AIAA 94-2626
The New Distributed Computerized Control System of the JPL 25-Ft. Space Simulator
Kenneth R. Johnson
Jet Propulsion Laboratory
4800 Oak Grove Drive
Pasadena, CA 91109-8099
USA

18th AIAA Aerospace Ground Testing Conference

June 20-23, 1994 / Colorado Springs, CO

For permission to copy or republish, contact the American Institute of Aeronautics and Astronautics
370 L'Enfant Promenade, S.W., Washington, D.C. 20024

THE NEW DISTRIBUTED COMPUTERIZED CONTROL of JPL's 25-FT Space Simulator

Abstract

A project to refurbish the JPL 25-FT Space Simulator facilities which began in May 1991 will be complete by **June 1994.** This project included the installation and implementation of a new distributed computerized control system using GE-Fanuc 90™-70 Programmable Local Controller (PLC) hardware and LogicMaster™ programming software. Vacuum, temperature, pressure and solar simulation control elements and instruments arc connected to modular GE-Fanuc Genius™ control blocks. The Genius blocks arc distributed among ten field-mounted Computer Control Stations (CCS), bussed to the Central Processing Unit (CPU) through seven separate Genius Networks (GENETS). Redundant CPUs, each connected to all field 1/0, were installed to provide continuous on-line backup control. A dedicated uninterruptable power supply feeds both CPU racks to maintain control even during power failure situations. Critical devices were wired in two separate GENETs to provide double redundancy, and thus, control surety. This paper will discuss the design, installation, startup, troubleshooting and current status of this new control system.

Introduction

The initial construction of JPL's 25-FT Space Simulator was completed in 1961 and included a control system which utilized technology current at that time, That initial control system was based on remotely-operated, centralized, hardwired controls using electromechanical relay logic with protective interlock circuitry. By the late 1980's, some replacement parts for this control system were becoming hard to find, especially the system-specific electromechanical relays. Additionally, PLC control systems which were introduced in the early 1970's, had become very feature-rich and reliable. Accordingly, it was decided to reconfigure the old control system with a new system based on remotely-operated, distributed PLC's using solid state relay logic with protective interlock circuitry.

After a review of existing market hardware, GE-Fanuc Genius equipment was selected, its self-diagnostic capabilities being one of the deciding factors in its selection, The Genius hardware was configured into seven separate networks, named GENETs, and each network was attached to two separate CPUs, one serving as the primary or main CPU and the other serving as a back-up. Both CPUS concurrently receive all inputs at all times. Figure 1 is a schematic which illustrates how the GENETs are configured within the 25-FT Space Simulator facility. Figure 2 shows how the GENETs are attached to the MAIN CPU RACK and the STANDBY CPU RACK. To insure against control failure of certain critical process system elements, control circuitry of these critical elements was wired in parallel to two separate GENETs, which in effect provides double redundant control for these elements. Thus, these critical elements would still operate if there was a simultaneous failure of a Genius block, a GENET and a CPU. Figure 3 presents one such configuration of this double redundant control.

Three separate new graphic control panels were fabricated and installed in the main control room to provide push-button control of system elements in the vacuum, the temperature, and the solar simulation control systems. These panels provide control and a complete view of the status of all facility system control elements.

The software application Wonderware was selected to develop computer graphic displays of control element status (open/closed; on/off, etc.). Wonderware provides a full set of tools for creating graphical representations of the various process elements and for linking field 1/0 so that process element status can be tracked. The software also provides the ability to adapt the graphical displays for cm-screen process control such that operators can control the various process elements either by the computer keyboard or by a mouse or other point-and-click device, For the JPL 2.5 FT Space Simulator, three separate control windows are planned, one each for vacuum, thermal, and solar simulation system control, At the time of this writing, these displays have not yet been created.

Vacuum System Operation Overview

A typical pumpdown of the 25-ft Space Simulator chamber begins by using a two-stage axial compressor to evacuate the chamber from atmospheric pressure to 7(I torr in about 10 minutes. For the next 60 minutes, a mechanical pumping system, consisting of four Stokes 1722HC small blower/mechanical pump combinations and two large Roots type blowers (Stokes 171 3), lowers the pressure to the 5×10^{-3} torr range. This phase of pumping is referred to as "roughing" and requires about 70 minutes. During the roughing period, a liquid nitrogen (LN2) cooled baffle (cryotrap) prevents mechanical pump oil vapors from backstreaming into the vacuum chamber. After each evacuation, this cryotrap is warmed to ambient temperature and residual condensate is drained.

