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ERDA CONTRACT NO. E(04-3)-1109

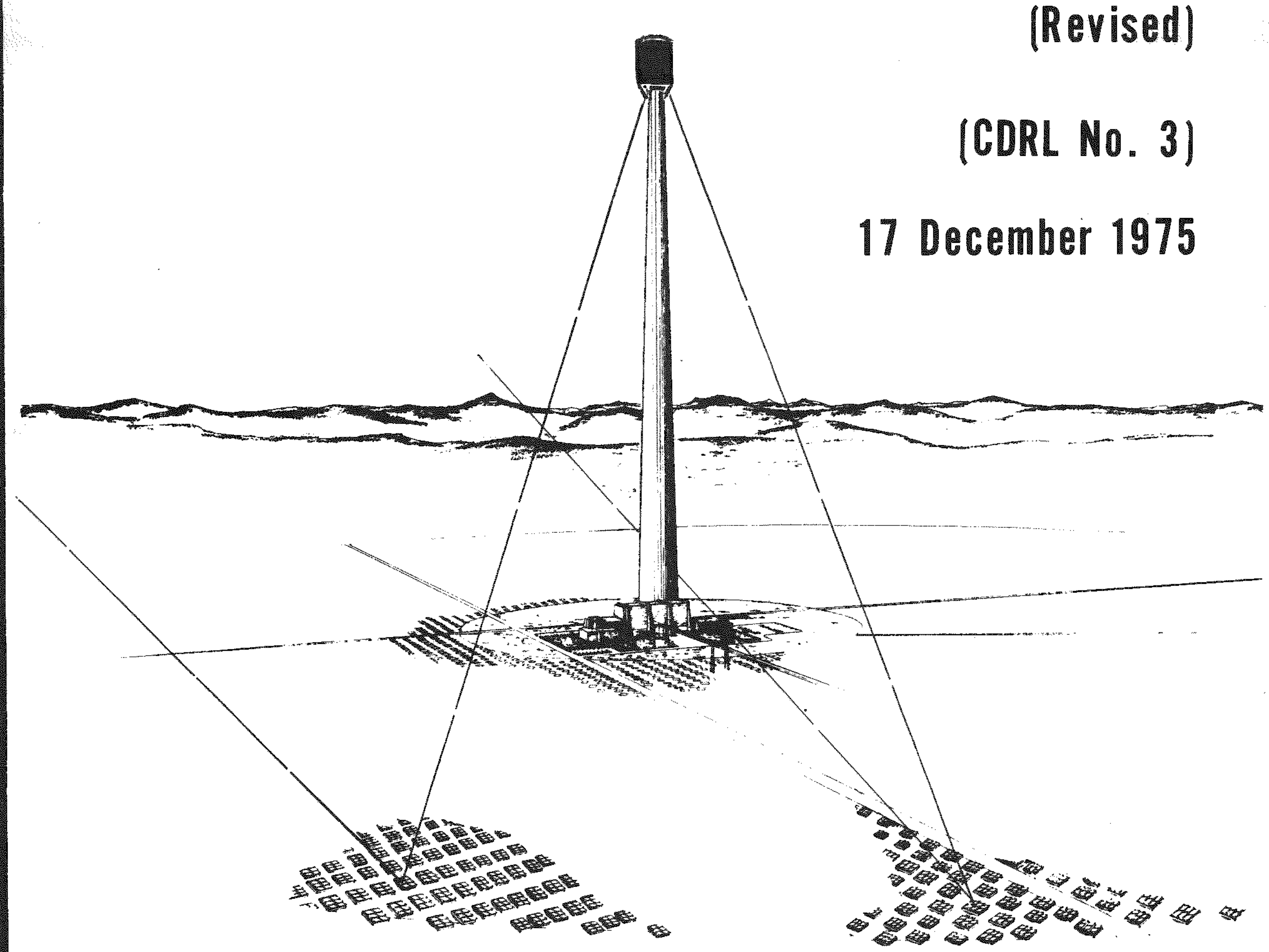
SOLAR PILOT PLANT

Phase I

Collector Subsystem Research Experiment Conceptual Design Report (Revised)

(CDRL No. 3)

17 December 1975



HONEYWELL INC.

F3419-DR-102A

BLACK & VEATCH

Honeywell

ERDA Contract No. E(04-3)-1109 17 December 1975

SOLAR PILOT PLANT
PHASE I

CONCEPTUAL DESIGN REPORT

Collector Subsystem Research Experiment
CDRL Item No. 3
(REVISED)

Systems & Research Center
2600 RIDGWAY PARKWAY,
MINNEAPOLIS, MINNESOTA 55413

40295 Printed in U.S.A. F3419-DR-102A

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FOREWORD

This is the second submittal of the Solar Pilot Plant Collector Subsystem Research Experiment Conceptual Design Report per CDRL No. 3 under ERDA Contract E(04-3)1109. This report is submitted for review and approval by ERDA.

Revised paragraphs are indicated by a ▌ on the right margin.

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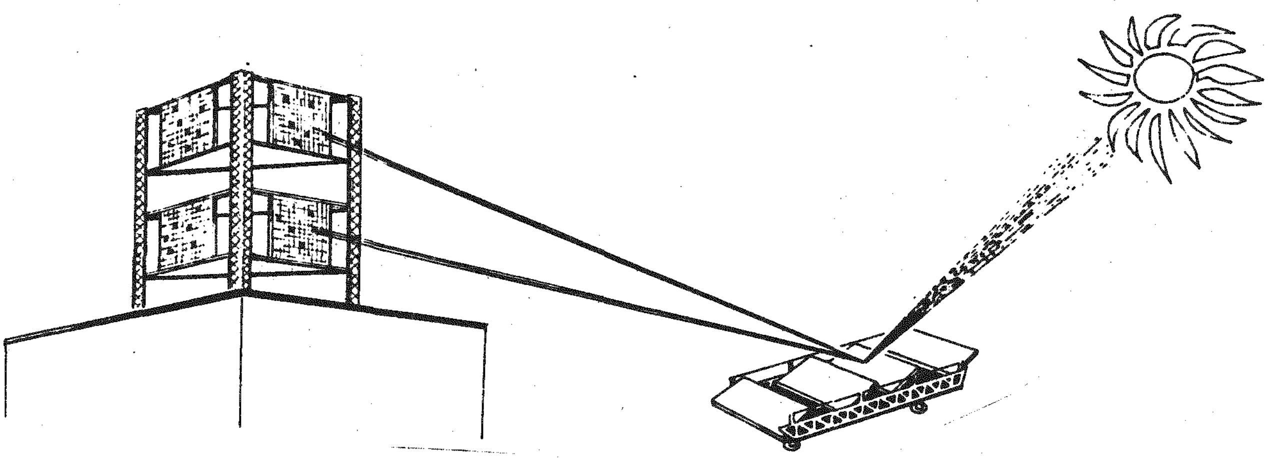
SOLAR COLLECTOR SUBSYSTEM



Collector Subsystem

Program Overview

HIGHLIGHTS OF SOLAR COLLECTOR SUBSYSTEM RESEARCH EXPERIMENT

A well-planned Research Experiment will (a) provide an orderly design of the hardware and control system to be evaluated, (b) define test objectives compatible with the test specimen, the requirements, and with the Pilot Plant concepts, and (c) set down a program to accomplish these objectives considering inspection, analysis, and test as the means of verification.

The heliostats to be designed for the Research Experiment are the same heliostats proposed for the Pilot Plant. The only difference is quantity-- only 4 for the Research Experiment and 3,000 for the Pilot Plant. The first heliostat will be built during the detail design process; slowly, and in phase with the design activity, as a test vehicle to support the design analysis. Various elements of the structure, electronics, or software will be fabricated, breadboarded, or coded and tested as necessary to compare test results with design analysis.

Then this first heliostat with its electronics becomes an engineering test bed to duplicate, simulate, analyze and solve problems that develop on the three operational heliostats. The three operational heliostats are built to the design resulting from the detail design review.

The test program is designed to address four key issues: (1) signal distribution to the heliostats, (2) noise rejection and signal detection at the Calibration Array, (3) tracking and control concepts, and (4) environmental effects on subsystem operation in the field.

With the significant quantity difference, there will naturally be some slight differences in manufacturing techniques for the Research Experiment. The Pilot Plant will use high volume, mass production techniques of the same design concept proven in this Research Experiment. Therefore, the Research Experiment tests will evaluate concepts and the Pilot Plant design will be qualified in Phase 2 or 3 of the Central Receiver Power System effort.

0975-242

ELEMENT	RESEARCH EXPERIMENT	PILOT PLANT
1. HELIOSTAT	40 SQUARE METER TILT-TILT HELIOSTAT	SAME
2. FOUNDATION	ONE LARGE VERY STABLE CONCRETE SLAB AND TWO OR MORE LOW COST STEEL POST AND CONCRETE CONFIGURATIONS	ONE OR TWO OF THOSE BEING TESTED
3. POWER DISTRIBUTION	110V 60 HZ PLUS BATTERY. NO HI-VOLTAGE	HI-VOLTAGE, 110V 60 HZ PLUS BATTERY
4. SIGNAL DISTRIBUTION	SERIAL DATA BUS	SAME
5. TOWER	STEEL STRUCTURE, 86 FT HIGH, 3 LEGS	CONCRETE, ABOUT 400 FT HIGH
6. CALIBRATION ARRAY	LIGHT DETECTORS ON TOWER, 12 FT BY 12 FT GRID WITH ELECTRONICS	SAME
7. TARGET	LIGHT DETECTORS ON TOWER TO SIMULATE RECEIVER, 12 FT BY 12 FT GRID WITH ELECTRONICS	RECEIVER
8. PROCESSOR	ONE H-716 WITH GLOBAL I/O	COULD BE SAME EXCEPT INCREASED QUANTITY
9. CONTROL SOFTWARE	SIZED FOR PILOT PLANT, SIMULATES OPERATOR AND CENTRAL CONTROLLER I/O	SAME, DIFFERS ONLY IN GEODETIC AND FIELD LAYOUT CONSTANTS
10. TEST SOFTWARE	AS NECESSARY FOR DATA COLLECTION AND CORRELATION FOR RESEARCH EXPERIMENT	AS NECESSARY FOR INITIALIZATION AND MAINTENANCE FOR PILOT PLANT
11. TEST EQUIPMENT	METEOROLOGICAL AND OTHER COMMERCIAL INSTRUMENTATION FOR TEST DATA COLLECTION	NO NONSTANDARD INSTRUMENTATION, METEOROLOGICAL AND OTHER COMMERCIAL INSTRUMENTATION FOR STATION MAINTENANCE

FIGURE 1. COMPARISON OF RESEARCH EXPERIMENT ELEMENTS TO BE TESTED WITH PILOT PLANT CONCEPTS

ACCOMPLISHMENT OF THE TEST OBJECTIVES

The best program to evaluate the key issues is to put the system into operation and evaluate the system effects of the stimuli (with natural and controlled environments).

The objective of the program is to evaluate four key issues:

1. Signal distribution to the heliostats.

2. Noise rejection and signal detection at the calibration array.

3. Tracking and control concepts, and.

4. Environmental effects on subsystem operation in the field.

The power distribution will be at the same 110 volts ac level but without the high voltage first tier distribution system. It is not necessary to simulate other heliostat loads because there are no transient conditions with batteries supplying the primary power. However, the signal distribution will have simulated heliostat terminations periodically to evaluate the reflected impedance effects of multitap, long transmission lines.

The rejection of background light on the calibration array will be proven in the lab on breadboard models and in the field tests. The layout of heliostats at the Honeywell facility allows the engineering test bed heliostat to be directed at the same calibration array as the close in heliostat. The test bed heliostat can be defocussed and partially filtered to produce any degree of background scatter as noise for the calibration array.

The tracking and control concepts, including communication, are identical and will be proven directly. Timing and program sizing is important so the Research Experiment software will compute and generate and issue commands for one-quarter of a Pilot Plant size field. Some of these commands will go to simulated loads and be evaluated by count comparison.

During the operational test phase, the three heliostats will be set on ytation, tested manually to their electrical and mechanical requirements, integrated with the control system, and then begin daily operational tests. For these daily tests, the heliostats will be integrated with the computer and will direct the reflected energy onto a sensor grid to simulate the receiver. The sensor grid will allow a performance measurement of the operating helio stats under natural and simulated environmental conditions.

The natural effects of rain, wind, sand, and Sun will be severe enough for a good evaluation. But in addition to this, simulated conditions of temperature by heaters and heat lamps and of wind by fans and aircraft engines/props will create the severe extremes of these environments.

The results of this Research Experiment will thoroughly evaluate the design concepts and provide information that will be helpful and directly applicable to the design of the Pilot Plant.

0975-237

- Signal distribution to the heliostats
- Noise rejection and signal detection at the calibration array
- Tracking and control concepts
- Environmental effects on subsystem operation in the field

FIGURE 1. KEY ISSUES OF THE RESEARCH EXPERIMENT

Collector Subsystem

Configuration of Test Item Heliostat

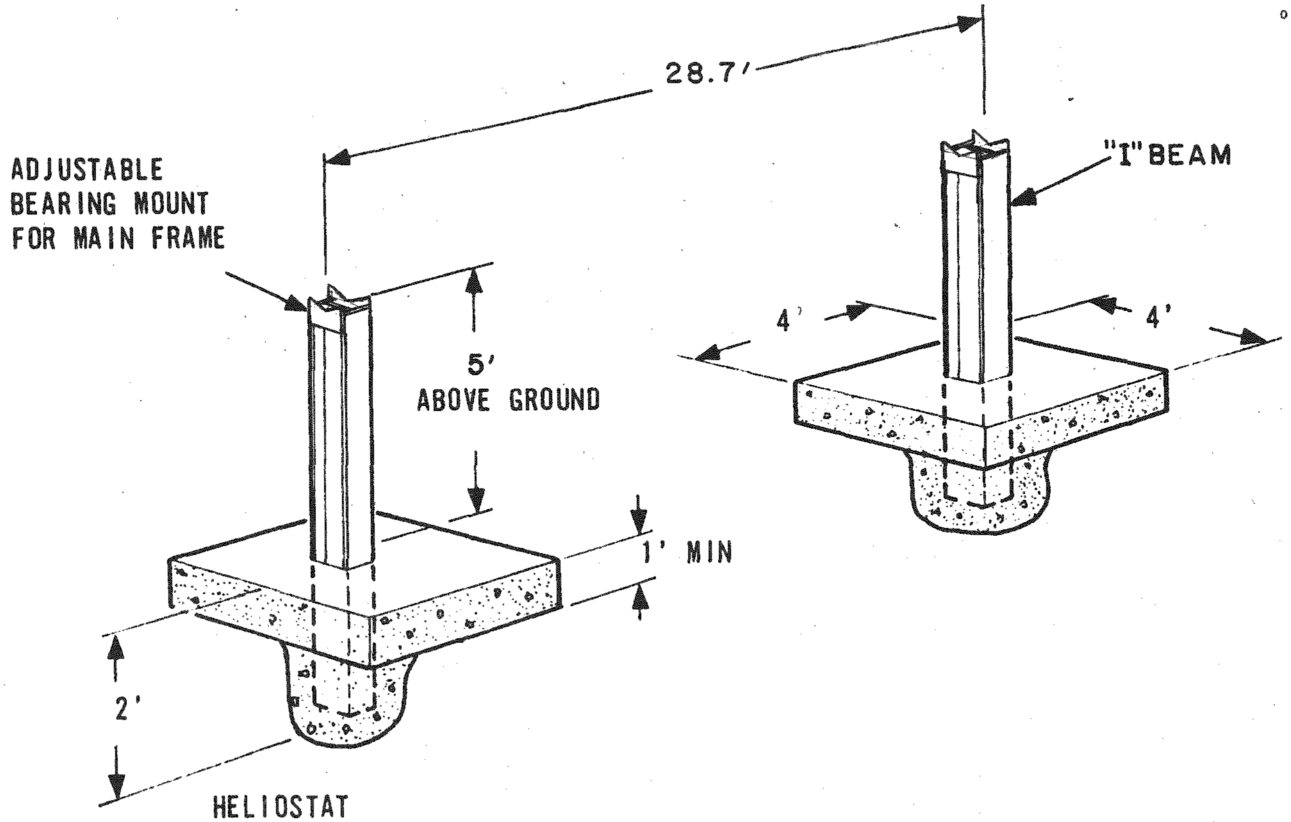
EVALUATION OF FOUNDATION INFLUENCE ON STABILITY

The foundation configuration must support heliostat loads and windloads within stability requirements.

