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ELEVATION SCANNING LAS ER/MULTI-SENSOR HAZARD DETECTION SYSTEM CONTROLLER AND MIRROR/MAST SPEED CONTROL COMPONENTS

by

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Also, Bill Cambalik, Todd Comins, Dave Cipolle, and Jeff Turner who worked on vehicle oriented tasks which freed me to pursue the new ML/MD System.

ABSTRACT

Positioned at the front of the R.P.I. Mars Roving Vehicle is an electro-mechanical assembly called the Elevation Scanning Mast. With associated electronics, it is capable of pointing a laser beam anywhere in three-space below the top of the mast. Photo-detectors mounted on the mast record any back scattered light returned from the local terrain to the mast. Described in this paper are the electro-mechanical and electronic systems involved with pointing the laser beam along the desired vector. The system makes use of a rotating 8-sided mirror, driven by a phase-locked DC motor servo system, and monitored by a precision optical shaft encoder. This upper assembly is then rotated about an orthogonal axis to allow scanning into all 360° around the vehicle. This axis is also driven by a phase-locked DC motor servo-system, and monitored with an optical shaft encoder. The electronics are realized in standard TTL integrated circuits with UV-erasable proms used to store desired coordinates of laser fire. Related topics such as the interface to the existing test vehicle at R.P.I. are discussed.

1. INTRODUCTION

The Mars Rover Project was begun at R.P.I. in 1972. Under a NASA grant several students began working in various directions on concepts for an unmanned vehicle which would be capable of exploring the surface of Mars. In early vehicle designs much emphasis was placed on mechanical aspects such as folding to fit in a capsule, wheel design, and maneuverability. Later goals were to develop a vehicle with remote control capability via a "command" R.F. link , and to return vehicle state data to an off-board computer via a "telemetry" R.F. link. The vehicle state data consists of strut positions, wheel tachometer reading, steering angle, gyro information, etc. Sufficient capacity was allowed for in the telemetry system to accommodate future systems. By 1974, the main goal of the project was to develop a test vehicle which was capable of autonomous roving, that is, of obstacle detection and avoidance under closed-loop computer control. The vehicle was to gather information with some sort of "vision" system and return it along with vehicle state data via telemetry. The obstacle detection system was chosen to employ a "laser triangulation" scheme. A laser is at the top of a vertical mast at the front end of the vehicle and points downward toward the ground, it's beam making an angle of perhaps 40° with the vertical mast (this is called the elevation angle, β). The mast rotates about its long axis in an oscillatory type of movement, thus causing the laser spot on the ground to describe an arc of about 140° in the azimuth (θ) direction in front of the vehicle. Mounted at a lower point on the mast is a detector with a narrow field of view ($\sim 3°$) aimed at an angle with respect to the mast called α, toward the ground such that on flat terrain it will always "see" the laser spot, but when an obstacle of appreciable size ($\sim 10''$) intercepts the laser beam, the laser spot will be outside the field of view of the detector, and the obstacle is detected. As the mast sweeps thru the azimuth direction the laser is fired at 15 different locations (7 to the left of the vehicle, 7 to the right, and 1 straight ahead of the vehicle). Thus, triangulation occurs in the plane which contains the vertical mast. The angle the laser makes with the mast (β) and the angle at which the receiver is pointed (α) are fixed. The system yields the information: "direction blocked" or "direction open" for 15 different directions in front of the vehicle. Using this system, autonomous roving was achieved and tested under various conditions and with varying degrees of success through 1977 and into 1978. While results were sometimes impressive, and much was learned by having an actual machine to work with, by March 1977, it was felt that a higher level terrain sensing system should be implemented, particularly if the rover was to behave optimally in the real pitch and roll situations which it would encounter on Mars.

The higher level obstacle detection system continues to use the concept of laser triangulation. However, the new system is capable of firing the laser at various values of point angle β, and the detector is capable of "looking" at various angles (α) at the terrain. Triangulation still occurs within the plane which contains the mast. The new system, called the "multi-laser/multi-detector" or "elevation scanning" system is capable of placing up to 1024 points of laser light on the terrain with each azimuth scan as compared to 15 in the former system.

During the 1977/78 academic year the group concerned itself with conceptualizing and developing the necessary systems to implement this higher level system. Many concepts were considered on the way to developing the new system. The new mast will rotate continuously instead of oscillating. The former mast had problems with alignment which were in part caused by the accelerations it underwent in reversing direction. The fully rotating mast necessitates the use of slip rings to transfer data and power to and from the mast. To simulate many lasers at different pointing angles, the new system uses a single laser which is reflected by an 8-sided rotating mirror at the top of the mast. (Increasing the number of sides decreases the rate at which the laser must fire, but also decreases the angle (in β) through which the beam may be pointed). With 8 sides the laser can be pointed at any desired angle within a 90° field. A new laser was purchased which has a capability of 10 Khz firing rate (the former laser had a 1 Khz maximum). Speeds of this order are dictated by geometry and desired system performance. Finally the new system will have a multi-element detector. Either a 20 element photo diode array, or a 1024 element CCD linear array will be used, though neither is complete at this time. With this system the height of terrain can be computed (from β, α, and θ) for up to 1024 points around the vehicle. Existing systems such as telemetry and the computer interface, as well as the command link had to be modified slightly to adapt to the new data flow. Concurrently throughout 1977/78, the software group has been exploring the possible methods to handle the increased amount of data the new system will deliver.

The major objective of the study described herein was the design and construction of the electronic controller to control and monitor this advanced scanning concept. The controller's function is to monitor mirror and mast positions and to output control signals to the laser, receiver, and telemetry systems, such that the overall system will place the array of laser light points on the terrain as desired, and, upon receiving the data from the multi-element detector, buffer it, and serve as an interface to the telemetry system. The locations of the 1024 laser shots are programmable. The sections which follow detail the capabilities and operation of the multi-laser, multi-detector controller, how it integrates with other system components, and some early test results. Details of several related subsystems are given in Part 6.

2. SYSTEM CAPABILITIES

Figure 2.0 shows schematically the elvation scanning system. The mirror will sweep the laser beam through angles of elevation (β) and the rotating mast will sweep in the azimuth (θ) direction. The choices for actual angles of fire in elevation (β_K) and in azimuth (θ_K) are limited by encoder resolution and orientation. The mirror imposes some additional limitations on possible angles. Available fire angles, naming conventions, and other considerations will be discussed, along with the rate buffer and interface with telemetry and command links.

2.1 Azimuth Angles

Consider a "grid" of 256 radial azimuth angles spaced 360/256 = 1.4° apart. These form the set of possible azimuth angles at which to initiate an elevation scan. The particular azimuth angle selected at which to initiate angle, θ_K, Figure 2.1.1 shows θ_K and a few subsequent radials (θ_{K+1}, $\theta_{K+2,\ldots}$). Since the mast is always rotating, all elevation shots in an elevation scan initiated at θ_K will occur within $\Delta\theta$ of θ_K. The angle $\theta_K + \Delta\theta/2$ is called the azimuth data angle. The azimuth location of any shot is known to be the azimuth data angle $\pm\Delta\theta/2$. Therefore, the set of possible azimuth angles at which to scan in elevation is the set of azimuth data angles, and the accuracy of the azimuth angle is $\pm\Delta\theta/2$. Table 2.1.1 lists the set of azimuth data angles. Since $\Delta\theta$ may be greater than 1.4° (as shown in Fig. 2.1.1), the next available azimuth initiate angle will be θ_{K+2}.

An 8-bit word in azimuth memory exists for each possible azimuth angle, θ_K. To select a particular θ_K, a "1" is stored in the most significant bit of θ_K's word. This is known as the fire bit, and will cause an elevation scan

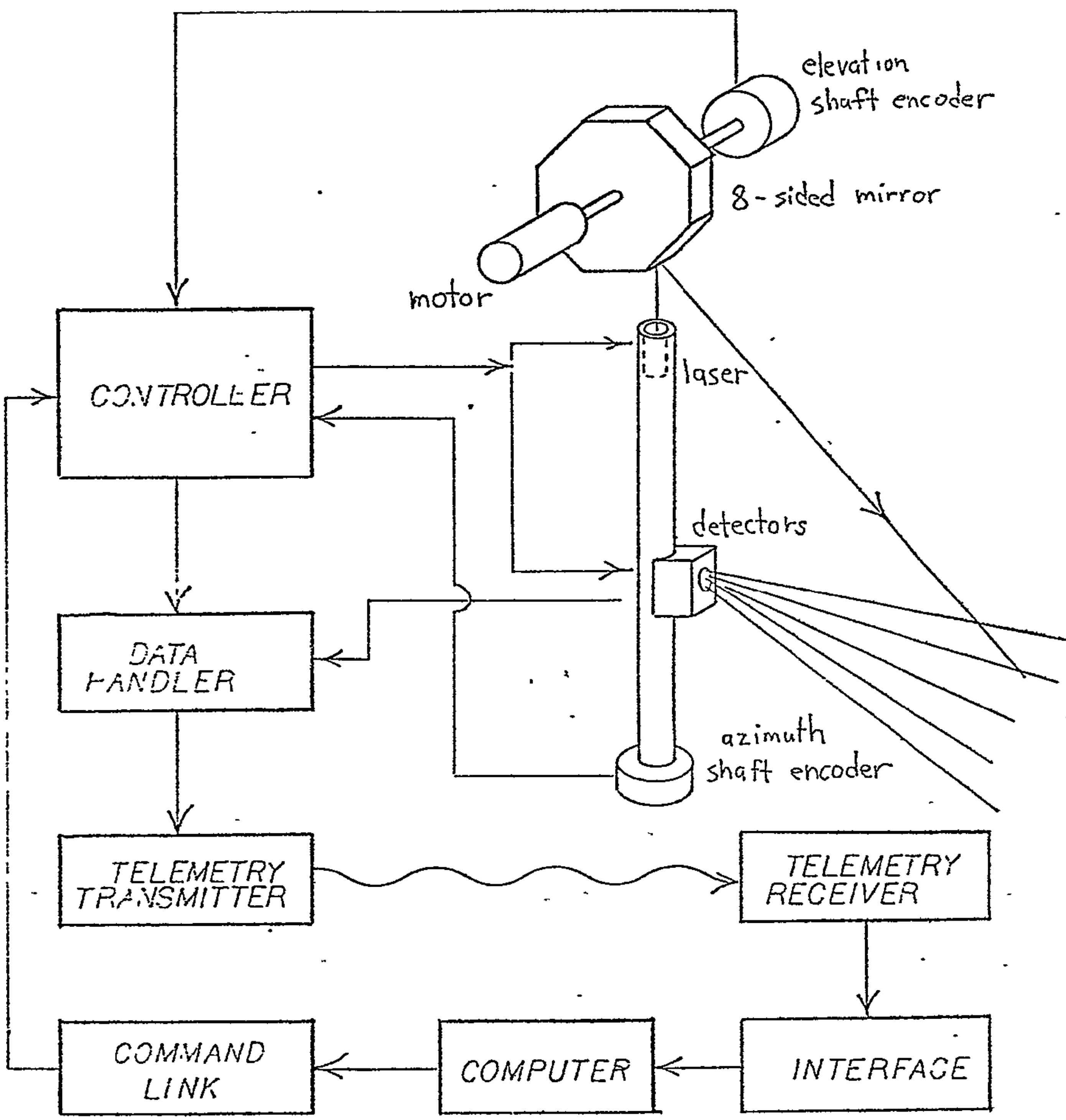

Figure 2.0

Elevation Scanning Conceptualization

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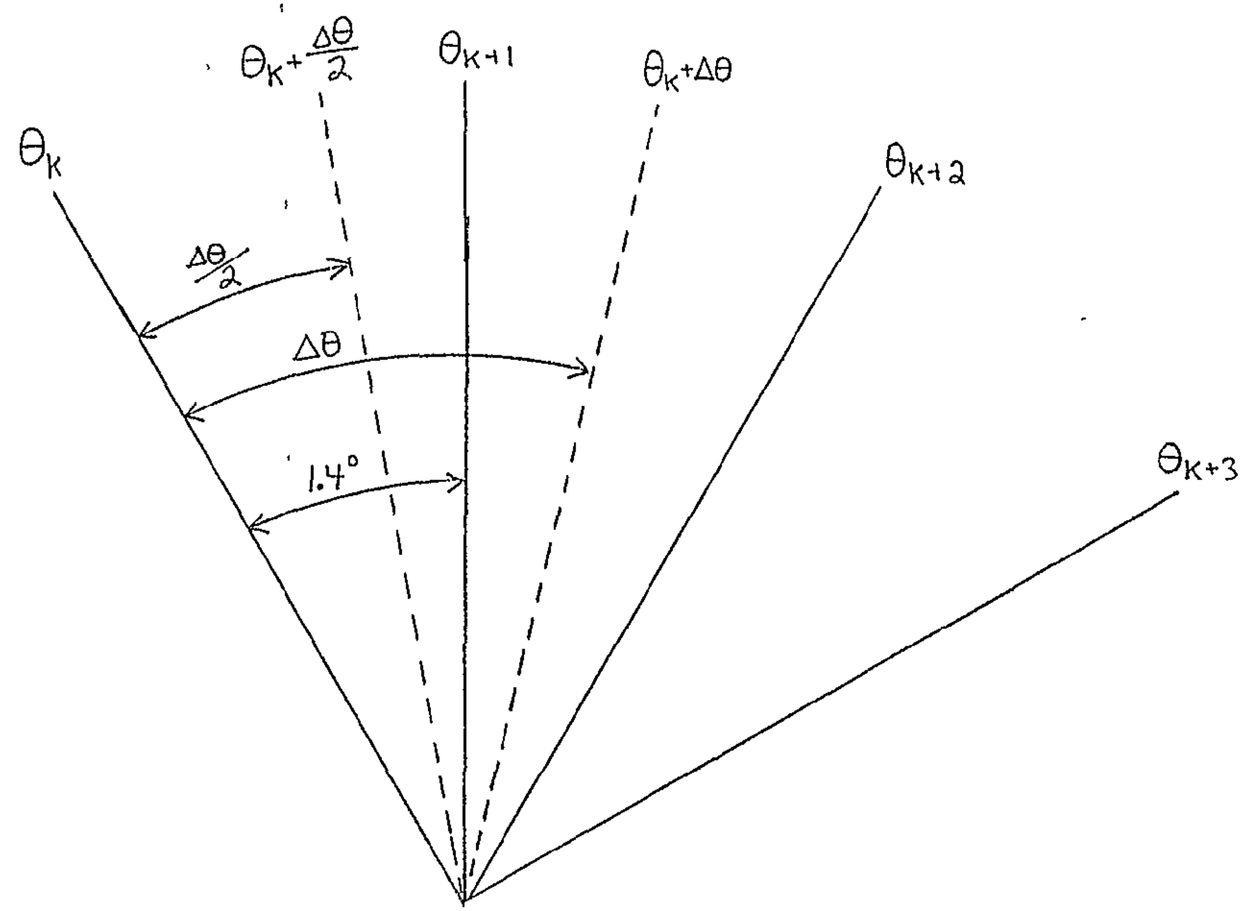

2.1.1 AZIMUTH ANGLES

to initiate at θ_K. The five least significant bits in θ_K's memory word should be programmed to contain a tag to identify θ_K. This tag is the azimuth shot number, which has a value between 0 and 31 encoded in five bits. The azimuth shot number will be used in the computer to index a look-up table which will contain the actual value of θ_K. An additional bit is set to a "1" in θ_K's memory word if θ_K is the last azimuth in the scan. This is called the azimuth end of scan bit (AMEOS) and will be used to generate the end of scan bit (EOS) sent back to the computer. In each scan up to 32 different azimuth initiate angles may be specified. Table 2.1.1 lists the set of possible azimuth data angles and their associated azimuth initiate angles. Note that this list was generated for $\Delta\theta = 1.875°$. The program may, of course, be rerun for other $\Delta\theta$'s.

The capability exists to offset the entire set of azimuth angles with the azimuth center of scan angle. This will have the effect of shifting the entire scanning pattern thru an angle in azimuth. Available center of scan (CSA) angles correspond to every other azimuth initiate angle. Therefore, there are 128 possible center of scan (CSA) angles spaced 2.8° apart. The computer can send the CSA via the command link. Table 2.1.2 shows the set of possible CSA's and the associated 8-bit computer command. When a center of scan angle is received it must remain in the command receiver's UART for a time period called data hold time, where data hold time = $1/256W_\theta$; W_θ = mast speed, rev/sec.

On the edge of the azimuth board of the controller, eight L.E.D.'s indicate the last azimuth at which an elevation scan was initiated. See layout in Appendix A for exact location of the indicator. This number can be converted from octal to degrees (vehicle fixed frame) using Table 2.1.1.

For test and alighnment purposes, the controller may be run in the azimuth test mode, in which the azimuth memory will not be used, but rather

TABLE 2.1.1

CODING OF AZIMUTH DATA ANGLES IN OCTAL, BINARY AND DECIMAL FORMATS

AZIMUTH DATA ANGLES	INITIATE ANGLE		ADDS. IN MEMORY		
DEGREES	DEGREES	OCTAL	BINARY	DECIMAL	HEX
-179.0625	-180.0000	000	00000000	0	00
-177.6563	-178.5938	001	00000001	1	01
-176.2500	-177.1875	002	00000010	2	02
-174.8438	-175.7813	003	00000011	3	03
-173.4375	-174.3750	004	00000100	4	04
-172.0313	-172.9688	005	00000101	5	05
-170.6250	-171.5625	006	00000110	6	06
-169.2188	-170.1563	007	00000111	7	07
-167.8125	-168.7500	010	00001000	8	08
-166.4063	-167.3438	011	00001001	9	09
-165.0000	-165.9375	012	00001010	10	0A
-163.5938	-164.5313	013	00001011	11	0B
-162.1875	-163.1250	014	00001100	12	0C
-160.7813	-161.7188	015	00001101	13	0D
-159.3750	-160.3125	016	00001110	14	0E
-157.9688	-158.9063	017	00001111	15	0F
-156.5625	-157.5000	020	00010000	16	10
-155.1563	-156.0938	021	00010001	17	11
-153.7500	-154.6875	022	00010010	18	12
-152.3438	-153.2813	023	00010011	19	13
-150.9375	-151.8750	024	00010100	20	14
-149.5313	-150.4688	025	00010101	21	15
-148.1250	-149.0625	026	00010110	22	16
-146.7188	-147.6563	027	00010111	23	17
-145.3125	-146.2500	030	00011000	24	18
-143.9063	-144.8438	031	00011001	25	19
-142.5000	-143.4375	032	00011010	26	1A
-141.0938	-142.0313	033	00011011	27	1B
-139.6875	-140.6250	034	00011100	28	1C
-138.2813	-139.2188	035	00011101	29	1D
-136.8750	-137.8125	036	00011110	30	1E
-135.4688	-136.4063	037	00011111	31	1F

MAST VELOCITY= 3.142 RAD/SEC = 30.0 RPM

MIRROR VELOCITY= 75.398 RAD/SEC = 720.0 RPM

DATA HOLD TIME= 7.812 MSEC

DELTA THETA= 1.8750 DEGREES

SCANS PER SECOND= 0.500

AZIMUTH DATA ANGLES DEGREES	INITIATE ANGLE DEGREES	OCTAL	ADDR. IN MEMORY BINARY	DECIMAL	HEX
-134.0625	-135.0000	040	00100000	32	20
-132.6563	-133.5938	041	00100001	33	21
-131.2500	-132.1875	042	00100010	34	22
-129.8438	-130.7813	043	00100011	35	23
-128.4375	-129.3750	044	00100100	36	24
-127.0313	-127.9688	045	00100101	37	25
-125.6250	-126.5625	046	00100110	38	26
-124.2188	-125.1563	047	00100111	39	27
-122.8125	-123.7500	050	00101000	40	28
-121.4063	-122.3438	051	00101001	41	29
-120.0000	-120.9375	052	00101010	42	2A
-118.5938	-119.5313	053	00101011	43	2B
-117.1875	-118.1250	054	00101100	44	2C
-115.7813	-116.7188	055	00101101	45	2D
-114.3750	-115.3125	056	00101110	46	2E
-112.9688	-113.9063	057	00101111	47	2F
-111.5625	-112.5000	060	00110000	48	30
-110.1563	-111.0938	061	00110001	49	31
-108.7500	-109.6875	062	00110010	50	32
-107.3438	-108.2813	063	00110011	51	33
-105.9375	-106.8750	064	00110100	52	34
-104.5313	-105.4688	065	00110101	53	35
-103.1250	-104.0625	066	00110110	54	36
-101.7188	-102.6563	067	00110111	55	37
-100.3125	-101.2500	070	00111000	56	38
-98.9063	-99.8438	071	00111001	57	39
-97.5000	-98.4375	072	00111010	58	3A
-96.0938	-97.0313	073	00111011	59	3B
-94.6875	-95.6250	074	00111100	60	3C
-93.2813	-94.2188	075	00111101	61	3D
-91.8750	-92.8125	076	00111110	62	3E
-90.4688	-91.4063	077	00111111	63	3F

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AZIMUTH DATA ANGLES	INITIATE ANGLE	ADDR. IN MEMORY			
DEGREES	DEGREES	OCTAL	BINARY	DECIMAL	HEX
-89.0625	-90.0000	100	01000000	64	40
-87.6563	-88.5938	101	01000001	65	41
-86.2500	-87.1875	102	01000010	66	42
-84.8438	-85.7813	103	01000011	67	43
-83.4375	-84.3750	104	01000100	68	44
-82.0313	-82.9688	105	01000101	69	45
-80.6250	-81.5625	106	01000110	70	46
-79.2188	-80.1563	107	01000111	71	47
-77.8125	-78.7500	110	01001000	72	48
-76.4063	-77.3438	111	01001001	73	49
-75.0000	-75.9375	112	01001010	74	4A
-73.5938	-74.5313	113	01001011	75	4B
-72.1875	-73.1250	114	01001100	76	4C
-70.7813	-71.7188	115	01001101	77	4D
-69.3750	-70.3125	116	01001110	78	4E
-67.9688	-68.9063	117	01001111	79	4F
-66.5625	-67.5000	120	01010000	80	50
-65.1563	-66.0938	121	01010001	81	51
-63.7500	-64.6875	122	01010010	82	52
-62.3438	-63.2813	123	01010011	83	53
-60.9375	-61.8750	124	01010100	84	54
-59.5313	-60.4688	125	01010101	85	55
-58.1250	-59.0625	126	01010110	86	56
-56.7188	-57.6563	127	01010111	87	57
-55.3125	-56.2500	130	01011000	88	58
-53.9063	-54.8438	131	01011001	89	59
-52.5000	-53.4375	132	01011010	90	5A
-51.0938	-52.0313	133	01011011	91	5B
-49.6875	-50.6250	134	01011100	92	5C
-48.2813	-49.2188	135	01011101	93	5D
-46.8750	-47.8125	136	01011110	94	5E
-45.4688	-46.4063	137	01011111	95	5F

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AZIMUTH DATA ANGLES DEGREES	INITIATE ANGLE DEGREES	OCTAL	ADDR. IN MEMORY BINARY	DECIMAL	HEX
-44.0625	-45.0000	140	01100000	96	60
-42.6563	-43.5938	141	01100001	97	61
-41.2500	-42.1875	142	01100010	98	62
-39.8438	-40.7813	143	01100011	99	63
-38.4375	-39.3750	144	01100100	100	64
-37.0313	-37.9688	145	01100101	101	65
-35.6250	-36.5625	146	01100110	102	66
-34.2188	-35.1563	147	01100111	103	67
-32.8125	-33.7500	150	01101000	104	68
-31.4063	-32.3438	151	01101001	105	69
-30.0000	-30.9375	152	01101010	106	6A
-28.5938	-29.5313	153	01101011	107	6B
-27.1875	-28.1250	154	01101100	108	6C
-25.7813	-26.7188	155	01101101	109	6D
-24.3750	-25.3125	156	01101110	110	6E
-22.9688	-23.9063	157	01101111	111	6F
-21.5625	-22.5000	160	01110000	112	70
-20.1563	-21.0938	161	01110001	113	71
-18.7500	-19.6875	162	01110010	114	72
-17.3438	-18.2813	163	01110011	115	73
-15.9375	-16.8750	164	01110100	116	74
-14.5313	-15.4688	165	01110101	117	75
-13.1250	-14.0625	166	01110110	118	76
-11.7188	-12.6563	167	01110111	119	77
-10.3125	-11.2500	170	01111000	120	78
-8.9063	-9.8438	171	01111001	121	79
-7.5000	-8.4375	172	01111010	122	7A
-6.0938	-7.0313	173	01111011	123	7B
-4.6875	-5.6250	174	01111100	124	7C
-3.2813	-4.2188	175	01111101	125	7D
-1.8750	-2.8125	176	01111110	126	7E
-0.4688	-1.4063	177	01111111	127	7F

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SCANS PER SECOND= 0.500

AZIMUTH DATA ANGLES	INITIATE ANGLE		ADDR. IN MEMORY		
DEGREES	DEGREES	OCTAL	BINARY	DECIMAL	HEX
0.9375	0.0000	200	10000000	128	80
2.3437	1.4063	201	10000001	129	81
3.7500	2.8125	202	10000010	130	82
5.1562	4.2188	203	10000011	131	83
6.5625	5.6250	204	10000100	132	84
7.9687	7.0313	205	10000101	133	85
9.3750	8.4375	206	10000110	134	86
10.7812	9.8438	207	10000111	135	87
12.1875	11.2500	210	10001000	136	88
13.5937	12.6563	211	10001001	137	89
15.0000	14.0625	212	10001010	138	8A
16.4062	15.4688	213	10001011	139	8B
17.8125	16.8750	214	10001100	140	8C
19.2187	18.2813	215	10001101	141	8D
20.6250	19.6875	216	10001110	142	8E
22.0312	21.0938	217	10001111	143	8F
23.4375	22.5000	220	10010000	144	90
24.8437	23.9063	221	10010001	145	91
26.2500	25.3125	222	10010010	146	92
27.6562	26.7188	223	10010011	147	93
29.0625	28.1250	224	10010100	148	94
30.4687	29.5313	225	10010101	149	95
31.8750	30.9375	226	10010110	150	96
33.2812	32.3438	227	10010111	151	97
34.6875	33.7500	230	10011000	152	98
36.0937	35.1563	231	10011001	153	99
37.5000	36.5625	232	10011010	154	9A
38.9062	37.9688	233	10011011	155	9B
40.3125	39.3750	234	10011100	156	9C
41.7187	40.7813	235	10011101	157	9D
43.1250	42.1875	236	10011110	158	9E
44.5312	43.5938	237	10011111	159	9F

MAST VELOCITY= 3.142 RAD/SEC = 30.0 RPM

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AZIMUTH DATA ANGLES DEGREES	INITIATE ANGLE DEGREES	OCTAL	ADDR. IN MEMORY BINARY	DECIMAL	HEX
45.9375	45.0000	240	10100000	160	A0
47.3437	46.4063	241	10100001	161	A1
48.7500	47.8125	242	10100010	162	A2
50.1562	49.2188	243	10100011	163	A3
51.5625	50.6250	244	10100100	164	A4
52.9687	52.0313	245	10100101	165	A5
54.3750	53.4375	246	10100110	166	A6
55.7812	54.8438	247	10100111	167	A7
57.1875	56.2500	250	10101000	168	A8
58.5937	57.6563	251	10101001	169	A9
60.0000	59.0625	252	10101010	170	AA
61.4062	60.4688	253	10101011	171	AB
62.8125	61.8750	254	10101100	172	AC
64.2187	63.2813	255	10101101	173	AD
65.6250	64.6875	256	10101110	174	AE
67.0312	66.0938	257	10101111	175	AF
68.4375	67.5000	260	10110000	176	B0
69.8437	68.9063	261	10110001	177	B1
71.2500	70.3125	262	10110010	178	B2
72.6562	71.7188	263	10110011	179	B3
74.0625	73.1250	264	10110100	180	B4
75.4687	74.5313	265	10110101	181	B5
76.8750	75.9375	266	10110110	182	B6
78.2812	77.3438	267	10110111	183	B7
79.6875	78.7500	270	10111000	184	B8
81.0937	80.1563	271	10111001	185	B9
82.5000	81.5625	272	10111010	186	BA
83.9062	82.9688	273	10111011	187	BB
85.3125	84.3750	274	10111100	188	BC
86.7187	85.7813	275	10111101	189	BD
88.1250	87.1875	276	10111110	190	BE
89.5312	88.5938	277	10111111	191	BF

MAST VELOCITY= 3.142 RAD/SEC = 30.0 RPM

MIRROR VELOCITY= 75.398 RAD/SEC = 720.0 RPM

DATA HOLD TIME= 7.812 MSEC

DELTA THETA= 1.8750 DEGREES

SCANS PER SECOND= 0.500

ORIGINAL PAGE IS OF POOR QUALITY

AZIMUTH DATA ANGLES DEGREES	INITIATE ANGLE DEGREES	ADDR. IN MEMORY OCTAL	BINARY	DECIMAL	HEX
90.9375	90.0000	300	11000000	192	C0
92.3437	91.4063	301	11000001	193	C1
93.7500	92.8125	302	11000010	194	C2
95.1562	94.2188	303	11000011	195	C3
96.5625	95.6250	304	11000100	196	C4
97.9687	97.0313	305	11000101	197	C5
99.3750	98.4375	306	11000110	198	C6
100.7812	99.8438	307	11000111	199	C7
102.1875	101.2500	310	11001000	200	C8
103.5937	102.6563	311	11001001	201	C9
105.0000	104.0625	312	11001010	202	CA
106.4062	105.4688	313	11001011	203	CB
107.8125	106.8750	314	11001100	204	CC
109.2187	108.2813	315	11001101	205	CD
110.6250	109.6875	316	11001110	206	CE
112.0312	111.0938	317	11001111	207	CF
113.4375	112.5000	320	11010000	208	D0
114.8437	113.9063	321	11010001	209	D1
116.2500	115.3125	322	11010010	210	D2
117.6562	116.7188	323	11010011	211	D3
119.0625	118.1250	324	11010100	212	D4
120.4687	119.5313	325	11010101	213	D5
121.8750	120.9375	326	11010110	214	D6
123.2812	122.3438	327	11010111	215	D7
124.6875	123.7500	330	11011000	216	D8
126.0937	125.1563	331	11011001	217	D9
127.5000	126.5625	332	11011010	218	DA
128.9062	127.9688	333	11011011	219	DB
130.3125	129.3750	334	11011100	220	DC
131.7187	130.7813	335	11011101	221	DD
133.1250	132.1875	336	11011110	222	DE
134.5312	133.5938	337	11011111	223	DF

MAST VELOCITY= 3.142 RAD/SEC = 30.0 RPM

MIRROR VELOCITY= 75.398 RAD/SEC = 720.0 RPM

DATA HOLD TIME= 7.812 MSEC

DELTA THETA= 1.8750 DEGREES

SCANS PER SECOND= 0.500

TABLE 2.1.1 (Continued)

AZIMUTH DATA ANGLES DEGREES	INITIATE ANGLE DEGREES	ADDR. IN MEMORY OCTAL	BINARY	DECIMAL	HEX
135.9375	135.0000	340	11100000	224	E0
137.3437	136.4063	341	11100001	225	E1
138.7500	137.8125	342	11100010	226	E2
140.1562	139.2188	343	11100011	227	E3
141.5625	140.6250	344	11100100	228	E4
142.9687	142.0313	345	11100101	229	E5
144.3750	143.4375	346	11100110	230	E6
145.7812	144.8438	347	11100111	231	E7
147.1875	146.2500	350	11101000	232	E8
148.5937	147.6563	351	11101001	233	E9
150.0000	149.0625	352	11101010	234	EA
151.4062	150.4688	353	11101011	235	EB
152.8125	151.8750	354	11101100	236	EC
154.2187	153.2813	355	11101101	237	ED
155.6250	154.6875	356	11101110	238	EE
157.0312	156.0938	357	11101111	239	EF
158.4375	157.5000	360	11110000	240	F0
159.8437	158.9063	361	11110001	241	F1
161.2500	160.3125	362	11110010	242	F2
162.6562	161.7188	363	11110011	243	F3
164.0625	163.1250	364	11110100	244	F4
165.4687	164.5313	365	11110101	245	F5
166.8750	165.9375	366	11110110	246	F6
168.2812	167.3438	367	11110111	247	F7
169.6875	168.7500	370	11111000	248	F8
171.0937	170.1563	371	11111001	249	F9
172.5000	171.5625	372	11111010	250	FA
173.9062	172.9688	373	11111011	251	FB
175.3125	174.3750	374	11111100	252	FC
176.7187	175.7813	375	11111101	253	FD
178.1250	177.1875	376	11111110	254	FE
179.5312	178.5938	377	11111111	255	FF

MAST VELOCITY= 3.142 RAD/SEC = 30.0 RPM

MIRROR VELOCITY= 75.398 RAD/SEC = 720.0 RPM

DATA HOLD TIME= 7.812 MSEC

DELTA THETA= 1.8750 DEGREES

SCANS PER SECOND= 0.500

TABLE 2.1.2

AVAILABLE AZIMUTH CENTER OF SCAN ANGLES

CENTER OF SCAN ANGLE	REF. ANGLE OCTAL	REF. ANGLE BINARY	REF. ANGLE HEX	COMPUTER COMMAND WORD OCTAL	COMPUTER COMMAND WORD BINARY
-180.0000	200	10000000	80	300	11000000
-177.1875	176	01111110	7E	277	10111111
-174.3750	174	01111100	7C	276	10111110
-171.5625	172	01111010	7A	275	10111101
-168.7500	170	01111000	78	274	10111100
-165.9375	166	01110110	76	273	10111011
-163.1250	164	01110100	74	272	10111010
-160.3125	162	01110010	72	271	10111001
-157.5000	160	01110000	70	270	10111000
-154.6875	156	01101110	6E	267	10110111
-151.8750	154	01101100	6C	266	10110110
-149.0625	152	01101010	6A	265	10110101
-146.2500	150	01101000	68	264	10110100
-143.4375	146	01100110	66	263	10110011
-140.6250	144	01100100	64	262	10110010
-137.8125	142	01100010	62	261	10110001
-135.0000	140	01100000	60	260	10110000
-132.1875	136	01011110	5E	257	10101111
-129.3750	134	01011100	5C	256	10101110
-126.5625	132	01011010	5A	255	10101101
-123.7500	130	01011000	58	254	10101100
-120.9375	126	01010110	56	253	10101011
-118.1250	124	01010100	54	252	10101010
-115.3125	122	01010010	52	251	10101001
-112.5000	120	01010000	50	250	10101000
-109.6875	116	01001110	4E	247	10100111
-106.8750	114	01001100	4C	246	10100110
-104.0625	112	01001010	4A	245	10100101
-101.2500	110	01001000	48	244	10100100
-98.4375	106	01000110	46	243	10100011
-95.6250	104	01000100	44	242	10100010
-92.8125	102	01000010	42	241	10100001
-90.0000	100	01000000	40	240	10100000
-87.1875	076	00111110	3E	237	10011111
-84.3750	074	00111100	3C	236	10011110
-81.5625	072	00111010	3A	235	10011101
-78.7500	070	00111000	38	234	10011100
-75.9375	066	00110110	36	233	10011011
-73.1250	064	00110100	34	232	10011010
-70.3125	062	00110010	32	231	10011001
-67.5000	060	00110000	30	230	10011000
-64.6875	056	00101110	2E	227	10010111
-61.8750	054	00101100	2C	226	10010110
-59.0625	052	00101010	2A	225	10010101
-56.2500	050	00101000	28	224	10010100
-53.4375	046	00100110	26	223	10010011
-50.6250	044	00100100	24	222	10010010
-47.8125	042	00100010	22	221	10010001
-45.0000	040	00100000	20	220	10010000
-42.1875	036	00011110	1E	217	10001111
-39.3750	034	00011100	1C	216	10001110
-36.5625	032	00011010	1A	215	10001101
-33.7500	030	00011000	18	214	10001100
-30.9375	026	00010110	16	213	10001011
-28.1250	024	00010100	14	212	10001010

TABLE 2.1.2 [illegible]