When a vacuum of 5×10^{-3} torr has been attained, the roughing period is complete. At this point, a contamination plate is flooded with liquid nitrogen to further reduce the chamber pressure by removing water vapor, and, when the chamber vacuum begins to asymptote, the new high vacuum (hi-vat) valves, made by Torr-Vat, Inc, are opened. Ten new Cry-O-Vat 45,000 liter/see cryogenic pumps, which were pre-evacuated and pre-chilled prior to pumpdown, are available for use **in this final stage of evacuation.** When the hi-vat valves are opened the chamber pressure reaches 1x 10-5 torr within 20 minutes. Each of the new hi-vat valves have a dedicated 100 psig air accumulator which contains enough pressure for three valve strokes - close/open /close. Therefore, even if all control systems fail, the chamber can still be isolated manually using hi-vat valve accumulators,

After the hi-vat valves have been opened and the chamber pressure begins to asymptote, the wall and floor shrouds are chilled with cold GN2 then flooded with LN2 to lower the vacuum pressure to the mid-10-6 t orr range, the minimum chamber pressure obtained with this system. Typically, an additional hour or more is required to reach the lowest asymptotic vacuum.

Two new Balzer 2200 liter/see turbomolecular pumps have been installed to be used when high loads of helium or hydrogen are encountered. Also, these pumps can be used for detecting leaks in the chamber and its nitrogen shrouds.

Thermal System Operation Overview

Temperature control of the space simulator chamber shrouds and mirror is achieved using GN2 and LN2 feed systems, to produce a temperature-controlled stream which is circulated through the shrouds and mirror to maintain specific test temperature conditions. For most thermal-vacuum testing, the chamber shrouds are filled (flooded) with LN2 to minimize chamber temperature and vacuum conditions. Also, LN2 is used to chill and GN2 is used to warm the cryopump baffles, the contamination plate and the cryotrap.

Solar Simulation System Operation Overview

The solar simulation system consists of 37 water-cooled xenon arc lamps each operating nominally at 30 kW and controlled by one of 37 new electric power supplies, an integrated lens unit which condenses then projects the light from the lamps, a chamber penetration window of fused silica which transmits the projected light into the chamber, and a 23-Ft diameter spherically-radiused collimator mirror which receives the projected light and reflects it as a uniform collimated beam onto the test article surface.

Control System Specifics

The GE-Fanuc Automation Series 90-70 PLC system provides a wide selection of control 90-70 PLC Modules, Genius Blocks and programming software with which to configure a control system. The JPL 25-ft Space Simulator installation utilized 17 different Modules and 5 different Blocks. Modules were mounted in 90-70 PLC 9-Slot Racks while Blocks were mounted in CCS Hoffman electrical boxes. All field 1/0 was connected to either a Module or a Block. Table 1 presents identifications of the modules and blocks used in this project. Table 2 shows the I'LC Module configuration in each of the 1790-70 PLC 9-Slot Racks. Table 3 lists the Genius Blocks and their associated GENET/Block# designations for all Blocks that are mounted in the field CCS 1 Hoffman boxes. Figure 3 illustrates how a typical Genius Block network is connected. In Table 3, the asterisk designates those Blocks which are redudant in two separate GENETS. Figure 4 shows an example of a typical redundant wiring arrangement for critical valves. Table 4 gives the Lamp Power Supply GENET/Block# designations. Finally, Table 5 presents a cross reference of GENET/Block# identification with respect to field location.

Programming of the control system logic was done using Logicmaster™ 90-70 Programming Software. Keyboard function keys (F!, F2, etc.) are used to select menu choices which are provided in several embedded layers. There are nine primary ladder logic program elemental functions: relay, timer/counter, math, relational, bit operation, data move, table, conversion and control. There are 28 different relay functions, 19 math functions, 7 relational functions and 13 bit operations operable on 11 data types. This thorough toolbox provides options for almost any conceivable control requirement.

Control device status or reference table information is displayed with the prefix %I for discrete inputs, %Q for discrete outputs, %M for discrete internal coils, %T for discrete temporary coils, %R for system registers, %AI for analog input, %AQ for analog output, %P for program registers, %L for local registers and %GA for discrete global data. Each 1/0 element is identified with a unique % label during PLC system configuration. These labels are used in preparing ladder logic for process control. Table 6 gives a listing of reference books available from GE-Fanuc Automation. These books describe the details of all Series 90-70 PLC hardware and software options.

Table 6. GE-Fanuc Automation Publications

Series 90™-70 Programmable Controller Reference Manual	GFK-0265E
Series 90™-70 Programmable Controller Data Sheets	GFK-0600A
Series 90™-70 Programmable Controller Installation Manual	GFK-0262D
Series 90™-70 Remote 1/0 Scanner User's Manual	GFK-0579A
Series 90™-70 Genius™ Bus Controller User's Manual	GFK-0398B
Series 90™-70 Genius™ 1/0 System and Communications User's Manual-Vol.1	GFK-90486D-1

Troubleshooting

The fabrication/installation of the control hardware and the development of the ladder logic programming took place over the period of 10-11 /92 and throughout 1993. There were many field wiring corrections to made to make the system function properly, but the diagnostic characteristics of the GE-Fanuc 1'1 .C system helped to minimize the time required to locate and correct field wiring anomalies. Nonetheless, by early 12/93, both the thermal and vacuum systems were read y to be tested.