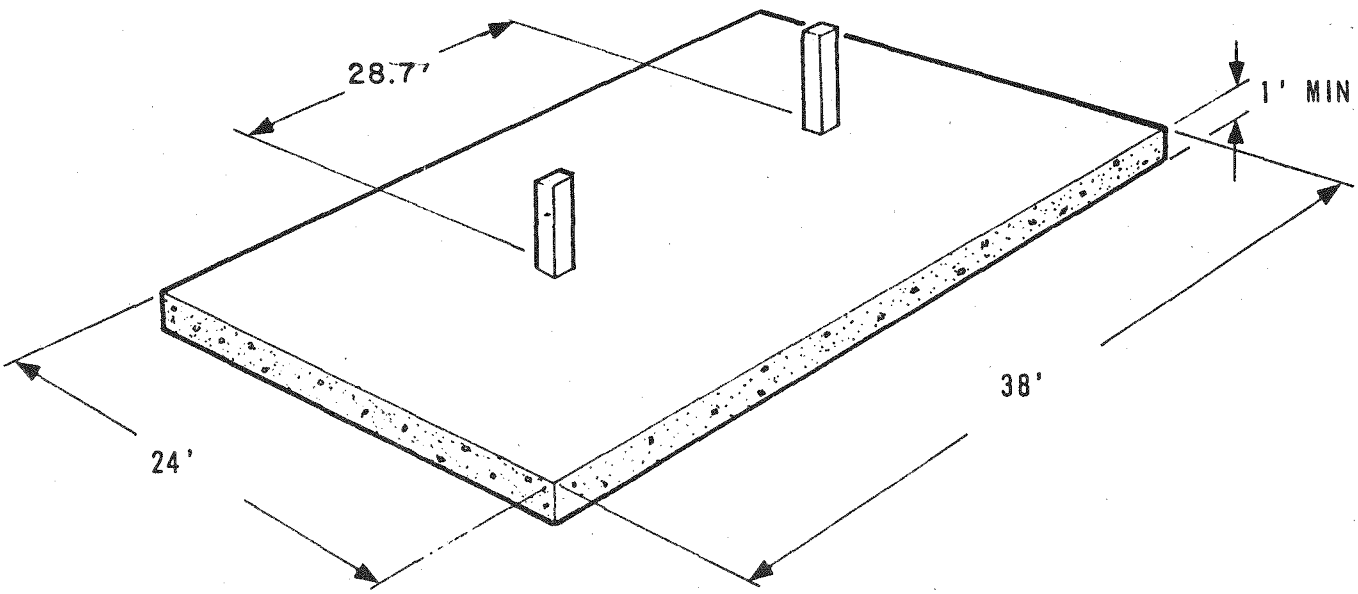
Four different foundation configurations will be built to test stability and determine cost effectiveness. The engineering test bed foundation will tie the supporting columns into one large slab foundation providing mass for lateral stability as well as providing an adequate work surface for the engineering test bed heliostat. Heliostat foundation No. 1 will be constructed of two individual 4 x 4 foot reinforced concrete slabs. Each slab will support a 3 foot high supporting column and will have a bearing plate for the tilt mechanism mount. Heliostat foundation No. 2 will be similar to No. 1 however with a 6 foot high supporting column. Heliostat foundation No. 3 will be similar to No. 1 and No. 2 however, the steel column will be extended through the slab and encased in concrete to a depth of 3 feet. This will provide a kicker action in an effort to minimize lateral movement of the slab and thus improve lateral stability. The slab size will be the minimum necessary for accuracy and stability.

Investigations indicate that the soil conditions at candidate heliostat installation sites, that is, Inyokern, California, and Albuquerque, New Mexico, are generally sandy loam with allowable bearing pressure, of 1000 to 2000 psf. These sites are also subject to freezing weather producing shrink-swell conditions. Soil conditions at the Honeywell research site in St. Petersburg, Florida, are generally fine sand and usually test 2000 to 4000 psf soil bearing pressure. The frost line is rather shallow. Hence, the evaluation of foundation influences on heliostat performance during the research experiment must be factored by the differences in soil conditions established from sample taken at proposed plant sites.

It is felt that data taken during the research experiment will enable extrapolating design factors like foundation depth and soil compaction for proposed plant sites.



HELIOSTAT
FOUNDATION - TYPE 3
THE PAD SIZE WILL BE DETERMINED BASED ON
ACCURACY AND STABILITY TESTS



ENGINEERING TEST BED FOUNDATION

Collector Subsystem

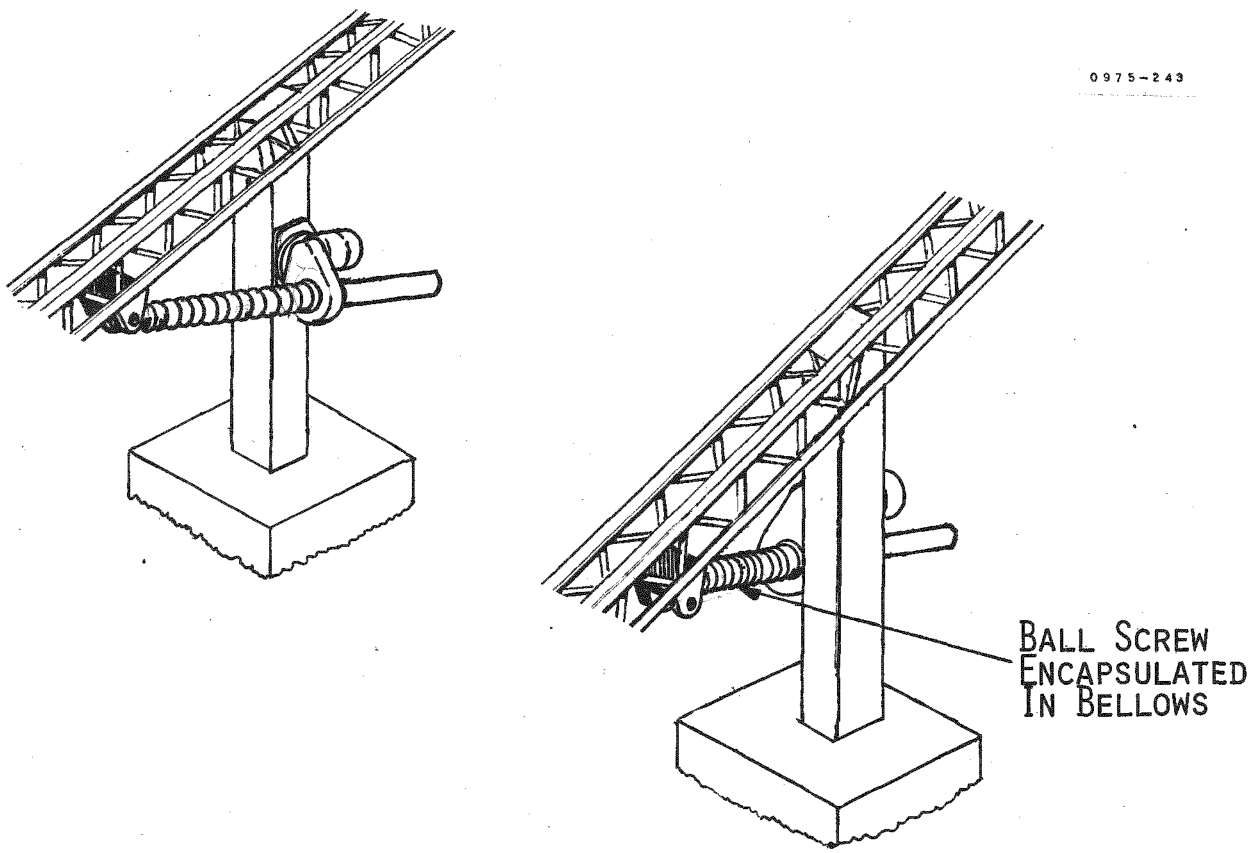
Configuration of Test Item Heliostat

POINTING ACCURACY GOVERNS OUTER GIMBAL DRIVE DESIGNS

Ball bearing screws provide precision gimbal motion as well as torsional stiffness for the frame.

A pair of ball bearing screws with drives will be used to actuate the outer gimbal. The screw itself is pivoted at the frame while the drive unit is pivoted on the post. The ball screw drive units are powered by a motor/reducer combination. Back-lash in the reducer is easily tolerated because of the high reduction ratio ahead of it.

The ball screws will be aligned on each heliostat to optimize torque over the range of operating angles.



OUTER GIMBAL DRIVE
(EXPLODED VIEW)

Collector Subsystem

Configuration of Test Item Heliostat

WEIGHT MINIMIZATION OF OUTER GIMBAL

Bar joist construction and proper gimbal axis selection provide minimum weight and inertial load on drive motors.

The outer gimbal frame utilizes steel bar joist welded into one rigid assembly. The two end cross beams are of box type construction approximately 15 by 18 inches to provide stiffness in both bending modes as well as clearance for the steel support posts. These beams also contain the support bearings located at the center of gravity of the heliostat. The center cross beam is a simple bar joist.

The two side joists which support the mirror modules will be less deep since less stiffness is required in this area. This also reduces inertia of the gimbal.

Overall size of the completed frame is approximately 10 feet by 43 feet by 18 inches deep. This will allow stacking horizontally for shipping by truck or rail.

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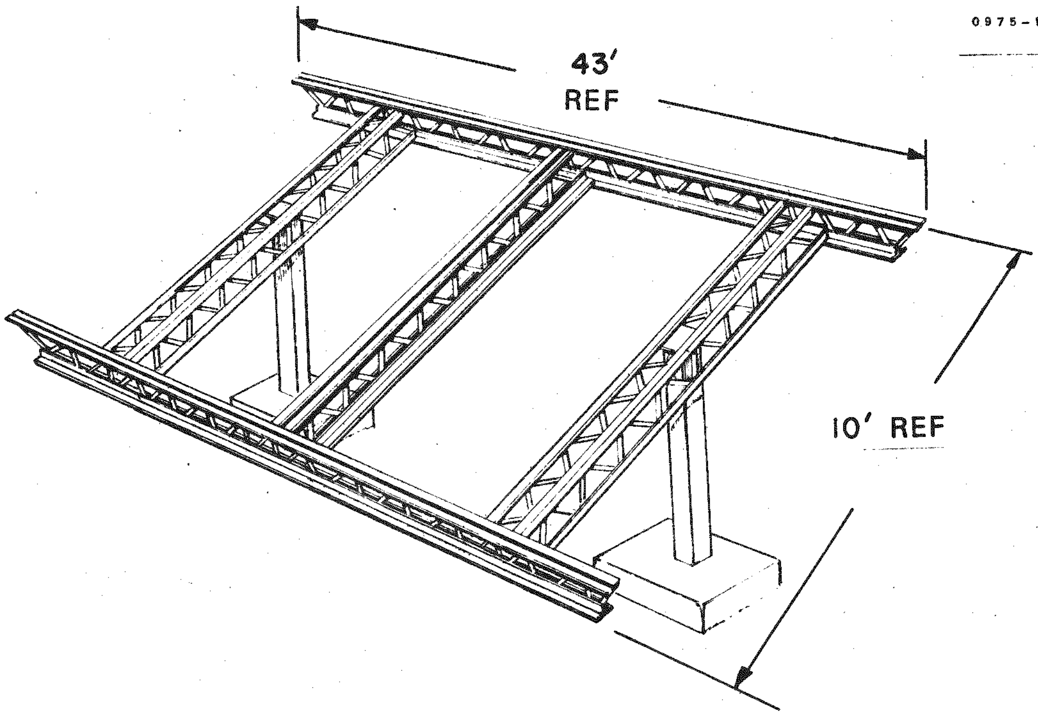
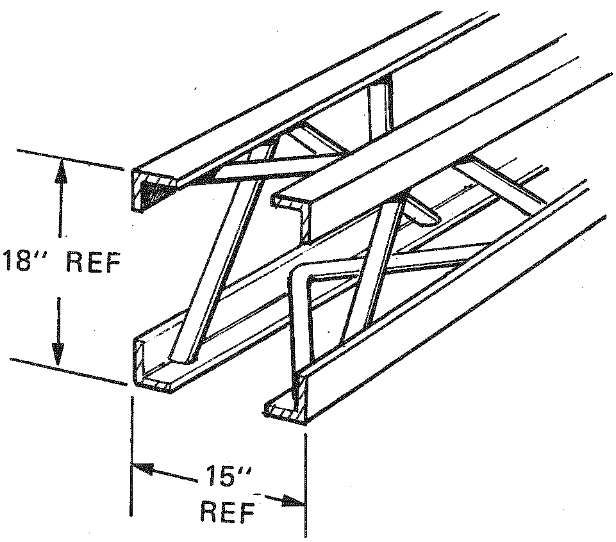