-25.3125	022	00010010	12	211	10001001
-22.5000	020	00010000	10	210	10001000
-19.6875	016	00001110	0E	207	10000111
-16.8750	014	00001100	0C	206	10000110
-14.0625	012	00001010	0A	205	10000101
-11.2500	010	00001000	08	204	10000100
-8.4375	006	00000110	06	203	10000011
-5.6250	004	00000100	04	202	10000010
-2.8125	002	00000010	02	201	10000001
0.0000	000	00000000	00	200	10000000
2.8125	376	11111110	FE	377	11111111
5.6250	374	11111100	FC	376	11111110
8.4375	372	11111010	FA	375	11111101
11.2500	370	11111000	F8	374	11111100
14.0625	366	11110110	F6	373	11111011
16.8750	364	11110100	F4	372	11111010
19.6875	362	11110010	F2	371	11111001
22.5000	360	11110000	F0	370	11111000
25.3125	356	11101110	EE	367	11110111
28.1250	354	11101100	EC	366	11110110
30.9375	352	11101010	EA	365	11110101
33.7500	350	11101000	E8	364	11110100
36.5625	346	11100110	E6	363	11110011
39.3750	344	11100100	E4	362	11110010
42.1875	342	11100010	E2	361	11110001
45.0000	340	11100000	E0	360	11110000
47.8125	336	11011110	DE	357	11101111
50.6250	334	11011100	DC	356	11101110
53.4375	332	11011010	DA	355	11101101
56.2500	330	11011000	D8	354	11101100
59.0625	326	11010110	D6	353	11101011
61.8750	324	11010100	D4	352	11101010
64.6875	322	11010010	D2	351	11101001
67.5000	320	11010000	D0	350	11101000
70.3125	316	11001110	CE	347	11100111
73.1250	314	11001100	CC	346	11100110
75.9375	312	11001010	CA	345	11100101
78.7500	310	11001000	C8	344	11100100
81.5625	306	11000110	C6	343	11100011
84.3750	304	11000100	C4	342	11100010
87.1875	302	11000010	C2	341	11100001
90.0000	300	11000000	C0	340	11100000
92.8125	276	10111110	BE	337	11011111
95.6250	274	10111100	BC	336	11011110
98.4375	272	10111010	BA	335	11011101
101.2500	270	10111000	B8	334	11011100
104.0625	266	10110110	B6	333	11011011
106.8750	264	10110100	B4	332	11011010
109.6875	262	10110010	B2	331	11011001
112.5000	260	10110000	B0	330	11011000
115.3125	256	10101110	AE	327	11010111
118.1250	254	10101100	AC	326	11010110
120.9375	252	10101010	AA	325	11010101
123.7500	250	10101000	A8	324	11010100
126.5625	246	10100110	A6	323	11010011
129.3750	244	10100100	A4	322	11010010
132.1875	242	10100010	A2	321	11010001
135.0000	240	10100000	A0	320	11010000
137.8125	236	10011110	9E	317	11001111
140.6250	234	10011100	9C	316	11001110

TABLE 2.1.2 (Continued)

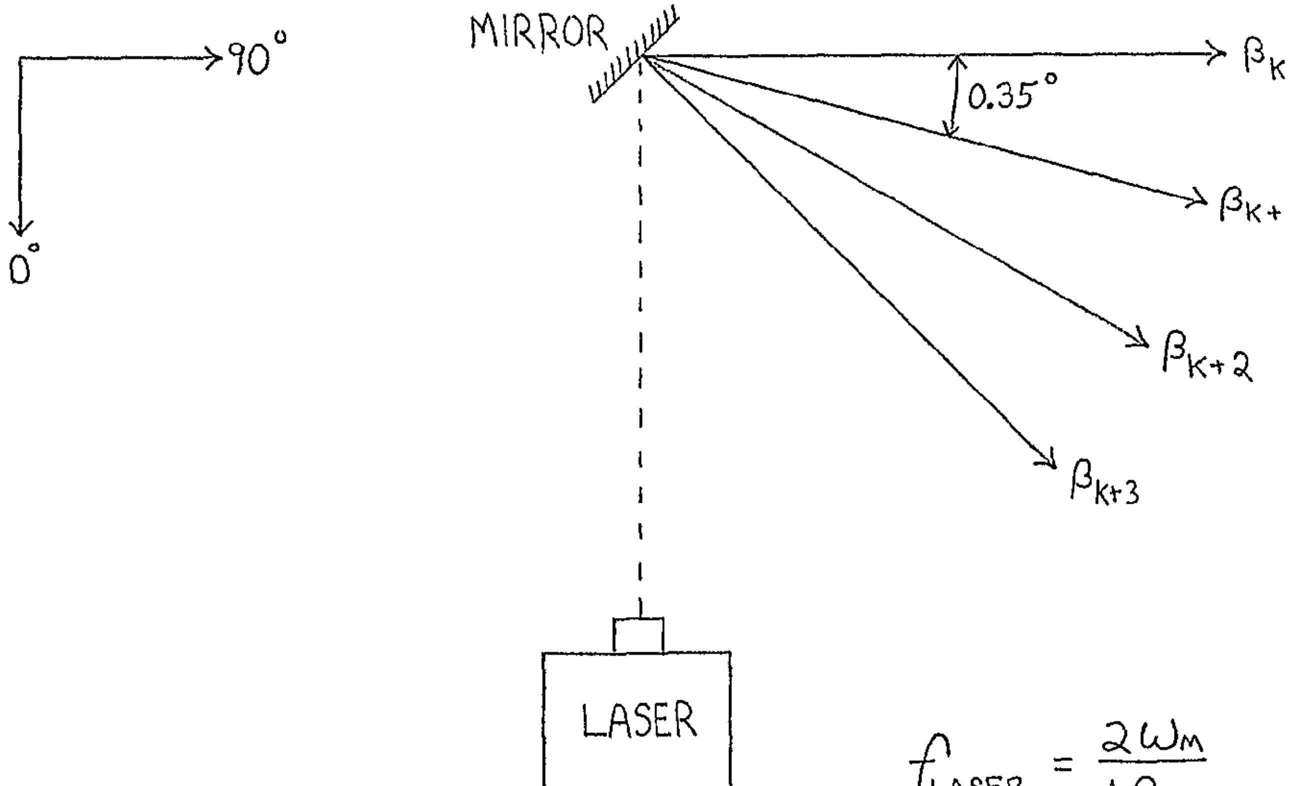
143.4375	232	10011010	9A	315	11001101
146.2500	230	10011000	98	314	11001100
149.0625	226	10010110	96	313	11001011
151.8750	224	10010100	94	312	11001010
154.6875	222	10010010	92	311	11001001
157.5000	220	10010000	90	310	11001000
160.3125	216	10001110	8E	307	11000111
163.1250	214	10001100	8C	306	11000110
165.9375	212	10001010	8A	305	11000101
168.7500	210	10001000	88	304	11000100
171.5625	206	10000110	86	303	11000011
174.3750	204	10000100	84	302	11000010
177.1875	202	10000010	82	301	11000001

one azimuth initiate angle (θ_K) may be entered using 8 mini-switches on the azimuth board (see Appendix A for location). In this mode the azimuth shot number will automatically be set to zero. For testing elevation scanning at a fixed azimuth, the "azimuth override" switch should be set.

The controller can output an "end of elevation scan" (EOES) and/or an "end of scan" (EOS) signal. The EOES signal will be high at the end of each elevation scan. The EOS signal will be high when the last elevation shot at the last azimuth angle is completed. Either of these signals may be sent to the computer in the telemetry word to initiate an interrupt. The choice will be made according to how the software handles the data.

2.2 Elevation Angles

The set of possible fire locations in the elevation direction (β) form a "grid" of 256 radials within a 90° scan sector. The angular separation between adjacent radials is 90/256 = 0.35°. The particular elevation angle at which a laser fire is desired is called β_K. Figure 2.2.1 shows β_K and a few adjacent β's. Table 2.2.1 lists all available β angles. Due to a constraint on how fast the laser can fire, the minimum separation in for consecutive laser shots will usually be greater than 0.35°. The value of the minimum separation of adjacent laser shots, $\Delta\beta_{min}$, is determined by the mirror speed, since: laser frequency = $2W_m/\Delta\beta_{min}$ where W_m is the speed of the mirror in revolutions/second. Table 2.2.1 shows $\Delta\beta_{min}$ for given scan speed, $\Delta\theta$, and laser speed capability. The $\Delta\beta_{min}$ restriction must be kept in mind when programming the elevation memory so pulse rates exceeding the laser capability are not requested. An additional constraint on β angles is imposed by the mirror. Since the laser beam has a finite width, and the mirror face a finite length, full laser power cannot be delivered into the



$$f_{LASER} = \frac{2\omega_M}{\Delta\beta_{MIN}}$$

2.2.1 ELEVATION ANGLES

TABLE 2.2.1

CODING OF AVAILABLE ELEVATION ANGLES

AVAILABLE ELEVATION ANGLES DEGREES	ADDR. IN MEMORY OCTAL	BINARY	DECIMAL	HEX
0.0000 *	000	00000000	0	00
0.3516 *	001	00000001	1	01
0.7031 *	002	00000010	2	02
1.0547 *	003	00000011	3	03
1.4063 *	004	00000100	4	04
1.7578 *	005	00000101	5	05
2.1094 *	006	00000110	6	06
2.4609 *	007	00000111	7	07
2.8125 *	010	00001000	8	08
3.1641 *	011	00001001	9	09
3.5156 *	012	00001010	10	0A
3.8672 *	013	00001011	11	0B
4.2188 *	014	00001100	12	0C
4.5703 *	015	00001101	13	0D
4.9219 *	016	00001110	14	0E
5.2734 *	017	00001111	15	0F
5.6250 *	020	00010000	16	10
5.9766 *	021	00010001	17	11
6.3281 *	022	00010010	18	12
6.6797 *	023	00010011	19	13
7.0313 *	024	00010100	20	14
7.3828 *	025	00010101	21	15
7.7344 *	026	00010110	22	16
8.0859 *	027	00010111	23	17
8.4375 *	030	00011000	24	18
8.7891 *	031	00011001	25	19
9.1406 *	032	00011010	26	1A
9.4922 *	033	00011011	27	1B
9.8438 *	034	00011100	28	1C
10.1953 *	035	00011101	29	1D
10.5469 *	036	00011110	30	1E
10.8984 *	037	00011111	31	1F

DELTA BETA MIN.= 1.05469 DEGREES

* ASTERISK INDICATES ONLY PARTIAL LASER POWER
AVAILABLE AT THIS ELEVATION

ABOVE DATA VALID WHEN:

LASER LIMITED TO 10000.0 HERTZ
MIRROR VELOCITY= 720.0 RPM
BEAM WIDTH= 0.3750 INCHES

AVAILABLE ELEVATION ANGLES DEGREES	ADDR. IN MEMORY OCTAL	BINARY	DECIMAL	HEX
11.2500 *	040	00100000	32	20
11.6016 *	041	00100001	33	21
11.9531 *	042	00100010	34	22
12.3047 *	043	00100011	35	23
12.6563 *	044	00100100	36	24
13.0078 *	045	00100101	37	25
13.3594 *	046	00100110	38	26
13.7109 *	047	00100111	39	27
14.0625	050	00101000	40	28
14.4141	051	00101001	41	29
14.7656	052	00101010	42	2A
15.1172	053	00101011	43	2B
15.4688	054	00101100	44	2C
15.8203	055	00101101	45	2D
16.1719	056	00101110	46	2E
16.5234	057	00101111	47	2F
16.8750	060	00110000	48	30
17.2266	061	00110001	49	31
17.5781	062	00110010	50	32
17.9297	063	00110011	51	33
18.2813	064	00110100	52	34
18.6328	065	00110101	53	35
18.9844	066	00110110	54	36
19.3359	067	00110111	55	37
19.6875	070	00111000	56	38
20.0391	071	00111001	57	39
20.3906	072	00111010	58	3A
20.7422	073	00111011	59	3B
21.0938	074	00111100	60	3C
21.4453	075	00111101	61	3D
21.7969	076	00111110	62	3E
22.1484	077	00111111	63	3F

DELTA BETA MIN.= 1.05469 DEGREES

* ASTERISK INDICATES ONLY PARTIAL LASER POWER AVAILABLE AT THIS ELEVATION

ABOVE DATA VALID WHEN:

LASER LIMITED TO 10000.0 HERTZ
MIRROR VELOCITY= 720.0 RPM
BEAM WIDTH= 0.3750 INCHES

AVAILABLE ELEVATION ANGLES DEGREES	ADDR. IN MEMORY OCTAL	BINARY	DECIMAL	HEX
22.5000	100	01000000	64	40
22.8516	101	01000001	65	41
23.2031	102	01000010	66	42
23.5547	103	01000011	67	43
23.9063	104	01000100	68	44
24.2578	105	01000101	69	45
24.6094	106	01000110	70	46
24.9609	107	01000111	71	47
25.3125	110	01001000	72	48
25.6641	111	01001001	73	49
26.0156	112	01001010	74	4A
26.3672	113	01001011	75	4B
26.7188	114	01001100	76	4C
27.0703	115	01001101	77	4D
27.4219	116	01001110	78	4E
27.7734	117	01001111	79	4F
28.1250	120	01010000	80	50
28.4766	121	01010001	81	51
28.8281	122	01010010	82	52
29.1797	123	01010011	83	53
29.5313	124	01010100	84	54
29.8828	125	01010101	85	55
30.2344	126	01010110	86	56
30.5859	127	01010111	87	57
30.9375	130	01011000	88	58
31.2891	131	01011001	89	59
31.6406	132	01011010	90	5A
31.9922	133	01011011	91	5B
32.3438	134	01011100	92	5C
32.6953	135	01011101	93	5D
33.0469	136	01011110	94	5E
33.3984	137	01011111	95	5F

DELTA BETA MIN.= 1.05469 DEGREES

* ASTERISK INDICATES ONLY PARTIAL LASER POWER
AVAILABLE AT THIS ELEVATION

ABOVE DATA VALID WHEN:

LASER LIMITED TO 10000.0 HERTZ
MIRROR VELOCITY= 720.0 RPM
BEAM WIDTH= 0.3750 INCHES

AVAILABLE ELEVATION ANGLES DEGREES	ADDR. IN MEMORY OCTAL	BINARY	DECIMAL	HEX
33.7500	140	01100000	96	60
34.1016	141	011CC001	97	61
34.4531	142	01100010	98	62
34.8047	143	011C0011	99	63
35.1563	144	01100100	100	64
35.5078	145	01100101	101	65
35.8594	146	01100110	102	66
36.2109	147	01100111	103	67
36.5625	150	01101000	104	68
36.9141	151	01101001	105	69
37.2656	152	01101010	106	6A
37.6172	153	01101011	107	6B
37.9688	154	01101100	108	6C
38.3203	155	01101101	109	6D
38.6719	156	01101110	110	6E
39.0234	157	01101111	111	6F
39.3750	160	01110000	112	70
39.7266	161	01110001	113	71
40.0781	162	01110010	114	72
40.4297	163	01110011	115	73
40.7813	164	01110100	116	74
41.1328	165	01110101	117	75
41.4844	166	01110110	118	76
41.8359	167	01110111	119	77
42.1875	170	01111000	120	78
42.5391	171	01111001	121	79
42.8906	172	01111010	122	7A
43.2422	173	01111011	123	7B
43.5938	174	01111100	124	7C
43.9453	175	01111101	125	7D
44.2969	176	01111110	126	7E
44.6484	177	01111111	127	7F

DELTA BETA MIN.= 1.05469 DEGREES

* ASTERISK INDICATES ONLY PARTIAL LASER POWER
  AVAILABLE AT THIS ELEVATION

ABOVE DATA VALID WHEN:

LASER LIMITED TO 10000.0 HERTZ
MIRROR VELOCITY= 720.0 RPM
BEAM WIDTH= 0.3750 INCHES

AVAILABLE ELEVATION ANGLES	ADDR. IN MEMORY			
DEGREES	OCTAL	BINARY	DECIMAL	HEX
45.0000	200	10000000	128	80
45.3516	201	10000001	129	81
45.7031	202	10000010	130	82
46.0547	203	10000011	131	83
46.4063	204	10000100	132	84
46.7578	205	10000101	133	85
47.1094	206	10000110	134	86
47.4609	207	10000111	135	87
47.8125	210	10001000	136	88
48.1641	211	10001001	137	89
48.5156	212	10001010	138	8A
48.8672	213	10001011	139	8B
49.2188	214	10001100	140	8C
49.5703	215	10001101	141	8D
49.9219	216	10001110	142	8E
50.2734	217	10001111	143	8F
50.6250	220	10010000	144	90
50.9766	221	10010001	145	91
51.3281	222	10010010	146	92
51.6797	223	10010011	147	93
52.0313	224	10010100	148	94
52.3828	225	10010101	149	95
52.7344	226	10010110	150	96
53.0859	227	10010111	151	97
53.4375	230	10011000	152	98
53.7891	231	10011001	153	99
54.1406	232	10011010	154	9A
54.4922	233	10011011	155	9B
54.8438	234	10011100	156	9C
55.1953	235	10011101	157	9D
55.5469	236	10011110	158	9E
55.8984	237	10011111	159	9F

DELTA BETA MIN.= 1.05469 DEGREES

* ASTERISK INDICATES ONLY PARTIAL LASER POWER AVAILABLE AT THIS ELEVATION

ABOVE DATA VALID WHEN:

LASER LIMITED TO 10000.0 HERTZ
MIRROR VELOCITY= 720.0 RPM
BEAM WIDTH= 0.3750 INCHES

AVAILABLE ELEVATION ANGLES DEGREES	ADDR. IN MEMORY OCTAL	BINARY	DECIMAL	HEX
56.2500	240	10100000	160	A0
56.6016	241	10100001	161	A1
56.9531	242	10100010	162	A2
57.3047	243	10100011	163	A3
57.6563	244	10100100	164	A4
58.0078	245	10100101	165	A5
58.3594	246	10100110	166	A6
58.7109	247	10100111	167	A7
59.0625	250	10101000	168	A8
59.4141	251	10101001	169	A9
59.7656	252	10101010	170	AA
60.1172	253	10101011	171	AB
60.4688	254	10101100	172	AC
60.8203	255	10101101	173	AD
61.1719	256	10101110	174	AE
61.5234	257	10101111	175	AF
61.8750	260	10110000	176	B0
62.2266	261	10110001	177	B1
62.5781	262	10110010	178	B2
62.9297	263	10110011	179	B3
63.2813	264	10110100	180	B4
63.6328	265	10110101	181	B5
63.9844	266	10110110	182	B6
64.3359	267	10110111	183	B7
64.6875	270	10111000	184	B8
65.0391	271	10111001	185	B9
65.3906	272	10111010	186	BA
65.7422	273	10111011	187	BB
66.0938	274	10111100	188	BC
66.4453	275	10111101	189	BD
66.7969	276	10111110	190	BE
67.1484	277	10111111	191	BF

DELTA BETA MIN.= 1.05469 DEGREES

* ASTERISK INDICATES ONLY PARTIAL LASER POWER
AVAILABLE AT THIS ELEVATION

ABOVE DATA VALID WHEN:

LASER LIMITED TO 10000.0 HERTZ
MIRROR VELOCITY= 720.0 RPM
BEAM WIDTH= 0.3750 INCHES

TABLE 2.2.1 (Continued)

AVAILABLE ELEVATION ANGLES DEGREES		ADDR. IN MEMORY		
	OCTAL	BINARY	DECIMAL	HEX
67.5000	300	11000000	192	C0
67.8516	301	11000001	193	C1
68.2031	302	11000010	194	C2
68.5547	303	11000011	195	C3
68.9063	304	11000100	196	C4
69.2578	305	11000101	197	C5
69.6094	306	11000110	198	C6
69.9609	307	11000111	199	C7
70.3125	310	11001000	200	C8
70.6641	311	11001001	201	C9
71.0156	312	11001010	202	CA
71.3672	313	11001011	203	CB
71.7188	314	11001100	204	CC
72.0703	315	11001101	205	CD
72.4219	316	11001110	206	CE
72.7734	317	11001111	207	CF
73.1250	320	11010000	208	D0
73.4766	321	11010001	209	D1
73.8281	322	11010010	210	D2
74.1797	323	11010011	211	D3
74.5313	324	11010100	212	D4
74.8828	325	11010101	213	D5
75.2344 *	326	11010110	214	D6
75.5859 *	327	11010111	215	D7
75.9375 *	330	11011000	216	D8
76.2891 *	331	11011001	217	D9
76.6406 *	332	11011010	218	DA
76.9922 *	333	11011011	219	DB
77.3438 *	334	11011100	220	DC
77.6953 *	335	11011101	221	DD
78.0469 *	336	11011110	222	DE
78.3984 *	337	11011111	223	DF

DELTA BETA MIN.= 1.05469 DEGREES

* ASTERISK INDICATES ONLY PARTIAL LASER POWER
AVAILABLE AT THIS ELEVATION

ABOVE DATA VALID WHEN:

LASER LIMITED TO 10000.0 HERTZ
MIRROR VELOCITY= 720.0 RPM
BEAM WIDTH= 0.3750 INCHES

TABLE 2.2.1 (Continued)

AVAILABLE ELEVATION ANGLES DEGREES	ADDR. IN MEMORY OCTAL	BINARY	DECIMAL	HEX
78.7500 *	340	11100000	224	E0
79.1016 *	341	11100001	225	E1
79.4531 *	342	11100010	226	E2
79.8047 *	343	11100011	227	E3
80.1563 *	344	11100100	228	E4
80.5078 *	345	11100101	229	E5
80.8594 *	346	11100110	230	E6
81.2109 *	347	11100111	231	E7
81.5625 *	350	11101000	232	E8
81.9141 *	351	11101001	233	E9
82.2656 *	352	11101010	234	EA
82.6172 *	353	11101011	235	EB
82.9688 *	354	11101100	236	EC
83.3203 *	355	11101101	237	ED
83.6719 *	356	11101110	238	EE
84.0234 *	357	11101111	239	EF
84.3750 *	360	11110000	240	F0
84.7266 *	361	11110001	241	F1
85.0781 *	362	11110010	242	F2
85.4297 *	363	11110011	243	F3
85.7813 *	364	11110100	244	F4
86.1328 *	365	11110101	245	F5
86.4844 *	366	11110110	246	F6
86.8359 *	367	11110111	247	F7
87.1875 *	370	11111000	248	F8
87.5391 *	371	11111001	249	F9
87.8906 *	372	11111010	250	FA
88.2422 *	373	11111011	251	FB
88.5938 *	374	11111100	252	FC
88.9453 *	375	11111101	253	FD
89.2969 *	376	11111110	254	FE
89.6484 *	377	11111111	255	FF

DELTA BETA MIN.= 1.05469 DEGREES

* ASTERISK INDICATES ONLY PARTIAL LASER POWER
AVAILABLE AT THIS ELEVATION

ABOVE DATA VALID WHEN:

LASER LIMITED TO 10000.0 HERTZ
MIRROR VELOCITY= 720.0 RPM
BEAM WIDTH= 0.3750 INCHES

full 90° sweep, (Fig. 2.2.2). An 8-bit word in elevation memory exists for each possible elevation fire angle, β_K. To select a particular β_K, a "1" is stored in the most significant bit of β_K's memory word. This is known as the fire bit, and will cause a shot at elevation β_K to be fired. The five least significant bits in β_K's word should be programmed to contain a tag to identify β_K. This tag is the elevation shot number, which has a value between 0 and 31 encoded in five bits. This elevation shot number will be used to index a look-up table in the computer which will contain the actual value of β_K. Each elevation scan may contain up to 32 shots at various β_K's. Table 2.2.1 shows the set of possible β_K angles, and the address of the corresponding elevation memory word. Note that the same pattern of elevation shots is repeated at each azimuth data angle.

An elevation angle can be added as a reference or offset angle by means of 8-mini switches at the top of the elevation board (see layout Appendix B). These switches will normally be set once to compensate for mechanical misalignment and be left alone. Changing the settings will shift the pattern of shots through angles of elevation.

On the edge of the elevation board of the controller, eight L.E.D.'s indicate the last elevation of fire. Note that what is shown will actually be one greater than the angle asked for in elevation memory. This is explained in Part 3, and is compensated for by the offset angle switches. The number shown on the indicator can be converted from octal to degrees in using Table 2.2.1.

For test and alignment purposes, or to emulate the single laser system, the elevation direction of the controller can be run in the test mode. In this mode (which is selected by the "elevation mode select" switch) the laser will fire at just one elevation as defined with the 8 mini-switches called "test mode elevation angle". See Appendix A for card layouts

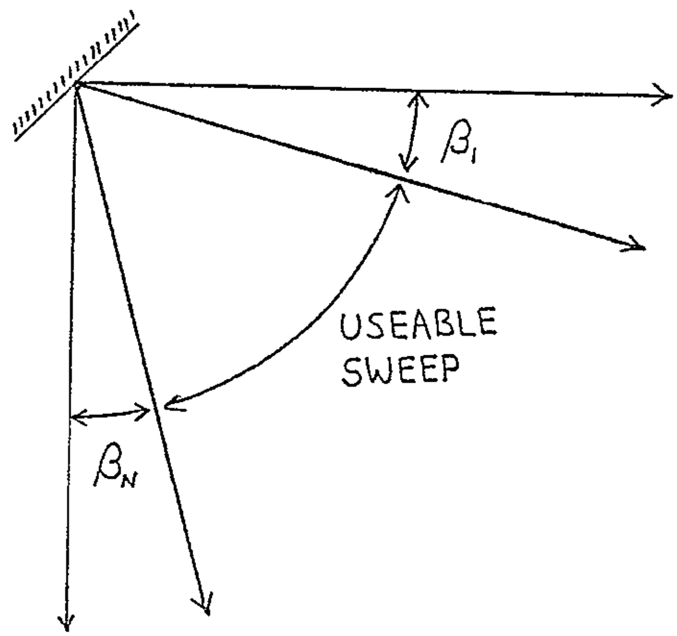


FIG. 2.2.2 - MIRROR LIMITATIONS ON β ANGLES

IT CAN BE SHOWN:

$$\beta_1 = 2\left\{\cos^{-1}\left(.383\frac{L-W}{L}\right)\right\} - 135^\circ$$

$$\beta_N = 135^\circ - 2\left\{\cos^{-1}\left(.383\frac{L+W}{L}\right)\right\}$$

FOR $L = 1.2426''$,

$$\beta_1 = 2\left\{\cos^{-1}(.383 - .308W)\right\} - 135^\circ$$

$$\beta_N = 135^\circ - 2\left\{\cos^{-1}(.383 + .308W)\right\}$$

to locate specific switches and L.E.D.'s. In the test mode the data is tagged with elevation shot number set equal to zero.

2.3 Rate Buffer

As illustrated in Figure 2.3.1, when an elevation scan initiates at an azimuth θ_K, and is finished by $\theta_K + \Delta\theta$, the rate buffer memory will in general still contain some information through an additional angle θ_c, or an additional time θ_c / ω_θ (ω_θ in Deg./sec.). The rate buffer is a first in-first out memory which is 40 words deep. Data can be generated at a rate of 10 Khz (speed of the laser), but telemetry may only transmit data at a rate of 2.5 Khz (word rate). The controller will fill up the rate buffer memory as data is generated and the telemetry system will pull out words and transmit them as fast as it can. Presently the interface to telemetry is a simple one which makes the laser data have top priority, and only when the rate buffer is empty can vehicle data be sent. Vehicle data is then sent continuously until more laser data appears in the rate buffer. A future modification may allow for just one 16-word block of vehicle data to be transmitted after each elevation scan, and then all data suppressed until the next elevation scan. Other configurations are possible with modest hardware additions.

How soon the rate buffer empties will perhaps have an effect on how closely packed the azimuths can be placed, and this time is related to the scan speed, the telemetry rate, the number of elevation shots per azimuth, etc. In Figure 2.3.1, at azimuth $\theta_K + \Delta\theta + \theta_c$ the rate buffer memory is clear, all information from the scan initiated at θ_K having been transmitted. A calculation of θ_c under worst case conditions yields:

$$\theta_c = N_{E/A} \left(\frac{W_\theta}{r_T} - \frac{\Delta\beta_{\min} \Delta\theta}{90^\circ} \right)$$

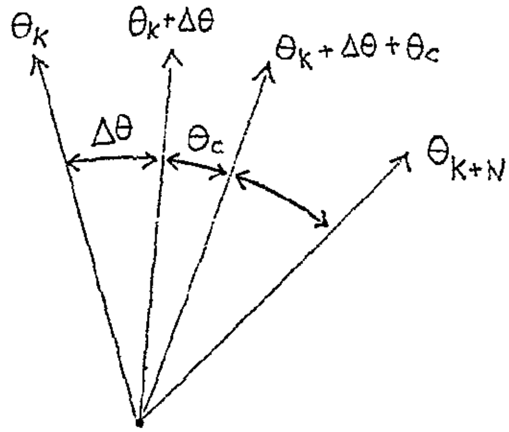


FIG. 2.3.1 - AZIMUTH ANGLES AND θ_c

$N_{E/A}$	ω_θ	r_T	$\Delta\beta_{MIN}$	$\Delta\theta$	θ_c
32	180	2500	1.05°	2°	1.557°
32	90	2500	1.05°	2°	0.405°
32	90	2500	0.70°	2°	0.654°
32	90	1500	0.70°	2°	1.422°

TABLE 2.3.1
'RATE BUFFER CLEAR' ANGLE θ_c

WHERE,

$$\theta_c = N_{E/A}\left(\frac{\omega_\theta}{r_T} - \frac{\Delta\beta_{MIN}\,\Delta\theta}{90^\circ} \right)$$

where:

$N_{E/A}$ = number of elevatiomn shots per azimuth

r_t = rate of telemetry link (words/sec)

W_θ = speed of mast rotation (deg./sec.)

$\Delta\beta_{min}$ = min. separation in β of elevation shots (deg.)

$\Delta\theta$ = 34 $\left(\frac{W_\theta}{W_m}\right.$ - "slop" in azimuth (deg.)

Some values are shown in Figure 2.3.1.

2.4 Features

A ability to stand still in azimuth while scanning in elevation (use "azimuth override" switch)

B ability to completely disable laser trigger pulses (use "laser disable" switch)

C test mode - a single angle may be set with "fire aware test mode" switches in elevation and/or azimuth. It is also possible to have one axis in test mode, and the other in memory mode. (Use "elevation mode select" and "azimuth mode select" switches, and "fire angle test mode" switches (8) to specify angle).

D L.E.D.'s readout last address of fire in both axes.

E fire protection circuit - this final output stage of the controller protects the laser from being fired at too rapid a rate (due to hardware failure, noise, incorrectly programmed memory, etc.). A 5 Khz or 10 Khz limit is switch selectable (use "5Khz/10Khz select" switch). A yellow L.E.D. warns that the 10 Khz limit is in effect.

F the system initializes itself with vehicle powerup.

G UV-Proms are used for memories, so that scanning patterns may be easily changed. (See Section 6.6).

H memories are mounted on a physically separate board so that other memory types may be substituted (ram, Gaproms, etc.). All are compatible as long as access time $\sim$4 ns.

I With only slight rewiring, the 32 azimuth with 32 elevation/azimuth scheme can be changed to a "16 with 64" or "64 with 16" scheme. Connections for signals S_{SA} and S_{SE} exist to expedite the changeover (see controller schematics, Appendix A).

3. CONTROLLER OPERATION

Introduction

Circuit operation is discussed in reference to the circuit diagrams in Appendix A. A block diagram representation in Figures A-9 and A-10 shows the various functional blocks of the ML/MD controller. The reader should refer often to the circuit diagrams and timing diagram in Appendix A while reading the following text.

3.1 Azimuth

The pulse output of the azimuth encoder (ASP) is counted in the 8-bit azimuth counter (Chips D7 and D8). The zero reference pulse (AZR) is used to clear this counter. Accordingly, with system start-up the mast must be allowed to rotate once before that data will be valid. The azimuth counter's output is being constantly added (in chips D33 and D34) to the contents of an 8-bit latch (D28) which should contain the desired reference or center of scan angle for the azimuth axis. Bit C is a control bit which means that the command link register contains a center of scan angle. On the first pulse on ASP after C goes high, the bits C1-C7 will be latched into D28. The "data hold time" is that time during which the command for a center of scan angle must remain in the command link UART to insure the controller will pick it up. The LSB of this angle will always be zero because of available capacity of the present command link (pin 18 of D28 is tied low). The output of chips D33 and D34 is then the sum of the actual mast position and the reference angle and is used to address the azimuth memory (AA -AA7); thus the memory is checked at each mast position to see if that position is one at which to fire. These same address lines are displayed with 8 L.E.D.S. The state of the lines is latched (25) at the time of a laser fire and can accordingly be thought of as "address of last laser fire". The same lines (AA -AA7) are constantly being compared (D10 and D11) with the 8-bit switch setting in case the "test mode" is selected, in which case if the present address matches the switch settings, the equivalence signal (ACMPE) goes high. The signal "AFIRE" is thus either the fire bit appearing as the memory is addressed, or the equivalence signal from the comparator if test mode is selected. With the occurrence of the next pulse on ESP, AFIRE is latched and AFIREL will remain high until the latch is re-enabled (pin #1 on D29). The circuit that determines when AFIREL is allowed to be cleared consists mainly of chips D21, D22, and D5, D21 and D22 from an 8-bit counter ($\Delta\theta$ CNTR), and D5 simply detects a full count of 255. The purpose of the circuit is to hold AFIREL until 256 pulses from ESP have been counted, thus assuring that all possible elevation angles have been checked as potential fire angles at that azimuth. Note that as soon as a fire azimuth is reached, the system will fire at the next desired elevation which appears. It does not wait for the start of a mirror face and then fire shots in a "top to bottom" order, as doing so would dictate twice the laser speed for the same scan rates. AFIREL acts as an enable for chips D21 and D22 by pulling the clear inputs high. When the counter reaches 255 the output of D5 goes high and D29 is allowed to be cleared (see timing diagram, Appendix A). Before AFIREL leaves the azimuth section of the circuit it may be overridden (set always high) with the "override azimuth" switch. This allows the system to work without regard to position in azimuth.

3.2 Elevation

D32 acts as a pulse stretcher to lengthen the elevation encoder's pulse output (ESP) and the zero reference pulse (EZR) from 1.5 μs to 5 μs. Due to the nature of the circuitry the memories must be capable of access within the width of ESP. The pulses were widened to allow system capability with all manner of memories (from slow Aproms to fast Rams). The controller was designed such that only the leading edges of the encoder output signal are used for critical timing, as they are the most accurate edges. The circuit formed by D6 plus an AND gate and an OR gate generates the elevation counter load signal (ECLOAD). Addition of the reference angle is accomplished by presetting the elvation counter (ECOUNTR), which is formed by D19 and D20. The ECLOAD circuit can be thought of as a black box with inputs EZR, ESP and OUTPUT ECLOAD. With ECLOAD being generated as shown in Fig. 3.2.1. The counter is loaded when ESP rises with ECLOAD low. The OUTPUTS of ECOUNTR address the elevation memories, and are also monitored by comparators (D8 and D9) and compared with the test mode elevation angle switches. The output of the counter is also, as in the azimuth axis, displayed via 8 L.E.D.S., whose states are latched in D26. This displays the last elevation angle of fire. Note that this address is always one greater than the specified fire address. D12 and D13 form a 2-to-1 selector to choose between memory and test mode. The selected signal EFIRE) becomes EFIREL when latched in D27 by the falling edge of ESP. EFIREL is ANDed with AFIREL and with ESP to produce the unprotected fire signal (FIREUN). Note that the system was designed to fire with the pulse on ESP following the one for which a desired fire angle was found, in order to make the system less dependent on the type of memories used. This operation is most clearly seen and understood in the system timing diagram (Appendix A).

3.3 Fire Protection Circuit

The circuit consists simply of 2 monostables with different pulse widths (D21) and a selector (D16). A 5 Khz or 10 Khz limit may be selected, or the laser may be completely disabled. The pulse widths used are simply the reciprocals of 5 Khz and 10 Khz (i.e. 200 μs and 100 μs). Therefore,

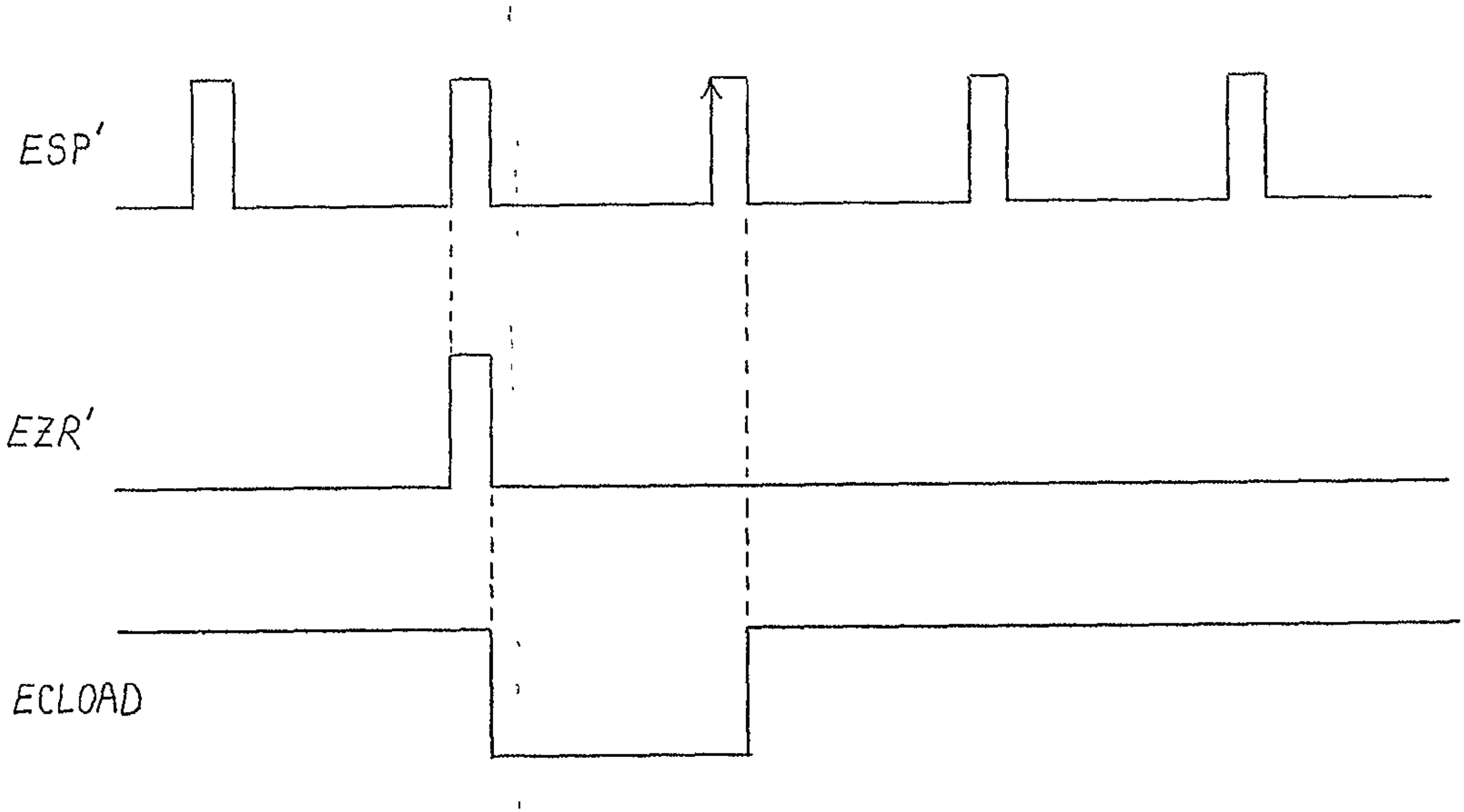


FIG. 3.2.1 ECLOAD CIRCUIT

rising edges can't occur at a rate faster than the limit selected. This will protect the laser from incorrectly programmed proms, hardware failures, etc.