System Startup

The new control system was first used to operate the thermal and the vacuum system controls during the period 12/6-7/93. Some problems with mechanical and electrical hardware were encountered but we experienced no failures of any of the GE-Fanuc hardware. Specifically, after being cold during normal vacuum operation, the 10 LN2 valves which are located on the discharge side of the cryopump baffles would not close when directed to close. Also, the LN2 feed valve upstream of the contamination plate froze open during normal operations and could not be closed without application of heat directly to the valve body by an operator, These 11 valves were all of the same type, . /, were all new, and will all be replaced with Annin control valves. Another problem which has recurred with excessive frequency is burnout of the indicator lights which are associated with the control panel switches. A considerable supply of small 24 VDC indicator lights has been procured to cover this burnout problem in the near term. one suggested long term solution is to replace the 24 VDC incandescent bulbs with 24VDC LEDs but that solution has not yet been tried.

During the 1-2/93 time period, a complete checkout of all the lamp power supplies was conducted. Several of the power supplies were inoperative and required field service but all 37 circuits are now functioning properly. All additional solar simulation system components will be tested in the 5-6/93 time period when a full-up system test will be conducted. No significant problems are anticipated.

Conclusions

The thermal and vacuum systems have been operated about 20 times since the initial startup and the thermal and vacuum control system have performed well. There have been no other problems with the new distributed control system to date other than those noted above. The GE- Fanuc 90-70 I'I.C-based control system is very versatile and, so far, has been reliable in this application.

