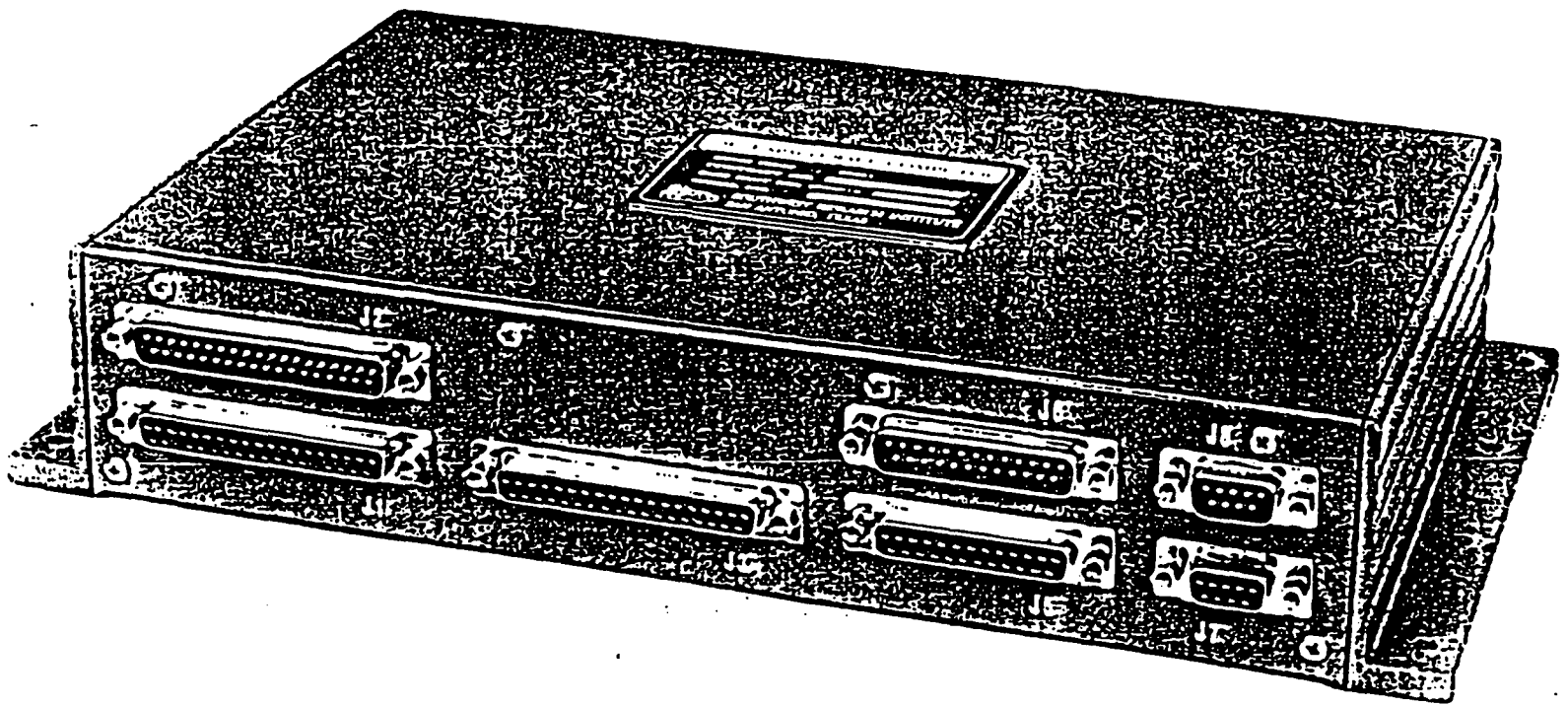

| | | |
|---|---|---|
| ENGINEER M.F. DOBBS | DRAFTSMAN | |
| SPACE AUTOMATION & ROBOTICS CENTER<br>ENVIRONMENTAL RESEARCH INSTITUTE of MI<br>ANN ARBOR, MI | GAS Can Assembly<br>Power Distribution Block Diagram<br>RoMPS<br>010-345 | 10/10/92<br>07/17/91<br>DATE |

17.0.2

# SCL Uplink Packet Definition



| | A | B | C | D | E |
|---|---|---|---|---|---|
| 1 | RoMPS Telemetry | | | | |
| 2 | Function | Description | Length | Rate | Comment |
| 3 | | | | | |
| 4 | Frame Header | sync | 2 | 1 | |
| 5 | | sync/id | 2 | 1 | |
| 6 | | | | | |
| 7 | RTE Packet | id, etc | 2 | 1 | |
| 8 | | rte state | 2 | 1 | |
| 9 | | agenda status | 2 | 1 | |
| 10 | | script status | 10 | 1 | |
| 11 | | script status | 10 | 1 | |
| 12 | | | | | |
| 13 | DUMP Packet | id/len | 4 | 1 | |
| 14 | | sample id | 2 | 1 | |
| 15 | | process id | 2 | 1 | |
| 16 | | sample temp | 2 | 1 | |
| 17 | | lamp intensit | 2 | 1 | |
| 18 | | lamp intensit | 2 | 1 | |
| 19 | | lamp intensit | 2 | 1 | |
| 20 | | lamp intensit | 2 | 1 | |
| 21 | | lamp current | 2 | 1 | |
| 22 | | elevation | 2 | 1 | |
| 23 | | theta | 2 | 1 | |
| 24 | | radial | 2 | 1 | |
| 25 | | grip | 2 | 1 | |
| 26 | | force | 2 | 1 | |
| 27 | | exp. current | 2 | 1 | |
| 28 | | eot status | 2 | 1 | |
| 29 | | error reports | 10 | 1 | 5 maximum |
| 30 | | housekeeping | 16 | 1 | 8 maximum |
| 31 | | | | | |
| 32 | TOTAL | | 90 | | |
| 33 | BUDGET | | 120 | | 1200 baud |



| ENGINEER | DRAFTSMAN | |
|---|---|---|
| SPACE AUTOMATION & ROBOTICS CENTER<br>ENVIRONMENTAL RESEARCH INSTITUTE of MI<br>ANN ARBOR, MI | 010-132 | 08/08/91<br>DATE |

TABLE 1.2.2-1

Preliminary Specification
SC-4 Single Board Spacecraft Computer

| | |
|---|---|
| Central Processor | 80C186/80C187 16 Bit |
| Clock Frequency | 10 MHz |
| Operating System | MS-DOS and VRTX Compatible |
| Onboard Memory | |
| RAM | 512K Bytes w/EDC |
| EEPROM | 256K Bytes w/EDC |
| UVPROM | 640K Bytes w/EDC |
| Hardware Vectored Interrupts | 16 User Configurable |
| Timer/Event Counters | 8, Software Configurable, 120 ns Granularity |
| Input/Output Capability | |
| Parallel I/O | 16 Input, 16 Output |
| Analog Input | 32 Channels, 12-bit Resolution |
| Analog Output | 4 Channels, 12-bit Resolution |
| RS-422 Serial I/O | 2 Channels |
| SCSI Interface | 1 Port |
| Software Controlled Power Switch | 4 Each |
| Mass Storage | 24M Bytes, Read/Write Non-volatile with Additional Battery |
| Expansion | Internal Daughterboard Connector |
| Size | 7.25 X 12 X 2.25 in |
| Weight | 3.7 Lb (Approximate) |
| Power | 28v @ 5w (Approximate) |