3.4 System Initialization

D30 generates a short pulse (SYSINIT) when the vehicle is powered up. It is used to clear various counters and latches throughout the system. It uses the "power up reset" signal which is generated elsewhere on the vehicle.

3.5 Rate Buffer

Input Side

Data loaded into the first in-first out memory (FIFO) consists of the laser shot number (LSN) from latches (R4 and R5), the EOS bit from the azimuth board, and the 10-bit address from the receiver. The FIFO is loaded when the controller receives the "receiver data ready" pulse from the detector. If the FIFO is full the data is simply lost. Care must be taken when programming the proms to consider scan speeds, etc., as explained in Sec. 2.3 so that the FIFO's capacity will not be exceeded. See Appendix B for manufacturer's data on the rate buffer chips.

Output Side

The output ready signals (OR1, OR2, OR3) from the 3 FIFO memory chips (R1, R2, R3) are ANDed to form the input to the "System Select" circuitry of the telemetry control system. When the FIFO has data to be sent it will force telemetry (presently given highest priority) to select laser data on the next output word. The shift data out signals (SO1, SO2, SO3) are generated simply by NANDing the "laser system selected" signal with the "word rate" signal from the telemetry system.

3.6 Memory

The memory is located on a physically separate card to facilitate changes in the future. Because of availability of the chips and the programmer 1024 word UVPROMS are used. Accordingly, address lines A8 and A9 (most significant bits) are tied low, so we use only the first 256 words. Pins 18 and 20 are held low to place the chip in "read" mode. Care must be taken that the -5 volt supply be the first supply switched on and the last switched off. A circuit for this power-up, power-down arrangement is on the memory board.

3.7 Diagnostic Procedures

As a starting point, always check power to all the cards in question, as this has proved to be a frequent cause of problems in the past. If trouble appears in the elevation section, check operation of the input circuit to see if it agrees with Figure 3.2.1. If it is working check EFIRE. In test mode you should see one pulse here for 256 on ESP. If the circuit appears to be working but the laser is firing randomly, check coupling of encoder to mirror for slippage. If no fire laser pulses are appearing, check what is disabling them -- FIREUN, AFIREL or ESP. In azimuth a frequency counter comparing AFIRE (in test mode) with ASP should show a ratio of 256 -- that is a quick way of finding a fundamental problem. The rate buffer is best checked as an integral part of the telemetry since stand alone testing would require additional test circuitry to emulate the telemetry control signals. Naturally check the obvious signals if trouble occurs (i.e., receiver data ready signal, FIREUN switch latches data, shift in, input ready, shift out, etc.).

Other problems must be dealt with as they arise, and an understanding of the circuit operation and reference to the schematics are the best guides for the trouble-shooter.

4. CONTROLLER I/O

4.1 Inputs

All inputs are standard TTL level signals.

1. ESP - the pulse output of the elevation or mirror encoder.

2. EZR - the zero reference pulse of the elevation or mirror encoder.

3. ASP - the pulse output of the azimuth or mast encoder.

4. AZR - the zero reference pulse of the azimuth or mast encoder.

5. C1 thru C7 - the 7 most significant bits from the command link's UART. Used for azimuth reference angle.

6. C0 - the 8th bit from the command link's UART. Will signify that an azimuth reference angle has been received.

7. POWER UP RESET - Generated in the existing electronics on the vehicle. Used to initialize the system.

8. RECEIVER DATA READY - Generated by the receiver signifying that the receiver's output (0- 9) is valid.

9. 0 thru 9 - information from the receiver.

10. WORD RATE - Signal from present telemetry system.

11. LASER = 1 - Signal from present telemetry system. Used with "word rate" to request data from the FIFO rate buffer.

4.2 Outputs

All outputs are standard TTL level signals.

1. FIRE LASER - Signal to fire laser on leading edge and used by receiver for time gating.

2. EOS' - End of scan signal (last elevation shot at last azimuth), rate buffered.

3. EOES' - End of elevation scan (last elevation shot at ith azimuth), rate buffered.

4. 0' thru 9' - Information from receiver, rate buffered.

5. LASER DATA HERE - Signal to inform telemetry that data is waiting in FIFO. Will force telemetry to take laser data for next telemetry word.

6. SO' thru S9' - laser shot number, rate buffered.

4.3 Notes on I/O

Information on lines C0-C7 from the command link must remain in UART for a long enough time for the controller to latch it. Latching occurs when a pulse on ASP coincides with C0 being high. Thus data hold time is equal to $(256W_\theta)^{-1}$ seconds, where W_θ is in revolutions per second.

The receiver data ready signals should be normally low and should go high only when the α_i data is valid, and the α_i data must remain valid 30 μs after receiver data ready goes high. Suggested is that the α_i be always valid when receiver data ready signal is high, and this signal should be 30 μs long.

Only the leading edge of the fire laser signal should be used by the laser and receiver.

All rate buffered data should be connected to the auxillary inputs of the telemetry system according to the format in Section 6.3.

5. ALIGNMENT, CALIBRATION, TEST PROCEDURES

5.1 Alignment in Elevation

With the mast vertical, and the vehicle on a flat surface, set "azimuth override" switch to off, which will cause it's L.E.D. indicator to go off. In this mode azimuth position is ignored, and the azimuth motor should be disabled so that the mast is stationary in azimuth. The laser must be adjusted with respect to the mirror (may be slid in or out). Refer to Section 6.2 for desired location of laser. Set the test mode select switch, and the elevation angle test mode switches so that the system should fire a single shot at 45°. Use Table 3 to find the switch settings which correspond to 45°. Remember that the switch's value is "1" if it is set to "off". By simple geometry mark the point on the ground where the spot should appear. Use the T.V. camera-monitor to find the spot's actual location. The encoder's case can be loosened with 3 bolts and rotated with respect to it's axis about 15°. This should be set to bring the spot to the desired location. Thus the system is basically electrically aligned using the reference angle switches. Once their proper setting has been experimentally so determined they should be left alone. The same settings will be used in memory mode so that the shots will appear as expected in locations corresponding to the listing of Table 2.2.1. The laser lensing system should be adjusted for minimum spot size on the terrain. As there is not a receiver at the time of this writing, its alignment won't be discussed here.

5.2 Alignment in Azimuth

In this axis the accuracy is not as critical and the alignment procedure is a mechanical one. Set controller to test mode in both axes. Select any reasonable θ angle (30° perhaps), and set the azimuth data angle to -90° (see Table 2.1.1). With power up the reference angle latch should be cleared which corresponds to a center of scan angle of 90° (see Table 2.1.2). The result of this setting is that the laser spot should appear at $\theta = 0°$, $\pm\Delta\theta/2$), or directly in front of the vehicle. If it does not, the encoder must be mechanically adjusted. It is rotatable through about 15° degrees in azimuth, if this is not sufficient, the shaft will have to be moved with respect to the drive gear by readjusting that coupling, Reference 1.

A second and perhaps easier method of azimuth alignment is to monitor the zero reference pulse (AZR) from the azimuth encoder. If the mast is at the"zero" location this signal should be at a high level. This should happen when the mast is pointing at $\theta = 180°$, or straight backwards. The mast should be set pointing backwards, and the encoder rotated until the signal AZR goes high.

5.3 System Calibration

Once aligned, the system will be calibrated according to the information in Tables 2.1.1 and 2.2.1. Table 2.1.2 shows how the desired center of scan angle should be sent by the computer.

5.4 Test Procedures

Using the test mode for a few various angles, check the results geometrically for a quick test of the system. Accuracy of the pointing angle in elevation can be measured by rotating the mirror slowly with the mast stationary in azimuth. The amount of wobble of the spot can be measured and related geometrically to a variation in pointing angle. This should be less than 0.1°. This is not as easy in azimuth since data in this axis is only expected to be known $\pm\Delta\theta/2$. Sufficient testing will show if all shots are always within the $\Delta\theta$ zone. For some notes on electrical troubleshooting and testing see Section 3.7.

6. RELATED SUBSYSTEMS

6.1 Mirror and Mast Speed Control

Introduction

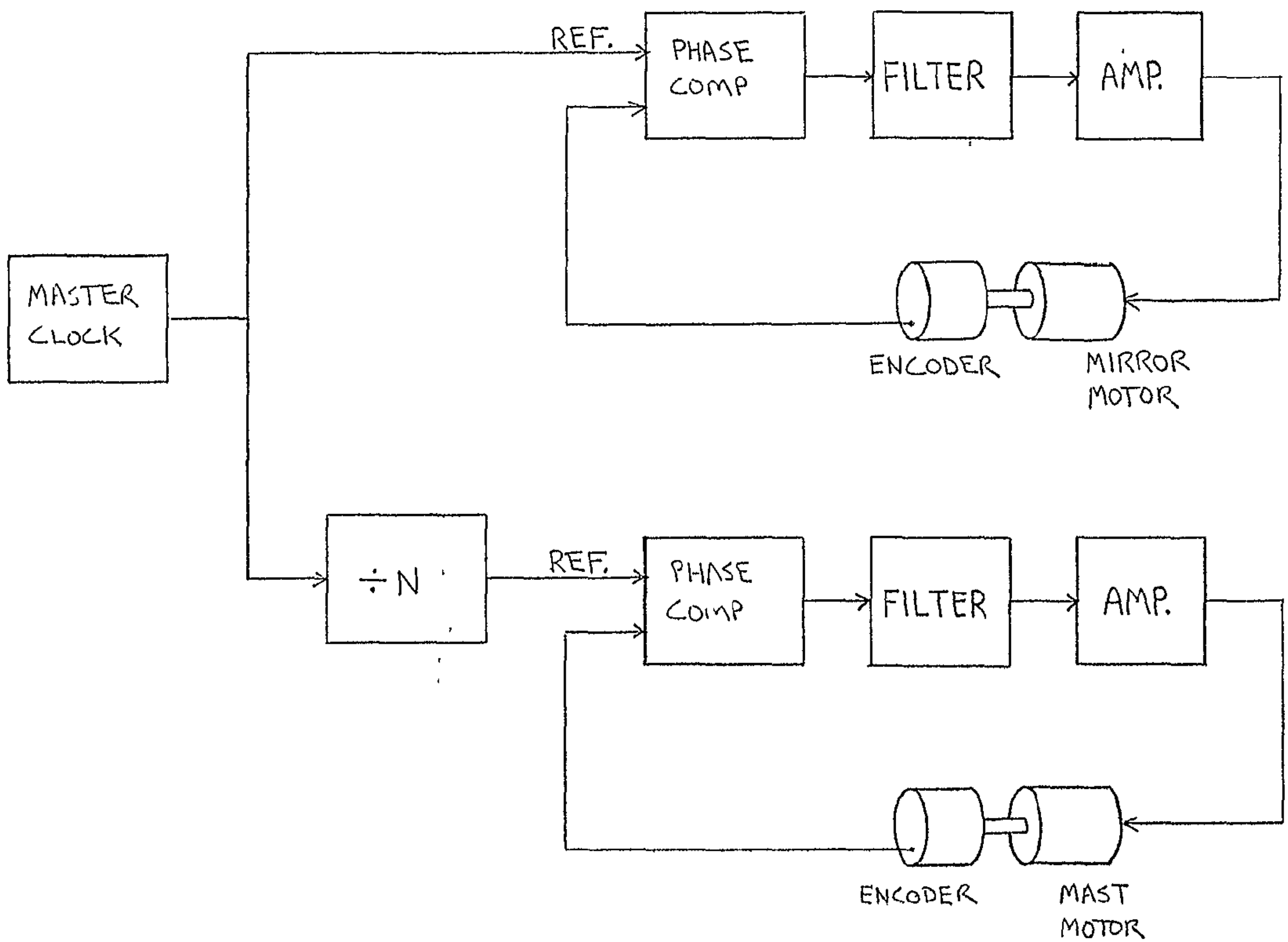
Since the speed of scanning will be an important factor in how fast the vehicle can travel, it is certainly desirable to be able to choose the mast speed (i.e. scan speed) and once set, have it be controlled accurately so that the overall integrity of the system is maintained.

The quantity $\Delta\theta$ (units of degrees) is that amount in θ which the mast moves during a complete elevation scan, and is obviously related to the ratio of mast speed (W_θ) and mirror speed (W_m), in fact: $\Delta\theta = 360(W_\theta/8W_m) = 45(W_\theta/W_m)$ degrees. Thus the θ angle of any shot is always known to be $\theta_k \pm \Delta\theta/2$, and for this reason, the speed of the mirror relative to the speed of the mast must be controlled accurately so that the value of $\Delta\theta$ is accurately known. Note that encoder supplied position information is always used to determine when a fire angle is reached, and is thus independent of motor speed, that is, no timing of motor speed is relied on. However, as mentioned above, exact placement of the shots in the azimuth (θ) direction will depend on the ratio of the two motor's speeds, since any elevation scan will initiate at the proper azimuth location (independent of motor speeds), but will be spread over $\Delta\theta$ (dependent on ratio of motor speeds).

6.1.1 Control Circuit

A phase locked loop motor control scheme was chosen to control the speed of both axes since encoder outputs were available because their use was dictated by other system performance criteria, and also since with this type of arrangement the ratio of the two speeds can be set quite exactly by using a master clock and a divide-by circuit. Overall scanning speed may be adjusted with the master clock frequency, and $\Delta\theta$ may be set by adjusting the divide by circuit. In a future system, the scan speed and $\Delta\theta$ could easily be sent by the computer because of the digital nature of this type of control scheme. Also, the set-up contains very little analog circuitry which can drift and become misaligned. Figure 6.1.1.1 shows a block diagram of the speed control system. The loop filter is basically an integrator, in this case approximated by an active low pass filter. The amplifier is just a motor driver circuit or D.C. amplifier. Presently the mirror motor's amplifier has a voltage gain of 10, and the mast motor's amplifier has a voltage gain of 20. The gain may be adjusted by altering the ratio of R_C to R_E in the amplifier circuit (see Figure 6.1.1.1). The first stage of the amplifier supplies voltage gain, the second two stages are a follower circuit with voltage gain near unity but with significant current gain. Both amplifiers have the same design except for resistance values which vary because the supply voltages are different. The loop filter uses a Darlington pair amplifier which is on the PLL Chip (to be used for just this purpose). Note that the filter's transfer function may be written as: $F(s) = R_2/R_1 + 1/R_1CS$, therefore it has a low pass characteristic, but represents a fixed gain of R_2/R_1 to frequencies beyong the passband. For this reason, the ratio of R_2/R_1 should be small, and 1/10 was used here. It was found during bench testing that performance wasn't affected much by varying the capacitor in the filter (i.e. moving the filter's zero) as long as the low pass characteristics was present. Also varying the gain in the amplifiers didn't change things much. Apparently, due to the relatively large inertias being driven by relatively small motors, both systems have long mechanical time constants, or on the root locus, a "slow" pole NGAR the origin, so that the location of the filter's zero isn't critica; or in other words, the motor-load systems are in fact too "slow" to react to any high frequency components of the drive signal so the filters break frequency is not critical, only its integrating action is needed. However our motors have small high speed armatures driving gearboxes, and if

6.1.1.1 Mast & Mirror Speed Control Block Diagram



here is any play in the gears at the input side of the gearbox (which there always is), the armature will be free to move back and forth a bit without driving the load inertia. In this situation the mechanical time constant of the motor's armature must be considered, and corresponding high frequencies of the drive signal removed to prevent the armature from rattling around in the gearbox, a situation which is presumably not good for the motor and gears. It should be stressed that although the system works as good as need be for our use, it could be optimized. In fact, much is to be learned here. I made a quantitative study, as is done in References 5 and 7 and found, according to my model, that this system which works on the bench should be completely unstable. Obviously, the model isn't accurate. I'm sure the problem is in the loop filter, as the loop's performance is quite sensitive to changes here, and the present realization of the filter probably doesn't exhibit the "ideal" transfer function which was used in my analysis. Some suggestions: Build the filter using an OP-Amp and be sure of the transfer function you're getting. Also to this end, a non-inverting buffer stage between filter output and DC amp input would reduce loading effects which may be responsible for some problems. Actually the use of PLL's in phase-locked DC motor servos is a new area in which quite a lot of work could be done -- few people understand them.

6.1.2 Motor Selection

1. Mirror Motor

The motor chosen was the Micro Mo #330/09 (see Appendix B). Figure 6.1.2.1 shows schematically the mechanical system driven by the mirror motor. The GSAR reduction ratio is N = 1/5.4, which leads to the following equation for the total system inertia as seen by the armature:

$$J_{tot} = J_{mot} + N^2(J_{mir} + J_{enc})$$

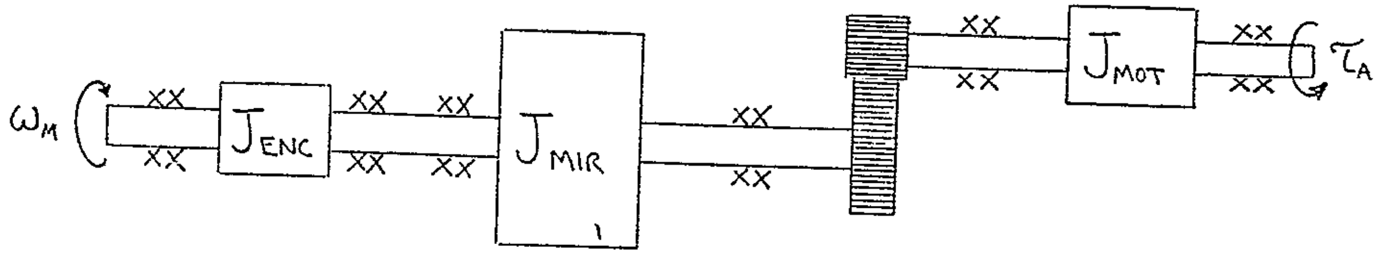


FIG. 6.1.2.1 SYSTEM INERTIA

where:

$$J_{mot} = 0.208 \times 10^{-4} \text{ Oz. in. sec.}^2$$

$$J_{mir} = 0.0311 \text{ Oz. in.sec.}^2$$

$$J_{enc} = 4.0 \times 10^{-5} \text{ Oz.in.sec.}^2$$

The inertias for the armature (J_{mot}) and for the encoder (J_{enc}) were given by the manufacturer, and the mirror's inertia (J_{mir}) was estimated by Dave Knaub of the Mechanical group. The calculation yields a value of J_{tot} equal to 1.088×10^{-3} Oz.in.sec.^{2} To develop a mechanical time constant of the system, the armature inductance (L_A) was considered small and the damping was assumed small. Then:

$$\tau_{M_{Tot}} = \frac{R_A J_{tot}}{K_E K_T} = 808.84 \text{ ms.}$$

where R_A = armature resistance = 21

K_E = back em.f. constant = $0.014133 \frac{\text{v.sec.}}{\text{rad}}$

K_T = torque constant = 2 in.oz./amp

τ_{mtot} = total mechanical time constant = 808.84 ms.

since the electrical time constant of the motor is LA/RA = .031 ms, it can certainly be neglected. Then a model of the electro-mechanical system is:

$$M_1(s) = \frac{(s)}{V_1(s)} = \frac{1/K_E}{s(\ _{mtot}s + 1)} = \frac{70.756}{s(.8088s+1)}$$

or $$M(s) = \frac{87.479}{s(s + 1.236)}$$

The system should come up to speed in about $4\tau_{mtot}$ seconds or 3.235 seconds, which is quite acceptable.

2. <u>Mast Motor</u>

The motor chosen is the Globe 168A229-2 (see Appendix B).

Figure 6.1.2.2 shows schematically the electro mechanical system of the motor-mast pair. The gear ratio is N = 1/192 which leads to the following equation for system inertia as seen by the armature:

$$J_{tot} = J_{mot} + N^2 (J_{mast})$$

where J_{mot} = armature and gear box inertia = 0.00135 oz. in. sec.^{2}

J_{mast} = estimate of mast slip ring, encoder inertia = 0.986 oz.in.sec.^{2}

which yields $J_{tot} = 1.3767 \times 10^{-3}$ oz.in.sec.^{2} Note this is just an approximation, derived by Dave Knaub before the mast was constructed. Then assuming a low inductance and damping in the system

$$\tau_{mtot} = \frac{R_a J_{tot}}{K_e K_T} = \frac{(36.3)\ (1.3767 \times 10^{-3})}{(0.0127)(1.8)} = 2.19 \text{ sec}$$

where R_A = armature resistance = 36.3

K_e = back E.M.F. constant = 0.0127 $\frac{\text{V.sec.}}{\text{rad}}$

K_T = torque constant = 1.8 oz.in./amp.

τ_{mtot} = mech. time constant = 2.19 seconds

The system transfer function is approximately:

$$M_2(s) = \frac{\Theta(s)}{V_2(s)} = \frac{1/K_e}{s(\tau_{mtot}\ s + 1)}$$

or

$$M_2(s) = \frac{35.96}{s(s + 0.457)}$$

The system will come up to speed in 4 τ_{mtot} or about 8.76 seconds. This in itself is acceptable, however the system may not be fast enough to adjust quickly to changing disturbance torques. There is still some question as to whether the motor is adequate and depends on the friction inherent in the gears, bearings, etc. Future experimentation will indicate whether a more powerful motor should be used.

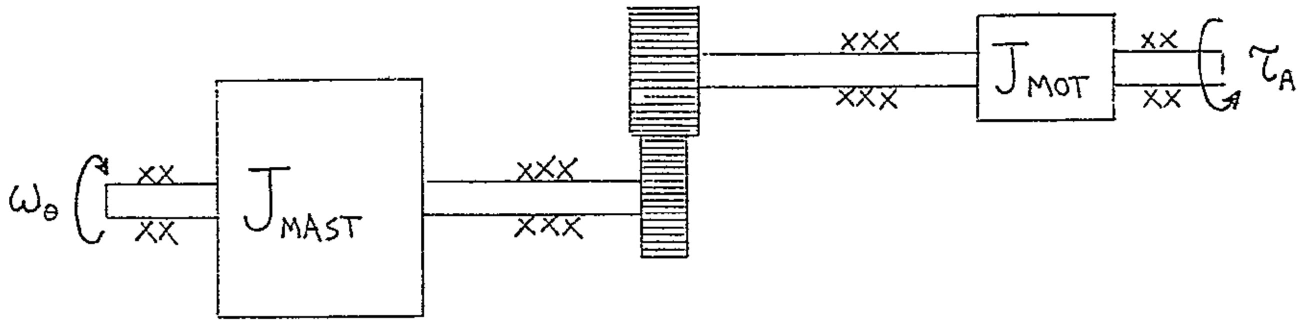


FIG. 6.1.2.2 SYSTEM INERTIA

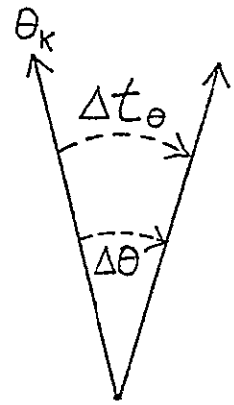
6.1.3 Test Results

Because of varying friction as the motors turn, and because the time constants of the rotating systems are too long to allow fast corrections by the control circuitry, neither axis locks in phase completely. Observing the waveforms on a dual trace scope shows that they nearly lock but friction and disturbance torques cause the signals to slide out of lock periodically. Averaged over 1 second, the mirror motor's speed matches the reference clock within $\pm$ 0.2%, and averaged over 10 seconds, it is within $\pm$ 0.01%. This performance is certainly better than needed, so not being always locked in phase is not a problem. The mast motor seems to have to battle the friction and should perhaps be replaced with a larger motor. If the gears are freshly oiled and aligned, its speed averaged over 1 second is within $\pm$ 1% of the reference, but normally only $\pm$ 5% regulation can be expected. The accuracy of these motor speeds dictates how precisely $\Delta\theta$ is known, so $\pm$ 5% may be acceptable, but the uncertainty should not be much more than this. Presently on the bench the motors are running in a ratio of 24, thus the $\Delta\theta$ is 1.875°, and the ratio holds within 5% so the "guaranteed" $\Delta\theta$ is about 1.9°. To insure that $\Delta\theta$ stays within the 2° which is hoped for, the motor speed should be checked periodically to insure that the ratio of 24 is held within 5%. Presently the overall scan speed can be set with a pot to any value from 1 scan per 3.80 seconds to 1 scan per 1.35 seconds. Moving outside this is possible but would require some minor modification to the clock circuit.

6.2 Mirror

Introduction

The following page shows the development of equation (8) which demonstrates that the frequency the laser must be able to fire is inversely proportional to the number of mirror faces (N). However, N is limited because the

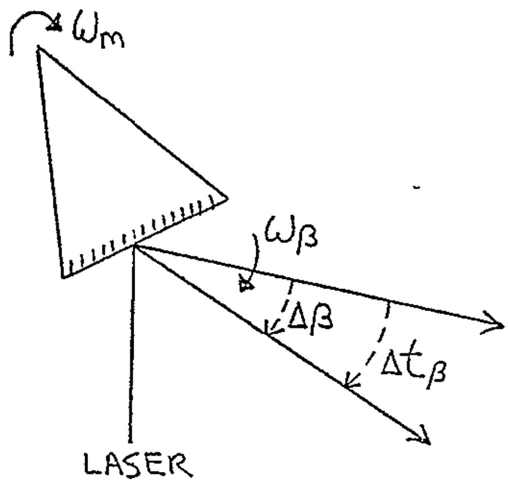


$$\Delta\theta = \Delta t_\theta \, \omega_\theta \qquad (1)$$

$$\Delta t_\theta = \frac{2\pi}{N} \frac{1}{\omega_m} \qquad (2)$$

$$\omega_m = \frac{2\pi}{N \Delta\theta} \omega_\theta \qquad (3)$$

DEVELOPMENT OF ω_m AS FUNCTION OF ω_θ



$$\Delta\beta = \Delta t_\beta \, \omega_\beta \qquad (4)$$

$$\omega_\beta = 2\omega_m \qquad (5)$$

$$\Delta\beta = 2 \Delta t_\beta \, \omega_m \qquad (6)$$

$$f_L = \frac{1}{\Delta t_\beta} = \frac{2\omega_m}{\Delta\beta} \qquad (7)$$

OR,

$$f_L = \frac{4\pi \omega_\theta}{N \Delta\theta \Delta\beta} \qquad (8)$$

$\Delta\theta$ = CHANGE IN θ DURING ELEVATION SCAN. (RAD.)

Δt_θ = DURATION OF ELEVATION SCAN

ω_θ = SPEED OF MAST ROTATION (RAD/SEC.)

N = NUMBER OF MIRROR FACES

ω_m = SPEED OF MIRROR ROTATION (RAD/SEC.)

f_L = REPITITION RATE OF LASER (SEC^{-1})

ω_β = SPEED OF β ANGLE CHANGE (RAD/SEC.)

total angular scan available off a polygonal mirror is also inversely proportional to N. A good compromise is to choose N = 8, so that β_{tot} is 90°, and the frequency of the laser (F_L) is also reasonable.

6.2.1 Mirror Description

An 8-sided mirror was located and purchased from Lincoln Laser Company, 625 South 5th Street, Phoenix, Arizona 85004, (602) 257-0407. The mirror is a stock item #PO-8-300-087 with high reflectivity coating. Some data sheets supplied by Lincoln Laser are in Appendix B. The mirror is 0.941" wide and each face has a length of 1.2426". The mirror is solid aluminum coated with nickel, coated with a reflecting coating. See data sheets for other information.

6.2.2 Cleaning

A. If dirty with gritty type dirt brush off lightly with camel hair brush.

B. Wipe mirror gently with surgical cotton wetted with acetone or isopropyl alcohol.

C. If still dirty, wipe with cotton wetted with water containing a mild detergent, then wipe with water to remove detergent, then wipe with acetone (or isopropyl) and let this coating evaporate off.

D. Other questions call: Randy Sherman at (602) 257-0407.

6.2.3 Notes

Figure 6.2.3.1 shows the relative placement of laser and mirror if it is desired to sweep through angles in β of 0° to 90°. The offset between the center of the laser's beam and the mirror's axis of rotation should be half the length of a mirror face. During the conceptual phase of developing the elevation scanning system, much thought was given to error arising from imperfect mirrors (non-flat faces, low accuracy angles between adjacent faces, etc.), but having found this precision mirror these considerations are no longer necessary, and have not been included.

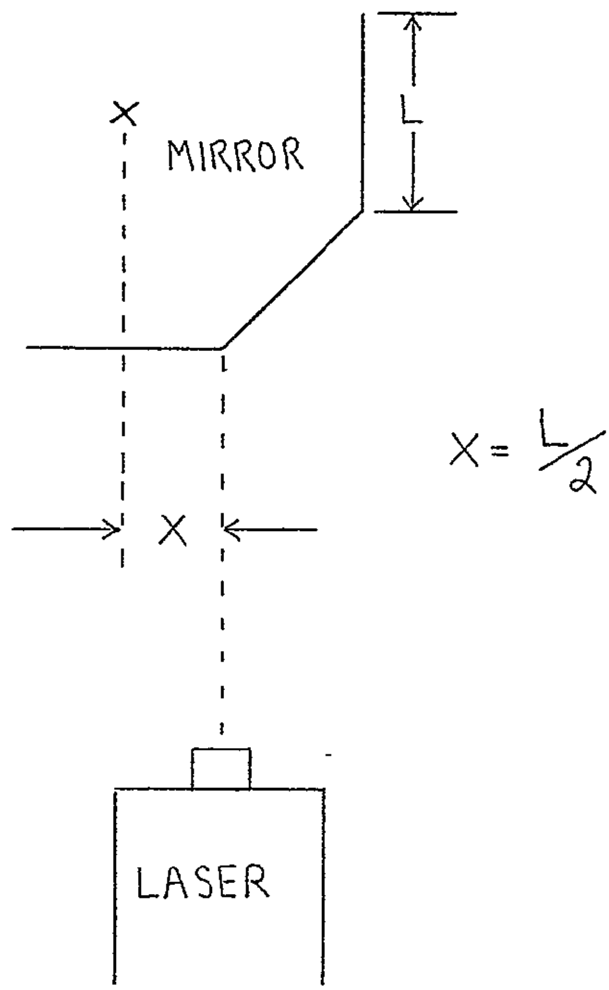


FIG. 6.2.3.1 LASER BEAM/MIRROR AXIS OFFSET

6.3 New Telemetry Data Format

The laser triangulation data generated by the elevation scanning/multi-detector system will be of quite different form as compared with the single elevation system. The following is a suggested format of the telemetry word's 26 bits, and how the DMA address is extracted from these bits. Each telemetry word contains 26 data bits (DBB1-DBB26). These bits are all loaded into the interface located in the expansion chassis of the Varian 620i Computer. The interface uses some of the bits to generate the address at which to load the data bits which are also some subset of the 26 telemetry data bits. The interface is wired to always load bits DBB6-DBB21 inclusive as DMA data. The address is formed as shown in Figure 6.3.2. The bits S_1 through S_7 are the outputs of latches which are loaded (via software) with the 7 most significant bits of the address of the beginning of the DMA data block. The figures and discussion here assume octal 1000 is loaded for the DMA block address. (That is $S_1 \rightarrow S_7$ = XX00000, S_1 and S_2 are don't cares). S_1 is always assumed high, and S_2 is always assumed low, they are "don't cares", and therefore starting addresses are limited to: 001000, 005000, 011000, 015000, etc. Figure 6.3.2 shows the logical function which should be realized for each of the E-bus lines during DMA address phase. This entails slight rewiring of the interface. Figure 6.3.1 shows the format of the telemetry word for vehicle state data and laser data. The A_i tag the vehicle words with an identifier. For vehicle words the bits N_6 through N_{10} will indicate the last azimuth number. In the data field, 14 bits are shown for α_i, but probably only 10 will be used, Reference 1 . The EOS bit will be high if the laser word containing it is the last in the scan pattern. Alternatively, this bit may be connected in the controller to be the end of elevation scan bit (EOES) in case an interrupt at each azimuth is desired. Figure 6.3.2 shows the logic which initiates an

BIT #	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26
VEHICLE WORD	0	A_1	A_2	A_3	A_4	D_1	D_2	D_3	D_4	D_5	D_6	D_7	D_8	D_9	D_{10}	D_{11}	D_{12}	D_{13}	D_{14}	D_{15}	D_{16}	N_{10}	N_9	N_8	N_7	N_6
LASER WORD	1	N_1	N_2	N_3	N_4	α_1	α_2	α_3	α_4	α_5	α_6	α_7	α_8	α_9	α_{10}	α_{11}	α_{12}	α_{13}	α_{14}	EOS	N_{10}	N_9	N_8	N_7	N_6	N_5

LOADED INTO CORE AS DATA (bits 6–21)

A_i = SENSOR ADDRESS

N_i = LASER SHOT NUMBER

D_i = VEHICLE WORD DATA BITS

α_i = LASER DETECTOR OUTPUT

EOS = END OF SCAN BIT

FIG 6.3.1 NEW TELEMETRY DATA FORMAT

E-BUS	FUNCTION
EB15	S_7
EB14	S_6
EB13	S_5
EB12	S_4
EB11	S_3
EB10	DBB1
EB09	$DBB1 \cdot DBB21 + \overline{DBB1}$
EB08	DBB22
EB07	DBB23
EB06	DBB24
EB05	DBB25
EB04	DBB26
EB03	DBB5
EB02	DBB4
EB01	DBB3
EB00	DBB2

SEE TEXT FOR EXPLANATION OF SYMBOLS.

EOS INTERRUPT INITIATE: $DBB1 \cdot DBB20$

FIG. 6.3.2 DMA ADDRESS FORMATION

interrupt request in the interface. Figures 6.3.3 and 6.3.4 show how the data will be placed in core.

6.4 Handshake Capability

Whenever a computer generated command is sent to the vehicle, a feedback path should exist to verify that the vehicle indeed received the command. Presently, if a steering command is sent, for example, the steering angle sent back (one of 16 vehicle words) can be monitored to see if it is in fact carrying out the desired command. Likewise with speed commands, since Tach readings are set back via telemetry. To provide another feedback path and one which is general for any command, a capability has been added which echos the commands received over the command link back to the computer via the telemetry link (see Figure 6.4.1). This capability should improve system integrity and help in diagnosing problems in the command and telemetry links. The new telemetry display box built by T. Comins and J. Turner will be able to indicate the last command received at the vehicle, and will provide a quick check of the command link. Indeed there may be instructions sent by the computer for which there is no other feedback path to tell whether the vehicle ever accepted the command; for example, when sending the desired center of scan angle in azimuth one certainly needs to know if the command was received as it changes the maning of all the laser shot numbers tagging the laser data.

The echoed command appears in the lower half of the first vehicle state word, called the "Latch Data" word. The new format for this word is shown in Figure 6.4.2. It is placed such that the lower 3 seven-segment readouts on the telemetry display box will indicate the instruction in octal. The software group is presently developing a subroutine to check the echoed command against the one sent as a standard part of the output routine.