WEIGHT MINIMIZATION OF OUTER GIMBAL

Collector Subsystem

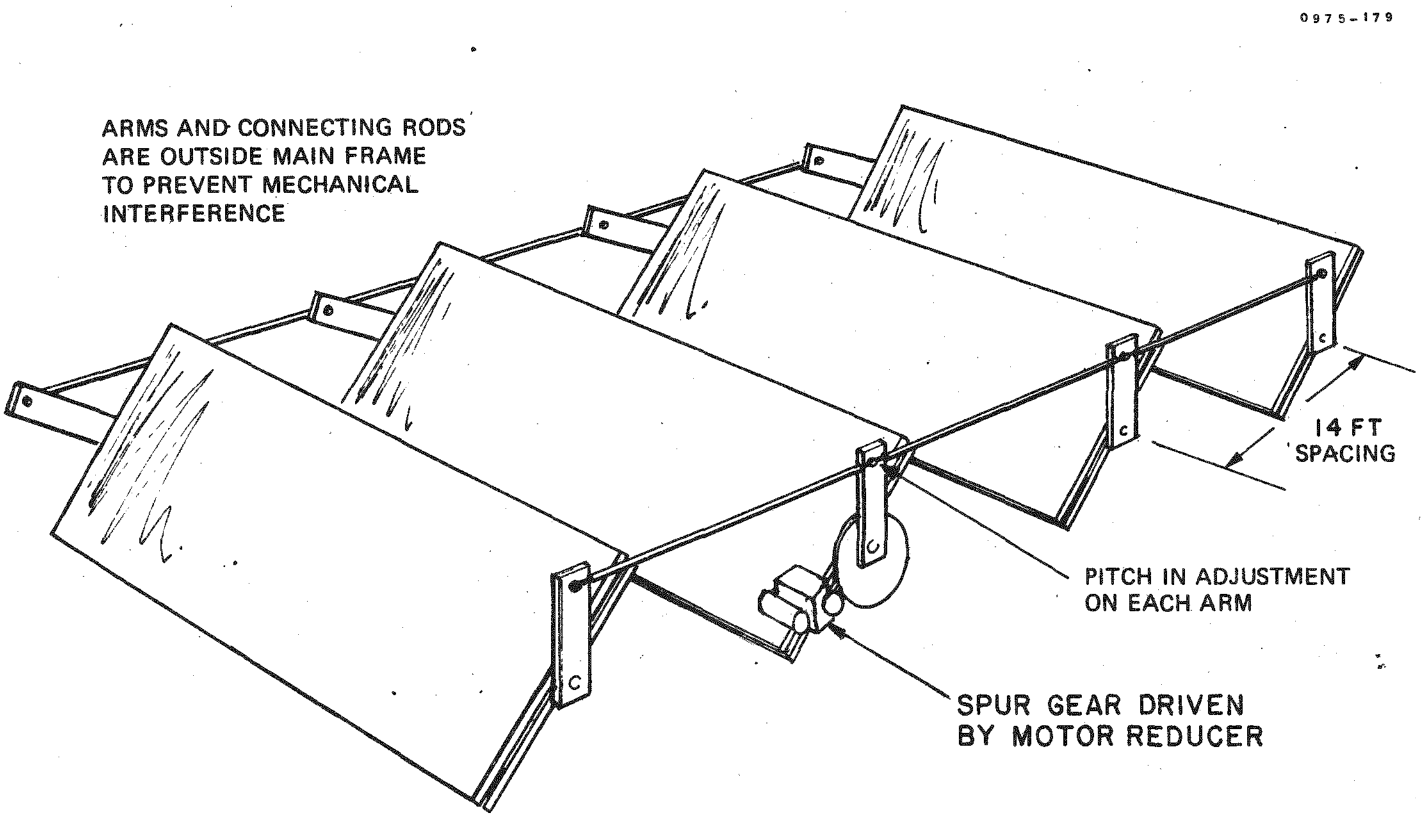
Configuration of Test Item Heliostat

CRANK ARM SELECTED FOR MIRROR MODULE DRIVE

A crank arm drive provides a tight, low inertia system with built-in focusing adjustments.

Drive power is provided to one of the center mirror modules by a sealed stepper motor/reducer through a spur gear drive. Crank arms are used to transmit movement from the driven mirror shaft to the others in the module. The crank arms are connected by the tie rods with ball bearing rod ends for accurate and positive control of mirror angles. The 24-inch long crank arms are set to the optimum angle at the center of its operational range on each heliostat. Turnover capability is obtained with a set of similar arms on the opposite end of the mirror, set at 90 degrees to the main arms.

The rod end/crank arm interface has two adjustment mechanisms; the first controls tie rod length to prevent binding at top dead center; the second provides fine adjustment of the relative angles between mirror modules.



MIRROR MODULE DRIVE SYSTEM

Collector Subsystem

Configuration of Test Item Heliostat

REFLECTANCE AND CONTOUR CONTROL IN THE MIRROR MODULE

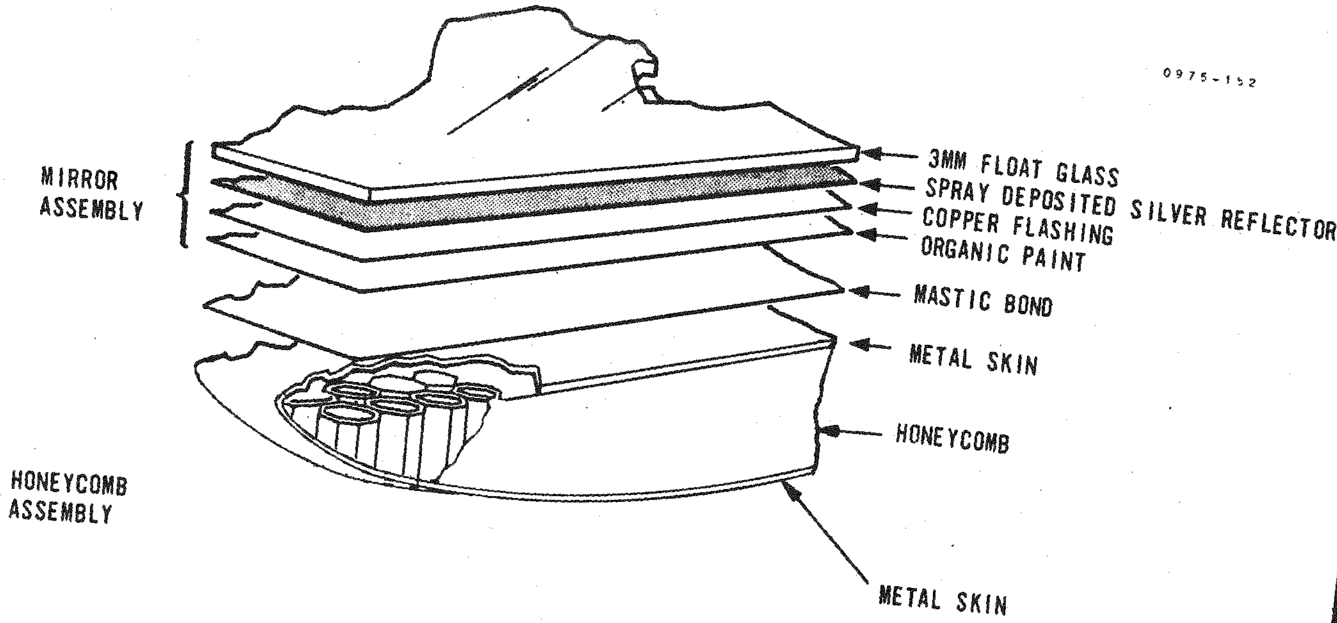
A back surface silvered, commercial float glass mirror bonded to a honeycomb support gives protection for the reflective surface plus high stiffness to weight ratio to control the mirror contour under wind and variable "g" conditions.

The mirror module is actually a complete inner gimbal (1 of 4) with mirrors, support structure and stub shaft axles for interface with the outer gimbal pillow block and mirror module drive.

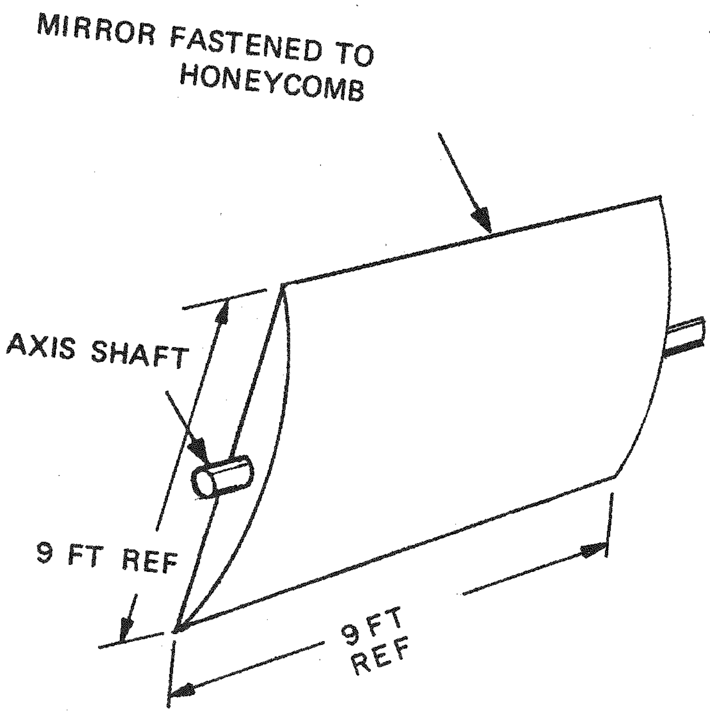
The reflective surface is a 3 mm thick, second surface, float glass mirror bonded to a supporting, honeycomb panel. Each mirror module consists of a 9 x 9 foot panel with four or more bonded mirror segments.

Thermal expansion effects are controlled by adhesive selection to provide shear compliance between the glass mirror and steel skin.

Printing errors are controlled by the torsional stiffness of the prism shaped structure. The same prism also provides bending stiffness to resist mirror contour change under variable "g" loads. The complete mirror module is balanced by placing the stub shafts in line with the center of gravity.



REFLECTIVE SURFACE PROTECTED AND CONTROLLED BY GLASS AND HONEYCOMB



MIRROR MODULE ASSEMBLY

HELIOSTAT INSTALLATION AND ALIGNMENT

Built-in adjustments and optical calibration provide cost effective alternatives to piece part tolerance control.

Pointing and focusing accuracy requirements dictate that heliostat parts and subassemblies be aligned within as little as 0.010 inch. Even if these tolerances could be held on parts like the outer gimbal frame, the stresses seen during shipping would cause some change. A second consideration is the focusing requirement where relative alignment of parts is a function of field location. Interchangeable parts built to commercial tolerances with adjustment mechanisms built in are the key to low cost heliostats.

The individual adjustment mechanisms and their functions are described below.

- Foundation. Vertical adjustments are installed at the top of each support post to accept the stub shafts of the outer gimbal support. Adjustment is by a stiff lightweight tooling bar and level which spans the distance between posts and rests in the gimbal supports.

- Outer Gimbal Assembly. Pillow block supports for each stub shaft have jack screw adjustments to control the parallelism and coplanarity of the mirror module axes and the perpendicularity of the inner and outer gimbal axes. Fixtures set up on a stable concrete slab at the plant site are envisioned for this assembly operation.

- Outer Gimbal Drive. Alignment here is performed at the site. The outer gimbal is set at its nominal tilt angle and a level installed on the end of the mirror module axles and parallel to the outer gimbal axis. The right angle ball screw drives are operated independently until level is obtained, then the drives are locked to the motor/reducer output.

- Mirror Module Drive. The connecting rods have two independent adjustments at each crank arm excluding the drive arm. The first adjusts the length of the rod itself to prevent binding at the top dead center and is completed during assembly of the heliostat at the plant site. After the heliostat is installed on its foundation, the second adjusts the relative alignment between mirror modules by an optical procedure. Taper lock hubs at each crank arm/stub shaft interface for course mirror alignment as well as easy repair and maintenance.

- Mirror Module. Use of a common contour for all mirror modules eliminates need for adjustment here.

- Optical Alignment. Heliostat alignment is completed at the assembly line and at the foundation to the largest extent possible using fixtures, level indicators or other instruments. Final focusing of the complete unit however is best done using feedback from the calibration array. Optical errors are magnified to provide high resolution at the line of sight distances between heliostats and calibration array.

A set of modulated Xenon lamps are located on top of the tower and spaced to simulate collimated light, that is, parallel lines of sight to the four mirror modules. With one light at a time, each mirror module is aligned (and focused if necessary) per calibration array feedback. As each mirror module is aligned, the other three are temporarily shaded. Night time now appears the best for this operation for minimum interference from adjacent heliostats, the best resolution and longest lamp life.

- Electrical Adjustments. The only electrical adjustment required at the heliostat will be that needed to set the address for that particular location in the field. This can be a programmable switch array or a hard wired setting. All other major subassemblies such as the power supply, battery, motor controller electronics, and motors will be identical and interchangeable.

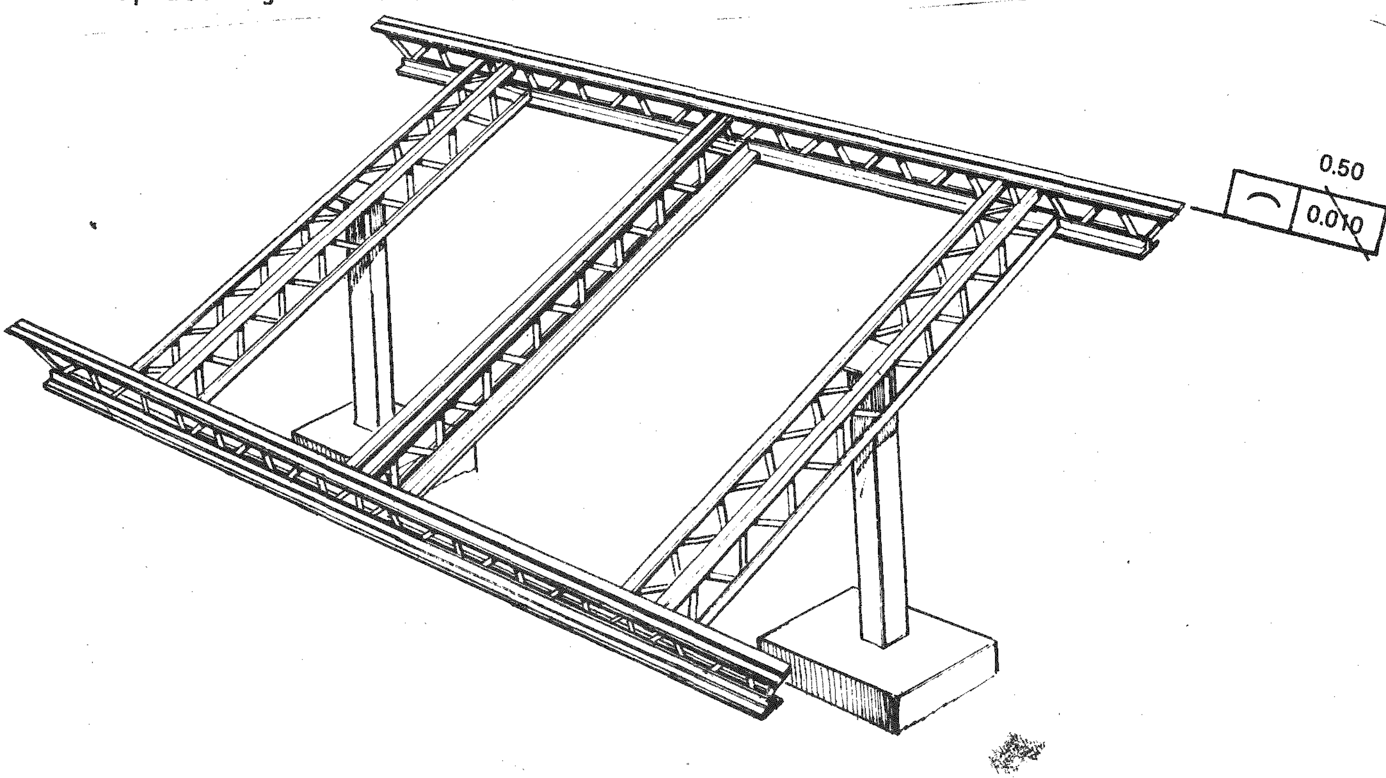
Adjustments:

0975-243

Foundation post height
Mirror module axle parallelism and coplanarity
Nominal outer gimbal tilt angle
Mirror module relative alignment

Fine optical alignment
Set electronics address

Replace tight tolerance control:



Collector Subsystem

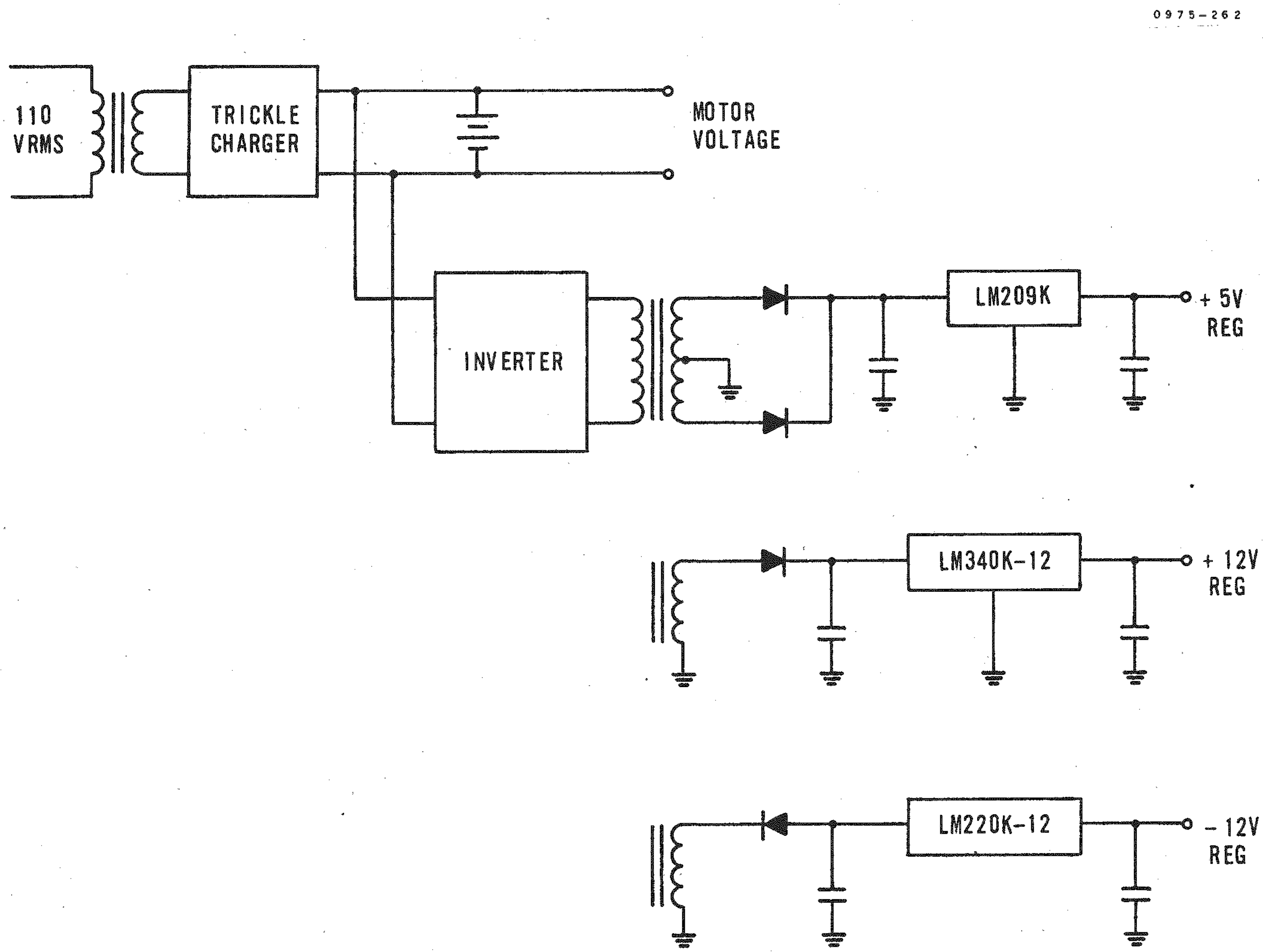
Configuration of Test Item Power and Control System

DISTRIBUTION AND CONVERSION OF POWER

The power distribution system hardware will differ somewhat from that porposed for the pilot plant, but this will not preclude a full evaluation of the concept.

The power distribution and conversion system used in the research experiment is similar to the pilot plant in that 110 volts will be distributed to each heliostat for maintaining charge on the battery there. But it will differ from the pilot plant in that no high voltage feed line will be used to convey power to the field site. This is because the power requirements for a single heliostat are so low that a 110 volt bus can easily and more safely support it and any test equipment that might be required. While it is not felt that there is any technical risk in not exercising this concept difference, a study of high voltage transmission problems will be done and separate experiments conducted if deemed necessary.

The heliostat power supply is shown in the illustration. A sealed battery will be used with several cells in series to achieve the final output voltage. Capacity will be of the order of 6 amp hours. The charger will be of the type which provides a voltage limited constant current source. The regulated voltages are expected to be +5, +12, and -12 volts dc. The regulators will be completely self-contained integrated circuits such as the LM109K for the +5 volt regulator and the LM340K-12 and LM220K-12 for the + and -12 volt retulators, respectively. The power supply prior to use at the field site will receive a full evaluation in the laboratory for such things as line and load regulation, power interrupts, and operation with temperature.



HELIOSTAT POWER SUPPLY

INTRODUCTION TO SYSTEM CONTROL

System control techniques for the research experiment will prove pilot plant system control concepts because the computational algorithms are the same, mode control routines will be similar, calibration techniques will be the same, and I/O routines will be the same.

Central computer control of the research experiment must successfully demonstrate the following concepts:

1. The computation of the line of site vector to the Sun.

2. The computation of the mirror normal vector.

3. The computation of the gimbal commands which point the mirror normal in such a way as to bisect the Sun vector and the receiver line of site vector.

4. Mode control to include normal tracking, offset pointing, calibration and emergency sequencing.

5. Processing of calibration data in a manner which best improves system performance.

6. Input/output of auxiliary data to/from peripheral equipment to support the major functions stated above.

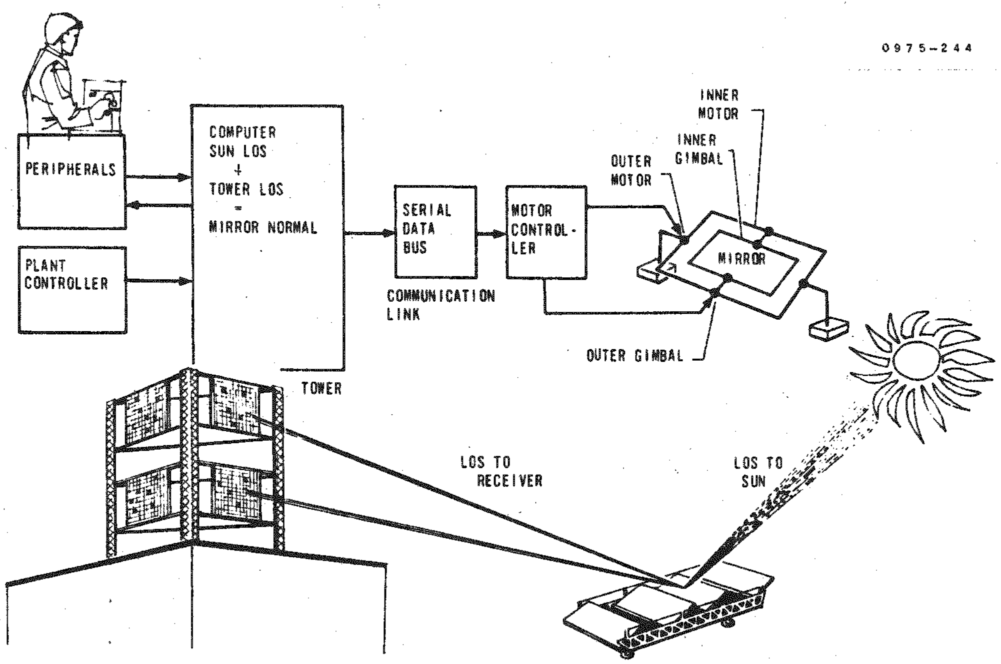
The computational algorithms employed in the research experiment will be the same as those described for the pilot plant. The Sun vector will be computed from the mean orbital elements described in the Nautical Almanac and rotated to an Earth fixed coordinate frame. A refraction correction will be made based on local temperature and pressure conditions.

The mirror normal vector will be computed by adding the Sun unit vector to the computer stored unit target vector, normalizing the vector and then rotating it in azimuth to the radial coordinates of the heliostat. The gimbal commands will be encoded in the control word format and issued via DMA to both real and synthetic heliostats to simulate a pilot plant size field.

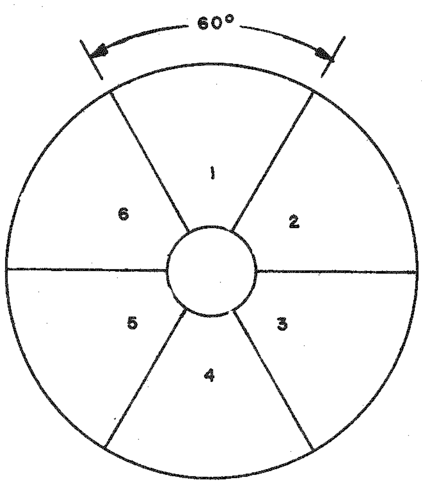
Mode control routines will be developed which will handle those conditions anticipated for the pilot plant. Additional modes will be designed to handle research experiment peculiar conditions so that they may be removed without software impact.

The thrust of the calibration effort will be to define the parameters and techniques for best application to the research experiment and pilot plant calibration concept. The present concept is to project the delta azimuth and delta elevation angles supplied by the calibration array to the receiver simulator array and update the heliostat line of site vector. The calibration array line of site will be computed from the receiver simulator array line of site and the known geometric displacement.

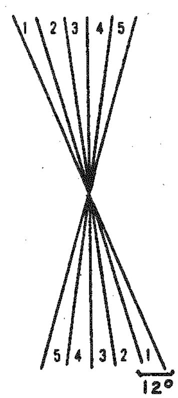
Input/output routines will also be developed which satisfy pilot plant requirements. Additional routines will be devised for the research experiment but they will have the capability of being removed with no software impact. In concept, the research software will be pilot plant software.



A FIELD OF 3000HELIOSTATS



Each Sextant Contains 500 Heliostats



Computer No 1 Controls Sextants 1 and 4 (1000 heliostats)
No 2 Controls Sextants 2 and 5
No 3 Controls Sextants 3 and 6

Each pair of Opposing Sextants is subdivided into 10 opposing sectors of 100 heliostats each

FIGURE 1. HELIOSTAT FIELD SUBDIVISION

FIGURE 2. OCTANT SUBDIVISION

ACCURACY FACTORS IN SUN TRACKING

Accurate sun tracking is best solved by a software approach with precise orbit parameters, knowledge of Greenwich Mean Time, and corrections for atmospheric refraction.

A software approach was chosen for the research experiment sun tracking on the basis of lower cost, higher reliability, a reduced interface requirement and potentially greater accuracy. The only disadvantage of the software concept is the difficulty in predicting refraction corrections at low elevation angles. With appropriate data inputs however, this error source can be eliminated for all practical elevation angles.

Computation of the sun's position in the sky can be accurately done with the computer under any kind of weather conditions. No synthetic tracking requirements are imposed on the heliostats. The mean orbital elements of the sun are given in the American Ephemeris and Nautical Almanac, published yearly, or they may be computed from equations documented in the same publication. See Appendix A-1 for details.

The strategy for obtaining the suns position is to treat the sun as a satellite of the earth. Using Greenwich Mean Time to determine the days and fractions of the day and using the orbital parameters determined from the Almanac, the true anomaly, which describes the position of the sun on the ecliptic, is computed. This value, in vector form is rotated through the argument of perigee (ω) and the mean obliquity of the ecliptic (i) to transform the vector to an inertial coordinate frame; Equatorial, East and Polar. Then, with knowledge of GMT and latitude and longitude of the station, the sun vector can be transformed to an earth fixed local vertical frame; Up, East and North. See Appendix A-2 for details.

The true elevation of the sun in the sky is not the apprent elevation due to atmospheric refraction. This error in elevation is zero when the sun is directly overhead but it is in excess of one-half degree at sunrise and sunset. This error source can be sufficiently compensated for co-altitude angles up to 80 degrees by using the equation

$$R_{\widehat{Sec}} = \frac{206P}{273+T} \tan\text{(co-altitude)}$$

Where T is the local temperature in degrees centigrade, P the local barometric pressure in centimeters of mercury, and R is the refraction correction in arc seconds. See Appendix A-3.

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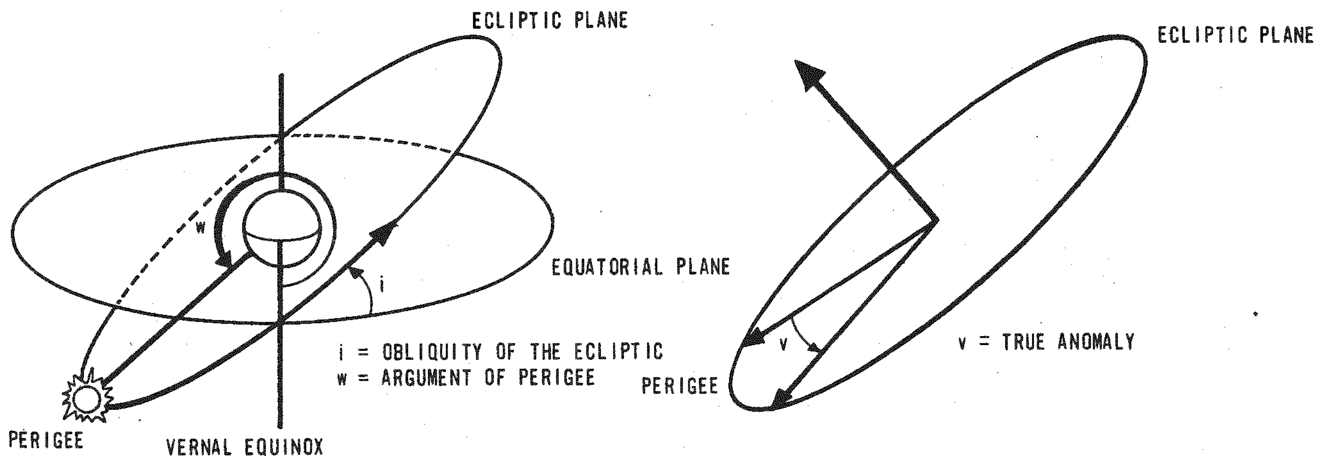
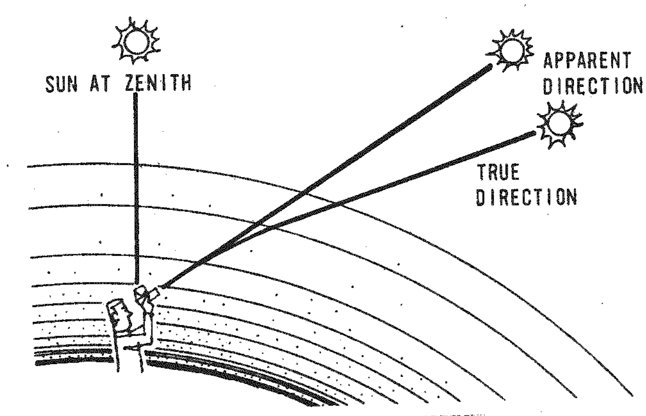




ATMOSPHERIC REFRACTION INCREASES THE SUN'S ALTITUDE

FUNDAMENTALS OF HELIOSTAT CONTROL

Heliostat command and control requires computer summations of all commands given and an accurate reference starting point.