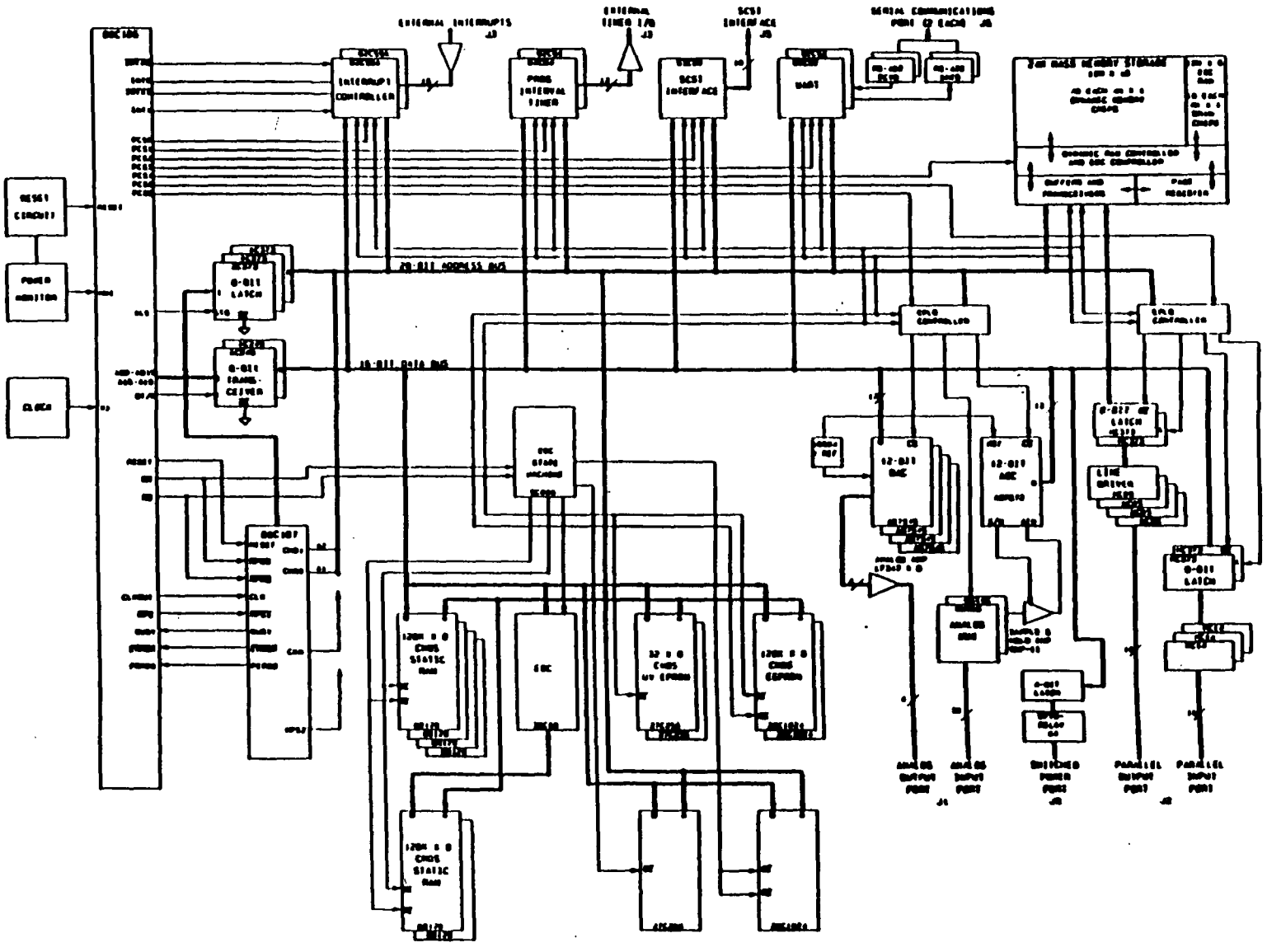


Figure 3.2-1 SC-4 Single Board Spacecraft Computer Block Diagram

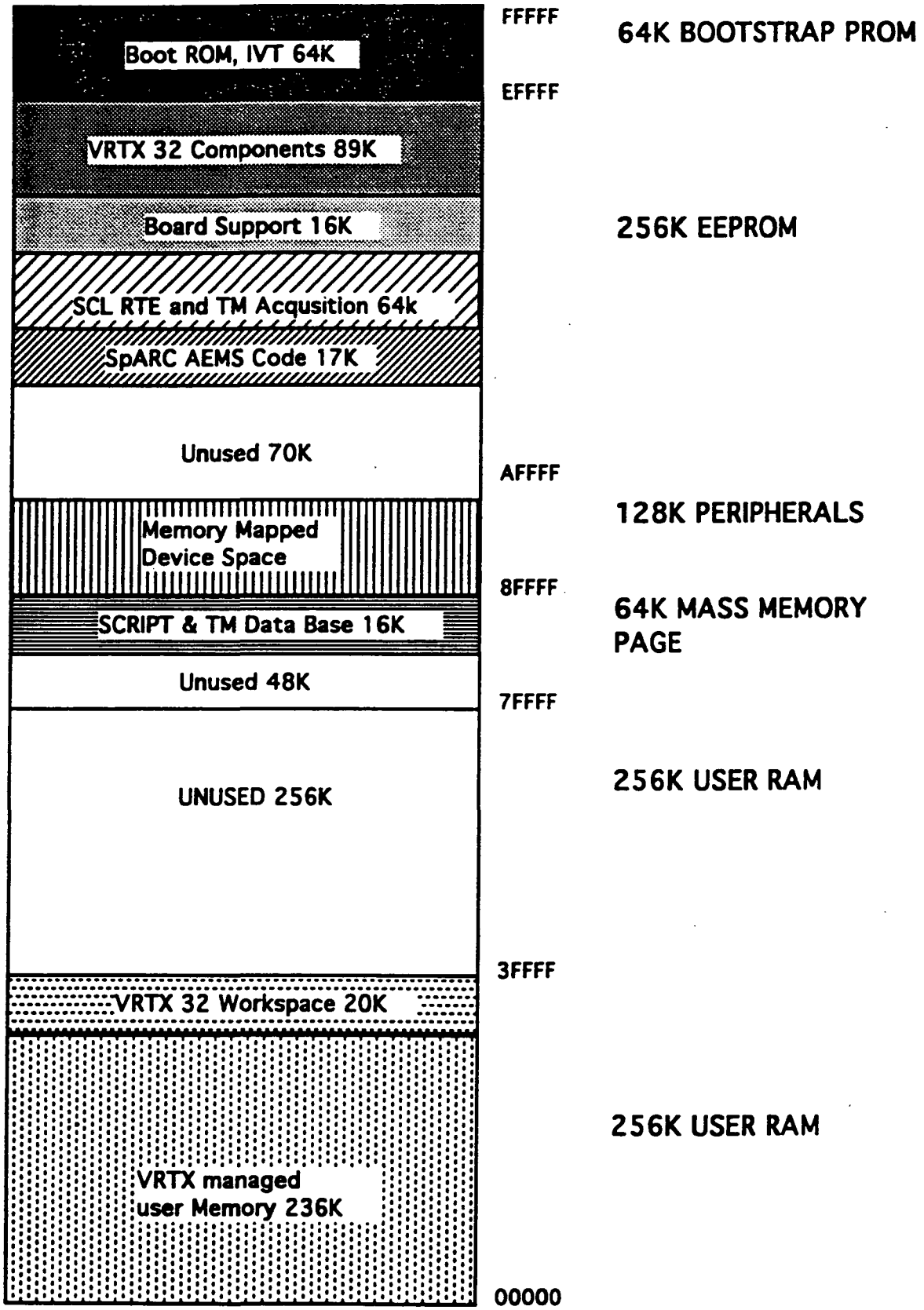
# RoMPS AMS Software Summary

| MODULE | VENDOR | FUNCTION | LANGUAGE |
|---|---|---|---|
| VRTX-32 | Ready Systems | Real Time Executive | "C", Assembler |
| RTL/86 VRTX-32 | Ready Systems | "C" Reentrent Run Time Library Interface | "C", Assembler |
| RT-SCOPE | Ready Systems | System Monitor, Debugger | "C", Assembler |
| RTL/86 RT-SCOPE | Ready Systems | "C" Language Interface to RT-SCOPE | "C", Assembler |
| SC-4 Board Support Package | ICS/SpARC | Interface Between VRTX and SC-4 Devices | "C", Assembler |
| Command Input | SpARC | Get Command Packets from HH Avionics | "C" |
| Zymate Interface | SpARC | SCL to Zymate Interface | "C" |
| Telemetry Acquistion | SpARC | Acquire the Data of the Telemetry Items and forward to Telemetry Reduction | "C" |
| Telemetry Output | SpARC | Format and send telemetry | "C" |