ADDRESS	MEANING
2000_8	AZIMUTH #0 ELEVATION #0
2001_8	AZIMUTH #0 ELEVATION #1
2002_8	AZIMUTH #0 ELEVATION #2
⋮	⋮
2037_8	AZIMUTH #0 ELEVATION #31
2040_8	AZIMUTH #1 ELEVATION #0
2041_8	AZIMUTH #1 ELEVATION #1
⋮	⋮
3776_8	AZIMUTH #31 ELEVATION #30
3777_8	AZIMUTH #31 ELEVATION #31

FIG. 6.3.3 LASER DATA CORE LOCATION

ADDRESS	MEANING
1000_8	AZIMUTH #0 VEH WORD # 0
1001_8	AZIMUTH #0 VEH. WORD # 1
1002_8	AZIMUTH #0 VEH WORD # 2
⋮	⋮
1017_8	AZIMUTH #0 VEH. WORD #15
1020_8	AZIMUTH #1 VEH. WORD #0
1021_8	AZIMUTH #1 VEH WORD #1
⋮	⋮
1776_8	AZIMUTH #31 VEH. WORD #14
1777_8	AZIMUTH #31 VEH. WORD #15

FIG. 6.3.4 VEHICLE DATA CORE LOCATION

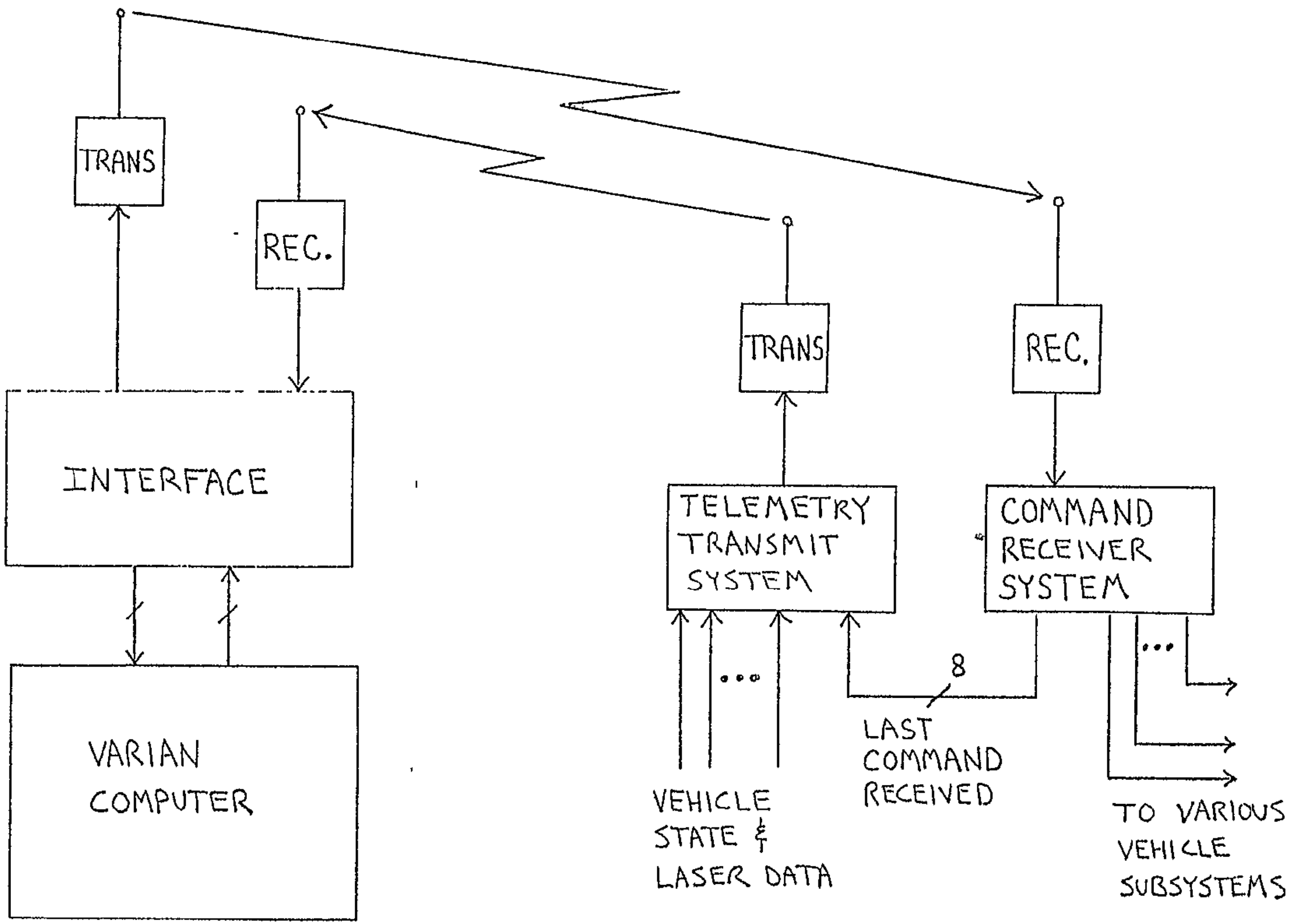


FIG. 6.4.1 "HANDSHAKE" CAPABILITY

D_1	RIGHT FRONT HEAT	
D_2	LEFT FRONT HEAT	
D_3	RIGHT REAR LATCH	
D_4	LEFT REAR LATCH	
D_5	24 VOLT LOW	
D_6	12 VOLT LOW	
D_7	SIGNAL LOSS	
D_8	0	
D_9	C_8 (MSB)	
D_{10}	C_7	
D_{11}	C_6	
D_{12}	C_5	LAST COMMAND RECEIVED
D_{13}	C_4	
D_{14}	C_3	
D_{15}	C_2	
D_{16}	C_1 (LSB)	

FIG 6.4.2 FORMAT OF "LATCH DATA" WORD

6.5 Encoders

Elevation Encoder Selection

It was desired to have a resolution of 2048 pulses for revolution which corresponds to a pointing angle resolution of 0.35°. Note that the angle through which the beam moves when a mirror is rotated is twice the amount of the mirror's angular rotation. Therefore the 2048 pulses per revolution were needed, not 1024 for 0.35° resolution. The 2048 pulses when counted and presented in parallel fashion appear as an 11-bit address. The top 3 bits are actually the face number (0-7) and the lower 8 bits are the 256 possible fire locations. Accordingly only an 8-bit counter is used in the controller, as all 8 sides of the mirror are assumed equivalent. The elevation encoder had to be selected for small size and weight since it is placed at the vertical top of the mast. The Teledyne Gurley 8602-69-1024-022 was selected for performance, size, weight, and proximity of the manufacturer. It includes a second piece of hardware called the "Signal Conditioner" which is mounted on the mast just above the upper mast bearing. Its output is a TTL level pulse train which goes directly into the controller. There is also an index pulse. See Appendix B for information from the manufacturer.

Azimuth Encoder Selection

An encoder was chosen with 256 pulses per revolution as an output, plus a zero reference. This corresponds to a resolution of 1.4° in azimuth. This is deemed sufficient since the data density in this direction is expected to be much less than in elevation (i.e. adjacent azimuth angles will probably be 10° apart, whereas adjacent elevation angles will be perhaps 1° apart). The size and weight of this encoder was not so crucial and it is physically larger and has the signal conditioner section actually built right in. It outputs standard TTL level pulses. The Teledyne-Gurley 8635-128-022 was selected. See Appendix B for manufacturer's specifications.

6.6 Proms

Prom Selection

Since it is desirable to be able to change the scan pattern occasionally, an erasable prom was chosen. Due to the availability of a compatible programming machine in the building, ultra-violet erasable proms of 1024 x 8 organization were used. We presently use 2708's manufactured by Intel.

Programming

Professor Das of the E.S.E. Department at R.P.I. has a programming system called "BYTESAVER". It is presently located in Room 6114 in the Engineering Center and operated by Greg White, a student. Desired addresses and desired data should be supplied to the operator of the programming machine in hexadecimal representation. This representation appears for this purpose in Tables 2.1.1 and 2.2.1 since words 256 through 1023 are never addressed, their contents do not need to be programmed. A data sheet appears in Appendix B.

Power Supplies

The memories require -5, +5, and +12 volts. Also, the -5v supply should be the first switched on and the last switched off. A circuit to accomplish this has been built on the memory board of the controller.

6.7 Programs for Angle Listings

The listings in Tables 2.1.1, 2.1.2, and 2.2.1 were all generated by a block of programs written by Bill Kennedy (Spein '78) in order to facilitate the selection of fire angles. It may quickly be seen which angles are available, and from this set, a set of desired fire locations can be chosen.

Since some portions of the output depend on supplying inputs such as $\Delta\theta$, scan speed, laser beam width, etc., the programs should be rerun as needed. The following summarizes the inputs and outputs for each of the programs. The program lists themselves appear in Appendix C.

File - AZIMANG

Descrip.- FORTRAN program to compute available azimuth data angles, their initiate angles, and addresses in memory.

Inputs - Mast velocity, and mirror velocity, in radians per second. To change values, replace the respective assignment in the initialization block of the program

Output - 1) list of azimuth data angles, their initiate angles (degrees), and addresses in memory in octal, binary and decimal formats.

2) mast velocity (rad/sec, and rpm)

3) mirror velocity (rad/sec, and rpm)

4) data hold time (seconds)

5) $\Delta\theta$ (degrees)

6) number of scans per second

File - ELEVANG

Descrip.- FORTRAN program to compute available elevation angles

Inputs - 1) LMIR, the length of one mirror face (inches)

2) WBEAM, the width in inches of the laser beam at the mirror's surface

3) LASLIM, the limiting frequency for continuous laser operation (hertz)

4) RPMIR, the angular velocity of the mirror (rpm)

These values may be changed by replacing the corresponding assignment in the initialization block.

Output - 1) list of available elevation angles, and their corresponding address in memory (octal, binary, and decimal). Asterisks are placed at angles where only partial power is available from the laser.

2) $\Delta\beta_{min}$ (degrees) - an integral multiple of the encoder resolution.

3) Laser limiting frequency (hz)

4) Mirror velocity (rpm)

5) Beam width (inches

File - COSANG

Descrip.- FORTRAN program to compute available center of scan angles for azimuth scanning.

Inputs - None

Outputs- 1) list of available center of scan angles (degrees), their reference angles in the controller (actal, and binary) and the corresponding computer command word (octal, and binary).

CONCLUSION

Early testing of the laser-mirror-encoder-controller laser beam pointing system shows that pointing accuracy well with 0.1° has been achieved in the elevation axis. Due to an as yet unreceived azimuth encoder, that axis has not yet been tested as of this writing. The system can fire up to 32 elevation shots at each of 32 azimuths, elevation shots may occur as close as 0.35° apart as long as the maximum fire rate of the laser is not exceeded. In azimuth the system can fire adjacent shots as close as 1.4° or 2.8° (depending on scan speeds, ω_e) in azimuth. The scanning speed and $\Delta\theta$ can be accurately adjusted for any configuration. The UVPROMS make it easy to change the scanning patterns to try any new concepts suggested by the group.

We feel we have developed a reliable, flexible system which with little or no modifications can be employed to implement many different scanning schemes. The ML/MD scanning shstem developed in the 1977/78 academic year will form the cornerstone of the R.P.I. Mars Roving Research Vehicle for years to come.

During the course of the ML/MD system development many ideas were suggested by various group members which couldn't be implemented this year.

A key to building a powerful autonomous system is to increase the bit rate capability of the command link. If it had the capacity of the present telemetry link, many new features could be considered. Rams could replace the controller's UVPROMS and the computer could, in real time, write in the desired fire angles, so that the scanning pattern can be dynamically changed as called for by local terrain (i.e. the rover may wish to focus all its shots into one sector of interest). Likewise the mirror and mast motor speeds could be sent in real time so the computer has continuous control of the scanning speed and $\Delta\theta$. A very useful addition would be a self calibrating routine, so once placed on flat ground the rover could automatically calibrate the entire mast system by itself. (Fire shot at known angle - see if it returns on proper detector given the terrain is flat, and so on). Many visual aids could be made to show the information returned by the detectors in some sort of graphic display.

A microprocessor on board to run a four wheel speed control algorithm would be a worthwhile investment. It could also take over some other functions. Digitizing the steering system (use an encoder instead of a pot with A/D) and the wheel speed system (encoders instead of tachs) would be a useful project. Presently the analog circuits drift, are unreliable, and usually are out of calibration.

The real challenge in the upcoming years will be in the software area, to find the best ways to use all the information which the elevation scanning/multi-detector system can return.

LITERATURE CITED, REFERENCES

1. Meshach, William "Elevation Laser Scanning/Multi-Detector Hazard Detection System: Pulsed Laser and Photodetector Components, Rensselaer Polytechnic Institute, Troy, N.Y. August 1978.

2. Knaub, Dave, "Elevation of the Propulsion Control System for a Planetary Rover and Design of an Elevation Laser Scanning Mast," Rensselaer Polytechnic Institute, Troy, N.Y., May 1978.

3. Texas Instrument, Inc., The TTL Data Book, Texas Instruments, Inc., 1973.

4. Fairchild Corp., MOS/CCD Data Book, Fairchild Components Group.

5. Moore, A.W., "Phase-Locked Loops for Motor Speed Control," IEEE Spectrum, April 1973.

6. Smithgall, D.H., "A Phase-Locked Loop Motor Control System," IEEE Transactions on I.E.C.I., Vol. 22, No. 4, November 1975.

7. Tal, Jacob,"Speed Control by Phase-Locked Servo Systems - New Possibilities and Limitations," IEEE Transactions on I.E.C.I., Vol. 24, No. 1, February 1977.

APPENDIX A

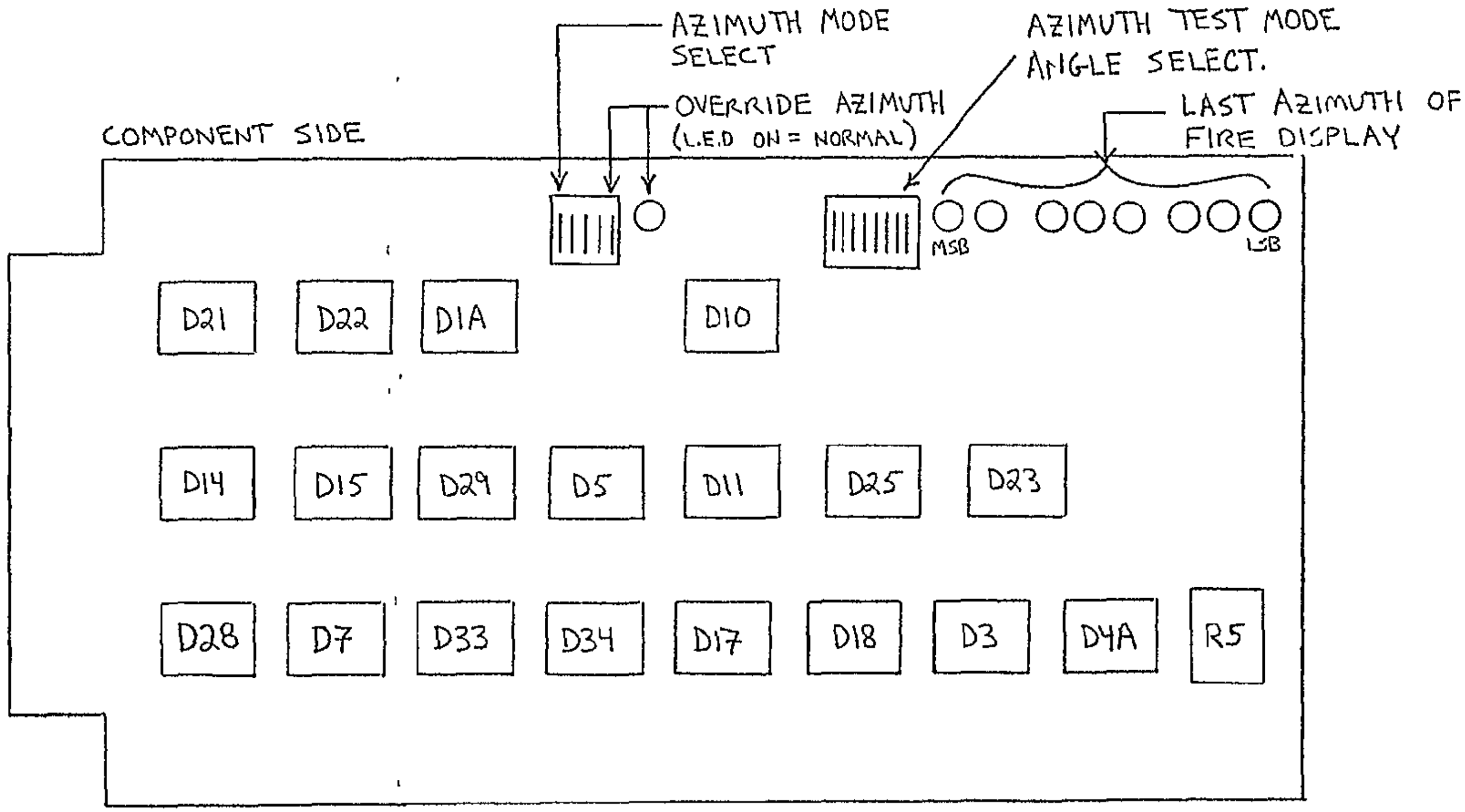


FIG. A.1 AZIMUTH BOARD CHIP LAYOUT

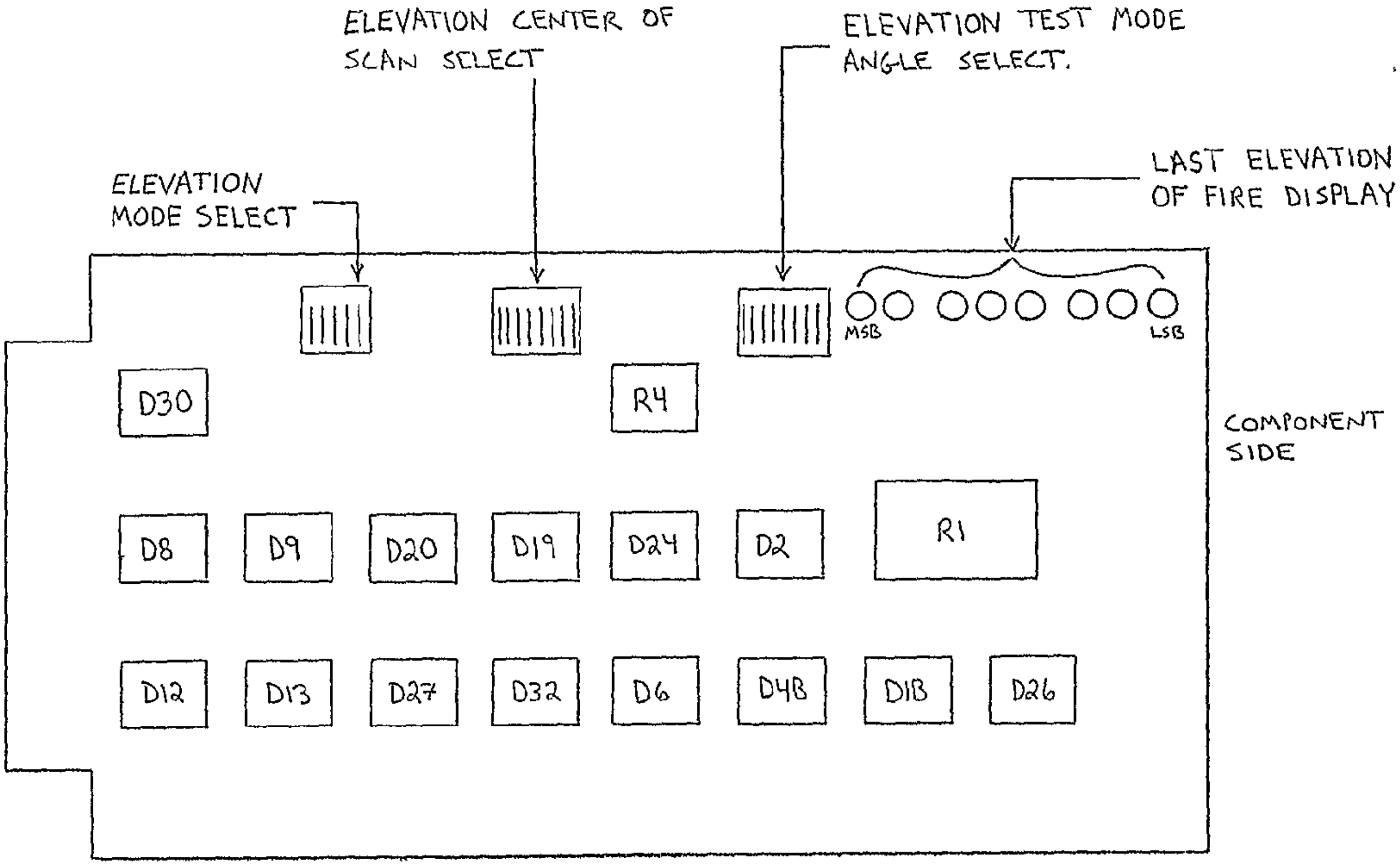


FIG A 2 ELEVATION BOARD CHIP LAYOUT

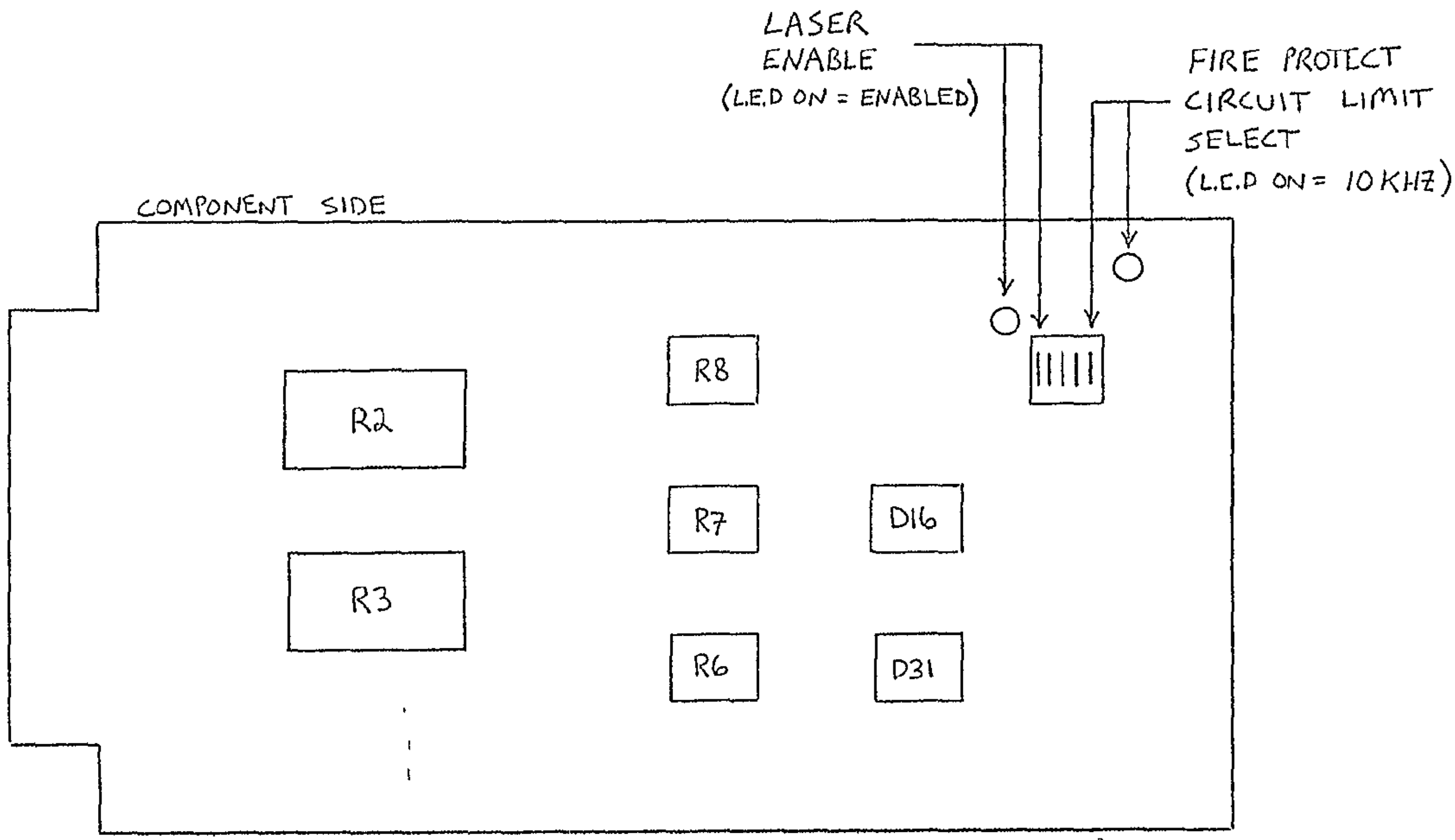


FIG A.3 RATE BUFFER BOARD CHIP LAYOUT

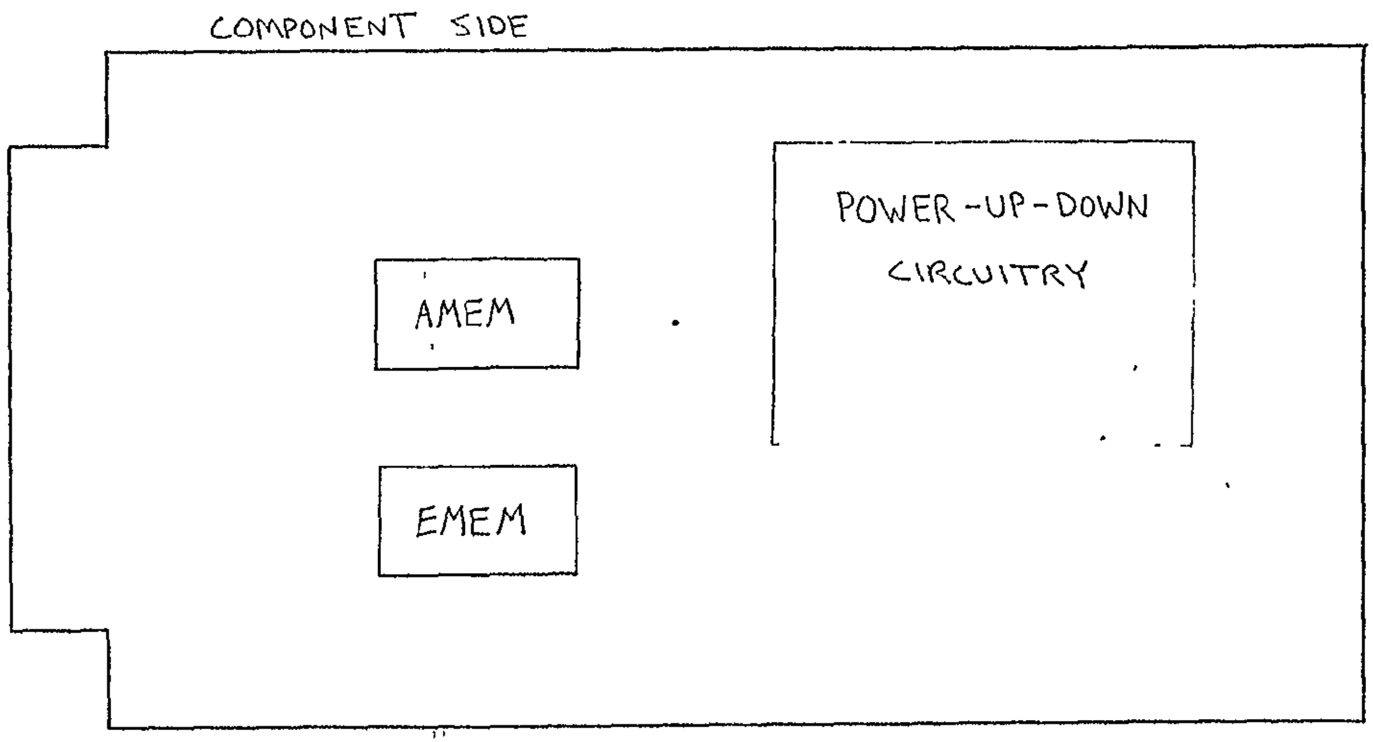


FIG. A.4 MEMORY BOARD CHIP LAYOUT

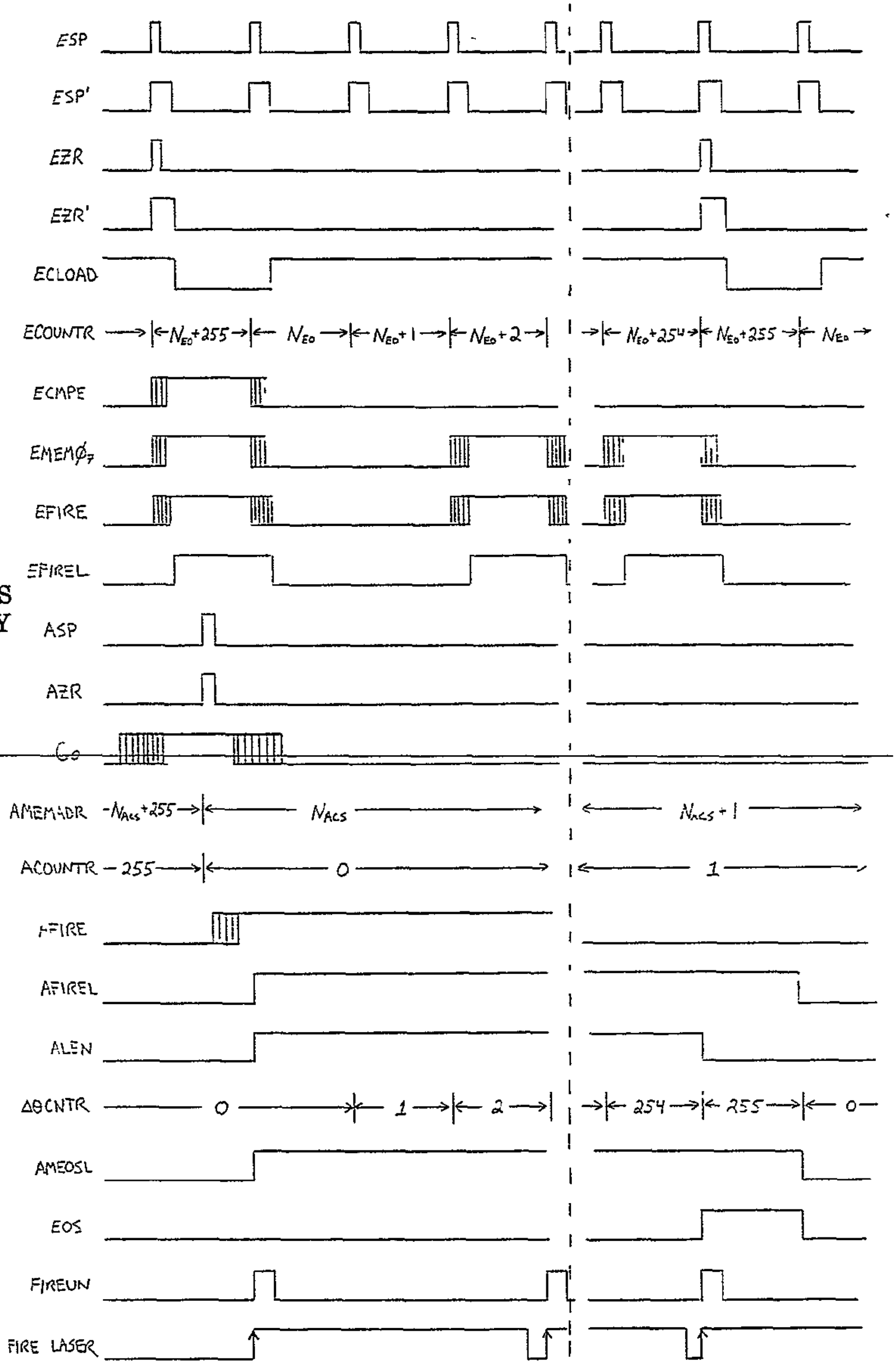


FIG A5 CONTROLLER TIMING DIAGRAM

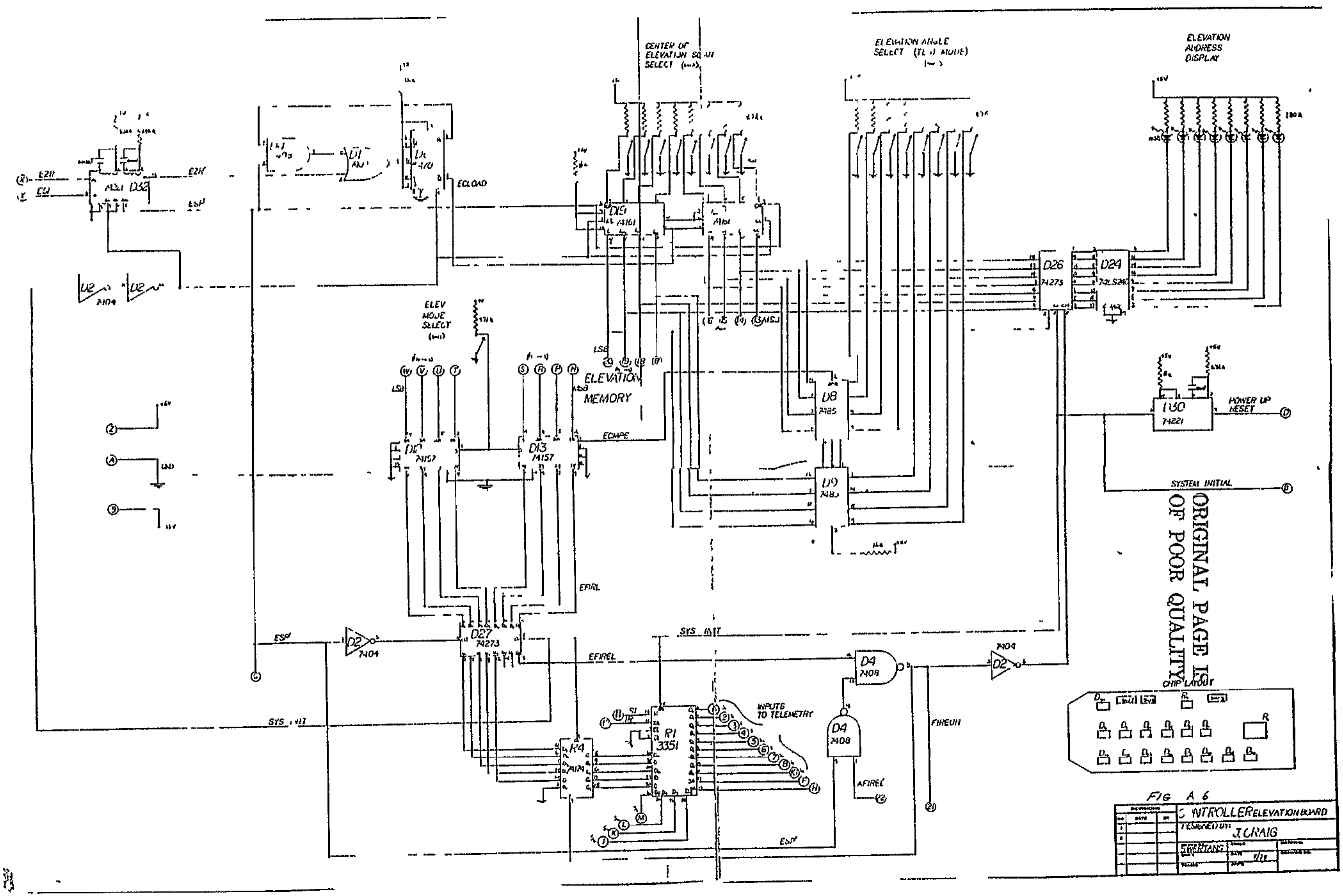

CENTER OF ELEVATION SCAN SELECT
ELEVATION ANGLE SELECT (TEST MODE)
ELEVATION ADDRESS DISPLAY
ECLOAD
ELEV MODE SELECT
ELEVATION MEMORY
ECMPE
POWER UP RESET
SYSTEM INITIAL
EFIRL
ESP
SYS INIT
EFIREL
INPUTS TO TELEMETRY
CHIP LAYOUT
CONTROLLER ELEVATION BOARD
J. CRAIG

FIG A 6

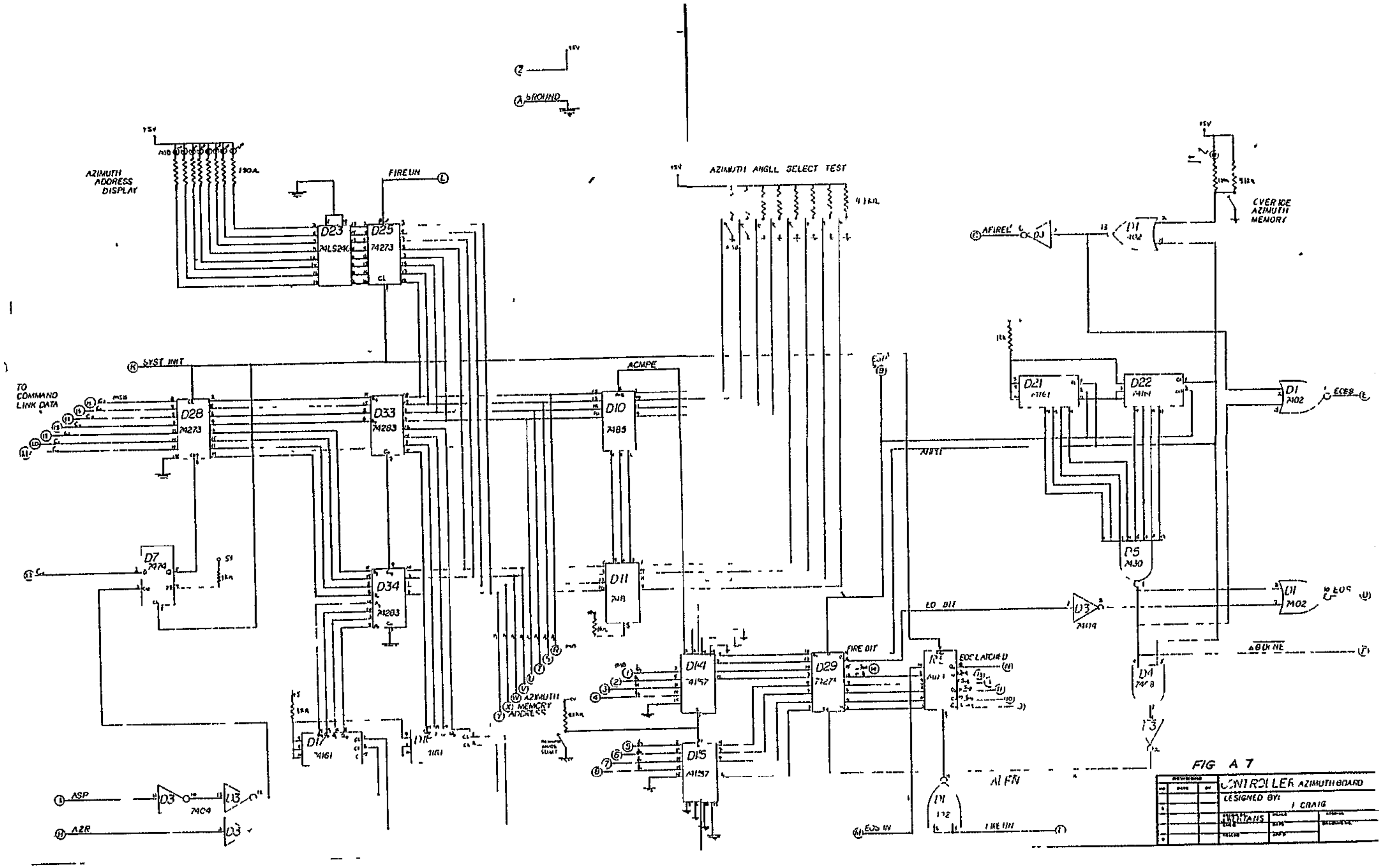

AZIMUTH ADDRESS DISPLAY
FIREUN
AZIMUTH ANGLE SELECT TEST
OVERIDE AZIMUTH MEMORY
TO COMMAND LINK DATA
SYST INIT
ACMPE
AZIMUTH MEMORY ADDRESS
FIRE BIT
LO BIT
EOS IN
CONTROLLER AZIMUTH BOARD
DESIGNED BY:
J CRAIG