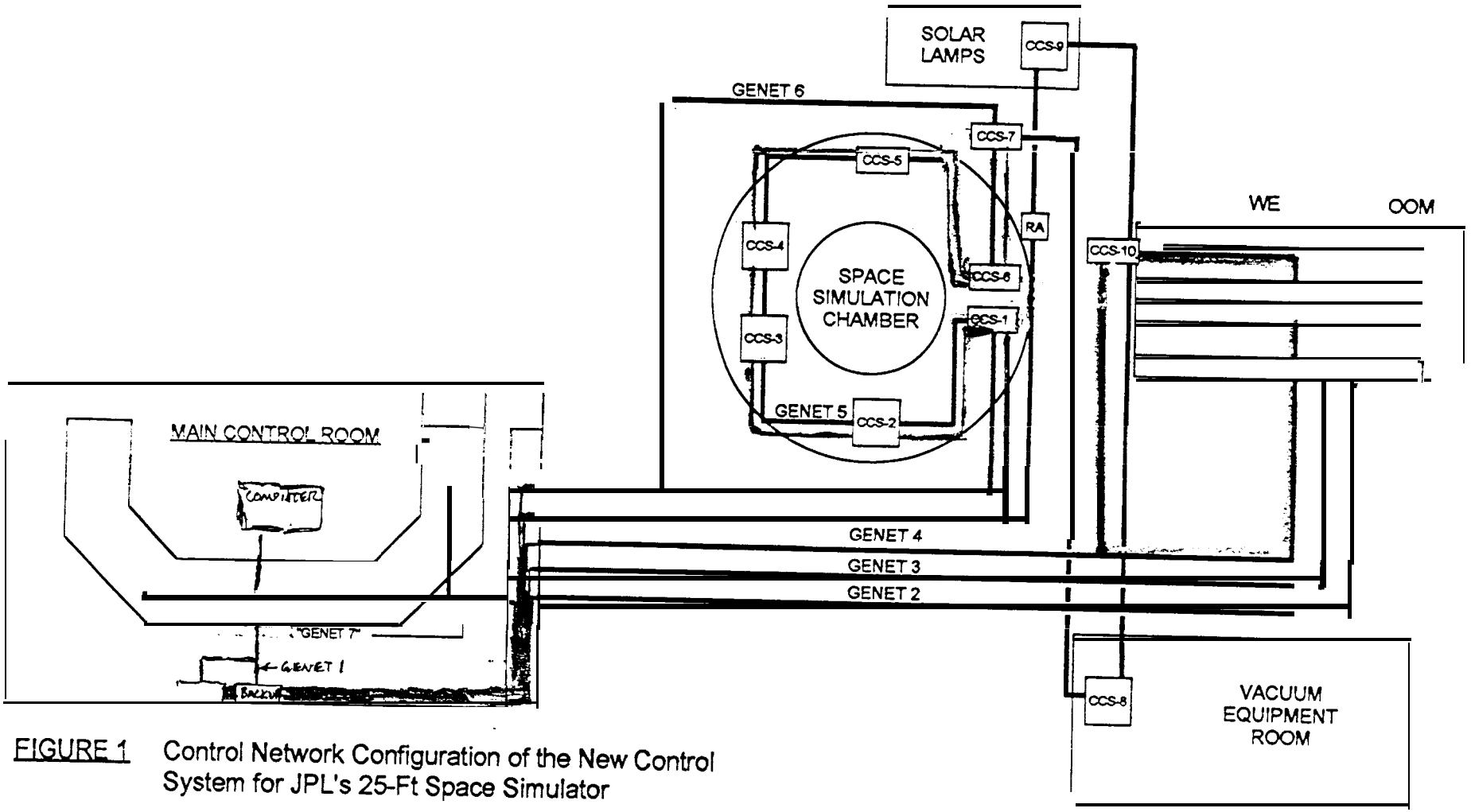


FIGURE 1 Control Network Configuration of the New Control System for JPL's 25-Ft Space Simulator

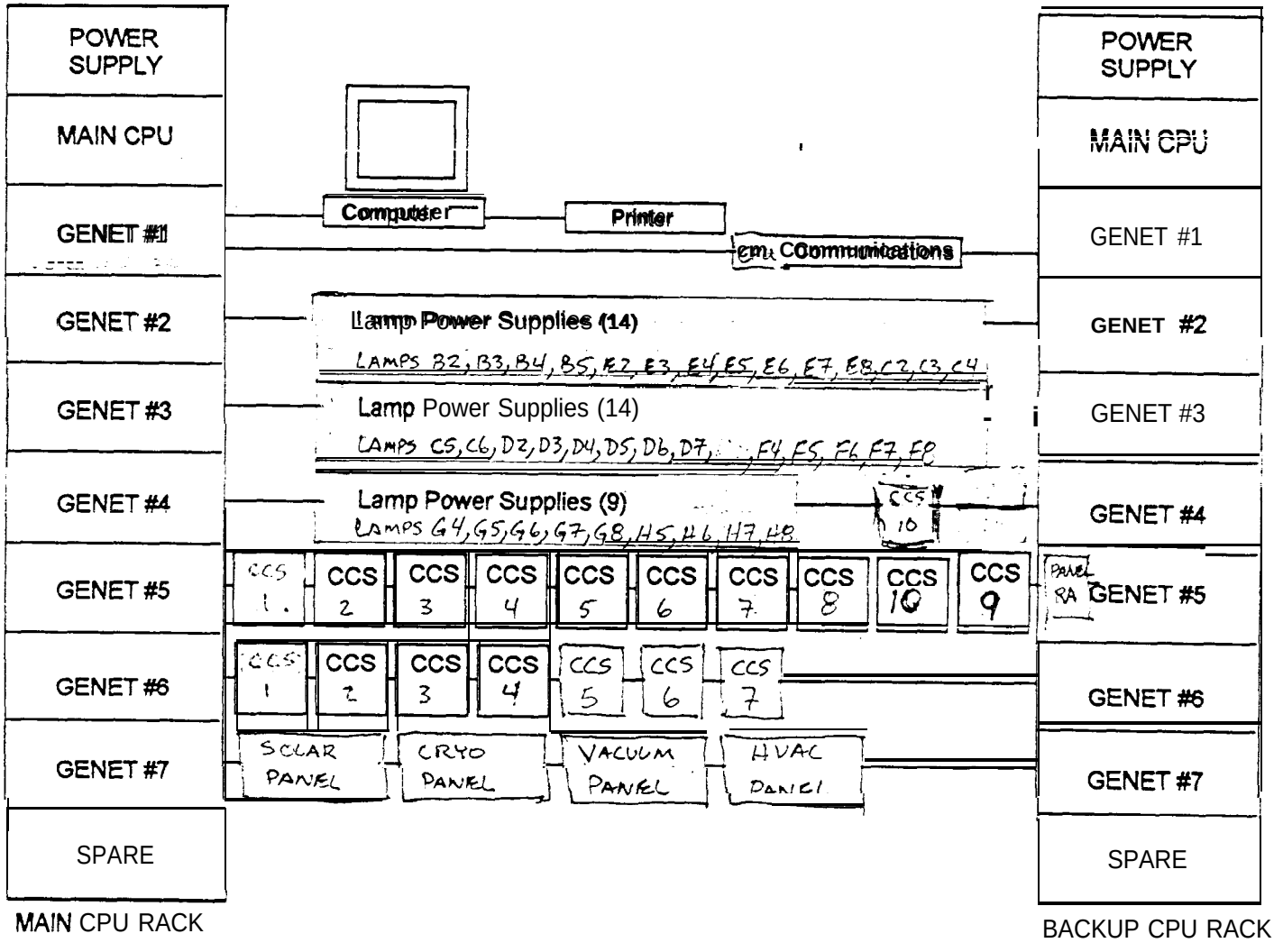


FIGURE 2. **Connectivity Between the Main CPU** RACK
~~Rack~~ and the ~~Standby~~ **CPU** Rack
BACKUP