# RoMPS AMS Software Summary

| MODULE | VENDOR | FUNCTION | LANGUAGE |
|---|---|---|---|
| SCL RTE | ICS | SCL Command Interpreter and Rules evaluation | "C" |
| Telemetry Reduction | ICS | Monitor Telemetry and post detected changes | "C" |
| Processing Scheduler | SpARC | Scheduled execution of scripts initiating EasyLab processing programs | SCL |
| Initiate Sample Processing | SpARC | Sends the EasyLab commands initiating sample processing | SCL |
| Initialize / Shutdown EasyLab | SpARC | Sends the EasyLab commands initiating/shutting down EasyLab | SCL |
| Send EasyLab Commnad | SpARC | Send an EasyLab Command | SCL |

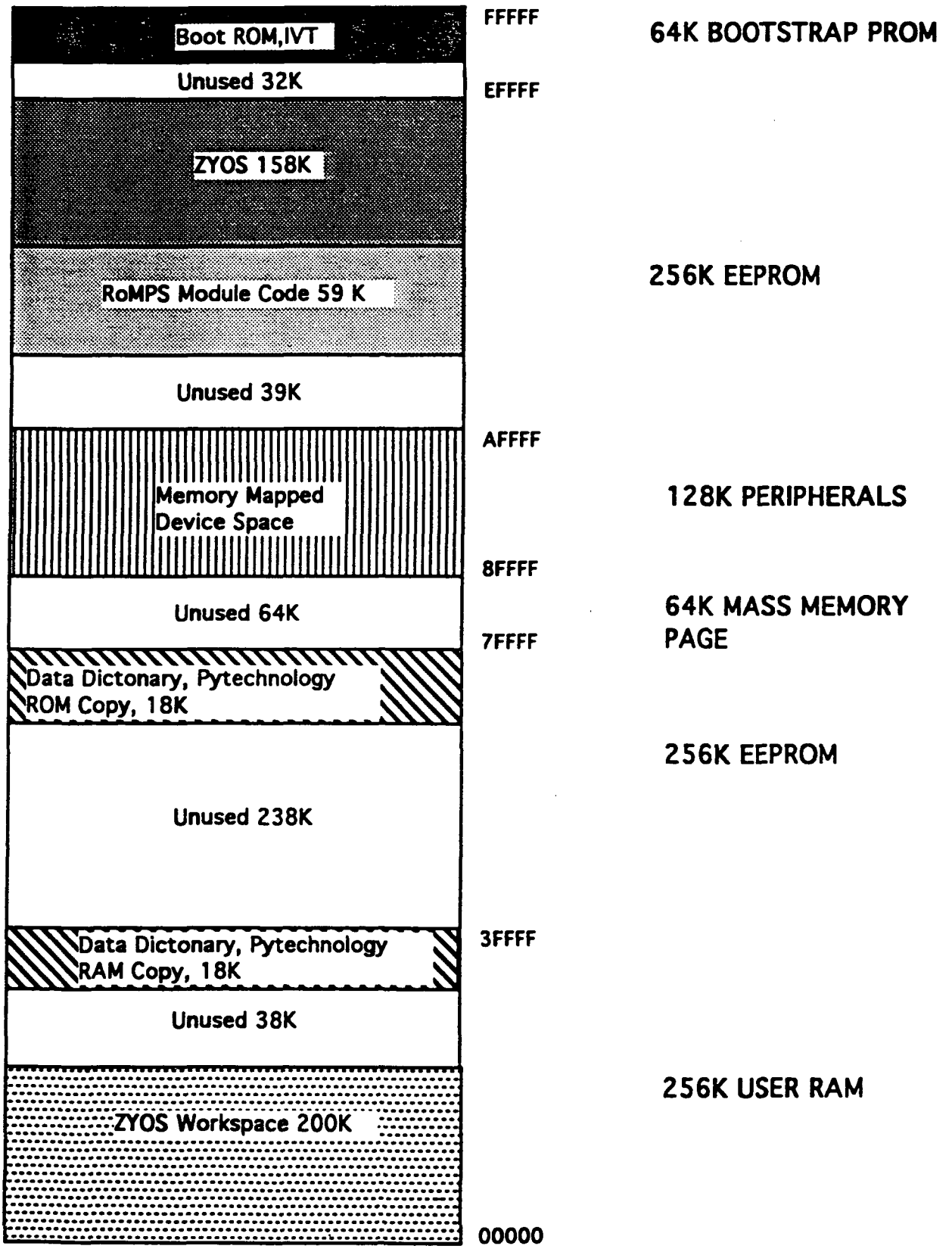
# AMS Memory Map



# RoMPS SC-4 EasyLab Software Summary

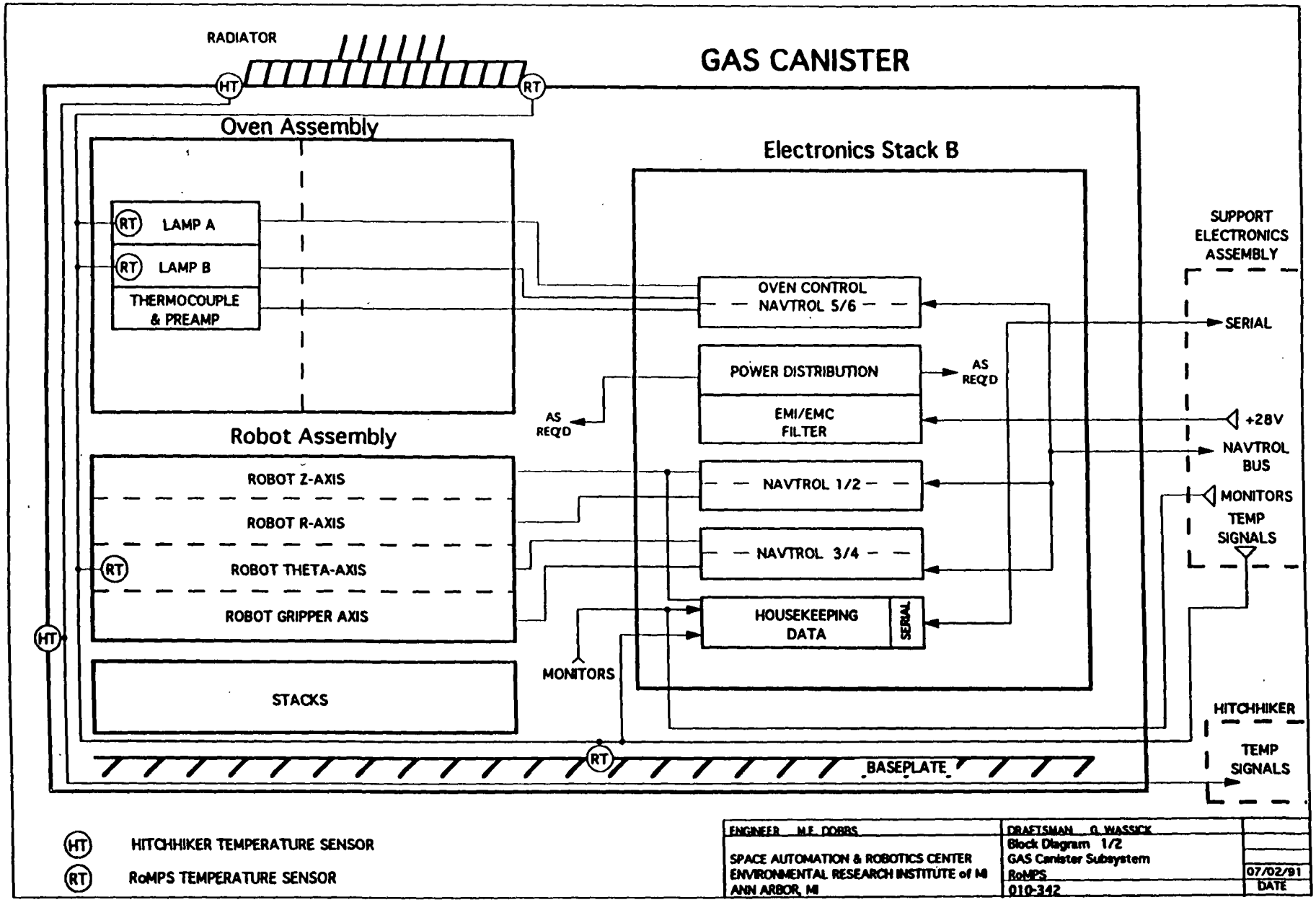
| MODULE | VENDOR | FUNCTION | LANGUAGE |
|---|---|---|---|
| ZYOS | Zymark | Zymate Operating System | "C", PLM 86 |
| Boot ROM | Zymark | Operating System Initialization | "C", PLM 86 |
| Robot Module | SpARC | High level robot controller and servo interface | "C" |
| Annealer Module | SpARC | Oven controller interface | "C" |
| Annealer PyTechnology | SpARC | Annealer control variables and navigation routines | EasyLab |
| Rack Pytechnology | SpARC | Rack navigation routines and variables | EasyLab |
| Robot PyTechnology | SpARC | Robot control and navigation variables | EasyLab |