FIG A 7

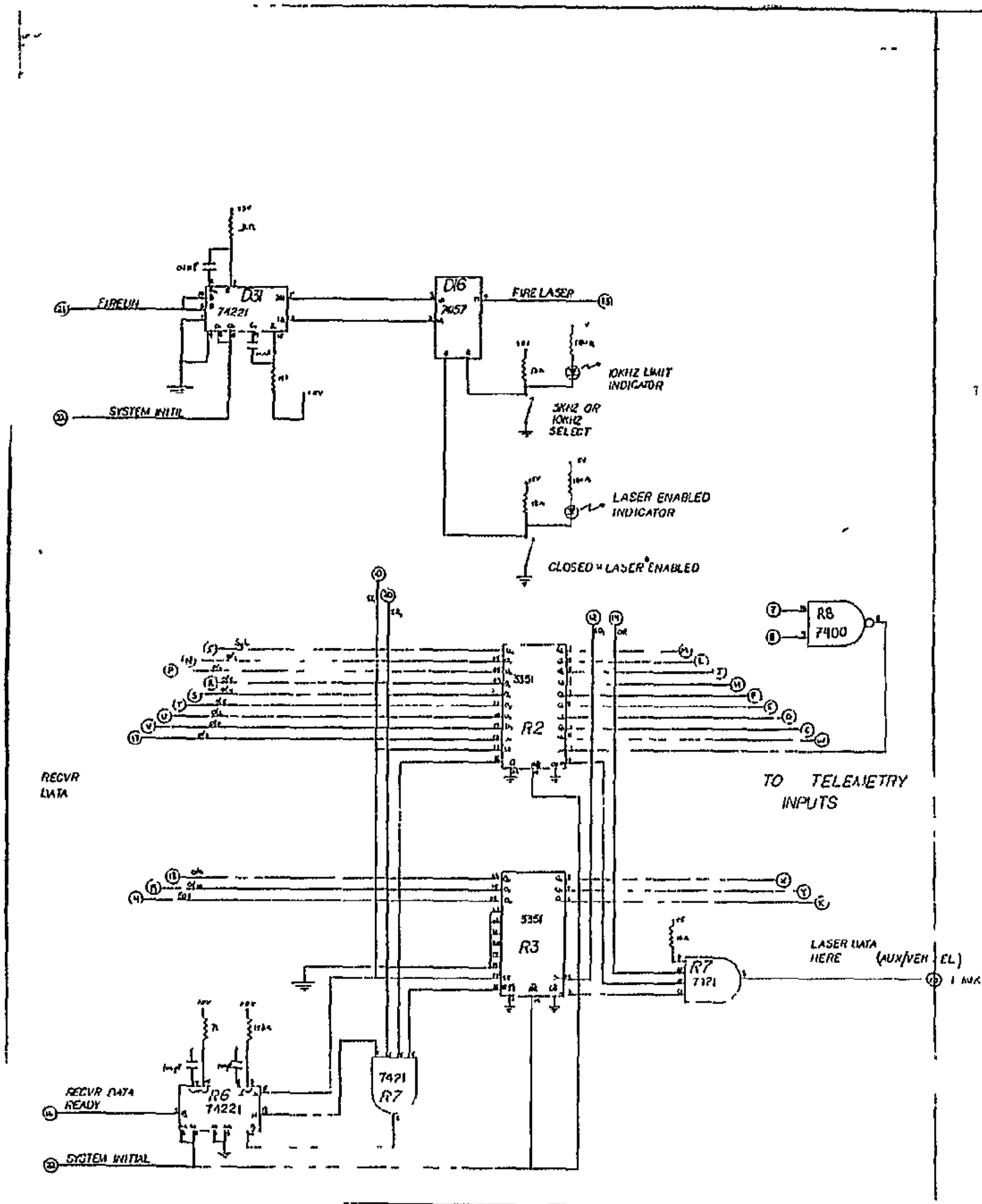
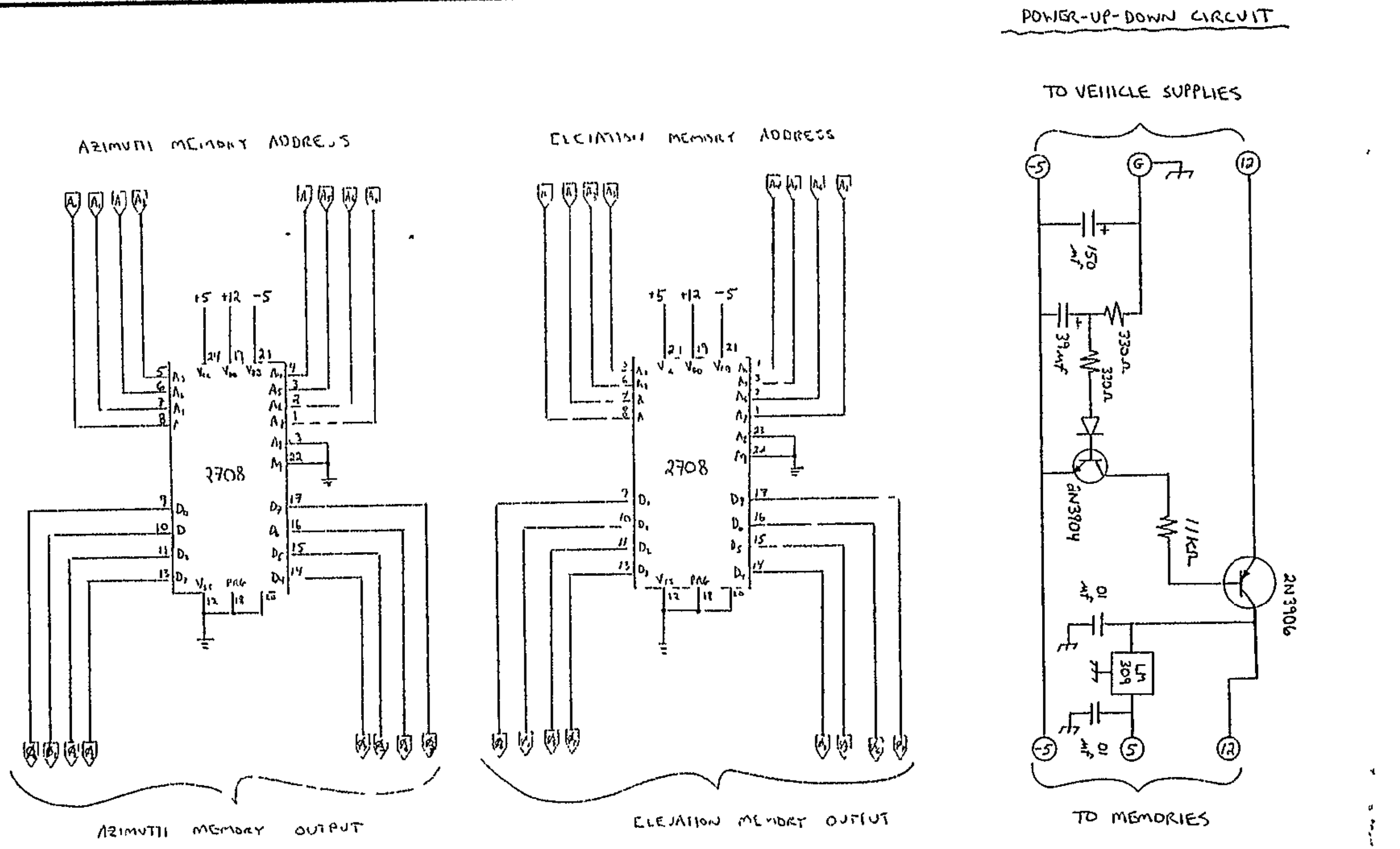


FIG A 8

CONTROLLER RATE BUFFER BOARD
DESIGNED BY J CRAIG



TOLERANCES (EXCEPT AS NOTED)	REVISIONS			CONTROLLER MEMORY		
	NO	DATE	BY			
DECIMAL	1					
±	2			DRAWN BY J CRAIG	SCALE	MATERIAL
FRACTIONAL	3			CHK D	DATE	DRAWING NO
±	4			TRACED	APP D	
ANGULAR ±	5					

FIG A.9

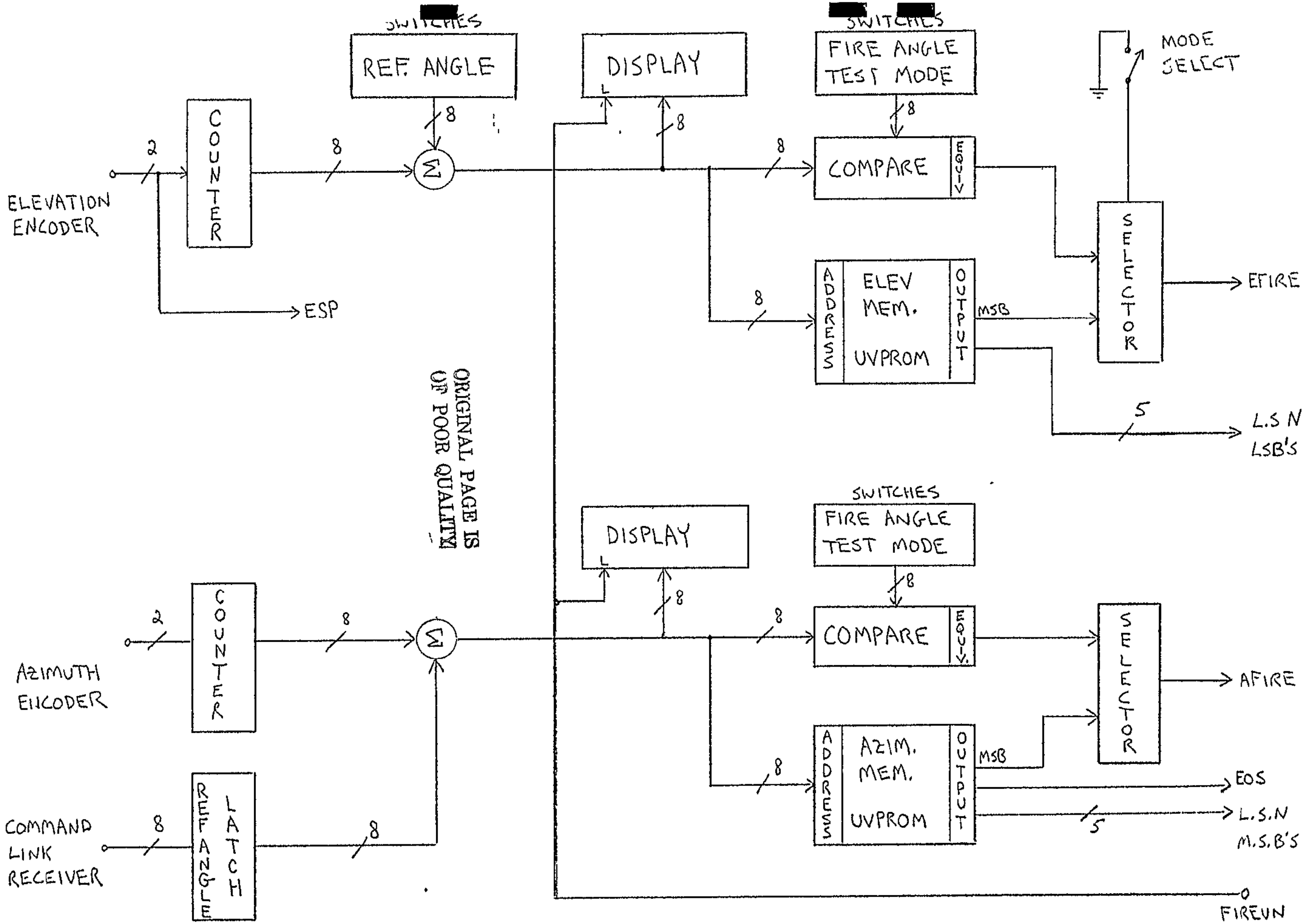


FIG. A.10 CONTROLLER BLOCK DIAGRAM (1 OF 2)

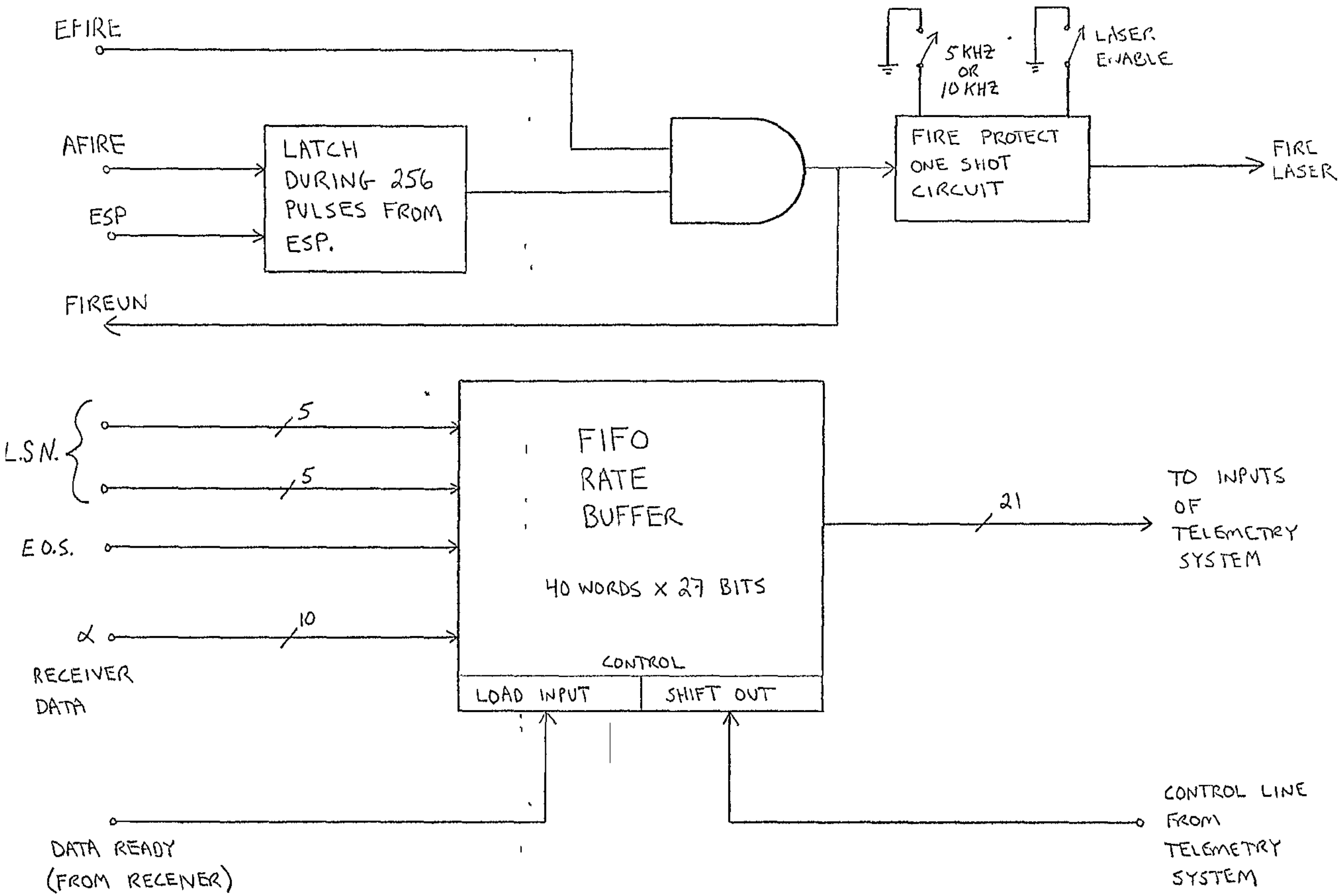


FIG. A.10 CONTROLLER BLOCK DIAGRAM (2 OF 2)

APPENDIX B

Encoder Data Sheets

First-In, First-Out Memory Data Sheets

8-Sided Mirror Data Sheets

Mirror Motor Data Sheets

UV-Erasable Prom Data Sheets

ENCODER DATA SHEETS

TELEDYNE GURLEY 514 FULTON STREET / TROY, NEW YORK 12181
(518) 272-6300 / TWX: (710) 443-8156

REVISED
APRIL, 1977

MODEL 8602-69 ROTARY INCREMENTAL ENCODER

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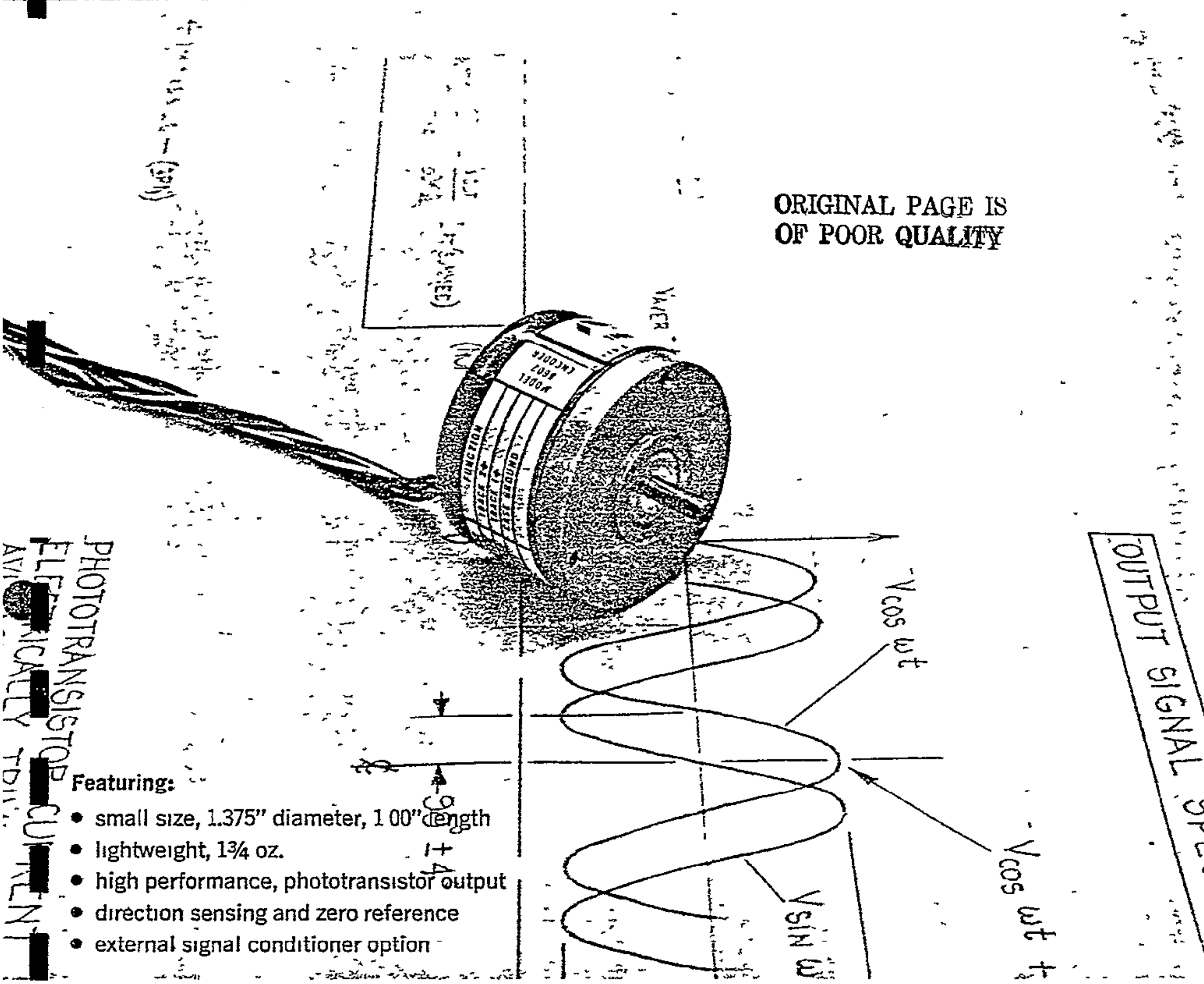


Featuring:

- small size, 1.375" diameter, 1 00" length
- lightweight, 1¾ oz.
- high performance, phototransistor output
- direction sensing and zero reference
- external signal conditioner option

DESCRIPTION

The Teledyne Gurley Model 8602-69 is an optical, rotary incremental encoder that generates a phototransistor output on a single channel or on two channels in quadrature, plus an optional zero index The encoder offers a selection of discs that range up to 1270 lines/rev

This device was developed to permit the electrical measurement of length, angle, speed or position in equipment where compact size, light weight, accurate outputs and reliability are required Optimum conservation and maximum utilization of space characterize this encoder.

Use of an external Model SC-602 signal conditioner can provide TTL-compatible square wave, or 1X, 2X or 4X pulse outputs Thus, resolutions up to 5080 pulses/rev are possible.

APPLICATION

The 8602-69 is particularly adaptable to instrumentation, computer and laboratory applications where small size and light weight are important

It may be used as an electronic tachometer to measure or control shaft speed in tape transports, computer memory drums, and other similar equipment.

The 8602-69 indicates linear position when used with rack and pinions on comparators, drafting machines, and inspection gaging machines

Specifications

NOTE These specifications are applicable under all variations of recommended supply voltage, speed, temperature and direction of travel. Improved performance is available under special conditions, please consult factory

• MECHANICAL

Materials	Aluminum housing with stainless steel shaft
Weight	1 75 oz. max
Size	
Encoder	See Figure 3
Wire	30 AWG, polyalkene insulation, 6 inch lengths
Torque	
Starting	0 15 in oz. typical
Running	0 05 in oz. typical
Moment of Inertia	4 0 X 10^{-5} in oz. sec^2
Angular Acceleration	7 5 X 10^6 rad/sec^2
Shaft Speed (non-operating)	10,000 RPM
Shaft Load	
Radial	0 5 lbs. max
Axial	0 5 lbs max
End Play	0 0005" max
Radial Play	0 0005" max
Bearing Life (at light load)	10^9 revolutions

NOTE Bearing complement consists of two ABEC Class 7 Stainless Steel bearings, spaced approximately 75 inches apart.

• ENVIRONMENTAL

Temperature	0° C to +70° C
Humidity	98% rh non condensing
Shock	50 g, 11 millisec
Vibration	2 g, 0 2000 Hz

• ELECTRICAL

Power +5 0 VDC ±0 2 VDC @ 65 mA max — single channel
@ 130 mA max — dual channels
@ 195 mA max — dual channels with zero index

Frequency Response — 25 KHz standard

(Up to 50 KHz optional, depending on amplifier design and specific application)

Output Circuit — Phototransistors standard, Photocells, optional.

Output waveforms — See Figure 1

Interchannel Phasing — 90° ±22.5°

• WITH MODEL SC-602 EXTERNAL SIGNAL CONDITIONER

See separate Signal Conditioner Data Sheet for physical size and electrical connections

• ELECTRICAL

Power
+5 0VDC ±0 2VDC, with 05VDC long-term regulation and low ripple (5% peak-to peak), 300 mA max

Output Waveforms — See Figure 2

Output Characteristics — Square Waves and Pulses

All outputs are DTL/TTL compatible (driver type 7404)

TTL fanout = 10 (I_{SINK} = 16 mA, I_{SOURCE} = 400 μ A)

V_{OH} = 3 7 V ± 1.3 V, $I_{OH} \leq$ 400 μ A

V_{OL} = + 0 2 V ± 0.2 V, $I_{OL} \leq$ −16 mA

1X, 2X and 4X pulse outputs are complemented (RZ and NRZ) and direction-sensed

Square wave outputs are uncomplemented

Power Buffer Option (Square waves only)

Open collector driver type 75451 or type 75452, $V_{CC} \leq$ 30V, $I_C \leq$ 200 mA

Line Driver Option (Square waves only)
Balanced differential line driver type DM8830

• PERFORMANCE

Frequency Response
To 25 KHz at disc data rate
To 100 KHz with 4X count multiplication option
Frequency response can be doubled under special conditions — consult factory

ACCURACY RATINGS (1)
arc minutes

Error Source	Incremental (adjacent Lines)	Absolute (line to any other line)
Disc Pattern	±0 08	±0 15
Disc eccentricity	None	±0 83
Uncompensated signal offset (2)	±1080/N	±1080/N
Quadrature phasing (3)	±670/N	±670/N
Typical R S S value (N=750)	±1 70	±1 89

N=line pairs/disc

(1) Ratings are based on 750 < N < 1270 Accuracy improves at lower line counts Improved accuracy also available at higher line counts under special conditions, please consult factory

(2) For adjacent zero crossings or at any odd interval (1/2N, 3/2N, 5/2N --- apart), error is 2160/N For zero crossings at any even interval (2/2N, 4/2N, 6/2N --- apart), error is essentially zero over any small segment of disc rotation

(3) If quadrature signals are used for determining direction only, or not at all, quadrature phasing error can be deducted

As part of our continuing product improvement program, these specifications are subject to change without notice

Definition of Parameters

1. ACCURACY

FUNDAMENTAL accuracy applies to data taken at positive (or negative) going transitions on the sine (or cosine) output It corresponds to data taken at the leading (or trailing) edges of the disc pattern lines, as in 1x count multiplication.

INTERPOLATION accuracy applies to data taken at points within a given square wave cycle For example, data taken at both positive and negative going transitions of a sine or cosine square wave (2x count multiplication) or data taken at positive and negative going transitions of both the sine and cosine square waves (4x count multiplication) are interpolated data Usually interpolated data is lower in accuracy than fundamental data due to the imperfect duty cycle of the square waves and the imperfect quadrature phasing between the sine and cosine square waves Refer to Fig 2

INCREMENTAL accuracy, or adjacent pulse accuracy, is measured from one pulse to the next Normally the incremental accuracy is valid over shaft rotations of approximately 15° (mechanical) Incremental accuracy is primarily determined by interpolation accuracy.

ABSOLUTE (CUMULATIVE) accuracy is measured from one pulse to any other pulse Normally the *greatest error occurs between pulses that are separated* by approximately one-half revolution of the encoder shaft Absolute accuracy is the sum of fundamental accuracy and interpolation accuracy.

2. COUNT MULTIPLICATION

An electronic technique for increasing the encoder's output resolution beyond the number of line pairs contained on the disc. Standard techniques allow for 1x, 2x or 4x multiplication of the fundamental disc resolution 4x multiplication requires that two quadrature square waves (sine and cosine), be generated electro-optically as in Fig 2 Transition detectors, "single shots," then form pulses at every 0 to 1 or 1 to 0 transition on both waveforms. This results in four pulses for every line pair on the disc, as shown in Fig 2 For 2x multiplication, pulses are formed at 0 to 1 and 1 to 0 transitions on one square wave output only. For 1x multiplication, pulses are formed at 0 to 1 (or 1 to 0) transitions on one square wave output only.

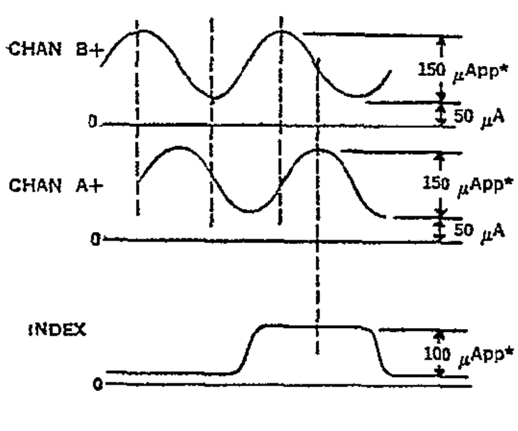
3 FREQUENCY RESPONSE

This is defined as the maximum frequency of fundamental data (number of disc lines per revolution x *revolutions/second) For encoders with* 2x or 4x count multiplication the output rate is 2 or 4 times the fundamental data frequency

4 RESOLUTION

The number of output data pulses per revolution For square wave outputs, resolution corresponds to the number of line pairs on the disc. A line pair consists of the opaque line and the clear space next to it Normally the term "line pair" and "line" are used interchangeably; they both correspond to one cycle of square wave output signal. For units with 1x, 2x or 4x count multiplication, resolution corresponds to 1, 2, or 4 times the number of line pairs on the disc Note that increasing resolution by the use of count multiplication logic usually results in a decreased cumulative accuracy, but does not affect fundamental accuracy.

Figure 1—Phototransistor Current Waveforms



*TYPICAL VALUES

Typical Customer Circuit

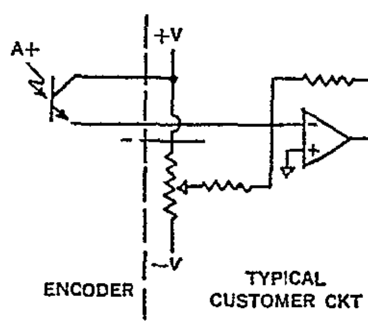


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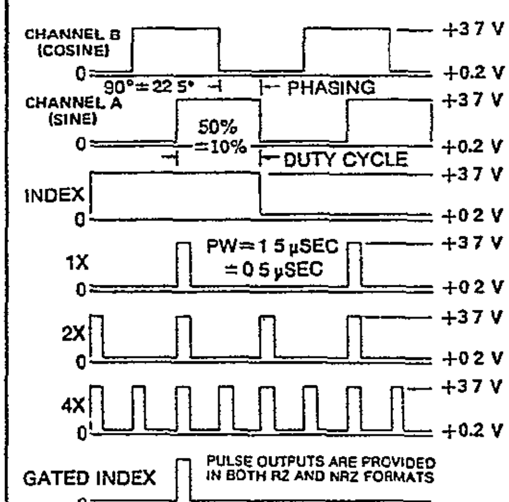
Figure 2—Quadrature and Pulse Output Waveforms available with Signal Conditioner option



NOTE Sine and cosine relationships are defined for clockwise rotation of the encoder viewed from shaft end, Channel B signal leads Channel A signal by 90 Index is normally aligned with cosine signal Pulse amplitudes are typical value

CONNECTIONS	
Orange	Cosine
Brown	Signal return
Yellow*	Sine
Green*	Signal return
Blue**	Index
White**	Signal return
Red	+5 V
Black	Lamp return
Grey	Case ground

* Two Channel versions only
** Optional

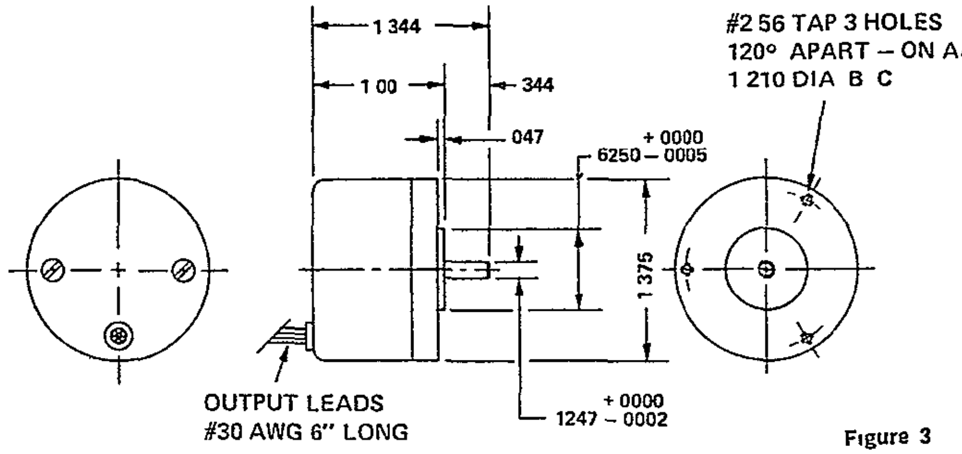


Figure 3

ORDERING INFORMATION

When ordering, please include maximum speed of shaft rotation, both operating and non operating Also, in unidirectional applications, please specify direction of rotation

8602-69 [ ] — [ ] — [ ]

Option codes with * require an external signal conditioner- insert **/SC**

LINES/REV ON DISC
10, 30, 36, 48, 50, 100, 120, 200, 225, 360, 500, 520, 1000, 1024, 1200, 1250, 1270 Additional standard discs may be added periodically, special discs can always be made on a custom basis

OPTION CODES		
Output Waveform	With Zero Index	Without Zero Index
Phototransistor- One Channel	001	101
Phototransistor- Two Channels	002	102
Square Waves- * One Channel	031	131
Square Waves- * Two Channels	032	132
Square Waves with * Line Driver	052	152
Square Waves with * Power Buffer	062	162
* 1x Pulses	012	112
* 2x Pulses	022	122
* 4x Pulses	042	142

* External Signal Conditioner required

TELEDYNE GURLEY CAPABILITY

In addition to its line of standard rotary and linear encoders, Teledyne Gurley has designed and customized encoders for applications involving military specifications, extreme environmental operating conditions, and high reliability performance, as well as low cost, limited performance requirements

Accuracies better than one arc second have been attained with our rotary encoders, and we have supplied linear encoders with a resolution of one micron

Teledyne Gurley will be pleased to discuss your requirements for customized encoders

WARRANTY

Teledyne Gurley warrants its products against defects in material and workmanship under normal and proper use for a period of one year from the date of shipment

Teledyne Gurley's obligation under this warranty is limited, at Teledyne Gurley's option, to replacement or repair, without charge, F O B Troy, N Y of any defective part

The foregoing warranty is exclusive and in lieu of all other warranties, and is not valid for any product which has been operated in excess of its electrical, mechanical or environmental ratings, or which has been subjected to abuse, or in which the housing has been opened, altered or tampered with

REPRESENTED BY

e-2

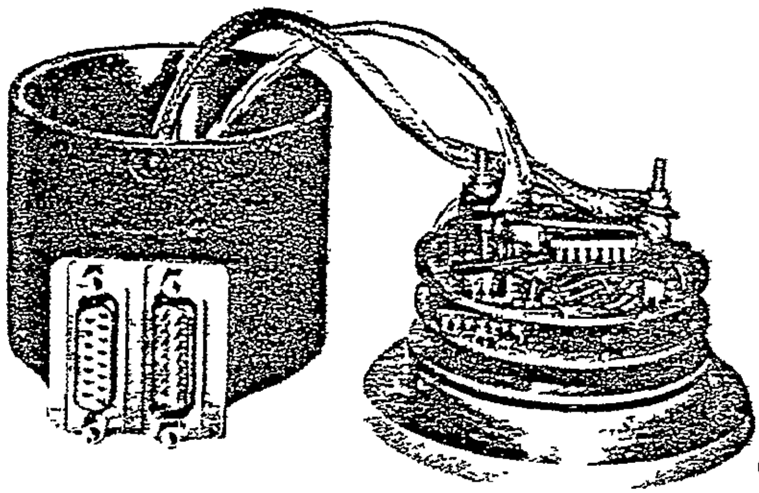
TELEDYNE GURLEY

514 FULTON ST., TROY, N. Y. 12181
(518) 272-6300 / TWX: (710) 443-8156

Printed in U S A

MODEL SC SERIES EXTERNAL SIGNAL CONDITIONERS

TELEDYNE GURLEY
MEASUREMENT COMPONENTS



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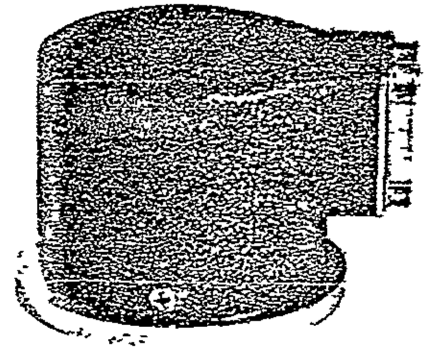
Featuring:

- DTL, TTL, HTL or C-MOS compatibility
- output options which include
  1X, 2X or 4X count multiplication
  differential line drivers
  power buffers
- rugged cast aluminum housing
- excellent electrical noise immunity
- plug-in PC boards



DESCRIPTION

The Model SC Series of external signal conditioners are designed for use with Teledyne Gurley's miniature optical, incremental encoders to provide those electrical output options not available in the encoder itself.