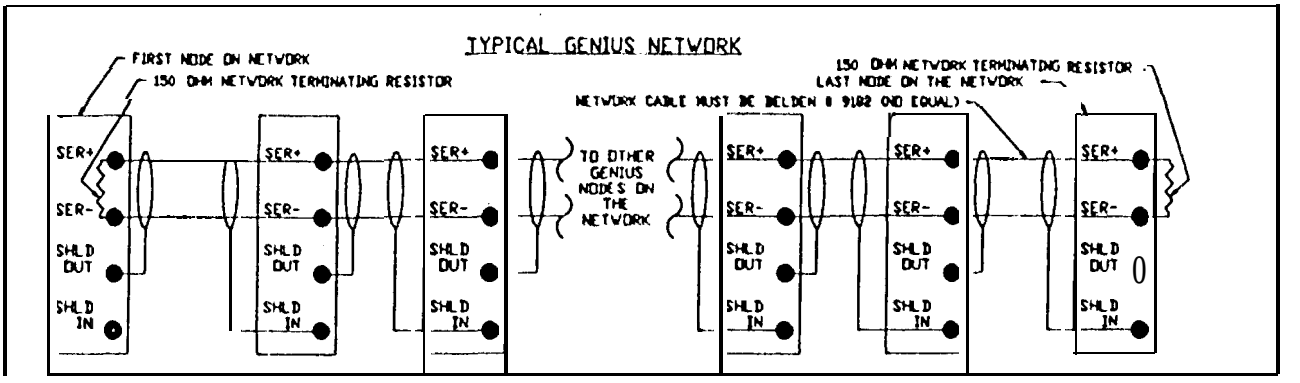
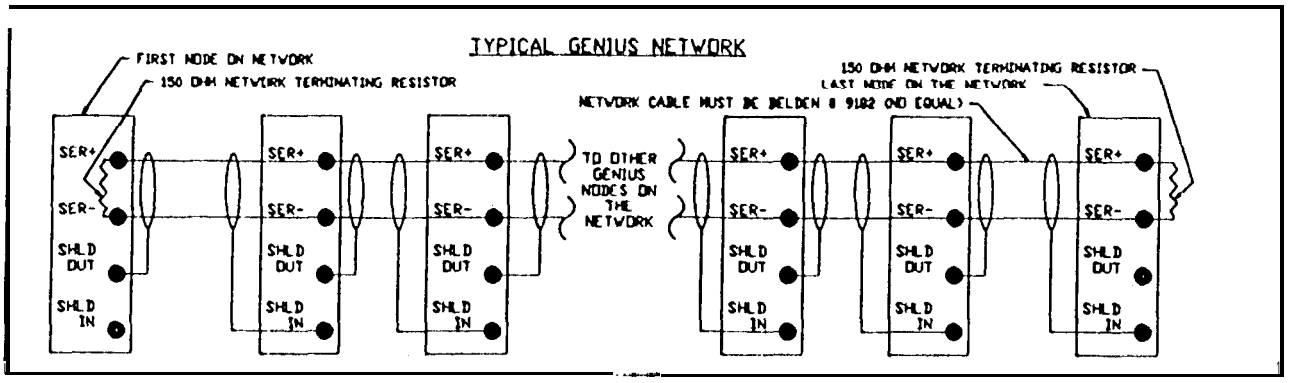


FIGURE 3. TYPICAL GENIUS NETWORK CONNECTION DETAIL


TYPICAL GENIUS NETWORK
FIRST NODE ON NETWORK
150 OHM NETWORK TERMINATING RESISTOR
150 OHM NETWORK TERMINATING RESISTOR
LAST NODE ON THE NETWORK
NETWORK CABLE MUST BE BELDEN # 9182 (OR EQUAL)
SER+
SER-
SHLD OUT
SHLD IN
TO OTHER GENIUS NODES ON THE NETWORK