# SC-4 EasyLab System Memory Map



## Processor Utilization

- RoMPS sample thruput limited by annealing time
- Spacecraft Command Language
  Compiled script 300 lines/second
- EasyLab
  Interpreted procedure 10 lines/second
- Memory Margin 37 %


GAS CANISTER
RADIATOR
HT
RT
Oven Assembly
LAMP A
LAMP B
THERMOCOUPLE & PREAMP
Electronics Stack B
OVEN CONTROL NAVTROL 5/6
POWER DISTRIBUTION
EMI/EMC FILTER
NAVTROL 1/2
NAVTROL 3/4
HOUSEKEEPING DATA
SERIAL
AS REQ'D
AS REQ'D
Robot Assembly
ROBOT Z-AXIS
ROBOT R-AXIS
ROBOT THETA-AXIS
ROBOT GRIPPER AXIS
STACKS
MONITORS
SUPPORT ELECTRONICS ASSEMBLY
SERIAL
+28V
NAVTROL BUS
MONITORS
TEMP SIGNALS
HITCHHIKER
TEMP SIGNALS
BASEPLATE
HT HITCHHIKER TEMPERATURE SENSOR
RT RoMPS TEMPERATURE SENSOR
ENGINEER M.E. DOBBS
SPACE AUTOMATION & ROBOTICS CENTER
ENVIRONMENTAL RESEARCH INSTITUTE of MI
ANN ARBOR, MI
DRAFTSMAN G. WASSICK
Block Diagram 1/2
GAS Canister Subsystem
RoMPS
010-342
07/02/91
DATE

## Robot Control Subsystems

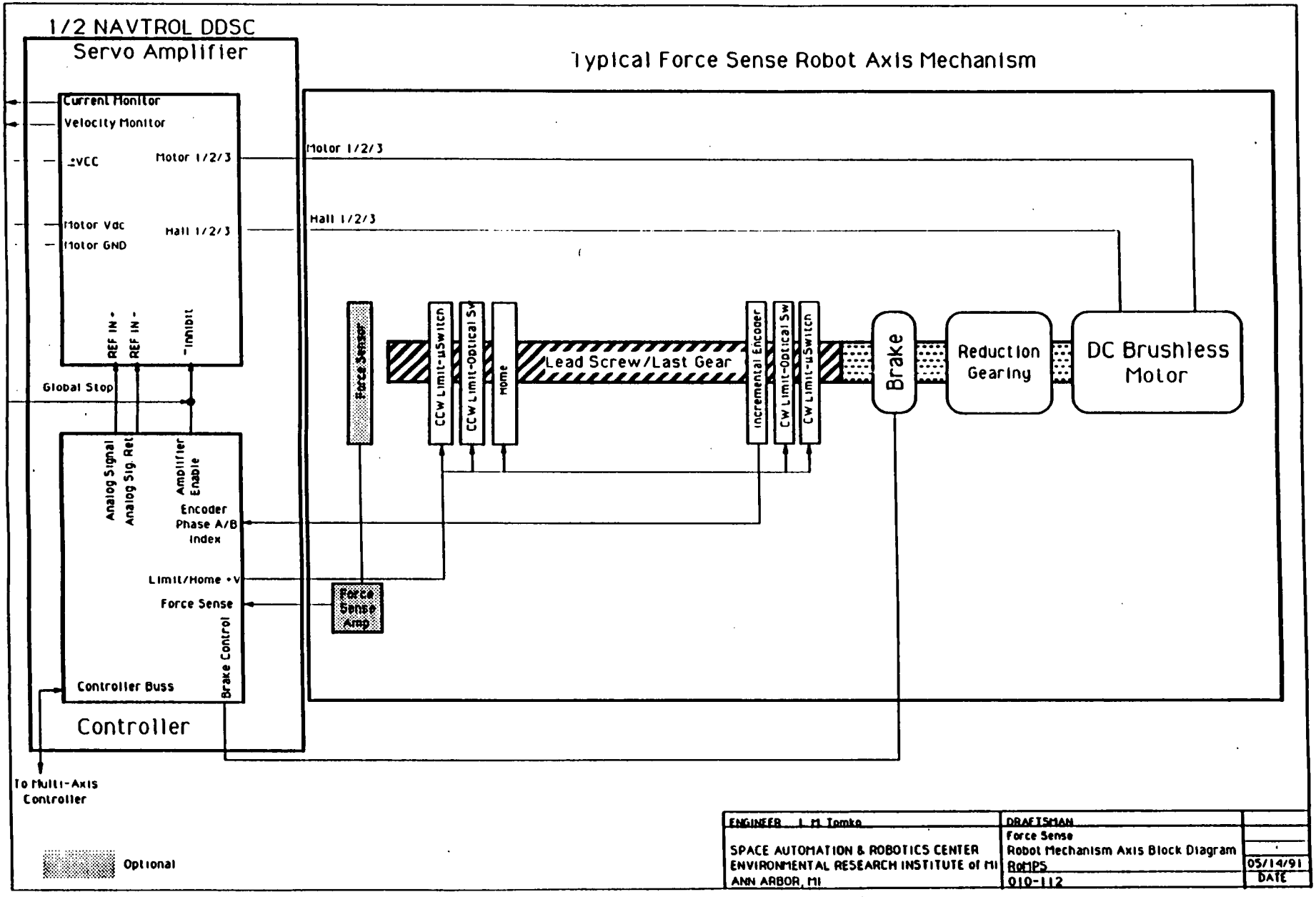
- 4 Degree-Of-Freedom Material Processing Robot
  - elevation, azimuth, reach, gripper axis
    - brushless dc motors
    - hall effect commutation
    - normally-on electrical brakes
    - quadrature output incremental position encoders
    - end-of-travel fiducials
    - current or force limited
    - compliant gripper
  - sequential operation