Specific signal conditioner models are available for each Teledyne Gurley miniature encoder, i.e., SC 602 series for Model 8602-69 encoders, SC 610 series for Model 8610 encoders and SC 708 series for Model 8708 encoders.

The signal conditioners offer differential line driver options and open collector power buffers. This provides interfacing compatibility with DTL, HTL, TTL or C-MOS equipment. In addition, higher electrical noise immunity is achieved and sufficient power is generated to drive signals over long lengths of coaxial cable, strip-line or twisted pair leads. The current drive capability is 200 mA maximum and the voltage driver is 30 volts maximum. The lines being driven should have characteristic impedances of 50 to 500 ohms.

The signal conditioners are housed in a cast aluminum enclosure which can be opened to provide access to the two plug-in circuit boards in the unlikely event that maintenance is required. This feature also accommodates future changes in circuitry, if desired.

APPLICATION

The SC Series of signal conditioners can extend the electrical options of the Models 8602-69, 8610 and 8708 encoders to square waves or TTL pulses which include 1X, 2X or 4X count multiplication of the line pairs on the encoder disc or scale. This increases the resolution of the encoder and the scope of applications. These signal conditioners are versatile. A unit which originally generated square waves can later be modified to produce TTL pulses by simply changing the plug-in PC boards.

By remotely locating the electronics, unparalleled space efficiency is realized in the encoder system.

The signal conditioners will transmit encoder information to drive optical couplers such as LED's, memory units, counter/displays, control circuits and relays or lamps.

General Specifications

• MECHANICAL

Materials	cast aluminum housing
Weight	20 oz. max.
Size	See Figure 3

(Consult drawings [Figure 3] for mounting provisions)

Mating Connector	Cannon DA 15S (furnished)

• ENVIRONMENTAL

Temperature	0° C to + 70° C
Humidity	98% rh, non-condensing
Shock	50 g, 11 millisec
Vibration	10 g, 0-2000 Hz

• ELECTRICAL

Output Circuit	See Figure 1
Output Waveforms	See Figure 2

Pulse output characteristics

All outputs are DTL/TTL compatible (driver type 7404).

TTL fan out = 10 (I_{SINK} = 16 mA, I_{SOURCE} = 400 μA)

V_{OH} = + 3.7 + 1.3 V, I_{OH} = 400 μA, V_{CC} = 5 0 V

V_{OL} = + 0.2 V + 0 2 V, I_{OL} = −1.6 mA, V_{CC} = 5.0 V

1X, 2X, 4X outputs complemented (RZ and NRZ)

Index output complemented (RZ and NRZ)

Balanced differential line driver type DM 8830 (square waves only).

Power buffer, open collector driver type 75451 or type 75452, complemented or non-complemented, V_{CC} = 30 V, I_C = 200 mA (square waves only).

System Specifications

• MODEL SC-602 SERIES

(Used with a Model 8602-69 Rotary Encoder)

Power +5 0 V ± 0 2 V @ 300 mA, max.

Frequency Resopnse
(defined as number of line pairs X revolutions per second of the disc)

To 50 KHz at disc data rate (100 KHz optional)
To 200 KHz with 4X count multiplication (400 KHz optional)

Accuracy
As specified in the Model 8602-69 Rotary Encoder Bulletin.

• MODEL SC-610 SERIES

(Used with a Model 8610 Rotary Encoder)

Power +5.0 V ± 0.2 V @ 250 mA, max.

Frequency Response
(defined as number of line pairs X revolutions per second of the disc)

To 50 KHz at disc data rate
To 200 KHz with 4X count multiplication

Accuracy
As specified in the Model 8610 Rotary Encoder Bulletin.

• MODEL SC-708 SERIES

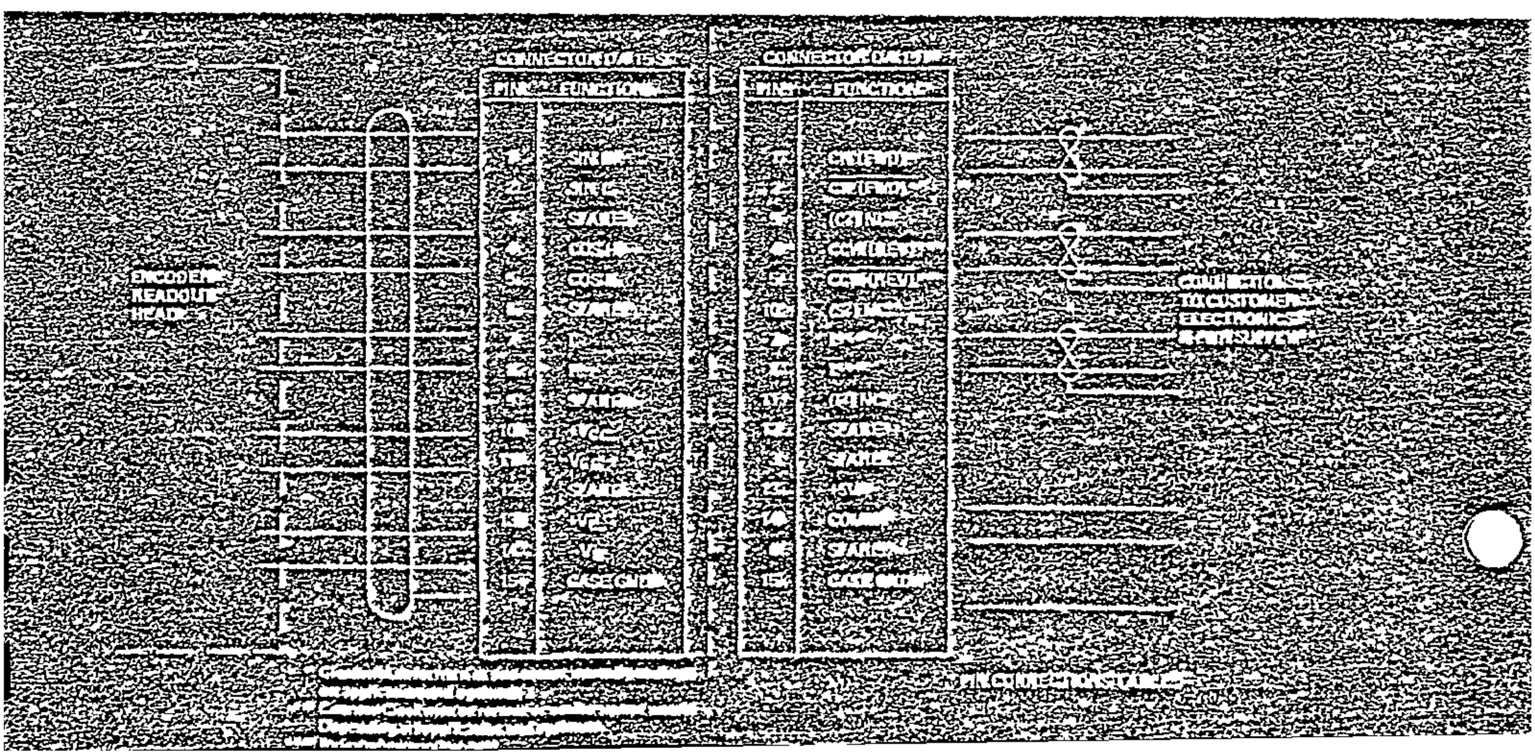
(Used with a Model 8708 Modular Encoder)

Power +5.0 V ± 0.2 V @ 300 mA, max.

Frequency Response
(defined as number of line pairs X revolutions per second of the disc)

To 50 KHz at disc data rate (100 KHz optional)
To 200 KHz with 4X count multiplication (400 KHz optional)

Accuracy
As specified in the Model 8708 Modular Encoder Bulletin.



Definition of Parameters

1. ACCURACY

ABSOLUTE (CUMULATIVE) accuracy is measured from one pulse to any other, arbitrary pulse. Normally the greatest error occurs between pulses that are separated by approximately one-half revolution of the encoder shaft. Absolute accuracy is the sum of fundamental accuracy and interpolation accuracy.

FUNDAMENTAL accuracy applies to data taken at positive (or negative) going transitions on the sine or cosine square wave outputs. It corresponds to data taken at the leading (or trailing) edges of the disc pattern lines (1x count multiplication).

INCREMENTAL accuracy, or adjacent pulse accuracy is measured from one pulse to the next. Normally the incremental accuracy is valid over shaft rotations of approximately 15° (mechnical). Incremental accuracy is primarily determined by interpolation accuracy.

INTERPOLATION accuracy applies to data taken at points within a given square wave cycle. For example, data taken at both positive and negative going transitions of a sine or cosine square wave (2x count multiplication) or data taken at positive and negative going transitions of both the sine and cosine square waves (4x count multiplication) are interpolated data. Usually interpolated data is lower in accuracy than fundamental data due to the imperfect duty cycle of the square waves and the imperfect quadrature phasing between the sine and cosine square waves. Refer to Fig. 2.

2. COUNT MULTIPLICATION

An electronic technique for increasing the encoder's output resolution beyond the number of line pairs contained on the disc. Standard techniques allow for 1x, 2x or 4x multiplication of the fundamental disc resolution 4x multiplication requires that two quadrature square waves (sine and cosine), be generated electro-optically as in Fig 2. Transition detectors, "single shots," then form pulses at every 0 to 1 or 1 to 0 transition on both waveforms. This results in four pulses for every line pair on the disc as shown in Fig. 2. For 2x multiplication, pulses are formed at 0 to 1 and 1 to 0 transitions on one square wave output only. For 1x multiplication, pulses are formed at 0 to 1 (or 1 to 0) transitions on one square wave output only.

3 FREQUENCY RESPONSE

This is defined as the maximum frequency of fundamental data (number of disc lines per revolution x revolutions/second). For encoders with 2x or 4x count multiplication the output rate is 2 to 4 times the fundamental data frequency.

4 RESOLUTION

The number of output data pulses per revolution. For square wave outputs, resolution corresponds to the number of line pairs on the disc A line pair consists of the opaque line and the clear space next to it. Normally the term "line pair" and "line" are used interchangeably; they both correspond to one cycle of square wave output signal. For units with 1x, 2x or 4x count multiplication, resolution corresponds to 1, 2, or 4 times the number of line pairs on the disc. Note that increasing resolution by the use of count multiplication logic usually results in a decreased cumulative accuracy, but does not affect fundamental accuracy.

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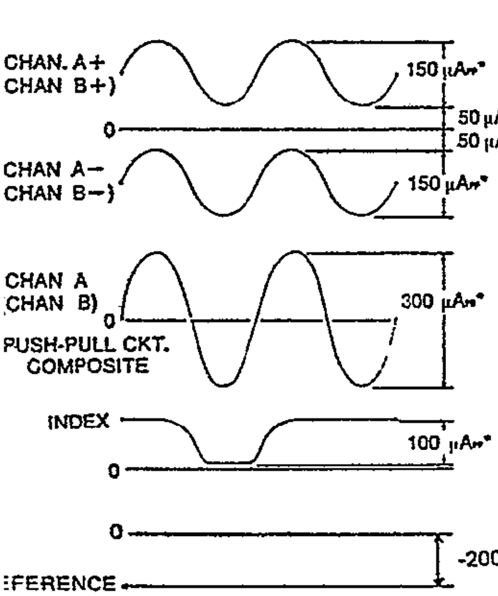
Figure 1 — Phototransistor Current Waveforms



*TYPICAL VALUES

Typical Customer Circuit

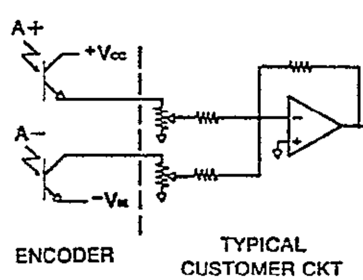
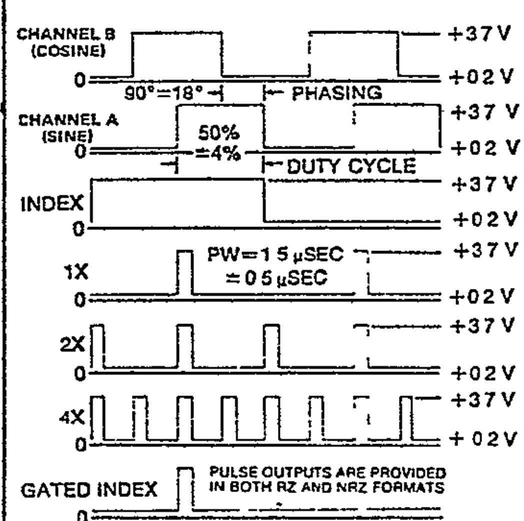


Figure 2 — Quadrature and Pulse Output Waveforms



NOTE SINE AND COSINE RELATIONSHIPS ARE DEFINED FOR LEFT TO RIGHT MOTION AS OBSERVED FROM THE PHOTOTRANSISTOR SIDE THE SCALE BEING FIXED WITH THE CHROME SIDE FACING THE VIEWER AND THE DATA TRACK UPWARDS IF ROTARY RELATIONSHIP DEFINED FOR CLOCKWISE ROTATION OF THE ENCODER VIEWED FROM THE SHAFT END CHANNEL B SIGNAL LEADS CHANNEL A SIGNAL BY 90° PULSE AMPLITUDES ARE TYPICAL VALUES

ORDERING INFORMATION

MODEL NUMBER (SC-702, SC 610, or SC-708) □ □ □ □ □

CYCLES/REV. – (ROTARY ENCODER)
CYCLES/IN. OR CYCLES/MM – (LINEAR ENCODER)

INDEX OPTIONS OF ENCODER
- 0 Zero Index
- 1 Without Zero Index

OUTPUT OPTIONS
- 0 Phototransistor
- 1 One-Count Logic with direction sensing
- 2 Two-Count Logic with direction sensing
- 3 Square Wave with direction sensing
- 4 Four-Count Logic with direction sensing
- 5 Square Wave with differential line driver output
- 6 Square Wave with power buffer output

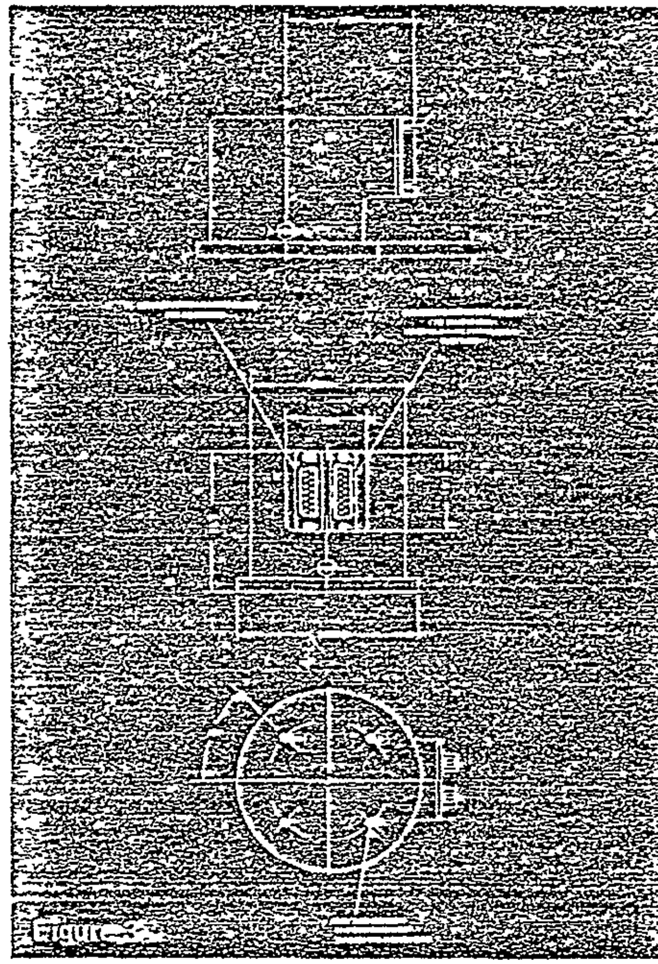
CHANNEL OPTIONS OF ENCODER
- 1 Single Channel
- 2 Direction Sensing (two channels in quadrature)

LIGHT SOURCE OF ENCODER
- 0 LED
- 1 Incadescent Lamp

EXAMPLE The ordering number for an External Signal Conditioner to be used in conjunction with a Model 8610 Rotary Encoder that generates 500 cycles/rev, no zero index, two channels in quadrature and incorporates LED's, the Signal Conditioner to have four count logic pulses output is SC 610-500-1-4-2-0

TELEDYNE GURLEY CAPABILITY

In addition to its lines of standard rotary and linear encoders, Teledyne Gurley has designed and customized encoders for applications involving military specifications, extreme environmental operating conditions, and high reliability performance.



Accuracies of one arc-second have been attained with our rotary encoders and we have delivered linear encoders with a resolution of one micron.

Teledyne Gurley will be pleased to discuss your requirements for customized encoders.

WARRANTY

Teledyne Gurley warrants it products against defects in material and workmanship under normal and proper use for a period of one year from the date of shipment.

This warranty is not valid for any product which has been operated in excess of its electrical or mechanical ratings or which has been subjected to abuse.

Teledyne Gurley's obligation under this warranty is limited at Teledyne Gurley's option, to replacement or repair, without charge, F.O.B. Troy, N.Y. of any defective part.

The foregoing warranty is exclusive and in lieu of all other warranties.

"ENCODER SAVVY AND THEN SOME"

TELEDYNE GURLEY

514 FULTON ST., TROY, N. Y. 12181
(518) 272-6300 / TWX: (710) 443-8156

AG/3M/574

PRINTED IN U.S.A.

TELEDYNE GURLEY
514 FULTON STREET / TROY, NEW YORK 12181
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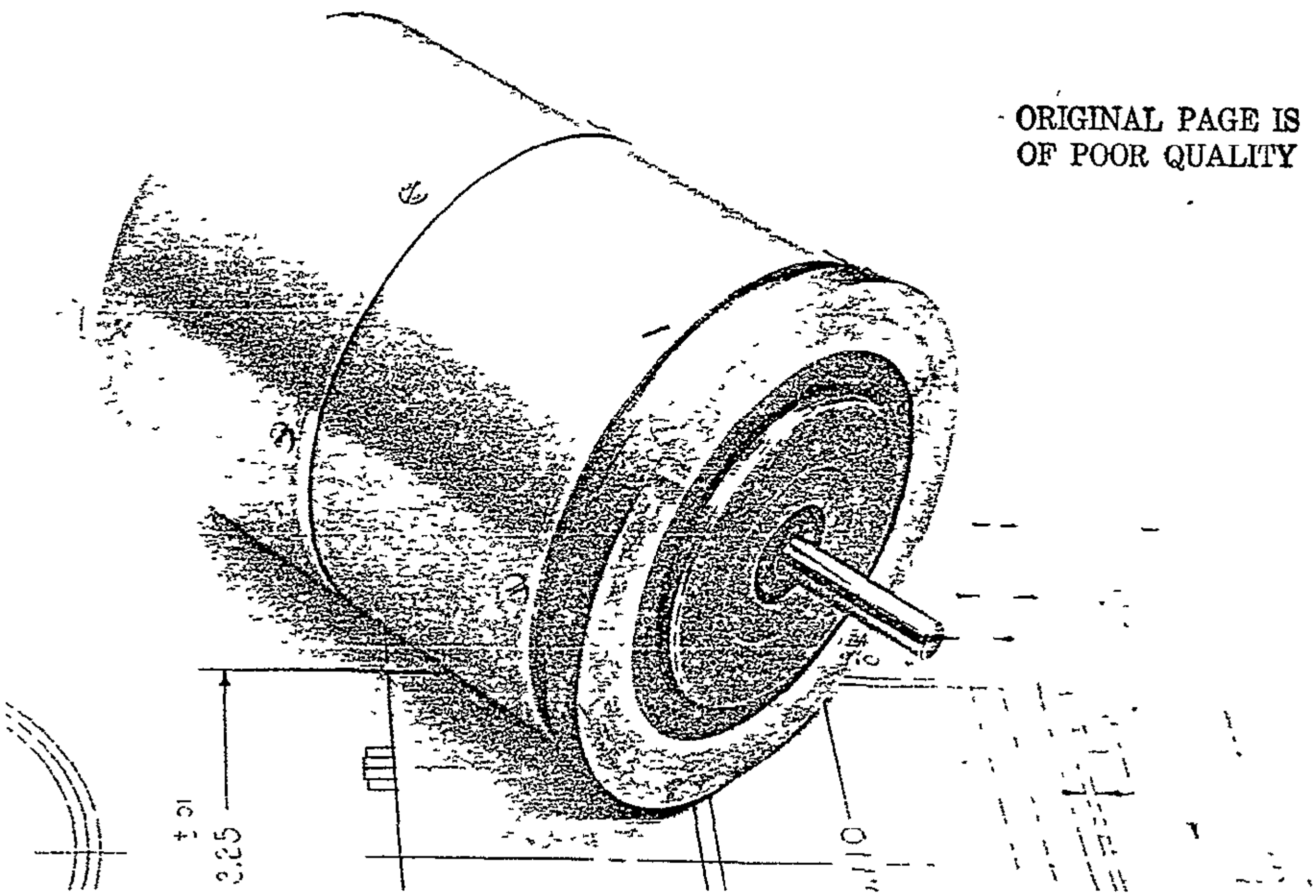
REVISED
JANUARY, 1977

MODEL 8635 ROTARY INCREMENTAL ENCODER

ORIGINAL PAGE IS
OF POOR QUALITY



Featuring:

- single voltage, integral electronics
- plug-in PC boards for easy field maintenance
- up to 21,600 counts/revolution with zero index
- power buffers and differential line drivers available
- optional ±20 arc-seconds accuracy via dual reading heads

DESCRIPTION

The Teledyne Gurley Model 8635 rotary incremental encoder utilizes advanced electro-optical signal generation techniques to provide high resolutions together with good reliability. Dual reading heads yielding ± 20 arc-seconds accuracy are available.

The single voltage electronics are integral components of the encoder, resulting in excellent noise immunity. With square-wave output, the use of optional differential line drivers or power buffer can provide greater noise immunity or C-MOS compatability

All of the electronics are mounted on two plug-in PC boards for simplified maintenance.

APPLICATION

The Model 8635 is especially suited for high resolution applications at a moderate cost. It can be used to control motion by generating signals for position feedback in a servo system, or it can be combined with our Model 8900 Counter/Display as a complete digital readout system. The Model 8635 has been used to measure or control position on machine tools, or rotational speed of paper machine rolls, computer tape transports and computer drums It can be used on lead screws of jig borers, comparators, milling machines, drafting machines and similar apparatus.

Specifications

NOTE: These specifications are applicable under all variations of recommended supply voltage, speed, temperature and direction of travel Improved performance is available under special conditions, please consult factory

• MECHANICAL

Materials	Anodized aluminum housing with stainless steel shaft and bearings
Weight	17 oz. max
Size	34 synchro — See Figure 3 for dimensions and mounting provisions
Torque	
Starting	0 4 in oz. typical
Running	0.2 in oz. typical
Moment of Inertia	2.3 X 10^{-3}oz. in sec^2
Angular Acceleration	2 5 X 10^5 rad/sec.^{2} max.
Shaft Speed (non-operating)	See Table 1
Shaft Load	See Table 1
End Play (8 oz reversing load)	0 0005 in max
Radial Play (8 oz. reversing load)	0 0005 in. max.

NOTE . Bearing complement consists of two ABEC Class 7 bearings, permanently lubricated, double shielded shaft seal

• ENVIRONMENTAL

Temperature	0° C to + 70° C
Humidity	98% rh, non-condensing
Shock	50 g, 11 millisec
Vibration	2 g, 0 2000 Hz

• ELECTRICAL

Power
+5 0VDC ±0 2VDC, with 05VDC long term regulation and low ripple (5% peak-to-peak)

With electronics, 375 mA max. Without electronics, 250 mA max

Output Waveforms — See Figs 1 and 2

Output Characteristics — Square Waves and Pulses

All outputs are DTL/TTL compatible (driver type 7404)

TTL fanout = 10 (I_{SINK} = 16 mA, I_{SOURCE} = 400 μ A)

V_{OH} = 3 7 V ± 1 3 V, $I_{OH} \leq 400\ \mu$ A

V_{OL} = + 0.2 V ± 0.2 V, $I_{OL} \leq$ –16 mA

IX, 2X and 4X pulse outputs are complemented (RZ and NRZ) and direction sensed

Square wave outputs are uncomplemented

Power Buffer Option (Square waves only)

Open collector driver type 75451 or type 75452, $V_{CC} \leq$ 30V, $I_C \leq$ 200 mA

Line Driver Option (Square waves only)
Balanced differential line driver type DM8830

• PERFORMANCE

Frequency Response
To 50 KHz at disc data rate
To 200 KHz with 4X count multiplication option
Frequency response can be doubled under special conditions

Accuracy, see Table 2
Higher accuracy (to ± 20 arc seconds) available utilizing dual reading heads.

TABLE 1

BEARING LIFE RATINGS, hours				
SPEED rpm	LOAD, pounds			
	2	5	10	15
100	750,000	230,000	30,000	9,000
200	375,000	115,000	15,000	4,500
500	150,000	46,000	6,000	1,800
1,000	75,000	23,000	3,000	900
2,000	37,500	11,500	1,500	450
5,000	15,000	4,600	600	180
10,000	7,500	2,300	300	90

NOTE Life ratings are based on fatigue failure criteria In many long duration applications, lubricant retention becomes the limiting factor
Higher shaft loads will degrade encoder accuracy Maximum recommended radial load (1 inch from encoder housing) is 1 lb in high resolution models, 2 lbs in low resolution models. Maximum thrust load, 2 lbs

TABLE 2

ACCURACY RATINGS (1) Arc minutes			
OUTPUT	INCREMENTAL	ABSOLUTE	
		Worst case	R S S (N=3000)
Square waves	< 1	± .5 ± 1080/N	± 6
1X pulses	< 1	± 5 ± 1080/N	± .6
2X pulses (2)	± 1080/N	± 5 ± 1080/N	± 6
4X pulses	± 1750/N	± 5 ± 1750/N	± 77

N=line pairs/disc

(1) Ratings are based on 2500 < N < 5400 Accuracy improves at lower line counts Improved accuracy also available at higher line counts under special conditions, please consult factory

(2) For adjacent zero crossings or at any odd interval (1/2N, 3/2N, 5/2N, --- apart), error is 2160/N For zero crossings at any even interval (2/2N, 4/2N, 6/2N, --- apart), error is essentially zero over any small segment of disc rotation

As part of our continuing product improvement program, these specifications are subject to change without notice

Definition of Parameters

1. ACCURACY

FUNDAMENTAL accuracy applies to data taken at positive (or negative) going transitions on the sine (or cosine) output. It corresponds to data taken at the leading (or trailing) edges of the disc pattern lines, as in 1x count multiplication.

INTERPOLATION accuracy applies to data taken at points within a given square wave cycle For example, data taken at both positive and negative going transitions of a sine or cosine square wave (2x count multiplication) or data taken at positive and negative going transitions of both the sine and cosine square waves (4x count multiplication) are interpolated data Usually interpolated data is lower in accuracy than fundamental data due to the imperfect duty cycle of the square waves and the imperfect quadrature phasing between the sine and cosine square waves Refer to Fig 2.

INCREMENTAL accuracy, or adjacent pulse accuracy, is measured from one pulse to the next. Normally the incremental accuracy is valid over shaft rotations of approximately 15° (mechanical) Incremental accuracy is primarily determined by interpolation accuracy.

ABSOLUTE (CUMULATIVE) accuracy is measured from one pulse to any other pulse Normally the greatest error occurs between pulses that are separated by approximately one-half revolution of the encoder shaft Absolute accuracy is the sum of fundamental accuracy and interpolation accuracy

2. COUNT MULTIPLICATION

An electronic technique for increasing the encoder's output resolution beyond the number of line pairs contained on the disc. Standard techniques allow for 1x, 2x or 4x multiplication of the fundamental disc resolution. 4x multiplication requires that two quadrature square waves (sine and cosine), be generated electro-optically as in Fig. 2. Transition detectors, "single shots," then form pulses at every 0 to 1 or 1 to 0 transition on both waveforms. This results in four pulses for every line pair on the disc, as shown in Fig 2 For 2x multiplication, pulses are formed at 0 to 1 and 1 to 0 transitions on one square wave output only. For 1x multiplication, pulses are formed at 0 to 1 (or 1 to 0) transitions on one square wave output only.

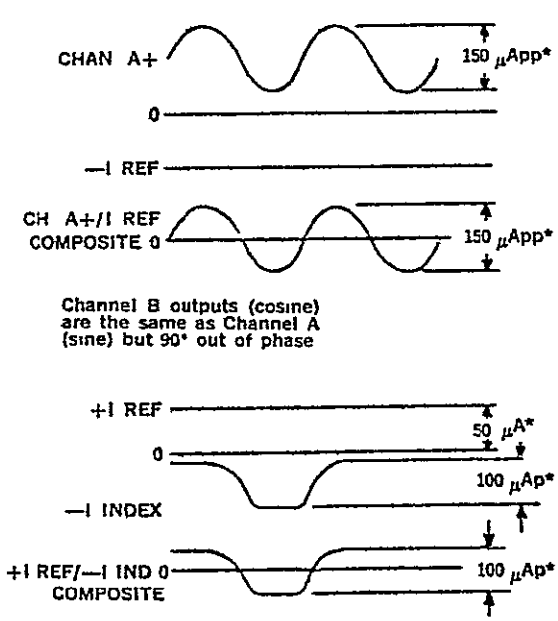
3. FREQUENCY RESPONSE

This is defined as the maximum frequency of fundamental data (number of disc lines per revolution x revolutions/second) For encoders with 2x or 4x count multiplication the output rate is 2 or 4 times the fundamental data frequency

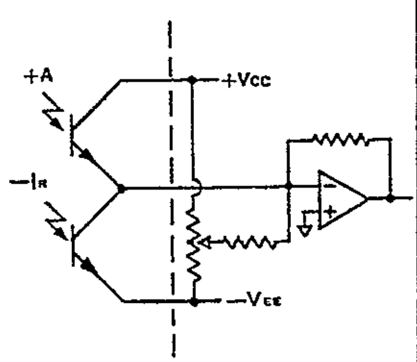
4. RESOLUTION

The number of output data pulses per revolution For square wave outputs, resolution corresponds to the number of line pairs on the disc. A line pair consists of the opaque line and the clear space next to it. Normally the term "line pair" and "line" are used interchangeably, they both correspond to one cycle of square wave output signal For units with 1x, 2x or 4x count multiplication, resolution corresponds to 1, 2, or 4 times the number of line pairs on the disc. Note that increasing resolution by the use of count multiplication logic usually results in a decreased cumulative accuracy, but does not affect fundamental accuracy.

Figure 1—Phototransistor Output Option Current Waveforms

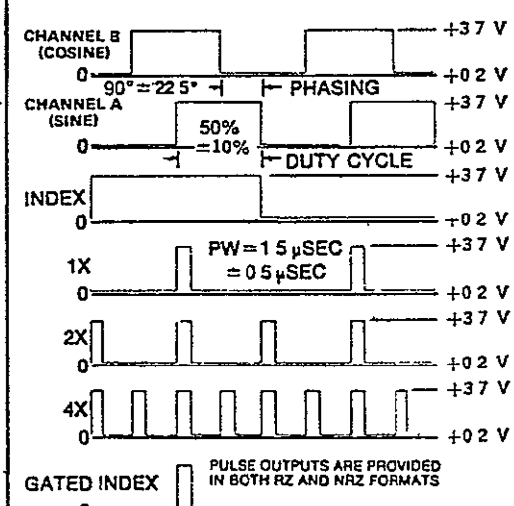


Typical Customer Circuit

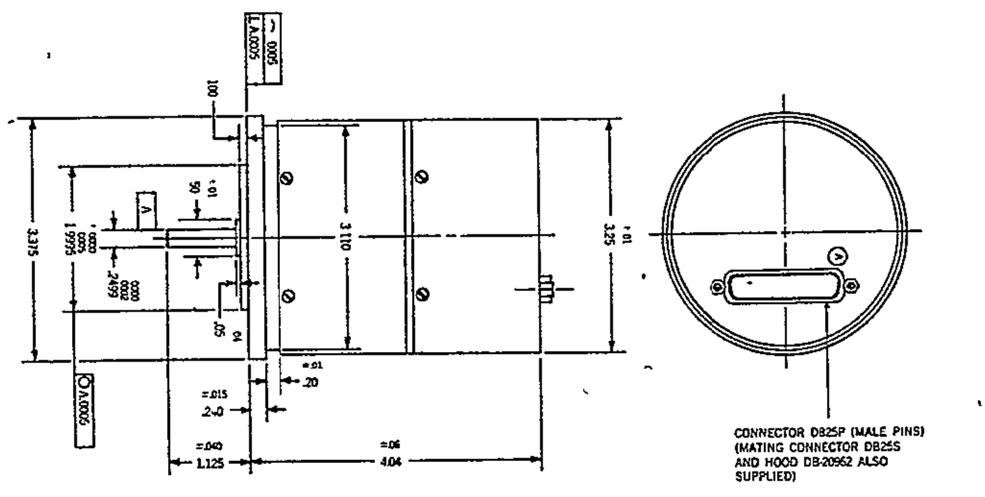


*TYPICAL VALUES

Figure 2—Square-wave and Pulse Output Waveforms



NOTE SINE AND COSINE RELATIONSHIPS ARE DEFINED FOR CLOCKWISE ROTATION OF THE ENCODER VIEWED FROM SHAFT END CHANNEL B SIGNAL LEADS CHANNEL A SIGNAL BY 90° INDEX IS NORMALLY ALIGNED WITH COSINE SIGNAL. PULSE AMPLITUDES ARE TYPICAL VALUES



PIN CONNECTIONS # 8635 ROTARY ENCODER DB25P CONNECTOR	
PIN	FUNCTION
1	CW PULSES OR SIN SQ. WAVE
2	$\overline{CW}$ PULSES OR $\overline{SIN}$ SQ. WAVE
3	SPARE
4	C (TEST POINT)
5	SPARE
6	CCW PULSES OR COS SQ. WAVE
7	$\overline{CCW}$ PULSES OR $\overline{COS}$ SQ. WAVE
8	SPARE
9	S' (TEST POINT)
10	SPARE
11	INDEX (OPTIONAL)
12	$\overline{INDEX}$ (PULSES OR)
13	SPARE
14	I1 (TEST POINT)
15	SPARE
16	SPARE
17	SPARE
18	SPARE
19	SPARE
20	SIG COMM (High Current Option)
21	SPARE
22	SPARE
23	−5 VDC
24	COMM
25	CASE GND

* Complemented square waves are available with the Power Buffer or Line Driver Options

Figure 3

ORDERING INFORMATION

When ordering, please include maximum speed of shaft rotation, both operating and non operating Also, in unidirectional applications, please specify direction of rotation

8635 - [ ] - [ ]

LINES/REV ON DISC
10, 16, 36, 48, 60, 100, 120, 128, 180, 200, 360, 500, 600, 792, 900, 1000, 1024, 1100, 1500, 1800, 2000, 2048, 2442, 2480, 2500, 3000, 3072, 3600, 4000, 4096, 4500, 4800, 5000, 5400 Additional standard discs may be added periodically, special discs can always be made on a custom basis

OPTION CODES		
Output Waveform	With Zero Index	Without Zero Index
Phototransistor-One Channel	001	101
Phototransistor-Two Channels	002	102
Square Waves-One Channel	031	131
Square Waves-Two Channels	032	132
Square Waves with Line Driver	052	152
Square Waves with Power Buffer	062	162
1x Pulses	012	112
2x Pulses	022	122
4x Pulses	042	142

TELEDYNE GURLEY CAPABILITY

In addition to its line of standard rotary and linear encoders, Teledyne Gurley has designed and customized encoders for applications involving military specifications, extreme environmental operating conditions, and high reliability performance, as well as low cost, limited performance requirements

Accuracies better than one arc second have been attained with our rotary encoders, and we have supplied linear encoders with a resolution of one micron

Teledyne Gurley will be pleased to discuss your requirements for customized encoders

WARRANTY

Teledyne Gurley warrants its products against defects in material and workmanship under normal and proper use for a period of one year from the date of shipment.

Teledyne Gurley's obligation under this warranty is limited, at Teledyne Gurley's option, to replacement or repair, without charge, F O B Troy, N Y of any defective part

The foregoing warranty is exclusive and in lieu of all other warranties, and is not valid for any product which has been operated in excess of its electrical, mechanical or environmental ratings, or which has been subjected to abuse, or in which the housing has been opened, altered or tampered with

REPRESENTED BY.