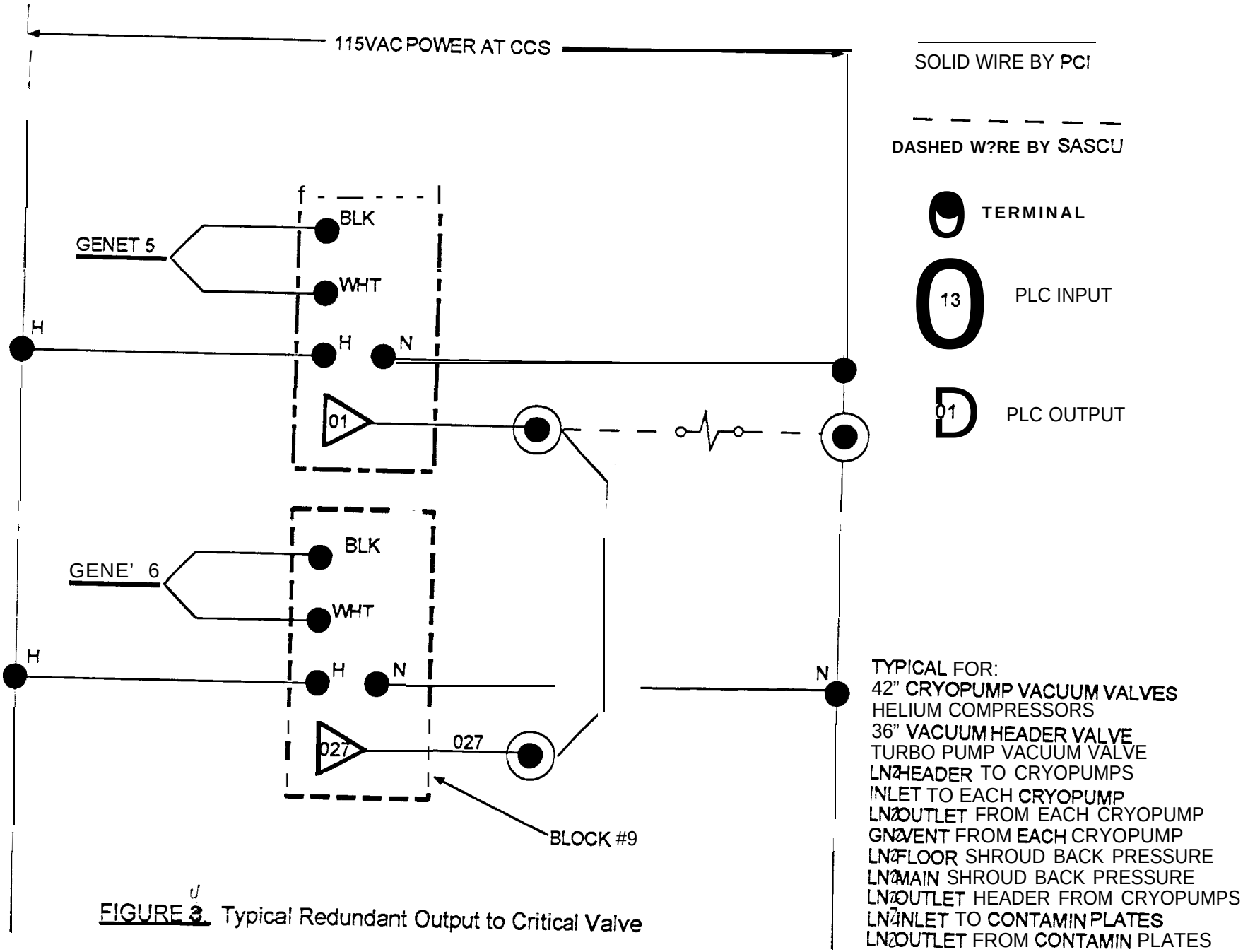


FIGURE 3. Typical Redundant Output to Critical Valve

(PREPARED BY) | (DATE) | (REPORT NO.)

(CHECKED BY) | (DATE) | (PROJECT)