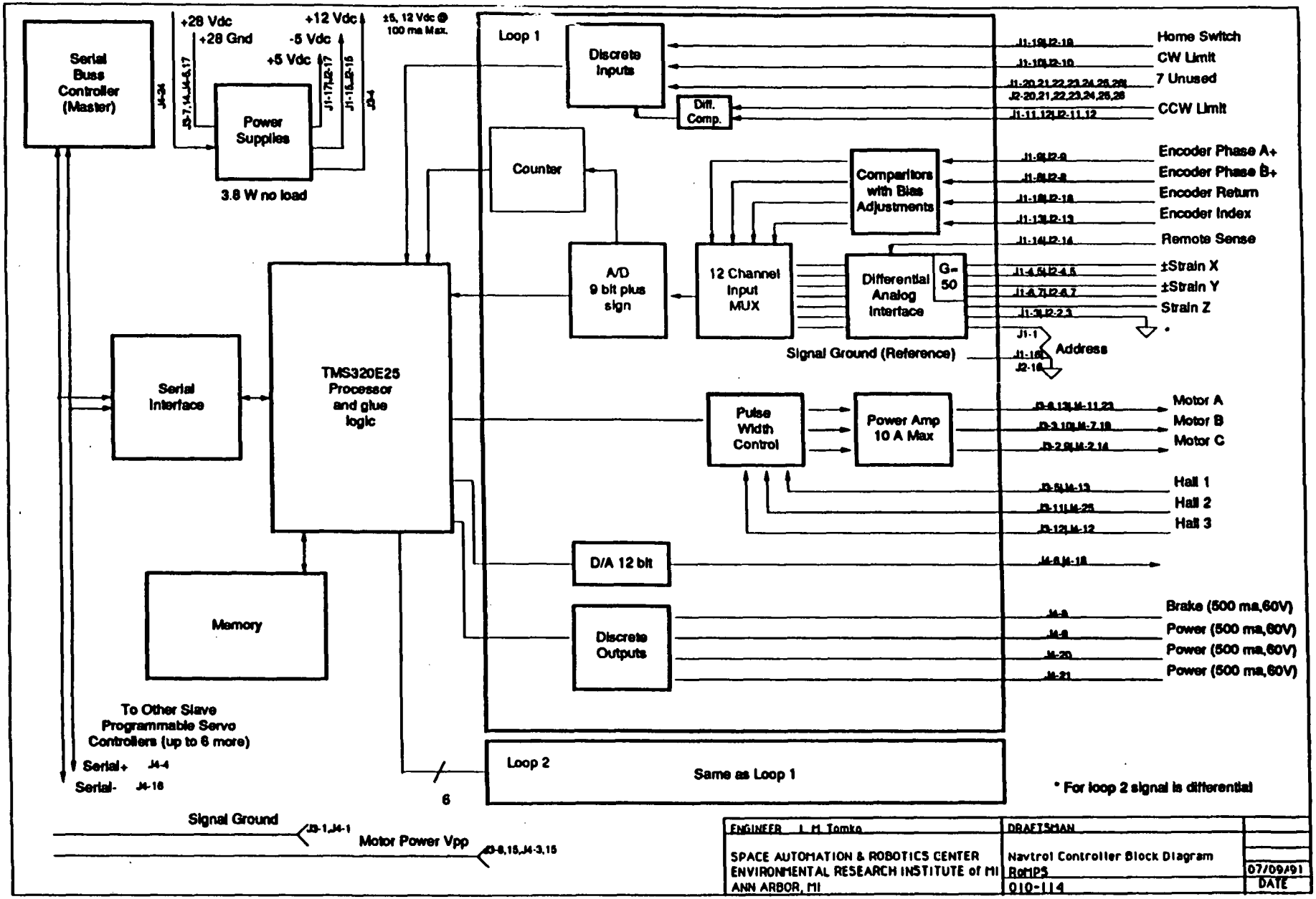
- Digital Servo Position Control

| | |
|---|---|
| positioning accuracy | +- 0.025 inch |
| velocity range | 0.1 to 2.0 inches/sec |
| force limiting | +- 1 lbf |

  - Proportional-Integral-Deriviative algorithm
  - <5 msec control loop cycle time

- PWM Drive Amplifier
  - chassis isolated output stage
  - 32 volt maximum phase voltage
  - 10 amp maximum phase current
  - fold-back current limiting
  - over-temperature protection
  - output inhibit