The heliostats are to be driven by stepper motors, in an open loop discrete fashion. Normal tracking rates for the tilt/tilt configuration will not exceed 23°/hour. This criteria is satisfied with the planned one command per second rate of 40°/hour. An additional slew rate of 1080°/hour will also be available for calibration and emergency conditions.

The mirror normal vector will be found by adding the sun LOS unit vector(s) to the receiver LOS unit vector (T). This vector will then be normalized and rotated in azimuth to the radial coordinates of the heliostat. The outer and inner gimbal commands will then be extracted from the resultant vector (R) using the arctangent subroutine.

Since the system is open loop, the computer must keep track of the gimbal angle positions of each heliostat by integrating all the commands sent out. The control law is then simply the commanded angle minus the actual angle. The resultant delta angle is then evaluated to determine which control bits are to be set in the control word for that particular heliostat. This control word and the heliostat address are then stored in an output DMA table. The same delta angle is then used to update the actual angle stored in the computer. This process is then repeated for both gimbal angles on all heliostats within the sector. When this is completed, the DMA output is initiated and the computer begins the same computations for the next sector.

If control is ever lost on any heliostat, the initialize bit is set and the heliostat control electronics drive the heliostat to a known reference position. Once there, recovery operations can begin.

Control can be lost in several different ways. One way is the loss of power to the heliostat control electronics. The battery system will hold up heliostat operation for some period of time but it will then, of its own, proceed to the stowage position. The computer will be aware of this by loss of receiver signals or failure to receive calibrate signals. A second way to lose control is to lose the communication link. The heliostat responds in the same manner to this type failure, and again the computer is aware of the condition by failure to calibrate. A third type of control loss is the failure to receive calibration signal after slewing to the calibration array. In this case we assume an intermittent loss of either power or communications which caused a loss of pulses to the motors. The strategy in all three cases is to command initialization and then try calibration again. If calibration fails a second time, the heliostat would be flagged as a failure and commanded to the stow position in the usual vector control fashion. Of course, it may not get there exactly depending on the nature of the error but it should be in a sufficiently safe position. If calibration is successful, the heliostat would be returned to service on the receiver.

TILT/TILT CONFIGURATION
RADIAL LAYOUT
UEN FRAME

0975-153

1. $\overline{N} = \overline{S} + \overline{T} / |\overline{S} + \overline{T}|$

2. $\overline{R} = [AZ]\ \overline{N}$

3. OUTER COMMAND = ARCTAN – $R_3/\sqrt{R_1^{\,2} + R_2^{\,2}}$

4. INNER COMMAND = ARCTAN R_2/R_1

5. FORM Θ COMMANDED – Θ ACTUAL

6. CONSTRUCT HELIOSTAT CONTROL WORD AND STORE IN DMA OUTPUT ARRAY

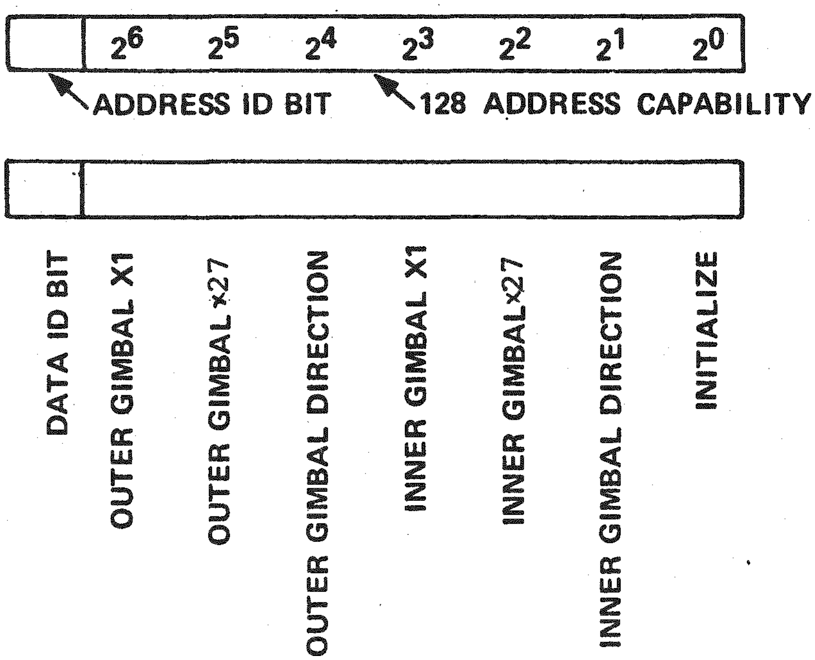
7. UPDATE Θ ACTUAL IN COMPUTER

8. REPEAT 5–7 FOR SECOND AXIS

9. REPEAT 1–8 FOR ALL HELIOSTATS IN SECTOR

10. OUTPUT DMA TABLE

11. CONTROL WORD FORMAT



COMMAND AND CONTROL

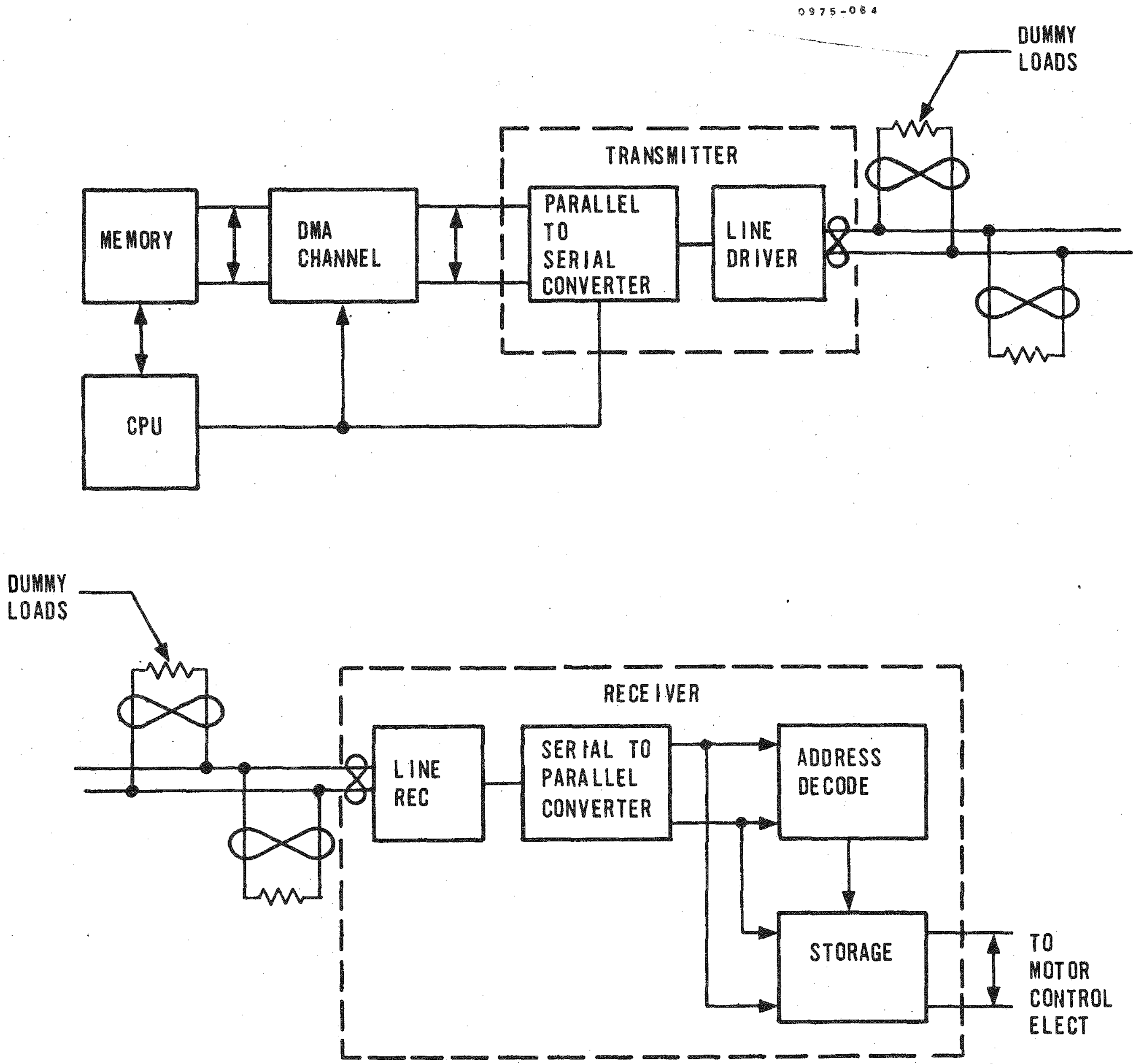
SERIAL DATA BUS PROVIDES HELIOSTAT COMMUNICATIONS

Though the serial data bus will not have a full complement of 100 heliostats to communicate with, distributed dummy loads will allow a complete evaluation of the concept.

As in the Pilot Plant concept, the serial data bus will consist of a transmitter, a bus line, and a receiver which interfaces the computer with the motor controller electronics. The operation of the hardware in the Research Experiment will be identical to that used for the Pilot Plant. A big difference however is in the number of heliostats along the line which greatly affects the transmission line characteristics. At the Pilot Plant level there will be 100 heliostats per line compared to only one to three at the experiment level. To account for the difference, a full length line will be fabricated with a full complement of dummy loads simulating heliostat terminations distributed along the line at the proper distance intervals. Data can then be taken anywhere along the line under conditions equivalent to a fully loaded line.

Some equipment used in the serial data bus mechanization will be leased for the Research Experiment in order to save time and money in the evaluation phase. A piece of equipment called a GLOBAL manufactured by Schulz Instruments of Gainesville, Florida was designed specifically to communicate over a single line to randomly spaced peripherals with interface to several mini-processors, including the H-716 computer. It will accept 16 bit data in parallel form from the 716 memory via its DMA channels, format it with start, stop, and parity bits and clock it out in serial fashion on a line. This is exactly the way it is intended to be done at the Pilot Plant level. The same company also makes a piece of equipment which performs the same function as our receiver at the heliostat end of the bus line.

This test philosophy proves the transmission concepts to the heliostat field. Selecting the GLOBAL as the I/O allows developing and proving communication concepts that are not dedicated to a single processor. The choice of Pilot Plant processor can be made later and still be compatible with the GLOBAL.



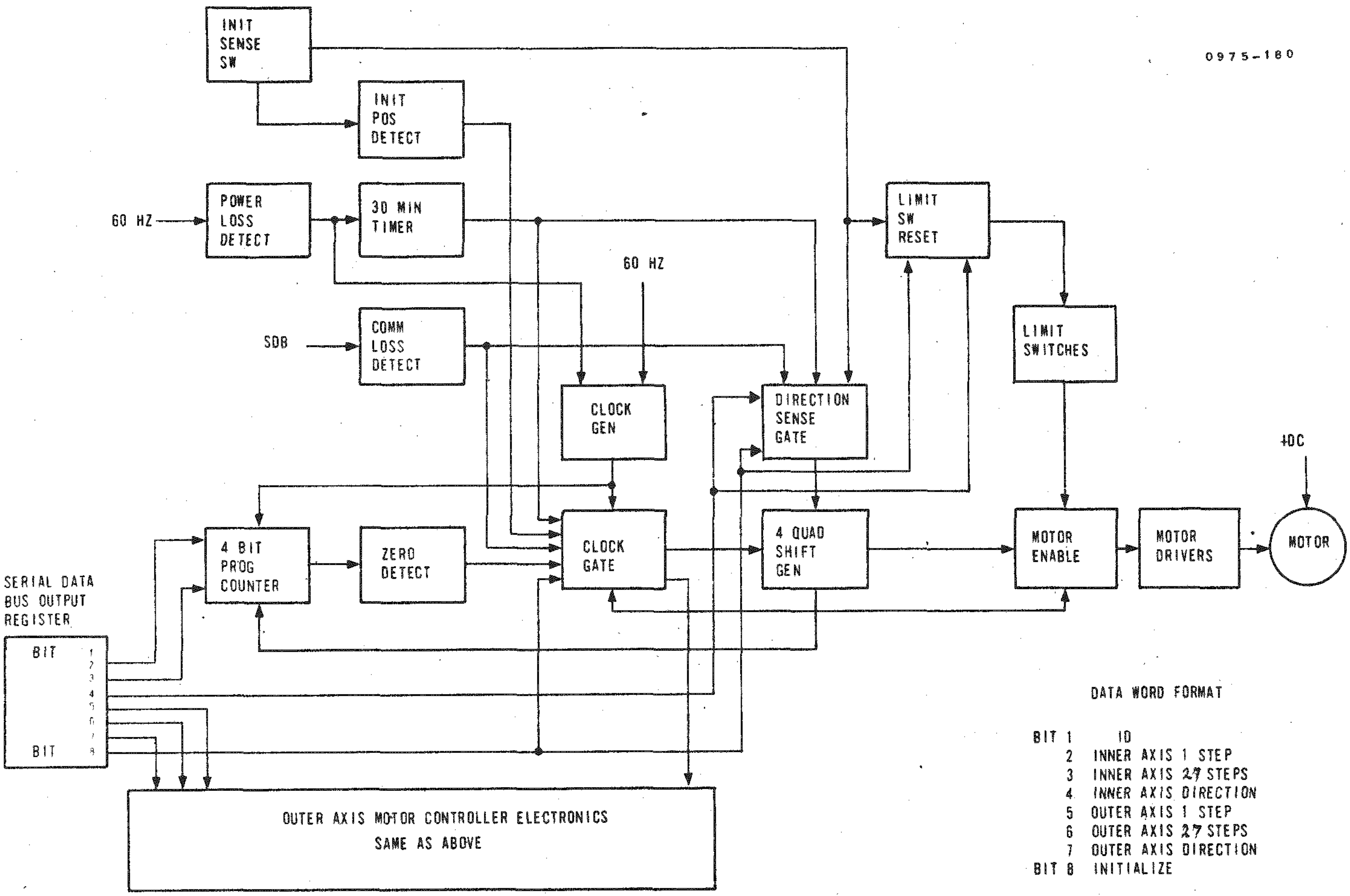
SERIAL DATA BUS

MOTOR CONTROLLER FOR GIMBAL DRIVES

The Motor Controller meters out the motor pulses under processor control and has the capability to protect the heliostat and the tower in the event of an emergency such as a communications or power loss.