TELEDYNE GURLEY

514 FULTON ST., TROY, N. Y. 12181
(518) 272-6300 / TWX: (710) 443-8156

FIRST-IN FIRST-OUT MEMORY

DATA SHEETS (used as rate buffer)

3351

40×9 FIRST-IN FIRST-OUT MEMORY

GENERAL DESCRIPTION — The 3351 is a First In First Out (FIFO) Memory used in data rate buffering applications The 3351 has a capacity of 40 nine-bit words The words are accepted at the input automatically shifted toward the output and removed at any rate in the same sequence in which they were entered

The 3351 has status indicators on both the input and output to signal an available empty input or a valid data word at the output It also has separate input and output enable lines in addition to a master reset line A unique input stage interfaces to TTL without external components The 3351 is manufactured using the p-channel Isoplanar silicon gate process with ion implantation

- 2 MHz (3351-1) AND 1 MHz (3351-2) DATA RATES
- INDEPENDENT ASYNCHRONOUS INPUTS AND OUTPUTS
- FULLY TTL COMPATIBLE
- 3-STATE OUTPUTS
- INPUT AND OUTPUT ENABLES
- EXPANDABLE IN EITHER DIRECTION
- STATUS INDICATORS ON INPUT AND OUTPUT
- 28-PIN CERAMIC DUAL IN LINE PACKAGE

PIN NAMES

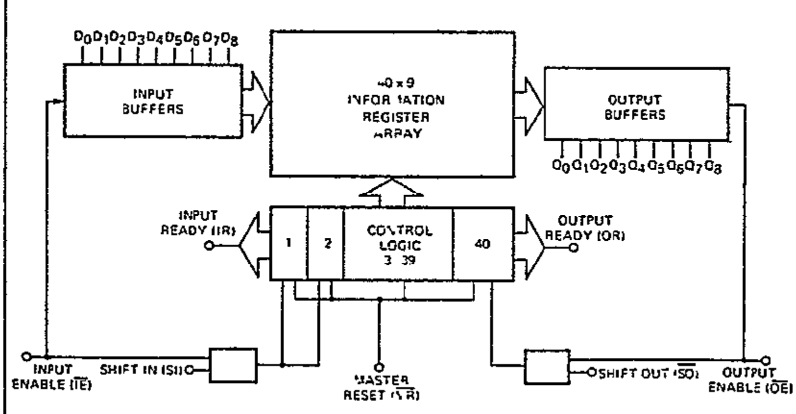
Q_n	Outputs	IR	Input Ready
D_n	Data Inputs	OR	Output Ready
$\overline{MR}$	Master Reset	$\overline{IE}$	Input Enable
SI	Shift In	$\overline{OE}$	Output Enable
SO	Shift Out		

ABSOLUTE MAXIMUM RATINGS

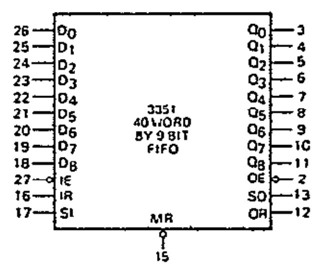
V_{GG} and Inputs	−20 V to +0 3 V
V_{DD} and Outputs	−7 0 V to +0 3 V
Output Sink Current	5 0 mA
Storage Temperature	−55°C to +150°C
Operating Temperature	0°C to +70°C

NOTE All Voltages with respect to V_{SS}

BLOCK DIAGRAM

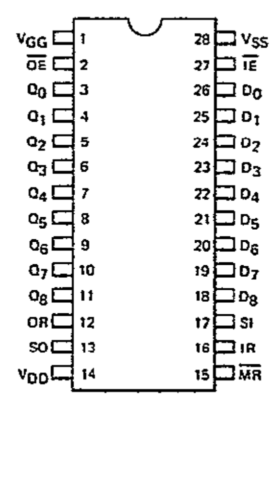


LOGIC SYMBOL



V_{SS} = Pin 28
V_{DD} = Pin 14
V_{GG} = Pin 1

CONNECTION DIAGRAM
DIP (TOP VIEW)



FUNCTIONAL DESCRIPTION — The 40 by 9 memory array is under the constant control of a control logic network (See Fig 1) Each word position in the array is clocked by a control register which also stores a marker bit a 1 signifies that that position s data is filled and a 0 indicates a vacancy at that location Each control register clocks data from the preceding nine data flip flops to its own set of nine data flip-flops The register logic detects the status of the preceding and succeeding registers marker bits to determine when to clock its data flip flops. When data has been transferred from location n to location n+1' the n+1 control circuitry changes the marker bit at control register n from a 1 ' to a 0", indicating that the data at location 'n has been transferred elsewhere in the array This 0 will then propagate back to the first control register signifying that the FIFO is capable of accepting more data

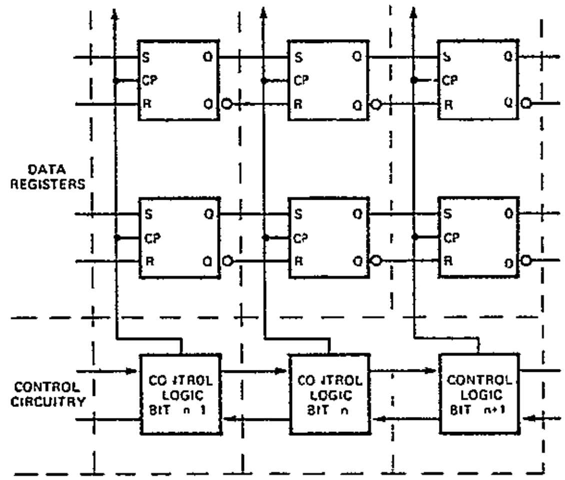


Fig 1

The 3351 buffers the first and last control registers and uses them as input/output status indicators Since all status marker 0 s propagate toward the first control register a 0 at the first register indicates the FIFO is ready to clock in more data Likewise all 1' s propagate towards the last control register and a 1 here means that data is valid at the outputs

A Master Reset control is provided to set all the control registers' status markers to 0 Note that the data registers are not reset by $\overline{MR}$

SHIFT IN (SI) INPUT READY (IR) — A LOW to HIGH transition of the Shift In command does two things 1) the first control register is enabled permitting input data to be loaded into the first set of data registers and setting the first marker bit to a 1 and 2) the second control register is locked out by means of an inverted SI command At this point data from the first data register cannot be transferred to the second data register The Input Ready signal indicates the status of the first marker bit and accordingly goes LOW(not ready)

The HIGH to LOW transition of the SI locks out the first control register and causes data from the first data registers to propagate down the FIFO under the control of the control logic This action sets the first marker bit to a 0 and the Input Ready returns HIGH (input ready) When the FIFO becomes full the IR will stay LOW after SI returns LOW and any further SI commands will be ignored by the circuit When a 0 ' ripples back from the last to the first control register the Input Ready (IR) will return to HIGH (if SI is LOW)

Fig 2

INPUT ENABLE ($\overline{IE}$) — A HIGH on the Input Enable disables the SI input and the current-sourcing capability of the special TTL pull up networks of the data inputs and the SI A LOW enables these inputs

SHIFT OUT (SO) OUTPUT READY (OR) — The HIGH to LOW transition of Shift Out command disables the clocking line of the last control register and changes the 40th bit marker to a 0 The Output Ready is then forced LOW Note that data is not transferred from the 39th position to the 40th position on this edge When SO makes the LOW to HIGH transition the FIFO is again under control of its control logic circuitry new data is transferred to the 40th location and the 40th marker bit is reset to a 1 The Output Ready returns to HIGH signifying the new data at the output leads is now valid

When the FIFO is empty the OR remains LOW after SO goes HIGH SO commands will be ignored until a 1 'marker ripples down to the last control register after which the OR goes HIGH (if SO is HIGH)

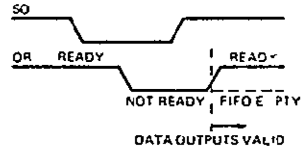


Fig 3

OUTPUT ENABLE ($\overline{OE}$) — A HIGH on Output Enable forces the nine outputs to a high impedance state, disables the shift out command and disables the current-sourcing capability of the special TTL pull up network of SO A LOW again enables SO and the outputs revert back to their normal TTL states

MASTER RESET ($\overline{MR}$) — A LOW on Master Reset sets all the control logic marker bits to 0 Consequently IR will go HIGH (if SI is LOW) and OR will go LOW, indicating that the FIFO is now empty

DC REQUIREMENTS V_{SS} = 5 0 V ±5% V_{DD} = 0 V V_{GG} = −12 V ±5% T_A = 0°C to +70°C

SYMBOL	PARAMETER	33511 LIMITS		33512 LIMITS		UNITS	CONDITIONS
		MIN	MAX	MIN	MAX		
V_{IH}	Input HIGH Voltage	V_{SS}−1 0	V_{SS}+0 3	V_{SS}−1 0	V_{SS}+0.3	V	Note 1
V_{IL}	Input LOW Voltage	V_{GG}	0 8	V_{GG}	0 8	V	Note 1

DC CHARACTERISTICS V_{SS} = 5 0 V ±5% V_{DD} = 0 V, V_{GG} = −12 V ±5% T_A = 0°C to +70°C

SYMBOL	PARAMETER	33511 LIMITS		33512 LIMITS		UNITS	CONDITIONS
		MIN	MAX	MIN	MAX		
V_{OH1}	Output HIGH Voltage	V_{SS}−0 5		V_{SS}−0.5		V	I_{OH} = 50 µA
V_{OH2}	Output HIGH Voltage	2 4		2 4		V	I_{OH} = −0.2 mA
V_{OL}	Output LOW Voltage		0 4		0 4	V	I_{OL} = 1 6 mA
V_{II}	Pull Up Initiation Voltage		2 2		2.2	V	Fig 2, Note 1 I_{IN} = −0 12 mA
V_{IP}	Peak Current Voltage		V_{SS}−1 5		V_{SS}−1 5	V	Fig 6 Note 1
I_{IP}	Peak Current		1 6		1 6	mA	Fig 6 Note 1
I_{IH}	Input HIGH Current	0 22		0 22		mA	Fig 6, Note 1 V_{IN} = V_{SS}−1 0 V
I_{IL}	Input LOW Current		50		50	µA	Fig 6 Note 1 V_{IN} = 0 4 V
I_{DD}	V_{DD} Current		65		50	mA	
I_{GG}	V_{GG} Current		10		8 0	mA	
P_D	Power Dissipation		520		420	mA	

AC REQUIREMENTS V_{SS} = 5 0 V ±5% V_{DD} = 0 V V_{GG} = −12 V ±5% T_A = 0°C to +70°C

SYMBOL	PARAMETER	33511 LIMITS		33512 LIMITS		UNITS	CONDITIONS
		MIN	MAX	MIN	MAX		
t_{IDS}	$\overline{IE}$ Disable Set Up Time	20		20		ns	Fig. 6
t_{IDH}	$\overline{IE}$ Disable Hold Time	20		20		ns	Fig. 6
t_{IES}	$\overline{IE}$ Enable Set Up Time	0		0		ns	Fig. 6
t_{IEH}	$\overline{IE}$ Enable Hold Time	0		0		ns	Fig 6
t_{DS}	Input Data Set Up Time	0		0		ns	Fig. 6
t_{DH}	Input Data Hold Time	220		440		ns	Fig. 6
t_{SIH}	SI HIGH Time	220		440		ns	Fig. 6
t_{SIL}	SI LOW Time	280		560		ns	Fig. 6
t_{ODS}	$\overline{OE}$ Disable Set Up Time	20		20		ns	Fig 8
t_{ODH}	$\overline{OE}$ Disable Hold Time	20		20		ns	Fig 8
t_{OES}	$\overline{OE}$ Enable Set Up Time	0		0		ns	Fig 8
t_{OEH}	$\overline{OE}$ Enable Hold Time	0		0		ns	Fig 8
t_{SOL}	SO LOW Time	200		400		ns	Fig 8
t_{SOH}	SO HIGH Time	300		600		ns	Fig 8
t_{RPW}	$\overline{MR}$ Pulse Width	100		200		ns	Fig. 8
t_{RS}	$\overline{MR}$ to SI Set Up Time	0		0		ns	Fig. 8

AC CHARACTERISTICS V_{SS} = 5 0 V ±5% V_{DD} = 0 V, V_{GG} = −12 V ±5% T_A = 0°C to +70°C

SYMBOL	PARAMETER	33511 LIMITS		33512 LIMITS		UNITS	CONDITIONS
		MIN	MAX	MIN	MAX		
$t_{SI-IRHL}$	SI to IR Delay Time		220		440	ns	Fig. 6 Note 2
$t_{SI-IRLH}$	SI to IR Delay Time		280		560	ns	Fig. 6 Note 2
$t_{SO-ORLL}$	SO to OR Delay Time		200		400	ns	Fig. 7 Note 2
$t_{SO-ORHH}$	SO to OR Delay Time		300		600	ns	Fig. 7 Note 2
t_{MR-IR}	$\overline{MR}$ to IR Delay Time		300		480	ns	Fig 8
t_{MR-OR}	$\overline{MR}$ to OR Delay Time		240		480	ns	Fig 8
t_{BT}	Bubble Through Time		9 0		15	µs	Fig 7, Note 3
t_E	Output Enable Time		300		600	ns	Fig 7
t_D	Output Disable Time		300		600	ns	Fig. 7

NOTES
1 Includes all Data Inputs $\overline{IE}$ $\overline{OE}$ SI SO and $\overline{MR}$ (See Feedback Resistor Figure 2)
2 HL means positive-going edge of first signal to negative going edge of second signal etc
3 Forward and reverse

TYPICAL INPUT CHARACTERISTICS

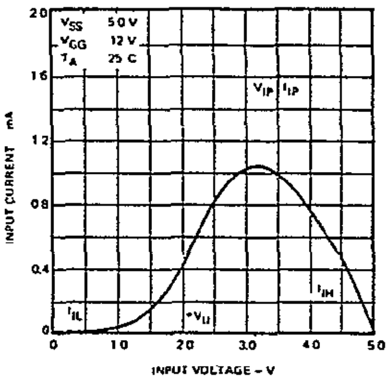


Fig 4

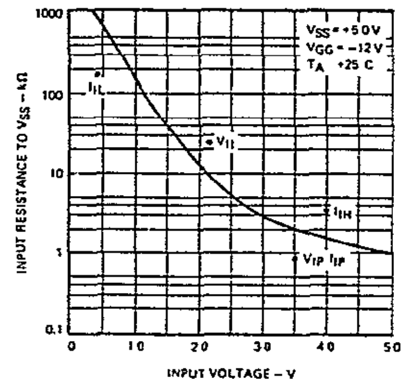


Fig. 5

TIMING DIAGRAMS

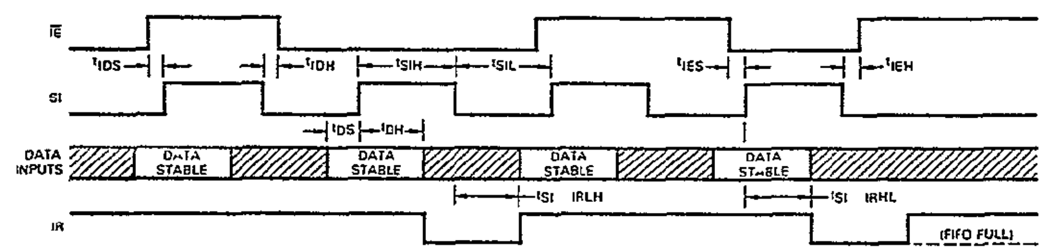


Fig 6 INPUT TIMING

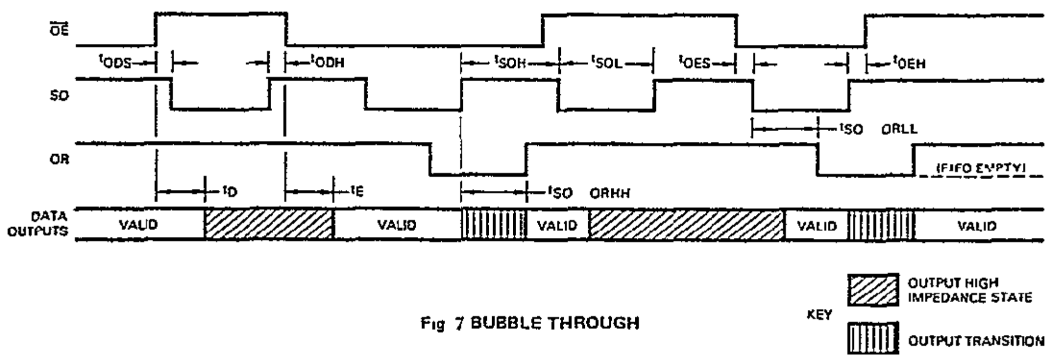


Fig 7 BUBBLE THROUGH

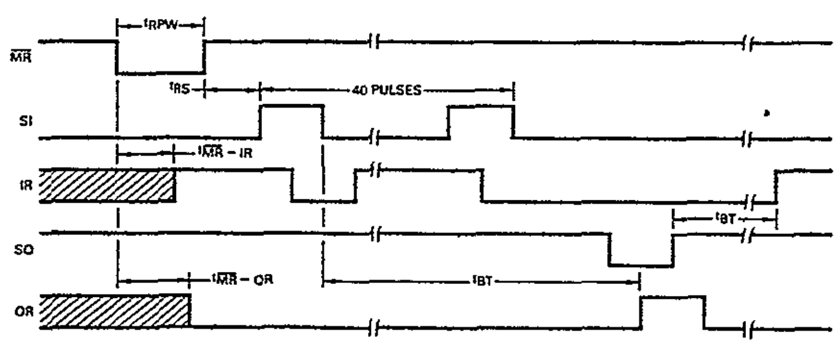


Fig 8 OUTPUT TIMING

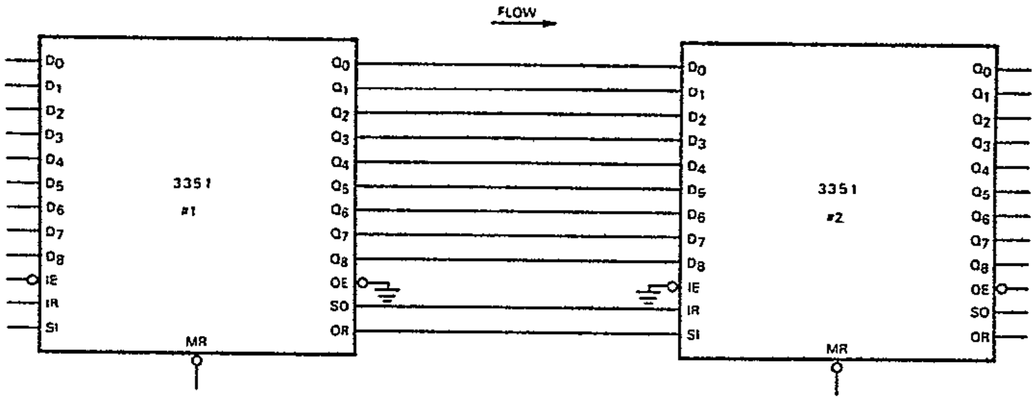
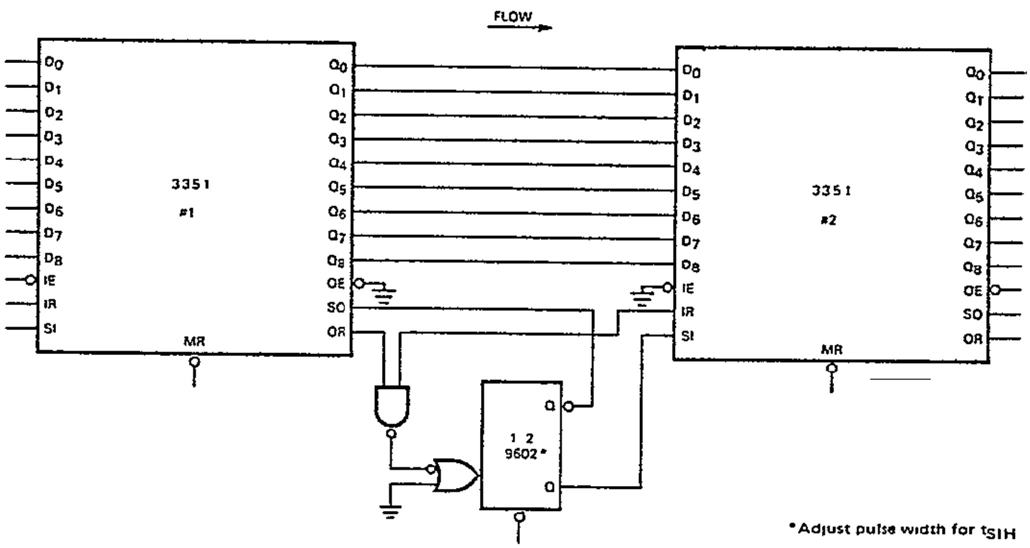
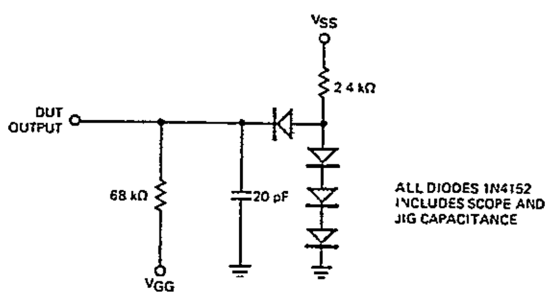


Fig 9 SIMPLE WORD EXPANSION



*Adjust pulse width for t_{SIH}

Fig 10 HIGH SPEED WORD EXPANSION



NOTES
A All input t_r and t_f 10 ns
B All times measurements referenced to 1 5 level

Fig 11 OUTPUT LOADING

GENERA
an on ch
select fro
from TTL

The 335
ceramic o

- 4 0 M
- TTL C
- SINGI
- LOW
- OPEN
- 8-PIN

PIN NAM
D_n
Q_n
SEL
CP

ABSOLU
V_{GG}
V_{DD}
Outp
Stora
Opera
Note

BLO

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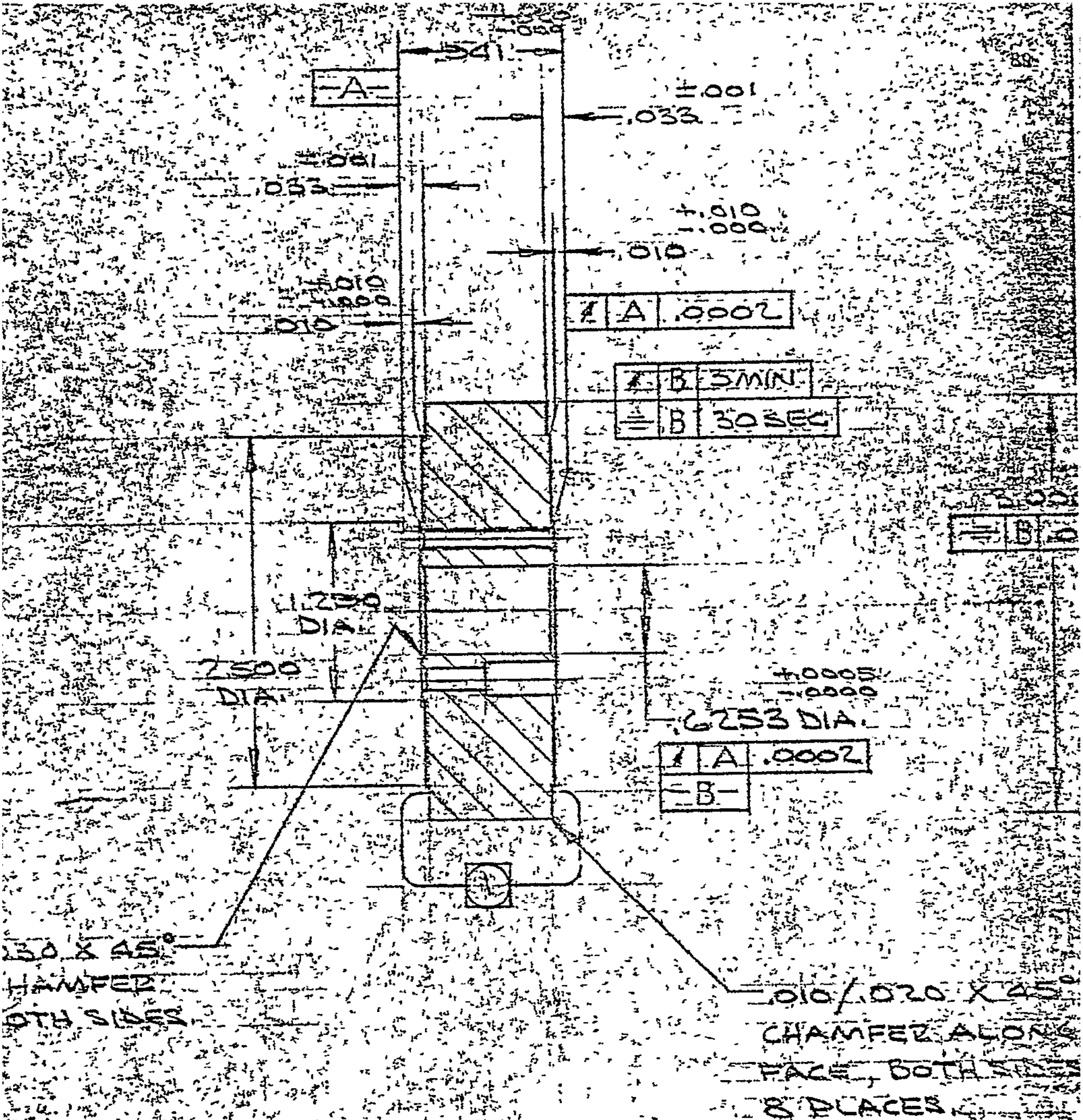
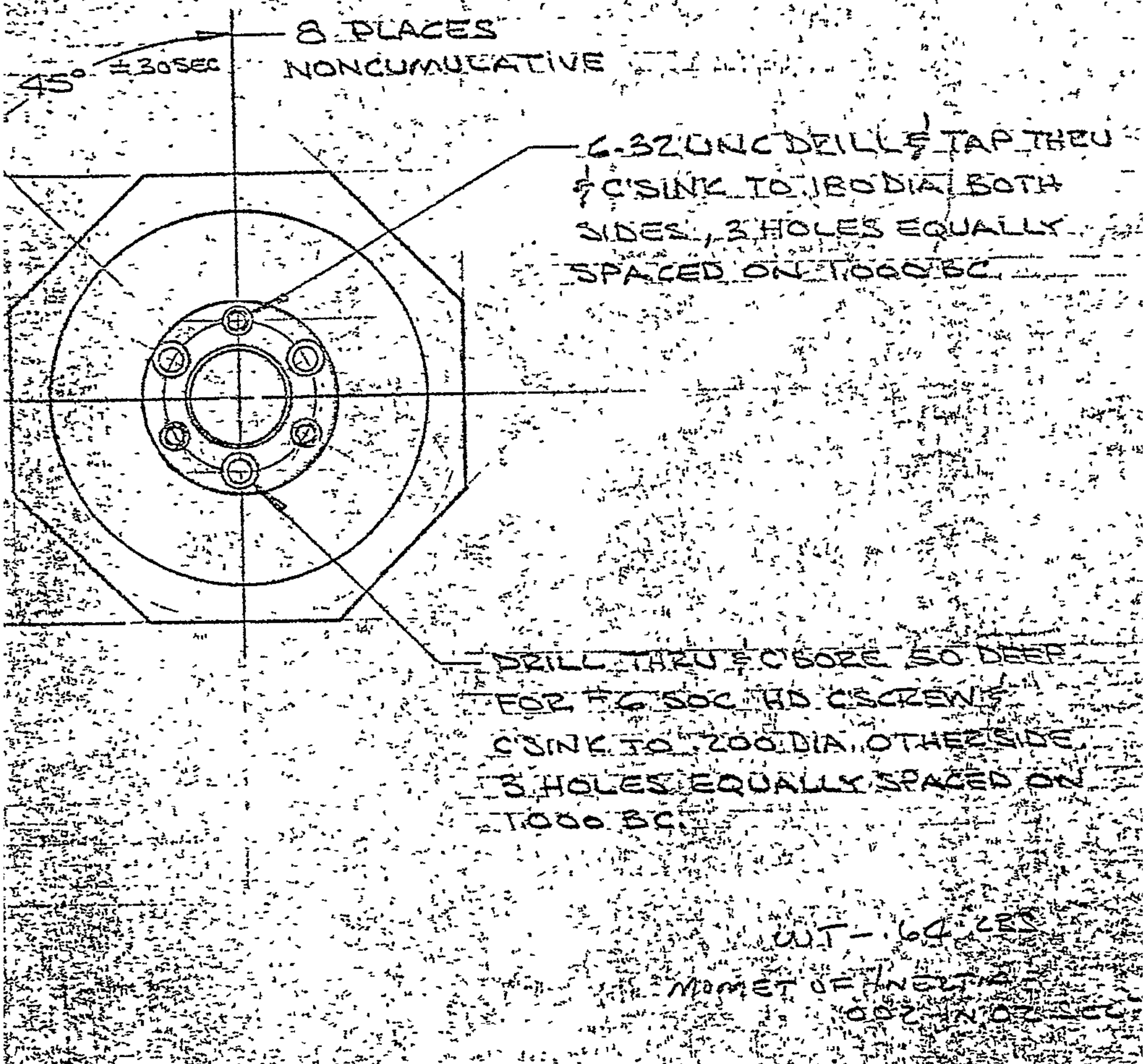
8-SIDED MIRROR DATA SHEETS



NOTE:
1. NICKEL PLATE .002/.003 PER INDICATED SURFACE. LAP & POLISH TO 1/4 λ @ 6328 Å.



ITEM | QTY. | PART NO | DESCRIPTION

TOL. UNLESS NOTED: .00 ±.03; .000 ±.010; ANGLES ±2°; CONCENT. .001

32/ ALL SURFACES EXCEPT NOTED

REMOVE ALL BURRS BREAK ALL EDGES & CORNERS AS EXCEPT NOTED

USED ON

MATERIAL: ALUM 6061-T6

FINISH

DRAWN D. HANSON 4-20-77

CHECKED

APPROVED

LINCOLN LASER COMPANY
Phoenix, Arizona 85004

MIRROR
PO-08-300-087

SCALE: FULL | CODE IDENT NO | DRAWING NO. 2-1046-100

LINCOLN LASER Co. — MIRROR CHECK-OUT SHEET

MIRROR No.: PO-08-300-087 SERIAL No: 061 JOB No: 271

COATING STATUS: Al + SiO DATE: 12-20-77 BY: D.P.

COLLIMATOR FACE TO AXIS READING:	DEVIATION IN ARC SEC. ±:	COLLIMATOR FACE TO FACE READING:	DEVIATION IN ARC SEC. ±:	ANGLE BETWEEN FACES:	45° ± ARC SEC.:
8.00	0	8.00	0	8+1	-22
7.54	-6	8.08	+8	1+2	+8
7.53	-7	8.02	+2	2+3	-6
7.48	-12	8.02	+2	3+4	0
7.48	-12	8.07	+7	4+5	+5
7.50	-10	8.16	+16	5+6	+9
7.53	-7	8.22	+22	6+7	+5
7.51	-9	8.22	+22	7+8	0

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MIRROR MOTOR DATA SHEET

Micro Mo ELECTRONICS, INC
3691 LEE ROAD, CLEVELAND, OHIO 44120
TELEPHONE- 216/921-1131, TWX-98 0850

MOTOR SPECIFICATIONS

- Measured at 25°C (77°F)
- Operational temperature range — 50°C (— 58°F) to +75°C (+167°F)
- Maximum rotor temperature. + 75°C (+ 167°F). special models up to + 125°C (+ 258°F)

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1*	2*	3*		4*	5	6*	7	8	9		10		11	12	13	14
Motor Type	Output Power (max.)	Stall Torque		Max Efficiency	Test Voltage	Noload Speed ± 15%	Specific Speed Per Volt ± 15%	Volts Per 1000 rpm ± 15%	Specific Torque ± 15%		Friction Torque (max)		Armature Resistance ± 10%	Armature Inductance	Typical Starting Voltage	Angular Acceleration (min)
Unit	Watts	gr cm	oz in.	%	Volts	rpm	rpm/v	Volts	gr cm/A	oz in/A	gr cm	oz in.	Ohm	µH	mV	(Rad/s²)•10³
1212E012	0.54	5 34	074	50	12 0	44000	3700	0.27	29 8	41	0.20	003	67 0	1640	190	53
1212E009	0.57	6 9	096	50	9 0	39500	4400	0 23	25.1	35	0.20	.003	33 0	1050	223	69
1212E006	0.50	6 6	092	50	6.0	33600	5900	0.17	18.7	26	0.20	003	17 0	590	300	66
060/ 006	0.50	3 7	05	60	4 5	25200	5900	0 17	16.5	.23	0.20	003	19 0	590	300	30
060/ 008	0.20	2.5	035	52	2.0	25500	13800	0 07	7 1	10	0.20	003	5.3	180	600	—
Type 050																
050/ 04	0 33	6 0	083	59	12 0	19200	1690	0 59	57 6	80	0.35	005	109 0	1200	250	28.5
050/ 055	0 26	5 6	078	59	6 0	18800	3320	0 30	29 4	41	0.33	005	30 0	250	220	26.0
050/ 08	0.26	8 0	110	66	4 0	16500	4280	0.23	22 8	32	0 30	004	11 0	230	95	38 0
050/_010	0.24	5.7	079	61	2 0	16300	8570	0 12	11 4	.16	0.30	004	3 8	40	70	29.5
050/_013	0.30	7.5	100	65	1 5	15100	10460	0 10	9 3	13	0 30	004	1 8	25	25	35.0
050/ 015	0.40	9 6	130	68	1 5	16500	11360	0 09	8 6	12	0.30	004	1 3	20	30	42.0
Type 1616																
1616E012	—	9 2	128	68	12 0	17200	1485	0.67	65.5	91	0.30	004	83 0	—	—	—
1616E004	—	12 5	175	72	4 0	17100	4388	0 23	22 2	31	0 30	004	6 9	—	—	—
Type 250																
250/_055	0.66	17 5	244	72	12 0	14700	1250	0.80	78 0	1 08	0.44	006	52 0	850	230	44 0
250/_07	0 43	1-0	195	72	6 0	11900	2030	0 49	48 0	67	0.35	005	20 0	350	130	38.7
Type 1624																
1624E012	—	39 5	550	81	12 0	14500	1278	0 82	79.9	1 11	0.40	006	24 0	850	360	82.0
1624E006	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
1624E003	—	47 0	65	81	3 0	11500	3875	0 26	25.2	35	0 50	007	1 6	230	360	70 0
Type 030																
030/_05	0 35	10 2	142	58	12 0	14100	1250	0 80	78 0	1 08	0 63	009	86 0	1000	—	14 0
030/_055	0 35	9 0	125	56	9 0	14000	1660	0 60	59 0	818	0 63	009	55 0	600	—	16.1
030/_08	0 41	13 7	190	64	6 0	13000	2270	0.44	43 0	597	0.59	008	18 0	300	—	16.4
030/ 010	0.43	9 4	131	55	3 0	16300	5830	0 17	17 0	236	0.66	009	5 0	60	—	20.4
030/_015	0.55	12 6	175	61	2 0	16400	8610	0 12	11 4	158	0 66	009	1 7	30	—	16.7
030/_020	0.61	17 9	.248	67	1 5	14300	9860	0 10	9 9	137	0.63	009	0 8	18	—	16.5
Type 230																
230/_06	0 53	24 2	.333	69	12.0	8200	700	1 43	139 0	1 92	0.71	010	67 0	1300	180	25.0
230/_017	1 10	47 1	652	77	3.0	8200	2780	0 36	35.0	0.49	0 71	010	2 2	65	30	33.5
230/ 020	0.77	34 2	475	77	2.0	6700	3420	0 29	28.0	0 39	0.65	009	1 3	50	25	27.5
Type 235																
235/ 06	0 53	27 3	380	71	12 0	7300	620	1 61	156.0	2 17	0 67	009	67 0	1300	180	25.0
235/_10	0 75	39 3	547	76	6.0	7200	1120	0.82	80 0	1 13	0 66	009	12 0	350	90	34 1
235/_15	0 75	40 8	293	77	3.0	7000	2350	0.43	41 0	570	0 66	009	3 0	85	40	32 3
Type 2232																
2232H012	—	116 0	1 61	82	12 0	11000	924	1 08	105 0	1 46	1 0	014	10 8	—	—	—
2232H003	—	136 0	1 89	84	3.0	10500	3560	0.28	27 4	38	1 0	014	0 6	—	—	—
Type 330																
330/_05	2.3	94 0	1.31	81	48 0	9360	200	5.00	494 0	6 25	1 00	0.014	250 0	4800	250	54 0
330/_055	1 9	79 8	1 11	81	30.0	10250	345	2 90	282.0	3 92	0.80	0.011	105 0	2200	190	73.6
330/ 07	2.6	100 4	1 44	84	24 0	9640	405	2 45	240 0	3 33	0.80	0.011	57 0	1600	110	75 0
330/_09 X	2.3	81 6	1 18	85	18 0	8050	510	1 96	191 0	2 65	0.68	0.009	25 0	600	90	70 0
330/ 09	1 5	136 7	1 90	83	12 0	9130	675	1 48	144 0	2 00	0 80	0.011	21 0	650	85	52 0
330/_12	2.46	147 4	2 05	84	12.0	9670	810	1 23	120 0	1 67	1 02	0.014	9 7	400	50	60 0
330/_17	3 10	142 8	1.98	86	6.0	9000	1510	0.66	65 0	90	0.77	0.011	2 9	130	22	70 0
330/_22	3 40	172 2	2 40	87	4 5	8730	1950	0 51	50 0	69	0.80	0 011	1 3	70	15	61 5

M[redacted]RCR MOTOR

*1 For model numbers containing a "slash" replace the digit after the slash with one of the following letters:
A = Pinion gear on shaft for gearboxes type 06/1 05/1, 05/2 05/3 05/40
B = Straight shaft — see motor drawings.
C = Special shafts.
D = Pinion gear on shaft for 03/2 gearbox
Example — Model 1212 A 001 = motor with pinion gear 06/1 gearhead
For model numbers not containing a slash contact the Cleveland office for proper designation.