TITLE

TABLE 1. IDENTIFICATION OF MODULES AND BLOCKS USED TO CONFIGURE THE JPL 25-FT SPACE SIMULATOR DISTRIBUTED CONTROL SYSTEM

CODE	CAT NO.	# USED	TITLE
C	IC 697 CPU 771	2	CPU 771, 12 MHz, Expandable, 512 KBytes, CMOS RAM
D	IC 697 MEM 735	2	32-BIT EXPANSION MEMORY, 512 KBytes, CMOS RAM
E	IC 697 BEM 731	14	GENIUS BUS CONTROLLER
A	IC 697 PWR 710	16	POWER SUPPLY MODULE, 120 VAC, 55W
B	IC 697 CBL 700	1	POWER SUPPLY EXTENSION CABLE
F	IC 697 BEM 711	7	BUS RECEIVER MODULE
G	IC 697 BEM 713	3	BUS TRANSMITTER MODULE
H	IC 697 BEM 733	8	REMOTE I/O SCANNER
I	IC 697 MDL 250	2	INPUT MODULE, 120 VAC, 32 CH
J	IC 697 MDL 340	5	OUTPUT MODULE, 120 VAC, 2A, 32 CH
K	IC 697 MDL 350	2	OUTPUT MODULE, 120 VAC, 0.5A, 32 CH
L	IC 697 MDL 653	30	INPUT MODULE, 24 VDC POS/NEG LOGIC, 32 CH
M	IC 697 MDL 750	29	OUTPUT MODULE, 24 VDC, 0.5A, 32 CH
N	IC 697 ALG 230	3	HIGH LEVEL ANALOG INPUT SYSTEM, BASE CONVERTER MODULE, 8
O	NOT USED		
P	IC 697 ALG 320	35	HIGH LEVEL ANALOG OUTPUT, VOLTAGE/CURRENT, 4 CH
Q	IC 697 ALG 440	1	HIGH LEVEL ANALOG INPUT SYSTEM, CURRENT EXPANDER MODULE, 1
R	IC 697 ALG 441	2	HIGH LEVEL ANALOG INPUT SYSTEM, VOLTAGE EXPANDER MODULE, 1
S	IC 660 BBD 024	2	32 CIRCUIT 12/24 VDC SOURCE I/O BLOCK
T	IC 660 BBD 025	14	32 CIRCUIT 5/12/24 VDC SINK I/O BLOCK
U	IC 660 BBA 100	49	115 VAC ANALOG I/O BLOCK, 4 IN/2 OUT
V	IC 660 BBD 101	44	115 VAC GROUPED LOW-LEAKAGE I/O BLOCK, 8 CH
W	IC 660 BBR 101	13	RELAY OUTPUTS BLOCK, NORMALLY-OPEN RELAYS, 16 CH
X		17	9-SLOT PLC MODULE RACK

PLC MODULE

TABLE 2. CONFIGURATION OF 17 9-SLOT PLC RACKS BY MODULE. CODE FROM TABLE 1.

SLOT #	MAIN CPU	BACKUP CPU	CCS-9	DROP 42	DROP 43	DROP 44 RACK 0	DROP 44 RACK 1	DROP 44 RACK 2	DROP 44 RACK 3
0	A	A	A	A	T-8484	A	A	A	A
1	C	C	H	H	.....	H	F	F	F
2	E	E	M	M	.....	G	M	M	N
3	E	E	M	L	.....	M	L	L	N
4	E	E	N	M	.....	M	N	M	Q
5	E	E	R	L	.....	M	L	L	P
6	E	E	R	M	.....	L	M	M	P
7	E	E		L	.....	L	L	L	P
8	E	E		M	.....	L	M	N	P
9						M		M	

SLOT #	DROP 45 RACK 0	DROP 46 RACK 1	DROP 46 RACK 0	DROP 46 RACK 1	DROP 46 RACK 2	DROP 46 RACK 2	DROP 47	PANEL DA
0	A	A	A	A	A	D	C	A
1	H	F	H	F	F	E	H	H
2	G	P	G	P	M	L	P	I
3	P	P	P	P	L	L	P	I
4	P	P	P	P	M	L	P	K
5	P	P	P	0	M	M	4	K
6	P	P	P	0	L	M	4	
7	P	P	P	0	L	M	4	
8	P	P	P	0	L	M	4	
9				L	L	L		

GENET	7			7	7	7	7	5
SLOCK	4-0		5-0	5-1	5-2	5-3	6	1

PAGE OF

(REPORT NO.)

(PROJECT)

(DATE)

(DATE)

(PREPARED BY)

(CHECKED BY)

TITLE

JPL 0999 S (REV 11/83)

CLASSIFICATION

TABLE 3. GENIUS BLOCK IDENTIFICATION BY BLOCK CODE FROM TABLE 1 AND BY INSTALLATION LOCATION

CCS-1			CCS-2			CCS-3			CCS-4			CCS-5		
CODE	GENET	BLOCK	CODE	GENET	BLOCK	CODE	GENET	BLOCK	CODE	GENET	BLOCK	CODE	GENET	BLOCK
W	6	1*	W	5	14*	W	5	15*	W	6	11*	W	6	16*
W	5	9*	W	6	2*	W	6	6*	U	6	12	T	6	17
T	5	11	T	6	3	T	6	7	U	6	10	U	6	19
T	5	12	T	6	4	T	6	8	T	6	15	W	5	17*
U	5	13	U	6	5	U	6	9	W	5	16*			
						U	1	10						