A Block Diagram of the Motor Controller Electronics is shown in the illustration. The operation of the Motor Controller centers around the clock gate which when open allows the motor to drive. Several sources control the opening and closing of the clock gate. Normal tracking operation is from a programmable counter which meters out the commands of the computer. In the initialization mode the gate is controlled by the initialization position detector which drives until that position is reached. In an emergency situation such as a loss of communications for a specified time period, probably 10 to 15 seconds, or a loss of ac power for 30 minutes or more, detectors on the power lines and data links will open the gate allowing the gimbals to drive to their ultimate stops which will be set at the stow position. At this point limit switches will disable the drive. To reset the limit switches in order to return to an operational mode will require a unique command and a direction drive sense that will only allow drive from the stop. Loss of ac power is by itself not cause for immediate return to the stow position since the battery can carry the load for up to one hour or more of normal operation. For all of the above modes direction sense will be interlocked with the operating mode so that proper motor direction drive will be adminstered for any operating condition. Therefore even without direct computer command or power to the field the heliostat can sense an emergency and depending on the situation:

- Remove the concentrated energy from the tower to prevent catastrophic loss of the tower,
- Stow itself to provide protection from storm damage and,
- Keep from tearing itself apart because of a manfunctioning electronics assembly by means of limit switches.



MOTOR CONTROLLER ELECTRONICS

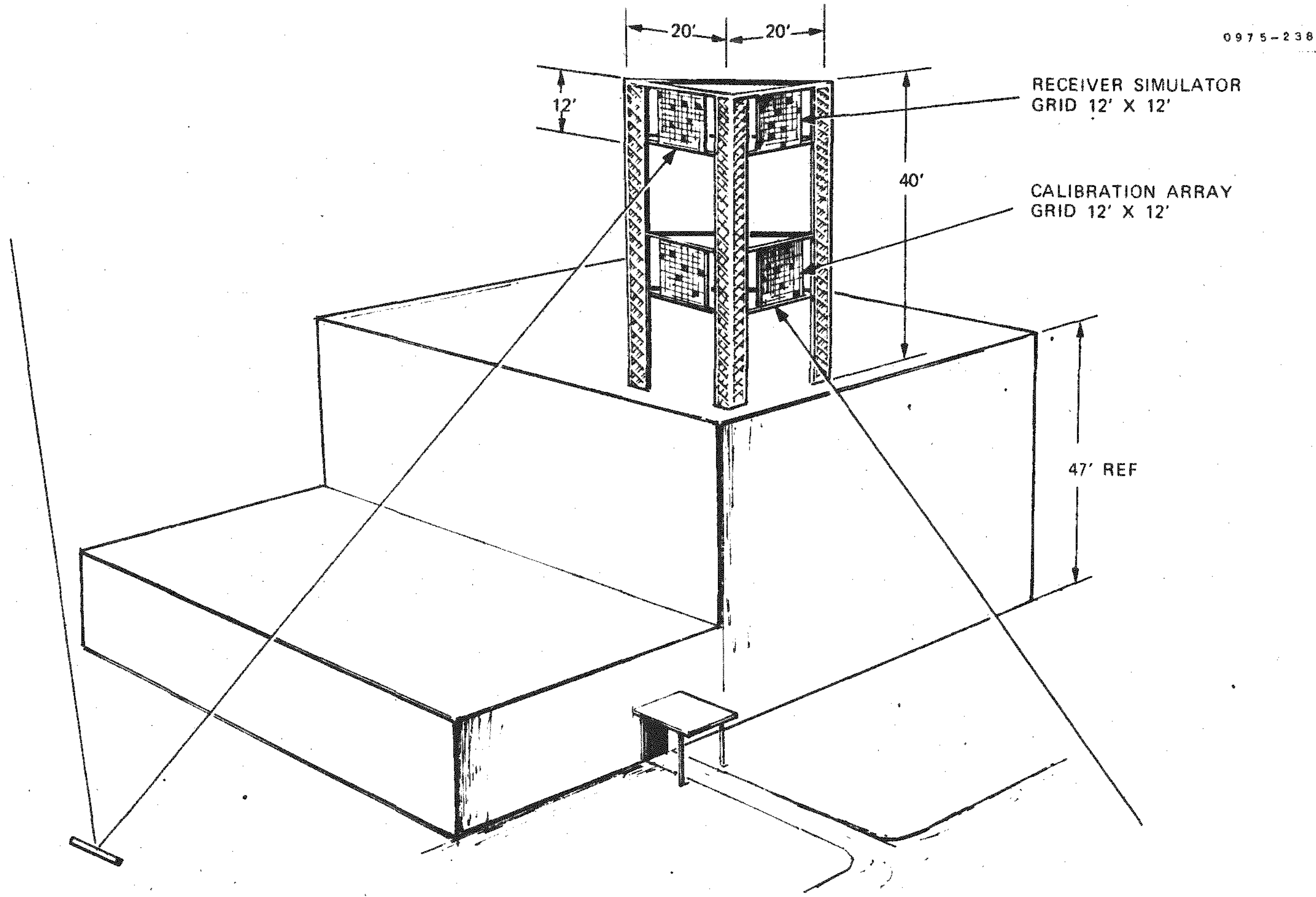
Collector Subsystem

Configuration of Test Item Power and Control System

EFFECTIVE HELIOSTAT CALIBRATION

Effective heliostat calibration can be demonstrated by a single heliostat with a bank of lamps to simulate the effects of dispersion and pointing inaccuracies of the full complement of heliostats required for the Pilot Plant.

At the Pilot Plant level, the large number of heliostats needed to generate the required output power will also generate unwanted signals on the calibration array by means of mirror dispersion about the exit angle of the redirected rays and variations in mirror pointing accuracies. These signals will tend to mark the signal of the heliostat under calibration. Background levels of 0.2 suns from general background reflections are expected with an additional TBD sun due to the dispersion effects of 3000 heliostats facing the array and TBD suns due to pointing inaccuracies for a background total of TBD suns. Since the $30m^2$ mirror area collects energy and focuses to a spot of approximately 6.2 to 12 m^2 depending on the position in the field, a signal power gain results which is the ratio of the areas which would range from 2.5/1 to 4.5/1. The expected signal to noise ratio is then 2.5/TBD or TBD to 1. To simulate this background, banks of lamps will be focused on the array during a calibration so as to demonstrate the ability of the hardware to extract the required calibration signal. Variable filters or power levels of the lamps will adjust the background level to simulate the ability of the equipment to extract the proper information for various signal to background levels.



CALIBRATION ARRAY MOUNTED ON E-2 BUILDING

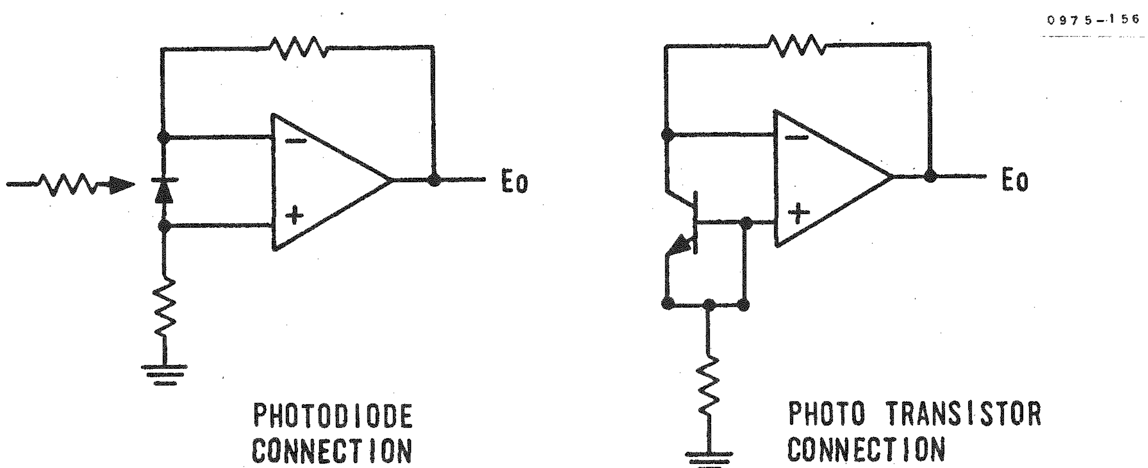


PHOTO DETECTORS

EMERGENCY DEFOCUS FOR BOILER PROTECTION

Emergency Defocus can be evaluated by measuring and verifying adequate gimbal slew rates.

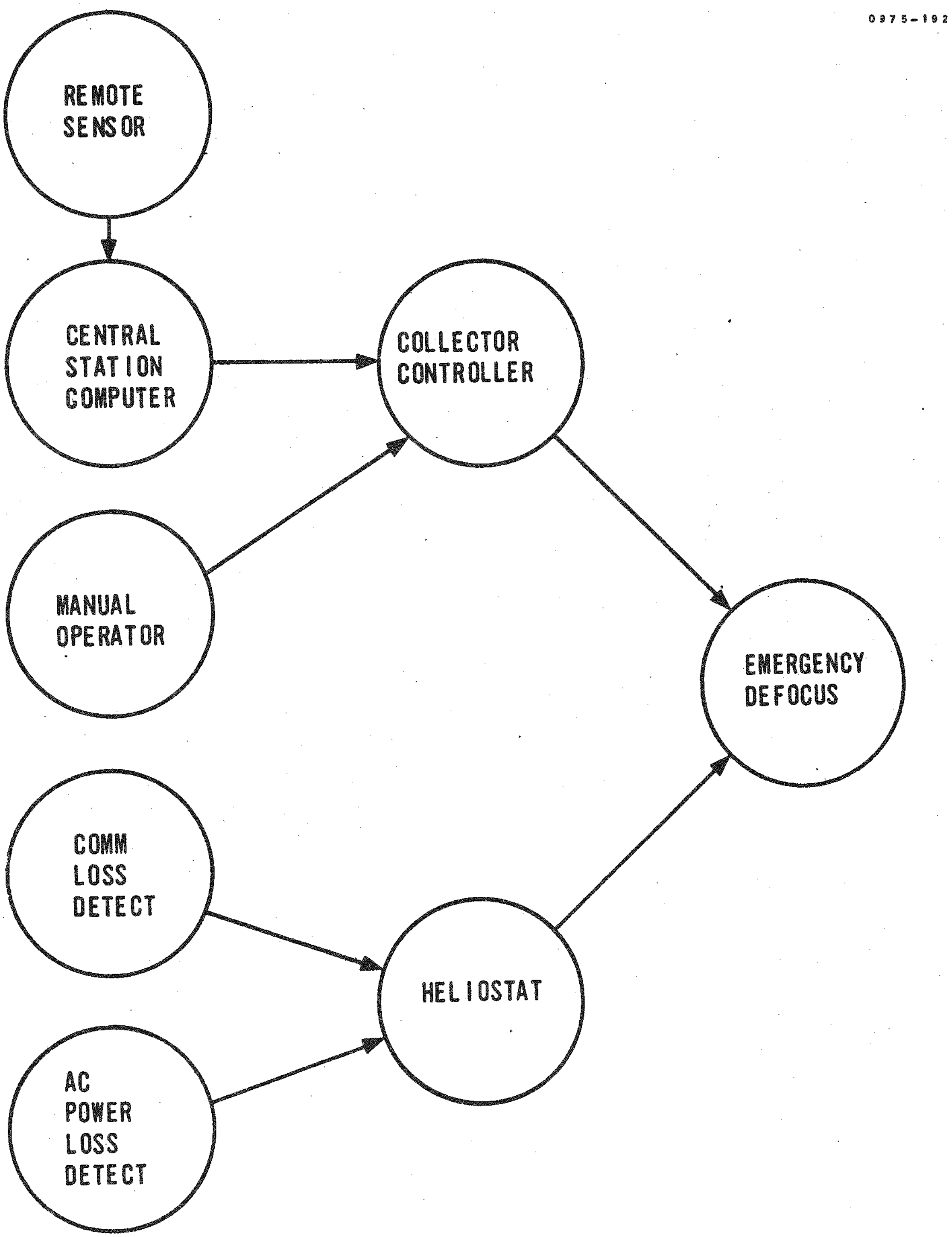
Emergency defocus is defined as the removal of the redirected Sun's energy from the tower in a specified period of time. This maneuver can be accomplished by the computer through the normal communications link or by the heliostat in the event of a communications or extended ac power failure.

In the computer controlled mode, any number of inputs could initiate emergency defocus, such as inputs from the central station computer, a remote sensor, or a station operator. In the event of such an input, the computer would command the heliostats to repoint the Sun's energy to a predetermined spot above the tower, where it would continue to track until otherwise directed. In the event of a communications loss or loss of ac power to the field, individual sensor circuits on each heliostat will detect these conditions and return the heliostat to the stow position which automatically performs the defocus function.

While several operations are involved in order to perform these various maneuvers, the key element associated with emergency defocus is the time it takes to remove the redirected Sun's energy from the tower. This can best be evaluated by which will be done as part of the research experiment measurement of the gimbal slew rates. This can then be applied to any heliostat in the field to determine individual defocus times.

Under computer control, defocus time is expected to be 10 seconds for the worst position in the field. Under heliostat control defocus time is expected to be 3 seconds not including the time required to define the emergency condition.

All aspects of the emergency defocus feature will be evaluated. This includes not only the minimum and maximum reaction times, but also the effectiveness and the detection features. The local detection features are loss of communication and loss of ac power. The central detection features are various inputs to the processor simulating power plant conditions.



EMERGENCY FOCUS FLOW

CONTROL SYSTEM OPERATION VIA SOFTWARE

System software for the research experiment will look exactly like pilot plant software and will operate on the Honeywell Model 716 computer.

The research experiment software will be designed and coded to look exactly like pilot plant software. It must function exactly like pilot plant software in order to prove that timing allocations are adequate. It must also validate all of the pilot plant concepts of calibration and control. Therefore, even though only three heliostates are planned for the research experiment, 997 other ficticious heliostats will be controlled and calibrated and command pulses to these heliostats will be evaluated for proper content.