*2 *3 *4 *6 At voltage specified in column 5.
*18 Rotor to case thermal resistance computed with rotor at zero velocity
*19 Radial shaft load rating at 3000 RPM
*23 Weights in parenthesis are for motor with gearbox (same case).

See Page 4 for English Metric Conversion Data

MAST MOTOR DATA SHEETS

Globe 168A229-2 gearmotor. (27 volts)

192:1 gear reduction, 93 torque multiplication

No Load Speed = (13,000 - 16,000)/192 = 68 - 83 rpm

Stall Torque = (1.50 oz in)(93) = 140 oz in.

Rated Torque = (.22)(93) = 20 oz in

$R_A = 36.3\ \Omega$

$K_E = \left(1.33\ \frac{\text{volt}}{1000\text{rpm}}\right)\left(\frac{1\text{rev}}{2\pi\text{ rad}}\right)\left(\frac{60\text{ sec}}{1\text{min}}\right) = .0127\ \frac{\text{volt sec}}{\text{rad}}$

$K_T = 1.8\ \frac{\text{oz in}}{\text{amp}}$

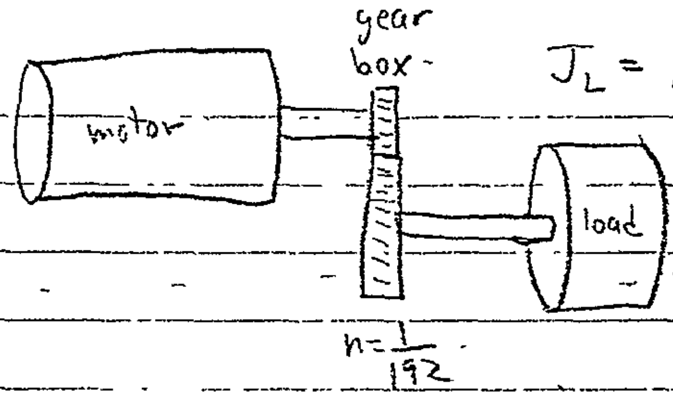
$J_{\text{Armature}} = \left(1.8\text{ gm cm}^2\right)\left(\frac{2.205\text{ lb}_m}{1000\text{ gm}}\right)\left(\frac{1\text{ lb}_F\text{ sec}^2/\text{ft}}{32.2\text{ lb}_m}\right)\left(\frac{1\text{ ft}}{12\text{ in}}\right)\left(\frac{1\text{ in}}{2.54\text{ cm}}\right)^2$

$\left(\frac{16\text{ oz}}{1\text{ lb}_F}\right) = .00106\text{ oz-in-sec}^2$

$J_{\text{Gear-box}} = \left(.5\text{ gm cm}^2\right) = .00029\text{ oz in-sec}^2$

$L_A = 8.8$ milli henries

(over)



$J_L = .986$ oz in sec^2

at load shaft, $$\dot{\omega} = \frac{T_m/(n\eta) - T_L}{\frac{J_m + J_G}{n^2} + J_L}$$

where T_m = motor torque = 1.50 oz in

$\frac{1}{n}$ = gear reduction = 192

$\frac{1}{n\eta}$ = torque multiplier = 93

T_L = 1.6 oz in + .04 $T_m/(n\eta)$ (note: 2nd term due to 1:1 mast gears)

$J_L + J_G$ = sum of motor and gearbox inertias = .00135 oz in sec^2

J_L = load inertia = .986 oz in sec^2

$$\dot{\omega} = \frac{.96\,(1.5\text{ oz in})(93) - 1.6\text{ oz in}}{(192)^2(.00135\text{ oz in sec}^2) + .986\text{ oz in sec}^2} = 2.6\text{ rad/sec}^2$$

$$\text{time} = \frac{\omega}{\dot{\omega}} = \frac{30\text{ rpm}}{2.6\ \frac{\text{rad}}{\text{sec}^2}}\left(\frac{2\pi\text{ rad/rev}}{60\ \frac{\text{sec}}{\text{min}}}\right) = 1.2\text{ sec}$$ to come up to speed.

UV-ERASABLE PROM DATA SHEETS

MOTOROLA Semiconductors

MCM2708L
MCM27A08L

1024 X 8 ERASABLE PROM

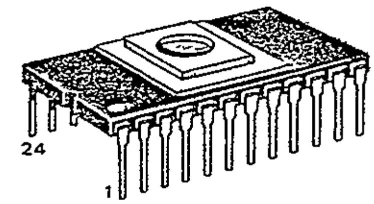
The MCM2708/27A08 is a 8192-bit Erasable and Electrically Reprogrammable PROM designed for system debug usage and similar applications requiring non volatile memory that could be reprogrammed periodically The transparent lid on the package allows the memory content to be erased with ultraviolet light Pin-for-pin mask-programmable ROMs are available for large volume production runs of systems initially using the MCM2708/27A08

- Organized as 1024 Bytes of 8 Bits
- Static Operation
- Standard Power Supplies of +12 V, +5 V and −5 V
- Maximum Access Time = 300 ns — MCM27A08L
450 ns — MCM2708L
- Low Power Dissipation
- Chip-Select Input for Memory Expansion
- TTL Compatible
- Three-State Outputs
- Pin Equivalent to the 2708
- Pin-for-Pin Compatible to MCM65308, MCM68308 or 2308 Mask-Programmable ROMs

MOS

(N-CHANNEL, SILICON GATE)

1024 X 8-BIT
UV ERASABLE PROM



CERAMIC PACKAGE
CASE 716-03

PIN ASSIGNMENT

Pin	Name	Name	Pin
1	A7	V_{CC}	24
2	A6	A8	23
3	A5	A9	22
4	A4	V_{BB}	21
5	A3	$\overline{CS}$/WE	20
6	A2	V_{DD}	19
7	A1	Progr	18
8	A0	D7	17
9	D0	D6	16
10	D1	D5	15
11	D2	D4	14
12	V_{SS}	D3	13

PIN CONNECTION DURING READ OR PROGRAM

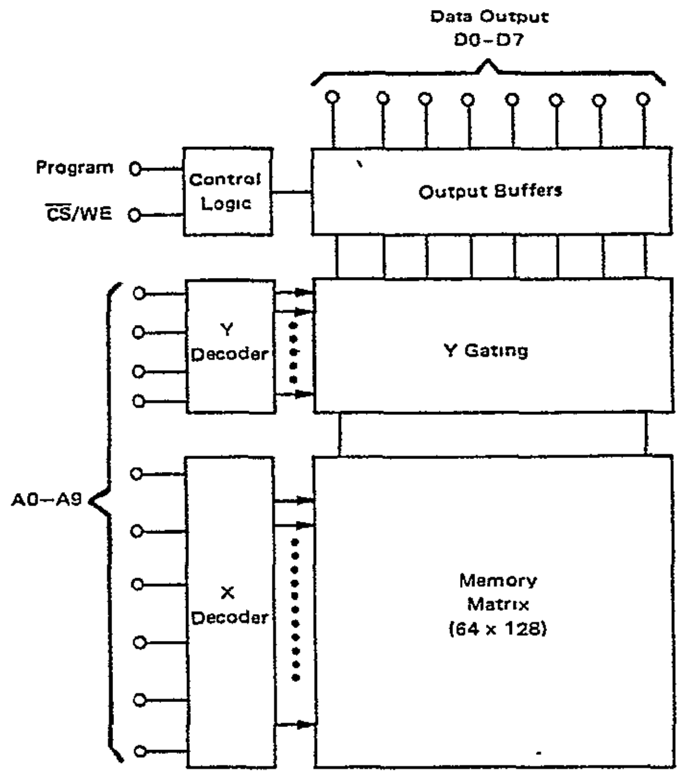
Mode	Pin Number						
	9-11, 13-17	12	18	19	20	21	24
Read	D_{out}	V_{SS}	V_{SS}	V_{DD}	V_{IL}	V_{BB}	V_{CC}
Program	D_{in}	V_{SS}	Pulsed V_{IHP}	V_{DD}	V_{IHW}	V_{BB}	V_{CC}

ABSOLUTE MAXIMUM RATINGS (1)

Rating	Value	Unit
Operating Temperature	0 to +70	°C
Storage Temperature	-65 to +125	°C
V_{DD} with Respect to V_{BB}	+20 to -0 3	Vdc
V_{CC} and V_{SS} with Respect to V_{BB}	+15 to -0 3	Vdc
All Input or Output Voltages with Respect to V_{BB} during Read	+15 to -0 3	Vdc
$\overline{CS}$/WE Input with Respect to V_{BB} during Programming	+20 to -0 3	Vdc
Program Input with Respect to V_{BB}	+35 to -0 3	Vdc
Power Dissipation	1 8	Watts

Note 1
Permanent device damage may occur if ABSOLUTE MAXIMUM RATINGS are exceeded Functional operation should be restricted to RECOMMENDED OPERATING CONDITIONS Exposure to higher than recommended voltages for extended periods of time could affect device reliability.

BLOCK DIAGRAM



DC READ OPERATING CONDITIONS AND CHARACTERISTICS

(Full operating voltage and temperature range unless otherwise noted.)

RECOMMENDED DC READ OPERATING CONDITIONS

Parameter	Symbol	Min	Nom	Max	Unit
Supply Voltage	V_{CC}	4 75	5 0	5 25	Vdc
	V_{DD}	11 4	12	12 6	Vdc
	V_{BB}	-5 25	-5 0	-4 75	Vdc
Input High Voltage	V_{IH}	3 0	–	V_{CC} + 1 0	Vdc
Input Low Voltage	V_{IL}	V_{SS}	–	0 65	Vdc

READ OPERATION DC CHARACTERISTICS

Characteristic		Condition	Symbol	Min	Typ	Max	Unit
Address and CS Input Sink Current		V_{in} = 5.25 V or V_{in} = V_{IL}	I_{in}	–	1	10	µA
Output Leakage Current		V_{out} = 5.25 V, $\overline{CS}$/WE = 5 V	I_{LO}	–	1	10	µA
V_{DD} Supply Current	(Note 2)	Worst-Case Supply Currents	I_{DD}	–	50	65	mA
V_{CC} Supply Current	(Note 2)	All Inputs High	I_{CC}	–	6	10	mA
V_{BB} Supply Current	(Note 2)	$\overline{CS}$/WE = 5 0 V, T_A = 0°C	I_{BB}	–	30	45	mA
Output Low Voltage		I_{OL} = 1 6 mA	V_{OL}	–	–	0 45	V
Output High Voltage		I_{OH} = -100 µA	V_{OH1}	3 7	–	–	V
Output High Voltage		I_{OH} = -1 0 mA	V_{OH2}	2 4	–	–	V
Power Dissipation	(Note 2)	T_A = 70°C	P_D	–	–	800	mW

Note 2

The total power dissipation is specified at 800 mW It is not calculable by summing the various current (I_{DD}, I_{CC}, and I_{BB}) multiplied by their respective voltages, since current paths exist between the various power supplies and V_{SS} The I_{DD}, I_{CC}, and I_{BB} currents should be used to determine power supply capacity only

V_{BB} must be applied prior to V_{CC} and V_{DD} V_{BB} must also be the last power supply switched off

AC READ OPERATING CONDITIONS AND CHARACTERISTICS
(Full operating voltage and temperature range unless otherwise noted.)
(All timing with t_r = t_f = 20 ns, Load per Note 3)

Characteristic	Symbol	MCM27A08 Min	MCM27A08 Typ	MCM27A08 Max	MCM2708 Min	MCM2708 Typ	MCM2708 Max	Unit
Address to Output Delay	t_{AO}	—	220	300	—	280	450	ns
Chip Select to Output Delay	t_{CO}	—	60	120	—	60	120	ns
Data Hold from Address	t_{DHA}	0	—	—	0	—	—	ns
Data Hold from Deselection	t_{DHD}	0	—	120	0	—	120	ns

CAPACITANCE (periodically sampled rather than 100% tested.)

Characteristic	Condition	Symbol	Typ	Max	Unit
Input Capacitance (f = 1.0 MHz)	V_{in} = 0 V, T_A = 25°C	C_{in}	4.0	6.0	pF
Output Capacitance (f = 1.0 MHz)	V_{out} = 0 V, T_A = 25°C	C_{out}	8.0	12	pF

Note 3
Output Load = 1 TTL Gate and C_L = 100 pF (Includes Jig Capacitance)
Timing Measurement Reference Levels Inputs 0.8 V and 2.8 V
Outputs 0.8 V and 2.4 V

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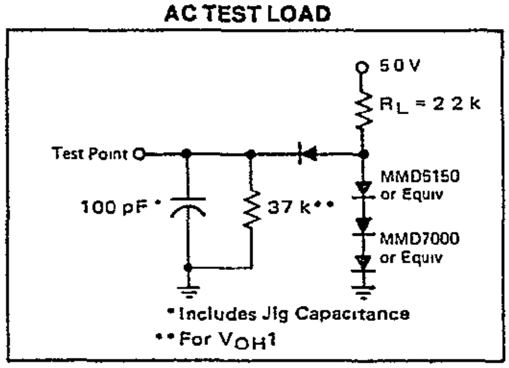
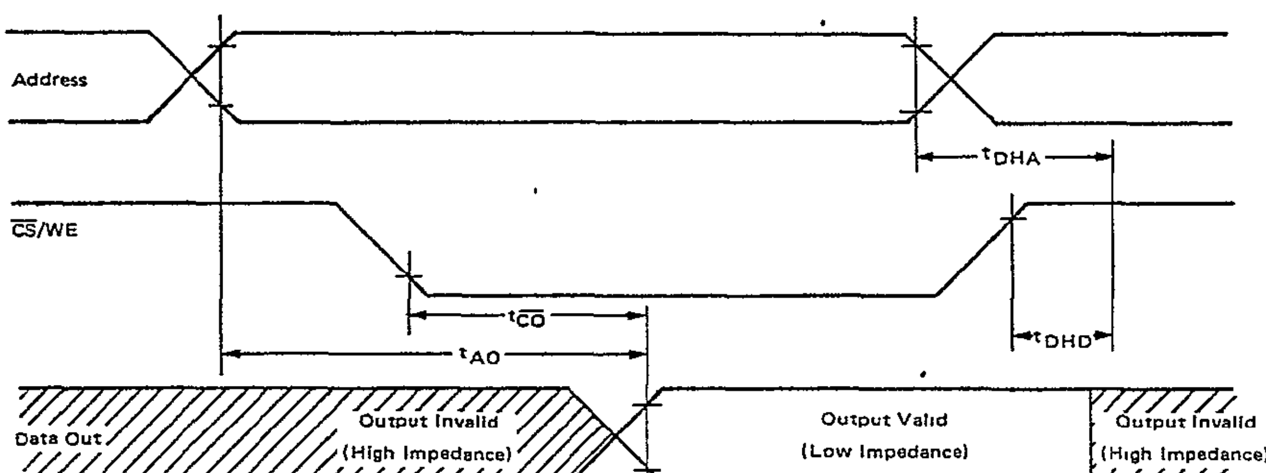
AC TEST LOAD



READ OPERATION TIMING DIAGRAM



DC PROGRAMMING CONDITIONS AND CHARACTERISTICS
(Full operating voltage and temperature range unless otherwise noted.)

RECOMMENDED PROGRAMMING OPERATING CONDITIONS

Parameter	Symbol	Min	Nom	Max	Unit
Supply Voltage	V_{CC}	4 75	5 0	5 25	Vdc
	V_{DD}	11 4	12	12 6	Vdc
	V_{BB}	−5 25	−5 0	−4 75	Vdc
Input High Voltage for All Addresses and Data	V_{IH}	3 0	–	V_{CC} + 1 0	Vdc
Input Low Voltage (except Program)	V_{IL}	V_{SS}	–	0 65	Vdc
$\overline{CS}$/WE Input High Voltage (Note 4)	V_{IHW}	11 4	12	12 6	Vdc
Program Pulse Input High Voltage (Note 4)	V_{IHP}	25	–	27	Vdc
Program Pulse Input Low Voltage (Note 5)	V_{ILP}	V_{SS}	–	1 0	Vdc

Note 4 Referenced to V_{SS}
Note 5. $V_{IHP} - V_{ILP}$ = 25 V min

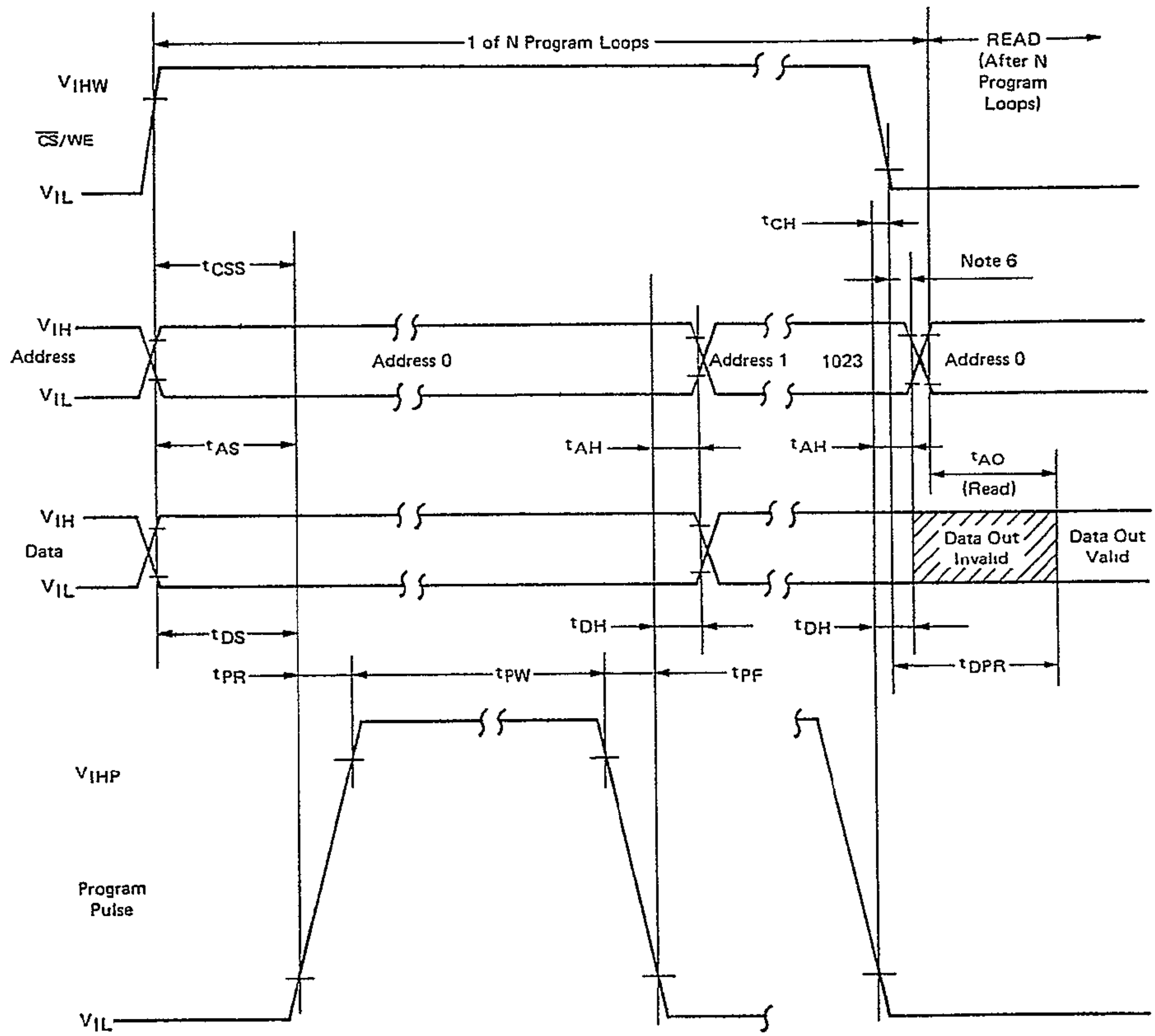
PROGRAMMING OPERATION DC CHARACTERISTICS

Characteristic	Condition	Symbol	Min	Typ	Max	Unit
Address and $\overline{CS}$/WE Input Sink Current	V_{in} = 5 25 V	I_{LI}	–	–	10	μAdc
Program Pulse Source Current		I_{IPL}	–	–	3 0	mAdc
Program Pulse Sink Current		I_{IPH}	–	–	20	mAdc
V_{DD} Supply Current	Worst-Case Supply Currents	I_{DD}	–	50	65	mAdc
V_{CC} Supply Current	All Inputs High	I_{CC}	–	6	10	mAdc
V_{BB} Supply current	$\overline{CS}$/WE = 5 V, T_A = 0°C	I_{BB}	–	30	45	mAdc

AC PROGRAMMING OPERATING CONDITIONS AND CHARACTERISTICS
(Full operating voltage and temperature unless otherwise noted)

Characteristic	Symbol	Min	Max	Unit
Address Setup Time	t_{AS}	10	–	μs
$\overline{CS}$/WE Setup Time	t_{CSS}	10	–	μs
Data Setup Time	t_{DS}	10	–	μs
Address Hold Time	t_{AH}	1 0	–	μs
$\overline{CS}$/WE Hold Time	t_{CH}	0 5	–	μs
Data Hold Time	t_{DH}	1 0	–	μs
Chip Deselect to Output Float Delay	t_{DF}	0	120	ns
Program to Read Delay	t_{DPR}	–	10	μs
Program Pulse Width	t_{PW}	0 1	1 0	ms
Program Pulse Rise Time	t_{PR}	0 5	2 0	μs
Program Pulse Fall Time	t_{PF}	0 5	2 0	μs

PROGRAMMING OPERATION TIMING DIAGRAM



Note 6. The $\overline{CS}$/WE transition must occur after the Program Pulse transition and before the Address Transition

PROGRAMMING INSTRUCTIONS

After the completion of an ERASE operation, every bit in the device is in the "1" state (represented by Output High) Data are entered by programming zeros (Output Low) into the required bits The words are addressed the same way as in the READ operation A programmed "0" can only be changed to a "1" by ultra-violet light erasure.

To set the memory up for programming mode, the $\overline{CS}$/WE input (Pin 20) should be raised to +12 V Programming data is entered in 8-bit words through the data output terminals (D0 to D7)

Logic levels for the data lines and addresses and the supply voltages (V_{CC}, V_{DD}, V_{BB}) are the same as for the READ operation

After address and data setup one program pulse per address is applied to the program input (Pin 18) A program loop is a full pass through all addresses Total programming time, $T_{Ptotal} = N \times t_{PW} \geq 100$ ms The required number of program loops (N) is a function of the program pulse width (t_{PW}), where $0.1 \text{ ms} \leq t_{PW} \leq 1.0 \text{ ms}$, correspondingly N is $100 \leq N \leq 1000$ There must be N successive loops through all 1024 addresses It is not permitted to apply more than one program pulse in succession to the same address (i e., N program pulses to an address and then change to the next address to be programmed). At the end of a program sequence the $\overline{CS}$/WE falling edge transition must occur before the first address transition, when changing from a PROGRAM to a READ cycle The program pin (Pin 18) should be pulled down to V_{ILP} with an active device, because this pin sources a small amount of current (I_{IPL}) when $\overline{CS}$/WE is at V_{IHW} (12 V) and the program pulse is at V_{ILP}

EXAMPLES FOR PROGRAMMING

Always use the $T_{Ptotal} = N \times t_{PW} \geq 100$ ms relationship

1 All 8192 bits should be programmed with a 0 2 ms program pulse width

The minimum number of program loops:

$$N = \frac{T_{Ptotal}}{t_{PW}} = \frac{100 \text{ ms}}{0.2 \text{ ms}} = 500$$

One program loop consists of words 0 to 1023

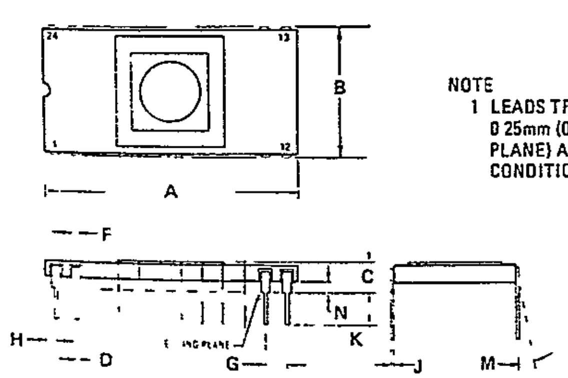
2. Words 0 to 200 and 300 to 700 are to be programmed. All other bits are "don't care". The program pulse width is 0 5 ms. The minimum number of program loops, $N = \frac{100}{0.5} = 200$ One program loop consists of words 0 to 1023. The data entered into the "don't care" bits should be all 1s

3. Same requirements as example 2, but the EPROM is now to be updated to include data for words 850 to 880 The minimum number of program loops is the same as in the previous example, N = 200 One program loop consists of words 0 to 1023 The data entered into the "don't care" bits should be all 1s Addresses 0 to 200 and 300 to 700 must be reprogrammed with their original data pattern

ERASING INSTRUCTIONS

The MCM2708/27A08 can be erased by exposure to high intensity shortwave ultraviolet light, with a wavelength of 2537 Å The recommended integrated dose (i e , UV-intensity x exposure time) is 12 5 Ws/cm^2 As an example, using the "Model 30-000" UV-Eraser (Turner Designs, Mountain View, CA94043) the ERASE time is 30 minutes The lamps should be used without shortwave filters and the MCM2708/27A08 should be positioned about one inch away from the UV-tubes

OUTLINE DIMENSIONS



NOTE
1 LEADS TRUE POSITIONED WITHIN 0 25mm (0 010) DIA (AT SEATING PLANE) AT MAXIMUM MATERIAL CONDITION

DIM	MILLIMETERS		INCHES	
	MIN	MAX	MIN	MAX
A	29 97	30 99	1 180	1 220
B	14 86	15 62	0 585	0 615
C	3 30	4 95	0 130	0 195
D	0 38	0 53	0 015	0 021
F	0 76	1 40	0 030	0 055
G	2 54 BSC		0 100 BSC	
H	0 76	1 78	0 030	0 070
J	0 20	0 30	0 008	0 012
K	2 54	4 19	0 100	0 165
M	–	10°	–	10°
N	0 51	1 52	0 020	0 060

716-03

APPENDIX C

Computer Program for the calculation of Azimuth Initiate Angles, Elevation Fire Angles and Center of Scan Angles.

```
/COMPILE
C PROGRAM TO COMPUTE AVAILABLE AZIMUTH DATA ANGLES
      INTEGER OCT(3),BIN(8)
C INITIALIZATION BLOCK
C
C WMAST=MAST VELOCITY(RAD/SEC)
C WMIR=MIRROR VELOCITY (RAD/SEC)
C RINCR=ENCODER RESOLUTION (DEGREES)
C DHOLD=DATA HOLD TIME FOR INPUT COMMANDS
C
      ANG=-180.
      WMAST=3.141592
      WMIR=WMAST*24.
      DTHETA=WMAST/WMIR*45.
      RINCR=360./256.
      RPMAST=WMAST*9.549298
      RPMIR=WMIR*9.549298
      DHOLD=2.0E3*3.141592/(256.*WMAST)
      SCANS=RPMAST/60.
C
      DO 20 I2=1,254,32
      I3=I2+31
      WRITE(6,100)
      WRITE(6,101)
      DO 10 I=I2,I3
      IBIN=I-1
C CONVERT IBIN TO ITS OCTAL AND BINARY REPRESENTATIONS
      CALL OCTBIN(OCT,BIN,IBIN)
      IBIN=I-1
      ANG2=ANG+DTHETA/2.
      WRITE(6,102)ANG2,ANG,(OCT(J),J=1,3),(BIN(J),J=1,8),IBIN,IBIN
      ANG=ANG+RINCR
   10 CONTINUE
      WRITE(6,104)
      WRITE(6,103)WMAST,RPMAST,WMIR,RPMIR,DHOLD,DTHETA,SCANS
   20 CONTINUE
      WRITE(6,100)
C
  100 FORMAT('1')
  101 FORMAT('0',2X,'AZIMUTH DATA ANGLES      ',4X,
     -'INITIATE ANGLE         ADDR. IN MEMORY'/' ',6X,
     -'DEGREES',20X,'DEGREES',6X,'OCTAL  BINARY   DECIMAL',
     -'    HEX')
  102 FORMAT(' ',5X,F9.4,18X,F9.4,6X,3I1,2X,8I1,4X,I3,6X,Z2)
  103 FORMAT('-','MAST VELOCITY= ',F7.3,' RAD/SEC = ',F7.1,
     -' RPM'/'0','MIRROR VELOCITY= ',F7.3,' RAD/SEC = ',F7.1,
     -' RPM'/'0','DATA HOLD TIME= ',F7.3,' MSEC'/'0',
     -'DELTA THETA= ',F7.4,' DEGREES'/'0',
     -'SCANS PER SECOND= ',F7.3)
  104 FORMAT('0')
      STOP
      END
C
C SUBROUTINE CONVERTS IBIN TO ITS OCTAL AND BINARY REPRESENTATION

      SUBROUTINE OCTBIN(OCT,BIN,IBIN)
      INTEGER OCT(3),BIN(8),PWR
      IBIN1=IBIN
C
      OCT(1)=IBIN/64
```

```
      IBIN=MOD(IBIN,64)
      OCT(2)=IBIN/8
      OCT(3)=MOD(IBIN,8)

      IBIN=IBIN1
      DO 10 I=1,7
      PWR=2**(8-I)
      BIN(I)=IBIN/PWR
      IBIN=MOD(IBIN,PWR)
   10 CONTINUE
      BIN(8)=IBIN

      RETURN
      END

/EXECUTE
```

```
/COMPILE
C PROGRAM TO COMPUTE AVAILABLE AZIMUTH CENTER OF SCAN ANGLES
      INTEGER OCT(3),BIN(8),OCT2(3),BIN2(8)
C INITIALIZATION
C RINCR=ENCODER RESOLUTION
      ANG=-180.
      RINCR=360./128.
C
      WRITE(6,100)
      WRITE(6,101)
      DO 10 I=2,130,2
C
C IBIN=REFERENCE ANGLE
C IBIN2=COMPUTER COMMAND WORD
      IBIN=128+2-I
      IBIN2=IBIN/2+128
      CALL OCTBIN(OCT,BIN,IBIN)
      CALL OCTBIN(OCT2,BIN2,IBIN2)
      WRITE(6,102)ANG,(OCT(J),J=1,3),(BIN(J),J=1,8),IBIN,
     -(OCT2(J),J=1,3),(BIN2(J),J=1,8)
      ANG=ANG+RINCR
   10 CONTINUE
C
      DO 20 I=2,126,2
      IBIN=256-I
      IBIN2=IBIN/2+128
      CALL OCTBIN(OCT,BIN,IBIN)
      CALL OCTBIN(OCT2,BIN2,IBIN2)
      WRITE(6,102)ANG,(OCT(J),J=1,3),(BIN(J),J=1,8),IBIN,
     -(OCT2(J),J=1,3),(BIN2(J),J=1,8)
      ANG=ANG+RINCR
   20 CONTINUE
C
  100 FORMAT('1')
  101 FORMAT(' ',21X,'AVAILABLE AZIMUTH CENTER OF SCAN ANGLES'//' ',3X,
     -'CENTER OF SCAN',15X,'REF. ANGLE',11X,'COMPUTER COMMAND WORD'/' '
     -7X,'ANGLE',15X,'OCTAL  BINARY  HEX',11X,'OCTAL    BINARY')
  102 FORMAT(' ',6X,F9.4,13X,3I1,2X,8I1,2X,Z2,11X,3I1,4X,8I1)
      WRITE(6,100)
      STOP
      END
C
C SUBROUTINE FOR DECIMAL TO OCTAL AND BINARY CONVERSION

      SUBROUTINE OCTBIN(OCT,BIN,IBIN)
C NUMBER TO BE CONVERTED IS PASSED THROUGH IBIN
C OCTAL AND BINARY REPRESENTATIONS ARE RETURNED IN
C ARRAYS OCT AND BIN RESPECTIVELY
C THE ARRAY ELEMENTS REPRESENT SINGLE DIGITS WITH
C OCT(1) AND BIN(1) BEING THE MOST SIGNIFICANT BITS
      INTEGER OCT(3),BIN(8),PWR
      IBIN1=IBIN
C
      OCT(1)=IBIN/64
      IBIN=MOD(IBIN,64)
      OCT(2)=IBIN/8
      OCT(3)=MOD(IBIN,8)
C
      IBIN=IBIN1
      DO 10 I=1,7
```

```
          PWR=2**(8-I)
          BIN(I)=IBIN/PWR
          IBIN=MOD(IBIN,PWR)
       10 CONTINUE
          BIN(8)=IBIN
          IBIN=IBIN1
    C
          RETURN
          END

    /EXECUTE
```

```
/COMPILE
C PROGRAM TO COMPUTE AVAILABLE ELEVATION ANGLES
      INTEGER OCT(3),BIN(8)
      REAL LMIR,LASLIM
C
C INITIALIZATION BLOCK
C LMIR=LENGTH OF FACE ON OCTOGONAL MIRROR (INCHES)
C WBEAM=WIDTH OF BEAM AT MIRROR SURFACE (INCHES)
C LASLIM=FREQUENCY LASER IS LIMITED TO FOR CONTIN. OPERATION (HZ)
C RPMIR=ANGULAR VELOCITY OF MIRROR (RPM)
C RINCR=ENCODER RESOLUTION (DEGREES)
C B1=ANGLE FROM HORIZONTAL WHERE BEAM IS AT FULL POWER (DEGREES)
C BN=ANGLE FROM VERTICAL WHERE BEAM IS AT FULL POWER (DEGREES)
C DBETA=MINIMUM ANGLE BETWEEN ELEVATION SHOTS
      LMIR=1.2426
      WBEAM=.375
      RINCR=90./256.
      B1=2.*(180./3.141592)*ARCOS(.383*(LMIR-WBEAM)/LMIR)-135.
      BN=-2.*(180./3.141592)*ARCOS(.383*(LMIR+WBEAM)/LMIR)+135.
      ANG=0.
      LASLIM=10000.
      RPMIR=720.
      DBETA=12.*RPMIR/LASLIM
C DBETA MUST BE AN INTEGRAL MULTIPLE OF RINCR, CONVERT IF NEC.
      DBETA=DBETA/RINCR
      IF(DBETA-FLOAT(IFIX(DBETA)).NE.0.) DBETA=DBETA+1.
      DBETA=RINCR*FLOAT(IFIX(DBETA))
C
C
      DO 20 I2=1,254,32
      I3=I2+31
      WRITE(6,100)
      WRITE(6,101)
      DO 10 I=I2,I3
      IBIN=I-1
      CALL OCTBIN(OCT,BIN,IBIN)
      IBIN=I-1
      WRITE(6,102) ANG,(OCT(J),J=1,3),(BIN(J),J=1,8),IBIN,IBIN
C IF ANGLE IS NOT WITHIN FULL POWER RANGE FLAG WITH ASTERISK
      IF((ANG.LT.B1).OR.((90.-ANG).LT.BN)) WRITE(6,103)
      ANG=ANG+RINCR
   10 CONTINUE
      WRITE(6,104) DBETA,LASLIM,RPMIR,WBEAM
   20 CONTINUE
      WRITE(6,100)
C
  100 FORMAT('1')
  101 FORMAT('0',2X,'AVAILABLE ELEVATION ANGLES',20X,
     -'    ADDR. IN MEMORY'/' ',11X,
     -'DEGREES',20X,6X,'OCTAL  BINARY   DECIMAL',
     -'    HEX')
  102 FORMAT(' ',10X,F9.4,18X,8X,3I1,2X,8I1,4X,I3,6X,Z2)
  103 FORMAT('+',20X,'*')
  104 FORMAT('-'/'-',2X,'DELTA BETA MIN.= ',F7.5,' DEGREES'/'0',
     -2X,'* ASTERISK INDICATES ONLY PARTIAL LASER POWER'/' ',
     -2X,'  AVAILABLE AT THIS ELEVATION'/'0',
     -2X,' ABOVE DATA VALID WHEN:'/'0',4X,'LASER LIMITED TO ',
     -F7.1,' HERTZ'/' ',4X,'MIRROR VELOCITY= ',F6.1,' RPM'/' ',
     -4X,'BEAM WIDTH= ',F7.4,' INCHES')
      STOP
```

```
      END
C
C SUBROUTINE FOR CONVERTING IBIN TO  OCTAL AND BINARY

      SUBROUTINE OCTBIN(OCT,BIN,IBIN)
      INTEGER OCT(3),BIN(8),PWR
      IBIN1=IBIN
C
      OCT(1)=IBIN/64
      IBIN=MOD(IBIN,64)
      OCT(2)=IBIN/8
      OCT(3)=MOD(IBIN,8)
C
      IBIN=IBIN1
      DO 10 I=1,7
      PWR=2**(8-I)
      BIN(I)=IBIN/PWR
      IBIN=MOD(IBIN,PWR)
   10 CONTINUE
      BIN(8)=IBIN
C
      RETURN
      END

/EXECUTE
```