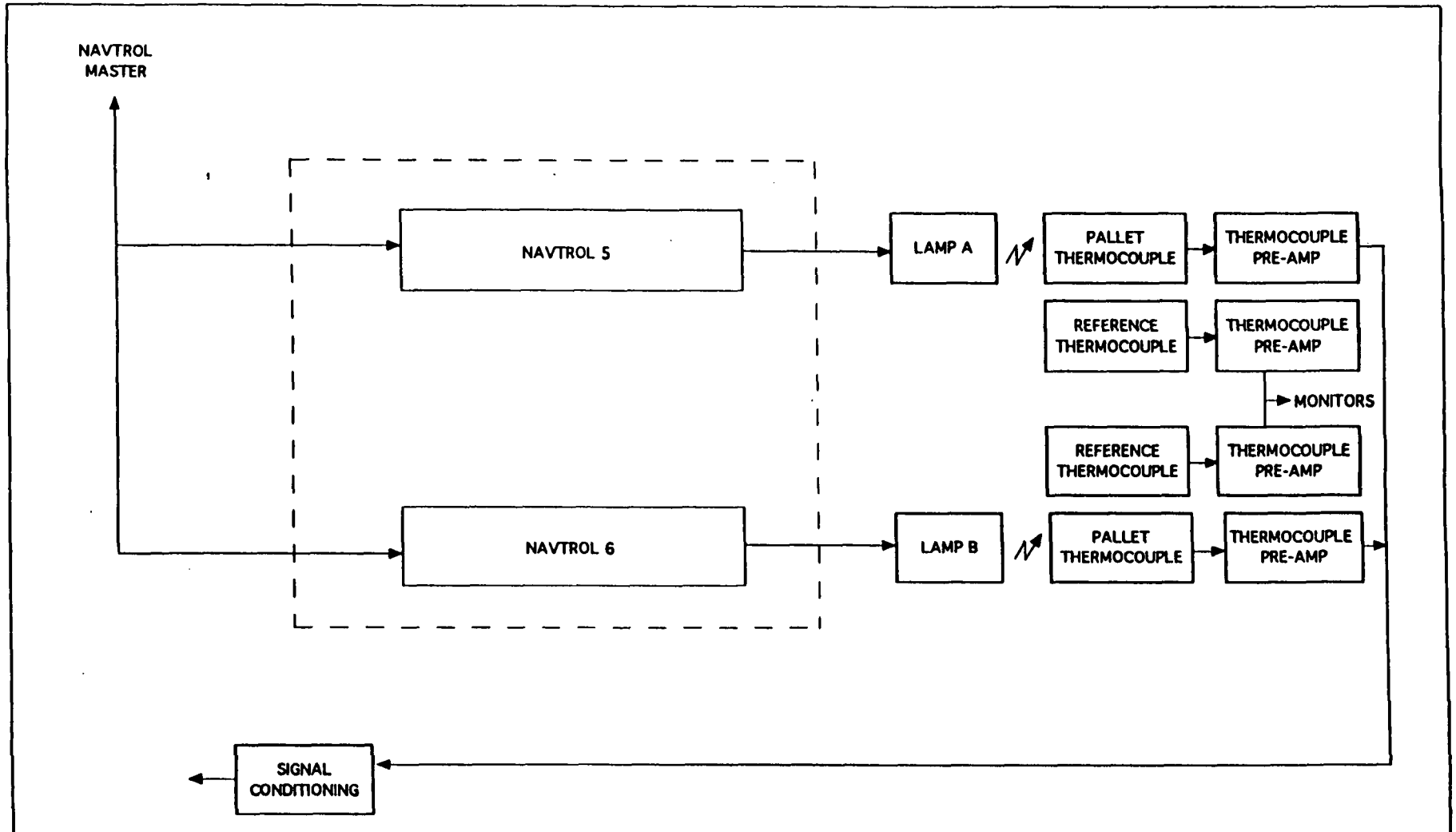


# Servo Axis Control Logic Suppliers

| Functional Characteristic | Navtrol | Zymark | Industrial | uC |
|---|---|---|---|---|
| control algorithm | custom | custom | pid | pid |
| control loop rate | 1.6 ms | 5 ms | 5 ms | 5ms |
| number of channels/unit | 2 | 6 | 1 | 1 |
| commandable pid parameters | no, ucode | rom'd | yes | yes |
| traje | ctory mode | yes | no | no |
| cpu | 32020 | 80186 | several | NEC |
| embedded code rom'd | no | yes | yes | yes |
| edc ram | no | no | no | no |
| position detection | pot,incr | pot+incr | incr. | incr. |
| auxilary inputs/outputs | yes/yes | yes/no | yes/yes | yes/no |
| standard functions | no | yes | yes | yes |
| interface library | no | yes | yes | yes |
| host i/o | AT bus | rs422 | rs422 | parallel |
| printed circuit board | smc | dip | dip | smc |
| temperature range | industrial | industrial | industrial | industrial |
| 883 | no | no | no | no |
| 883 available 1:1 | no | yes | no | no |
| industrial heritage | no | 1800 units | yes | yes |
| flight heritage | pending | no | no | no |
| industrial cost | 5k | tbd | 2.5k | 0.25k |
| mil-spec cost | na | na | na | na |
| 883B cost | >200k | >50k? | na | na |

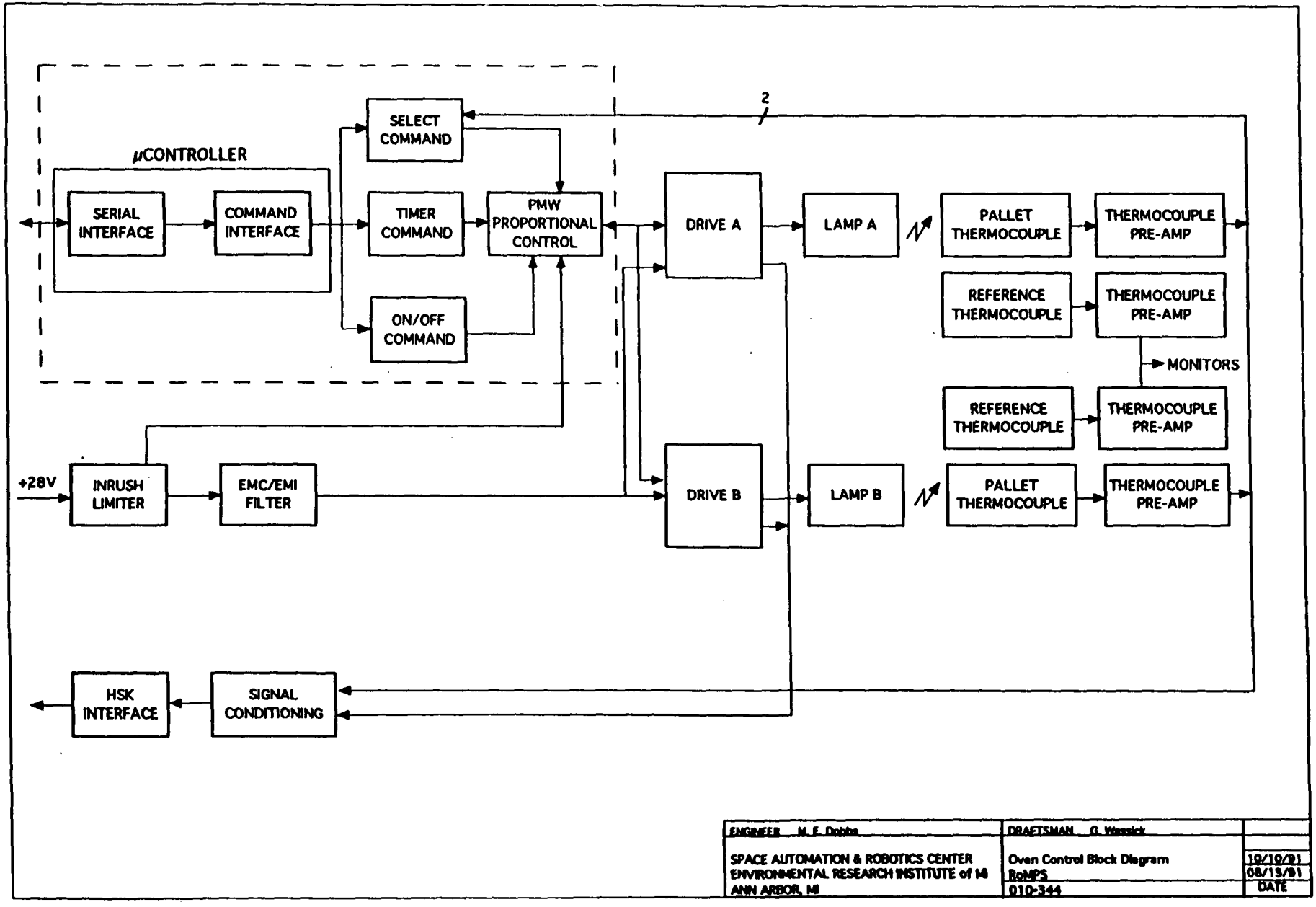
# Annealing Oven Control Subsystem

- Interfaces
  - Control — serial interface
  - Feedback — conditioned thermcouple output
  - Output — quartz halogen filament lamp
  - Protection — filament inrush protection
- Power Requirements
  - Voltage — 24 volt rated lamp
  - Current — 10 amp maximum
- Temperature Set Point
  - Range — 350°C to 1500°C
  - Resolution — +- 2% of setpoint (6 bits)
  - Repeatability — +- 2% of setpoint (6 bits)
- Time Set Point
  - Range — 3 to 7200 seconds
  - Resolution — +- 1 second (software controlled)
- Response Time
  - limited by thermal coupling to sample
- Time Profile
  - 2 step time-temperature profile
    - 1) preheat, 2) melt




| | | |
|---|---|---|
| ENGINEER M. F. Dobbs | DRAFTSMAN G. Wassick | |
| SPACE AUTOMATION & ROBOTICS CENTER<br>ENVIRONMENTAL RESEARCH INSTITUTE of MI<br>ANN ARBOR, MI | Oven Control Block Diagram<br>RoMPS<br>010-343 | 08/13/91<br>DATE |