CCS-6			CCS-7			CCS-8			CCS-10			HVAC		
CODE	GENET	BLOCK	CODE	GENET	BLOCK	CODE	GENET	BLOCK	CODE	GENET	BLOCK	CODE	GENET	BLOCK
V	5	18*	U	5	19*	W	5	21	V	4	19	T	7	7
T	6	20	V	5	20	W	5	22	V	5	26	W	7	8
V	6	21*	V	6	22*	T	5	23	T	5	27	T	7	9
			V	6	23	T	5	24	U	5	28			
			S	6	24	U	5	25						
			U	6	25									
			U	6	26									
			S	6	27									

* DENOTES REDUNDANT OPERATIONAL BLOCKS

(REPORT NO.) (PROJECT)

(DATE) (DATE)

(PREPARED BY)

(CHECKED BY)

TITLE

JPL

JPL 0999 S (REV 11/83)

CLASSIFICATION

TABLE 1

LAMP POWER SUPPLY

TABLE 1. Typical Layout Identifying GENET and Block Designations

LAMP	B2	B3	B4	B5	E2	E3	E4	E5	E6	E7	E8	C2	C3	C4
GENET	2	2	2	2	2	2	2	2	2	2	2	2	2	2
BLOCK	1	3	5	7	9	11	13	15	17	14	21	23	25	27
BLOCK	2	4	6	8	10	12	14	16	18	20	22	24	26	28

LAMP	C5	C6	D2	D3	D4	D5	D6	D7	F3	F4	F5	F6	F7	F8
GENET	3	3	3	3	3	3	3	3	3	3	3	3	3	3
BLOCK	1	3	5	7	9	11	13	15	17	19	21	23	25	27
BLOCK	2	4	6	8	10	12	14	16	18	20	22	24	26	28

LAMP	G4	G5	G6	G7	G8	H5	H6	H7	H8
GENET	4	4	4	4	4	4	4	4	4
BLOCK	1	3	5	7	9	11	13	15	17
BLOCK	2	4	6	8	10	12	14	16	18

All odd numbered blocks are 8 ch 115 vac 1/0: Block IC660 BBD101
All even numbered blocks are 4 in/2 out analog: Block IG660BBA100

(PREPARED BY) | (DATE) | (REPORT NO.)

(CHECKED BY) | (DATE) | (PROJECT)

TITLE

TABLE 5. GENET/BLOCK IDENTIFICATION CROSS-REFERENCE

GENET #	BLOCK 1	BLOCK 2	BLOCK 3	BLOCK 4	BLOCK 5	BLOCK 6	BLOCK 7	BLOCK 8
1								
2	B2	B2	B3	B3	B4	B4	B5	B5
3	C5	C5	C6	C6	D2	D2	D3	D3
4	G4	G4	G5	G5	G6	G6	G7	G7
5	PNL RA	CCS-9						
6	CCS-1	CCS-2	CCS-2	CCS-2	CCS-2	CCS-3	CCS-3	CCS-3
7	DROP 43	DROP 43	DROP 44	DROP 45	DROP 46	DROP 47	HVAC	HVAC

GENET #	BLOCK 9	BLOCK 10	BLOCK 11	BLOCK 12	BLOCK 13	BLOCK 14	BLOCK 15	BLOCK 16
1								
2	E2	E2	E3	E3	E4	E4	E5	E5
3	D4	D4	D5	D5	D6	D6	D7	D7
4	G8	G8	H5	H5	H6	H6	H7	H7
5	CCS-1		CCS-1	CCS-	CCS-	CCS-2	CCS-3	CCS-4
6	CCS-3	CCS-3	CCS-4	CCS-1		CCS-4	CCS-4	CCS-5
7	HVAC							

GENET #	BLOCK 17	BLOCK 18	BLOCK 19	BLOCK 20	BLOCK 21	BLOCK 22	BLOCK 23	BLOCK 24
1								
2	E6	E6	E7	E7	E8	F8	C2	C2
3	F3	F3	F4	F4	F5	F5	F6	F6
4	H8	H8	CCS-10					
5	CCS-5	CCS-6	CCS-7	CCS-7	CCS-8	CCS-8	CCS-8	CCS-8
6	CCS-5		CCS-5	CCS-6	CCS-6	CCS-7	CCS-7	CC S-7
7								

GENET #	BLOCK 25	BLOCK 26	BLOCK 27	BLOCK 28	BLOCK 29	BLOCK 30	BLOCK 31	BLOCK 32
1								
2	C3	C3	C4	C4				
3	F7	F7	F8	F8				
4								
5	CCS-8	CCS-8	CCS-10	CCS-10				
6	CCS-7	CCS-7	CCS-7					
7								

NOTE: ALL ODD NUMBERED LAMP BLOCKS ARE CODE V : IC 660 BBD 101
ALL EVEN NUMBERED LAMP BLOCKS ARE CODE U : IC 660 BBA 100