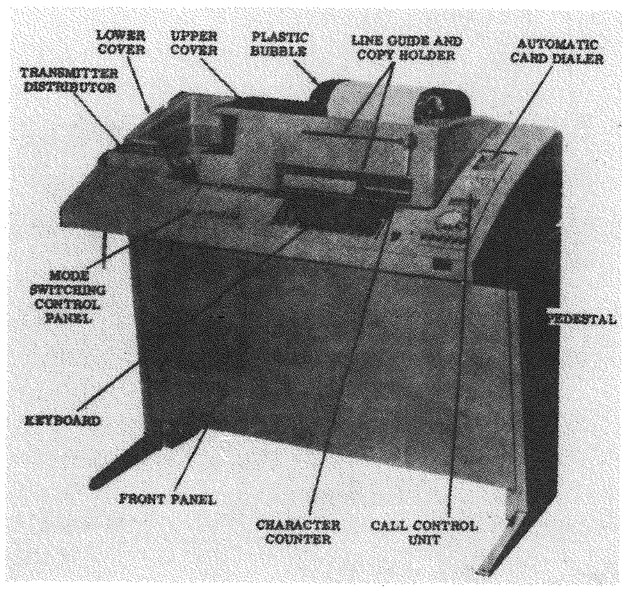
A real time computational mode will be used to integrate Sun tracking and heliostat command and control with a fixed time base synchronized to Greenwich Mean Time. A 20 Hz real time interrupt will be subdivided into twenty 50 millisecond time blocks. Two of these blocks will be used to compute the Sun vector and the refraction correction and ten other blocks will be used to compute the commands to the heliostat normal. This requires the vector addition of the Sun LOS and the heliostat LOS, the extraction of two arctangents and the construction of the heliostat control word. The control word and the heliostat address is then assembled into a consecutive memory array suitable for DMA output techniques. Meteorology data will also be input at a one hertz frequency rate so that digital filtering techniques may be employed to smooth the raw data.

Operator inputs will be accepted in the same manner as described for the pilot plant but additional modes will be added to facilitate data collection, storage and retrieval functions. Plant controller inputs will be simulated.

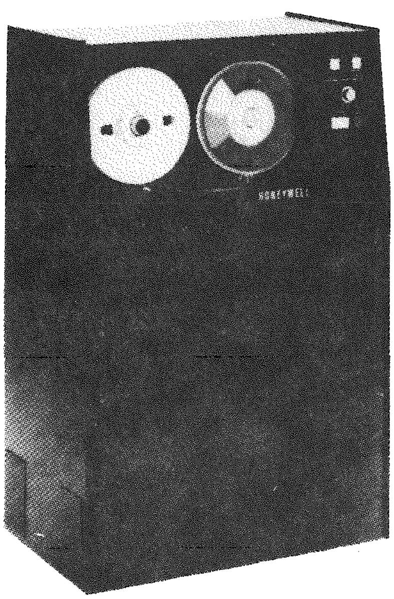
Software routines will also be developed which will statistically evaluate Sun tracking performance, calibration coefficients and pointing accuracy. Also, routines which correlate these factors with local weather conditions and with structural temperature and strain sensors are highly desirable. This type of data is voluminous in nature since it is describing an on-going continuous process. Computer listings of such data are difficult to read and even more difficult to correlate with other data. Computer recording, reduction, and plotting of such data will permit data evaluation on a timely, efficient basis. The recording routines will permit old data to be re-evaluated with different criteria determined at a later time. Another important advantage gained from recording actual data is the ability to replay that data using different experimental concepts in a high speed non-real time mode. This allows concept changes to be evaluated quickly and efficiently, at night or in inclement weather.

The computer chosen for the research experiment task is the Honeywell Model 716. This computer is a sixteen bit machine having an extensive instruction repertoire including half word and double precision capability. It has 32K of memory and up to 64 DMA channels available for communication with peripheral equipment. Add time and multiply time are 1.6 and 4.05 microseconds, respectively. Arc-tangent and square root functions are done with software. A two input arc-tangent routine with a 360 degree resultant angle output requires 100 microseconds for the worst case angle. The square root routine accepts a double precision argument and outputs a single precision result in 130 microseconds. It forms its own initial guess and completes three iterative passes to formulate the root. On the basis of instruction content, instruction speed, memory capacity and DMA capability, the H-716 computer is an ideal candidate for this task. The other candidates, the H-516 and the H-316, do not have sufficient speed or DMA capability for the task.

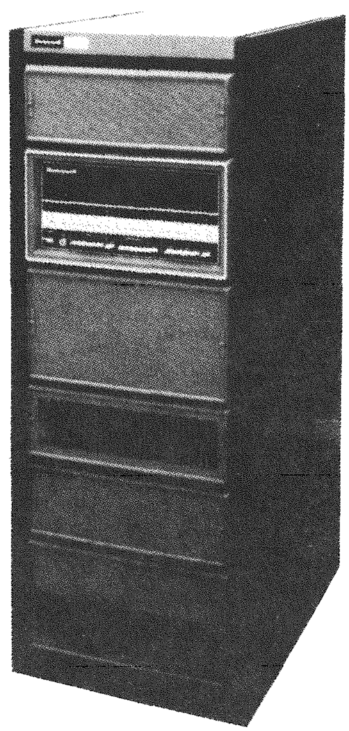
An additional software advantage in selecting the H-716 is its compatibility with our Software Development Facility. This permits software development to efficiently begin before the purchased 716 arrives. The SDF of course has a full complement of peripherals and support software.



ASR-35



TAPE DECK



H-716

MULTIPORT INPUT/OUTPUT SERVICES HELIOSTATS AND PERIPHERALS

The research experiment equipment will prove pilot plant concepts by using compatible processor I/O, operator control via teletype keyboard, and full field size output communication.

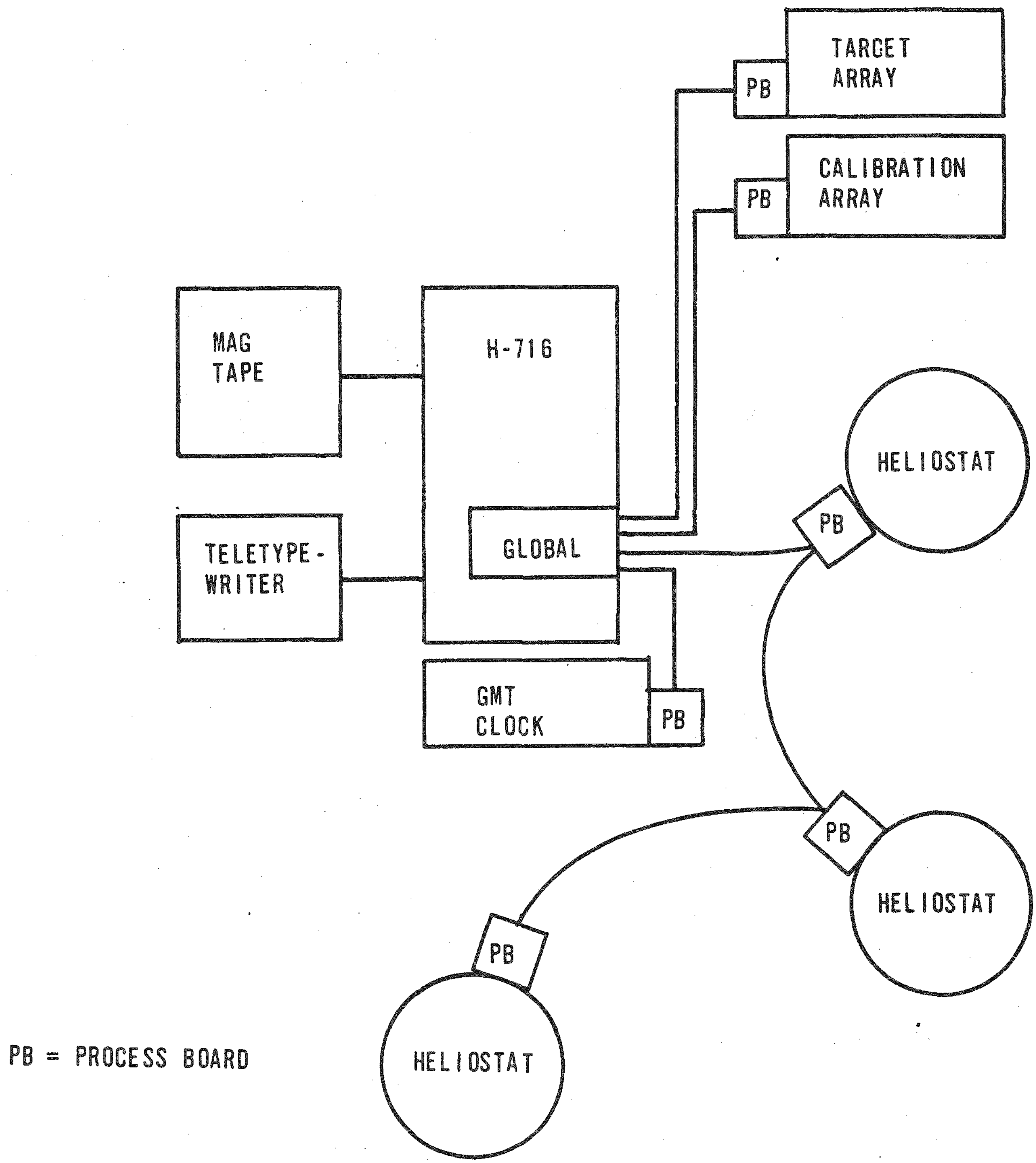
The 716 Global built by Schultz Instruments has been selected for the 716/heliostat interface. The Global is a highly flexible communications interface designed to be compatible with several mini-processors, including the Honeywell 716 computer. The Global uses direct memory access (DMA) techniques to transfer data, thereby allowing the software to work with blocks of data rather than individual characters. Each channel can be individually configured under software control for character size, parity, stop bits and baud rates. The exact end-of-file conditions are also under software control and independently set for direction and channel.

Physically the Global is a single self-contained board for each four communication lines. Each line can service up to 128 heliostats. The Global board plugs directly into the 716 backplane. In short, the Global has been designed to maximize communications throughput while minimizing software, installation and maintenance overhead. The Global is reliably being used in several other commercial applications now where similar data transfers are required.

An ASR-35 teletypewriter has been selected for the printer/keyboard requirement. The keyboard will be used for operator inputs to the system to command various modes and displays. The printer will be used to display current status and reduced statistical data on heliostat performance. The ASR-35 is a low cost teletypewriter device with many years of reliability history.

A magnetic tape unit will be used to develop and load programs and to record data obtained in the research experiment. Of course such recorded data can be retrieved for post-test data reduction and analysis. A standard Honeywell magnetic tape drive will be used for this purpose.

A Greenwich Mean Time Clock is also required. An always accurate digital clock based upon the monitoring of the time code provided by WWVB in Boulder, Colorado, will be purchased or designed. A clock based on this time code information would always be accurate as no counters are involved and the data would always correct itself after a power failure. This clock will provide a BCD output giving days, hours, minutes and seconds suitable for computer interrogation.



RESEARCH EXPERIMENT SIGNAL INTERFACES

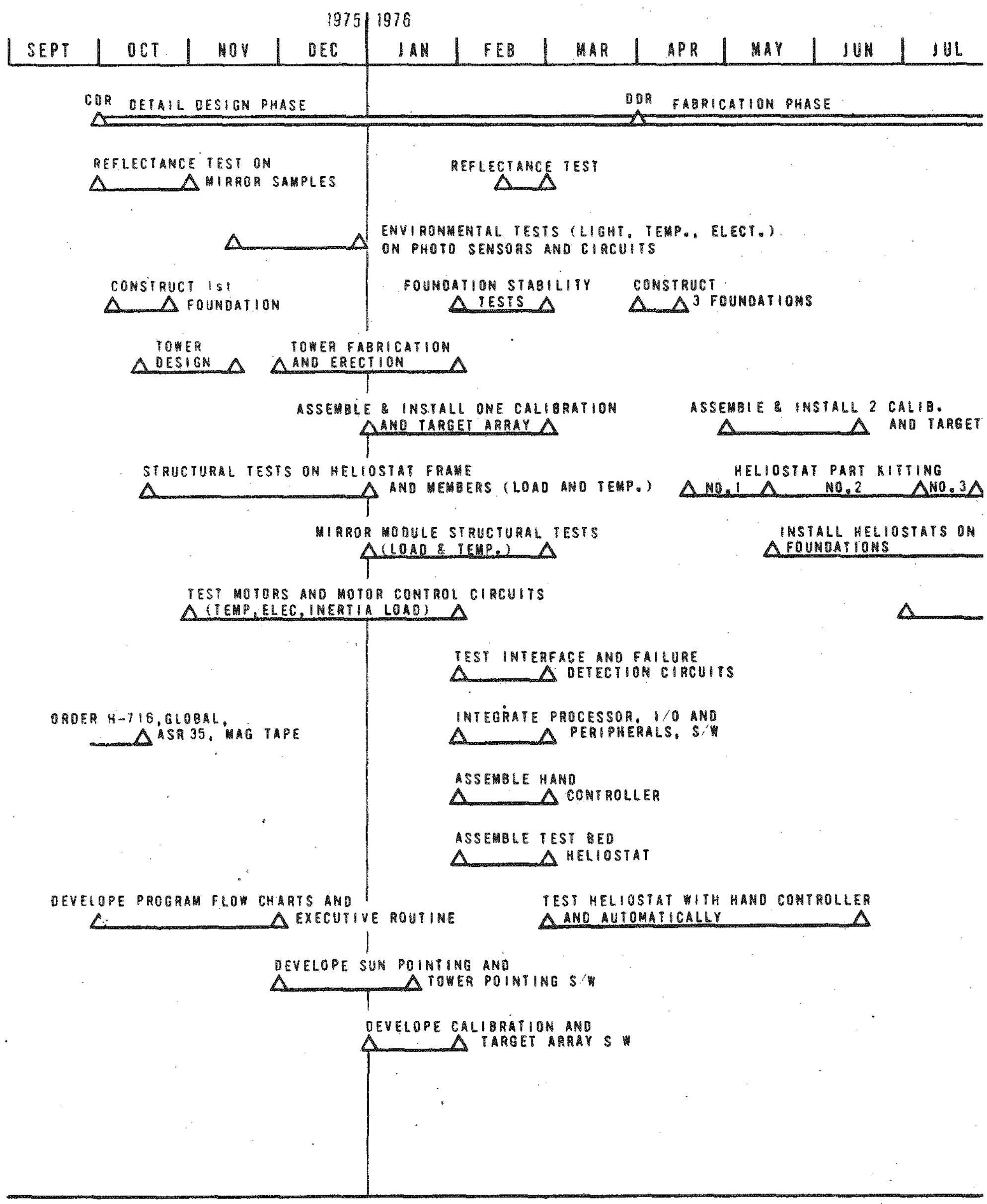
Collector Subsystem

Definition of the Experiment

SCHEDULE FOR DESIGN SUPPORT TESTS, INTEGRATION TESTS, AND SUBSYSTEM TESTS

The schedule for design support tests includes important subassembly mechanical and electrical tests to give confidence in the detail design results.