15.0A

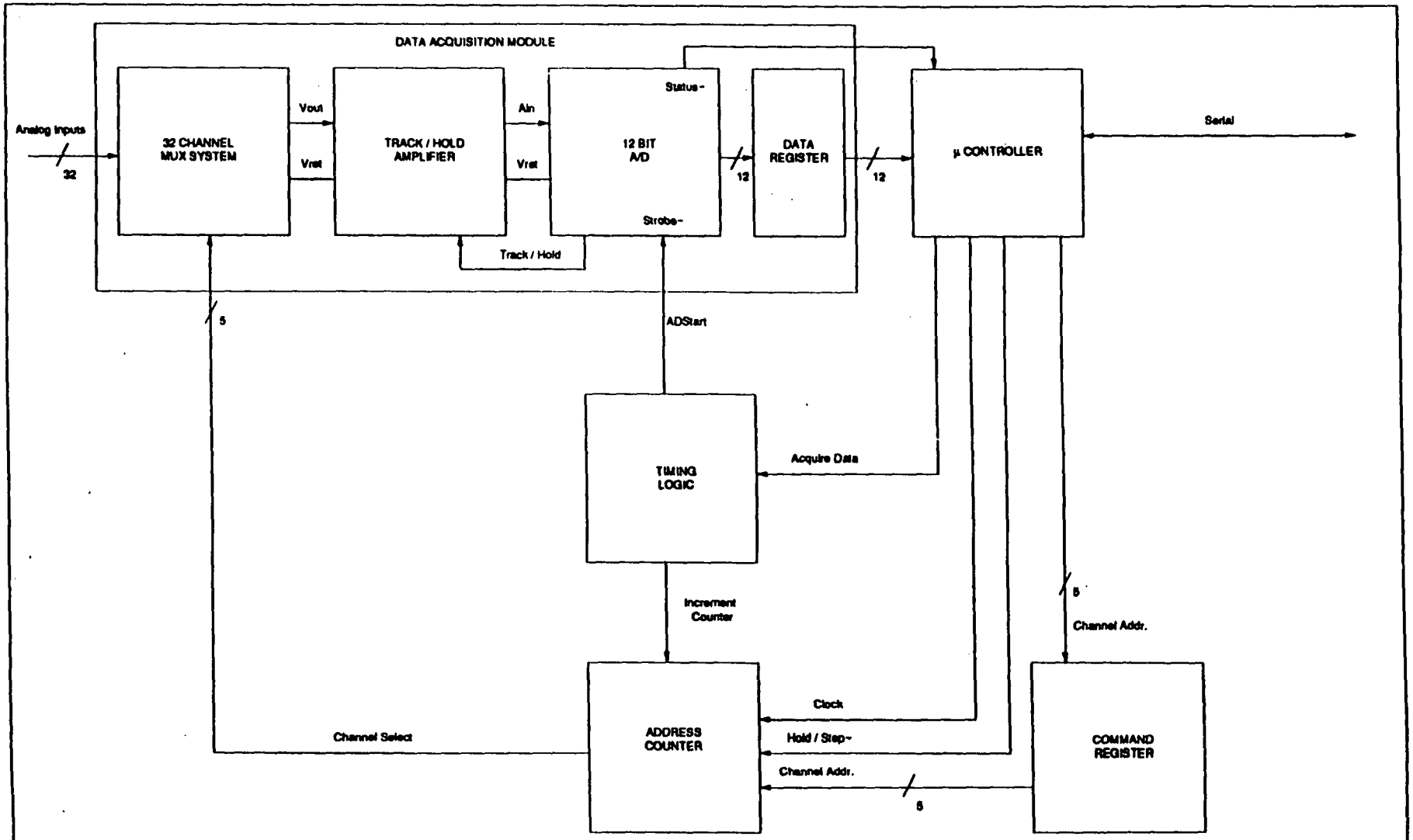



| | | |
|---|---|---|
| ENGINEER M. F. Dobbs | DRAFTSMAN G. Wenstick | |
| SPACE AUTOMATION & ROBOTICS CENTER<br>ENVIRONMENTAL RESEARCH INSTITUTE of MI<br>ANN ARBOR, MI | Oven Control Block Diagram<br>RoMPS<br>010-344 | 10/19/91<br>08/13/91<br>DATE |

15.0B

## Experiment Data Acquisition Subsystem

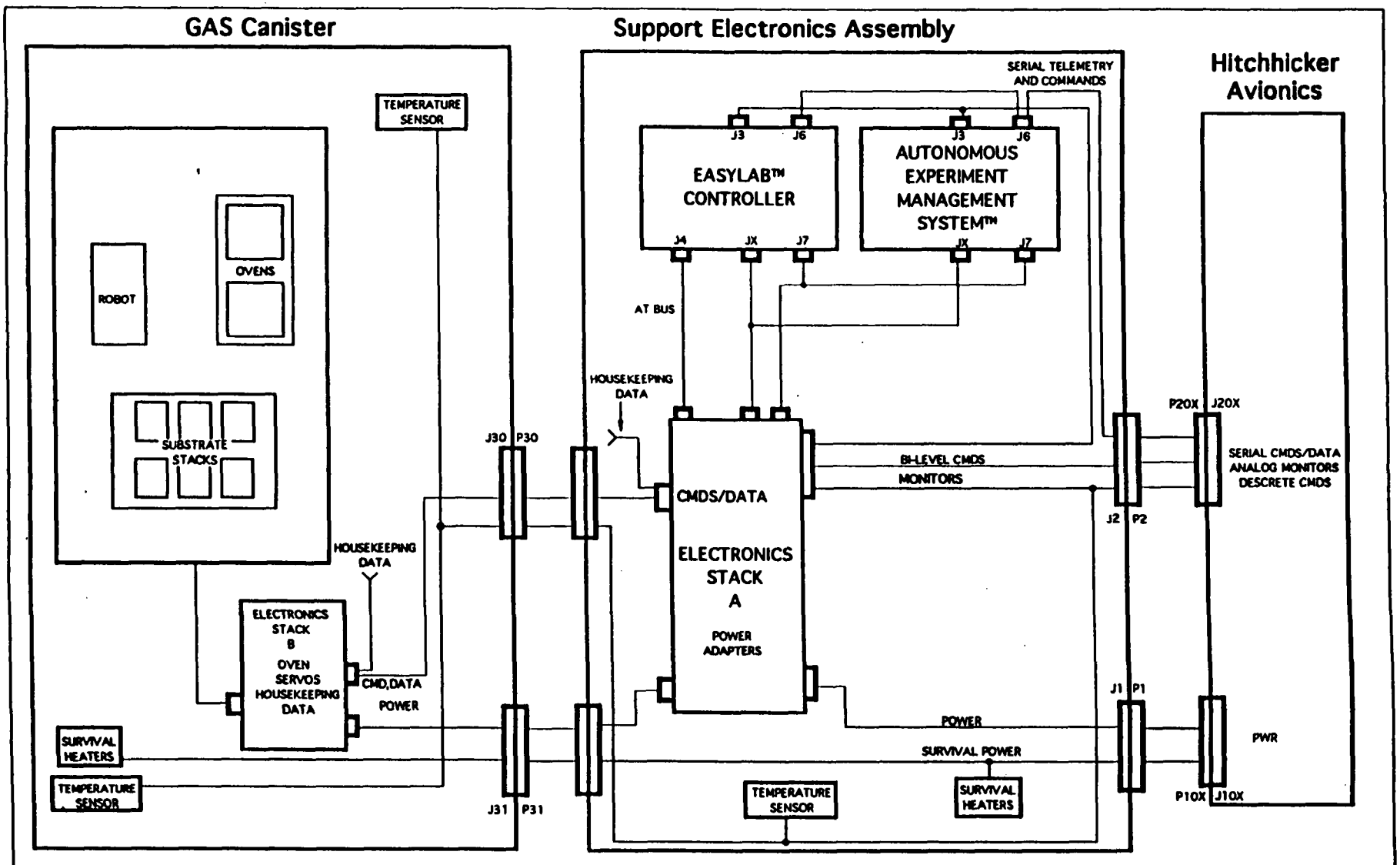
- RTA process monitor
  thermocouple lamp flux monitors
- Oven Status
  lamp current
- Robot Status
  4 axis position
  1 axis force
  EOT fiducials
  overtemp, current limit indicators
- Computer Status
  executive status
  script status
  rule evalutation
- Health and Safety Monitors
  radiator
  oven
  robot
  electronics stacks
  power supplies




| | | |
|---|---|---|
| ENGINEER I. M. Tomko | DRAFTSMAN | |
| SPACE AUTOMATION & ROBOTICS CENTER<br>ENVIRONMENTAL RESEARCH INSTITUTE of MI<br>ANN ARBOR, MI | Housekeeping Data Acquisition Block Diagram<br>RoMPS<br>010-338 | 10/10/91<br>07/16/91<br>DATE |

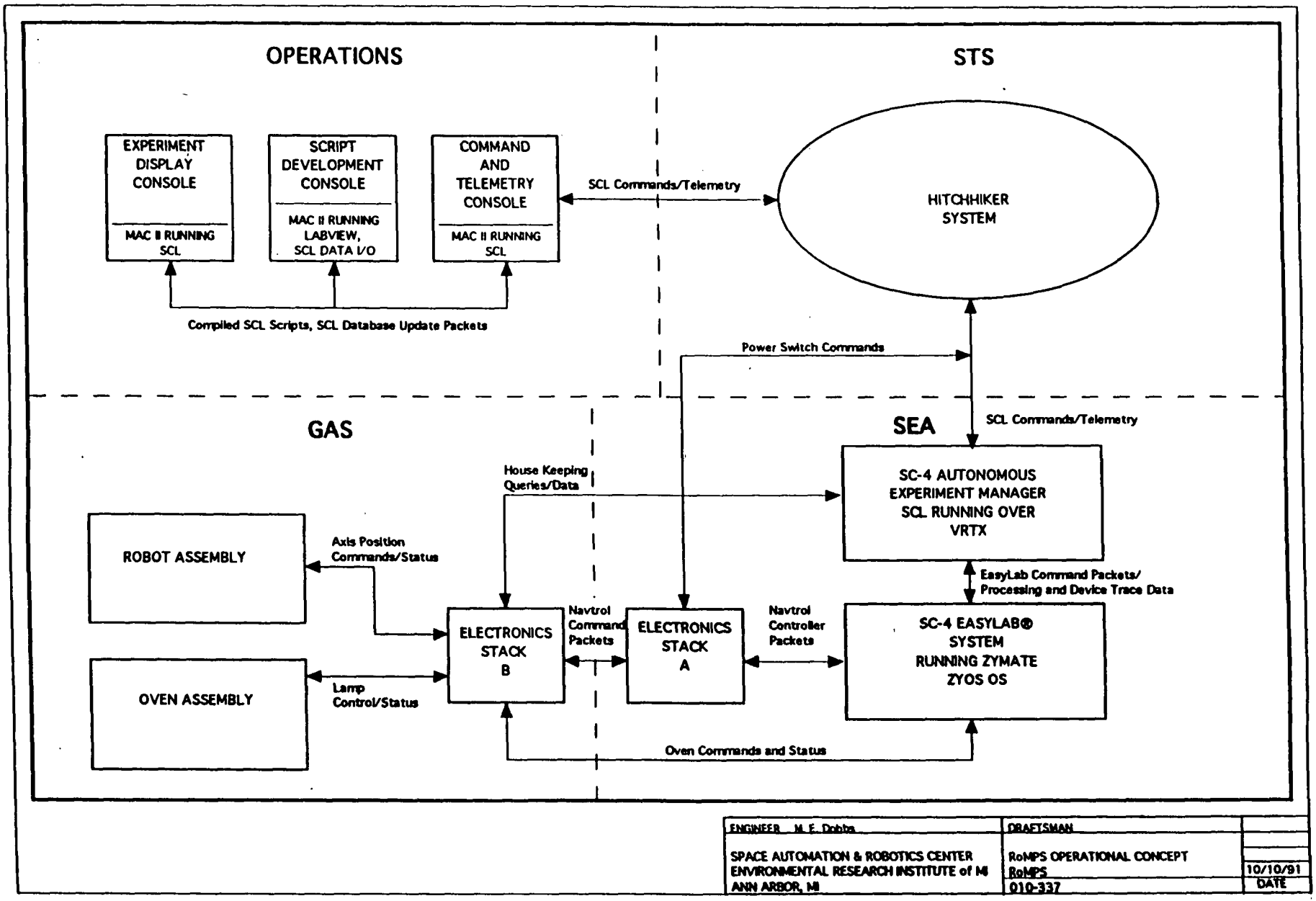
16.0.2

| | A | B | C | D | E |
|---|---|---|---|---|---|
| 1 | RoMPS Data Acquisition | | | | |
| 2 | Function | Description | Length | Rate | Comment |
| 3 | | | | | |
| 4 | | sample temp | 2 | 1 | process |
| 5 | | flux intensity | 2 | 1 | |
| 6 | | flux intensity | 2 | 1 | |
| 7 | | flux intensity | 2 | 1 | |
| 8 | | flux intensity | 2 | 1 | |
| 9 | | lamp current | 2 | 1 | |
| 10 | | force | 2 | 1 | robot |
| 11 | | eot status | 2 | 1 | |
| 12 | | exp. current | 2 | 1 | engineering |
| 13 | | elec temp | 2 | 1 | |
| 14 | | elec temp | 2 | 1 | |
| 15 | | radiator temp | 2 | 1 | |
| 16 | | oven temp | 2 | 1 | |
| 17 | | oven temp | 2 | 1 | |
| 18 | | robot temp | 2 | 1 | |
| 19 | | | | | |
| 20 | | | | | |
| 21 | | | | | |
| 22 | | | | | |
| 23 | | | | | |
| 24 | TOTAL | | 30 | | |




Note: The designation "P" means this connector is on the end of a cable.
The designation "J" means this connector is on a chassis mount connector.
PLUG JX IS 1553 OR nRS422

| | | |
|---|---|---|
| ENGINEER I. M. Tomko | DRAFTSMAN | |
| SPACE AUTOMATION & ROBOTICS CENTER | Interface Connectors | |
| ENVIRONMENTAL RESEARCH INSTITUTE of MI | Harnessing | 10/10/91 |
| ANN ARBOR, MI | RoMPS | 06/07/91 |
| | 010-140 | DATE |




| | | |
|---|---|---|
| ENGINEER M. F. Dobbs | DRAFTSMAN | |
| SPACE AUTOMATION & ROBOTICS CENTER<br>ENVIRONMENTAL RESEARCH INSTITUTE of MI<br>ANN ARBOR, MI | RoMPS OPERATIONAL CONCEPT<br>RoMPS<br>010-337 | 10/10/91<br>DATE |