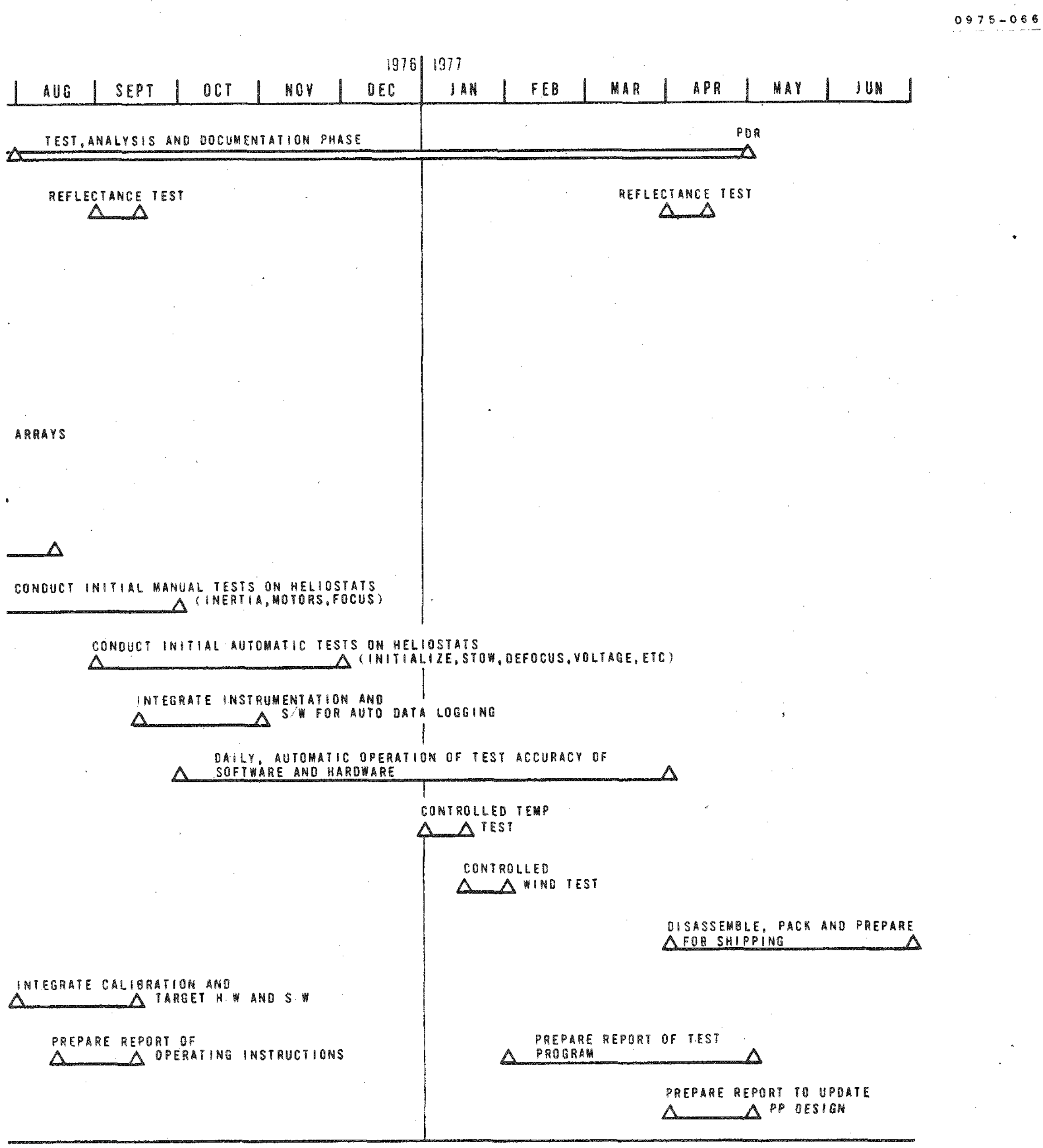
The tests during the detail design phase are important to support the design analysis. Structural tests of the heliostat frame and its members include load and deflection to confirm the stability as a support for the mirror modules. It will be necessary to construct and stabilize the first foundation and supports for these frame tests.



Mirror samples will be placed outside for natural environment exposure and periodically tested for reflectance properties. The tower will be erected initially to be a target for the engineering test bed heliostat and the quarter scale model heliostat.

The processor and peripherals will be ordered in October and received in February. This is satisfactory because the Honeywell Software Development Facility will be used until the leased equipment arrives.

The early test program will give high confidence in the design by the end of 1975 and will be proven on the engineering test bed heliostat by the time of DDR.



Collector Subsystem

Definition of the Experiment

PLAN FOR RESEARCH EXPERIMENT TESTS

Testing will be accomplished on the grounds of Honeywell's Aero-Florida facility. The heliostats shall be placed to represent near, mid and far field heliostats located in three different quatrants. Communications lines to these test heliostats will be loaded at intervals to simulate the full heliostat field. Target and Calibration arrays will be provided to actively test pointing and tracking capabilities.

Engineering tests will be conducted on live full scale heliostats. Static and dynamic loading of the foundation and structure will be done to test the stability, strength and the ability of the drive system to handle the additional loads due to wind or ice. Each heliostat will be monitored by wind speed and direction sensors. This information coupled with the additional weather instruments will provide a weather profile for use in the analysis of operational data. The operational data will be gathered by the 716 computer continually when the heliostats are in operation. Automatic tests will be augmented by manual tests in those areas which do not lend themselves to automation. These tests may include field power consumption, structure member temperatures, measurement of twisting and bending, reflectivity and insolation measurements, measurements of torquing scale factors and linearity, and measurements of focusing stability. Provisions will be made to interrupt or introduce transients to the field power to test the capability of the heliostat to recover and/or to cover up. Emergency conditions will be simulated to test the defocusing abilities of the heliostat. During the time of the engineering field test there will be an opportunity to verify that emergency, maintenance, calibration and operational procedures are adequate.

Environmental testing at the system level will be accomplished utilizing the natural Florida environment. This environment will be further augmented by the application of additional heat and wind to subject the heliostat to these upper level values. The cold temperature data will be extrapolated from the operational data gathered over the period of the research experiment.

The use of the computer will allow large amounts of data to be stored on tape for display or printing or hard copy. All the day-to-day data logging will be handled in this manner. Manual test data will be compiled in dedicated data books logged out to the research experiment test team and controlled by the Test Manager.

It is on the review of day-to-day and manual test data, plus the physical examination of the structure, drive assemblies and mirrors after the extended period of the research experiment, that final recommendations shall be based.

TEST PLAN

0975-268

MAJOR TEST AREAS	PARAMETERS	DATA LOGGING
FOUNDATION TESTS	STABILITY, LOADING, SETTLING	MANUAL
STRUCTURE TESTS	STABILITY, LOADING, BEND, TWIST	MANUAL
MIRROR TESTS	REFLECTIVITY, CLEANLINESS, DUST	MANUAL/AUTO
DRIVE SYSTEM	CAPABILITY, LOAD, SMOOTHNESS, REPEATABILITY	MANUAL/AUTO
DRIVE SCALE FACTORS	SCALE FACTOR AND LINEARITY	MANUAL/AUTO
TRACKING AND POINTING	ACCURACY, REPEATABILITY	MANUAL/AUTO
FOCUS STABILITY	LONG TERM STABILITY	MANUAL/AUTO
EMERGENCY CONDITIONS	COVER UP, SHUT DOWN, RECOVERY	MANUAL/AUTO
FIELD POWER CONSUMPTION	HELIOSTAT/FIELD CONSUMPTION	MANUAL
FIELD POWER OUTAGES AND TRANSIENTS	DROPOUTS, TOTAL OUTAGE	MANUAL
ENVIRONMENTAL:		
ADDITIONAL HEAT	RAISE TEMP TO UPPER LIMITS	MANUAL/AUTO
WIND	UPPER LIMITS – MIRROR LOADING AND FLUTTER	MANUAL/AUTO
NATURAL	RAIN, HAIL, TEMP, WIND	MANUAL/AUTO
WEATHER	CONSTRUCT WEATHER PROFILE	MANUAL/AUTO

Collector Subsystem

Definition of Support Elements

INSTRUMENTATION FOR DATA COLLECTION

The system must be instrumented for data collection by automatic or manual means for gathering, manipulating, and presentation of data for analysis.

Instrumentation for monitoring, data accumulating and evaluating will be used during the research experiment to evaluate the performance. The instrumentation will be leased, purchased or provided from capital equipment. The list of capital equipment is representative and should not be construed as the total list that will be used to perform the testing of the research experiment.

Environmental conditions will be monitored by wind sensors mounted on each heliostat and temperature, pressure and humidity sensors mounted in a central location. These sensors will provide environmental data to correlate with system performance data. Solar radiation at each heliostat will be measured by an insolation meter and the reflectance of the mirrors will be measured by a reflectometer.

Structural tests will be instrumented by strain gauges, force gauges, optical mirrors, collimators and theodolites for conducting, data gathering and analysis. These instruments will be used during all phases of testing to provide long term environment profiles for system operation.

General laboratory instruments and meters such as oscilloscopes, power supplies, multimeters, voltmeters, ammeters, wattmeters, pulse generators and counters will be used during all phases of the research experiment testing. These instruments will provide the data monitoring and evaluating for subsystem and system performance.

A Honeywell H-716 computer with associated peripherals will be used during the research experiment to provide the control for the system. After integration the computer will be used for all phases of system operation including data analysis.

0975-267

Capital	Purchased
Honeywell Model 153x17 Temperature Recorder	H-716 Computer (leased)
Wild Autocollimators	H-700-4041 Magnetic Tape Unit (leased)
Kern Model DKM2 Theodolites	ASR-35 Teletype (leased)
Tektronix Model 7704 Oscilloscope	Schultz Model 716 Global (leased)
Lambda Model LMCC15 Power Supply	MRI Model 1022 Wind Sensors
Power Design Model TW5005 Power Supply	MRI Model 815-1 Temperature Sensor
Simpson Model 260 Multimeter	MRI Model 751 Pressure Sensor
Fluke Model 8000 DVM	MRI Model 817-1 Humidity Sensor
Weston Model 433 Ammeter	
Weston Model 432 Wattmeter	
EH Model 139B Pulse Generator	
HP Model 5327B Counters	
Cary Model 14 Reflectometer (Mpls)	

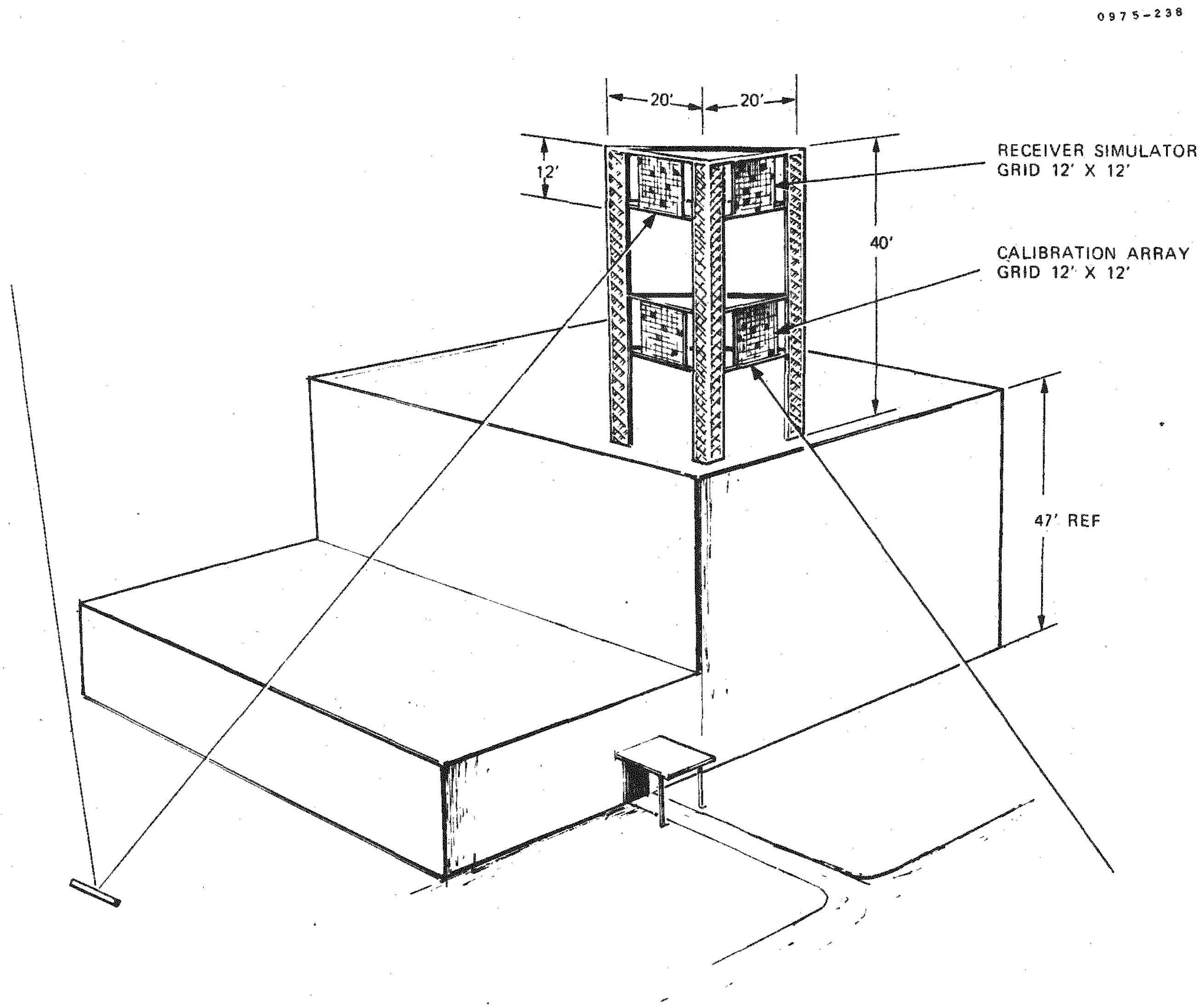
SUPPORT EQUIPMENT

SIMULATION OF THE RECEIVER

A photodetector array will provide a means for the continuous monitoring of pointing accuracy and image quality.

The purpose of the heliostat and its control system is to gather the sun's energy over a given area and redirect it to a smaller area on the tower. This involves the requirement to point as well as concentrate the redirected energy. With the heliostat operating in the tracking mode, a photodetector array will continuously monitor the energy spot. The array will be similar to that used for calibration but may contain more cells so as to provide better resolution of the variables. The energy centroid will be continuously measured and recorded as a measure of pointing accuracy. Concentration will be determined from image shape whereby a map will be made from the intensity measured at the individual detectors in the array. Background light is expected to be 0.2 suns with average signal strength equal to the ratio of the collected area/concentrated area or 2.5 suns. This provides a comfortable signal to background ratio of 12.5 to 1 and should provide good data.

The array simulating the receiver will be mounted on the tower above the calibration array.



RECEIVER SIMULATOR

Collector Subsystem

Definition of Support Elements

ERECTION OF TEST TOWER

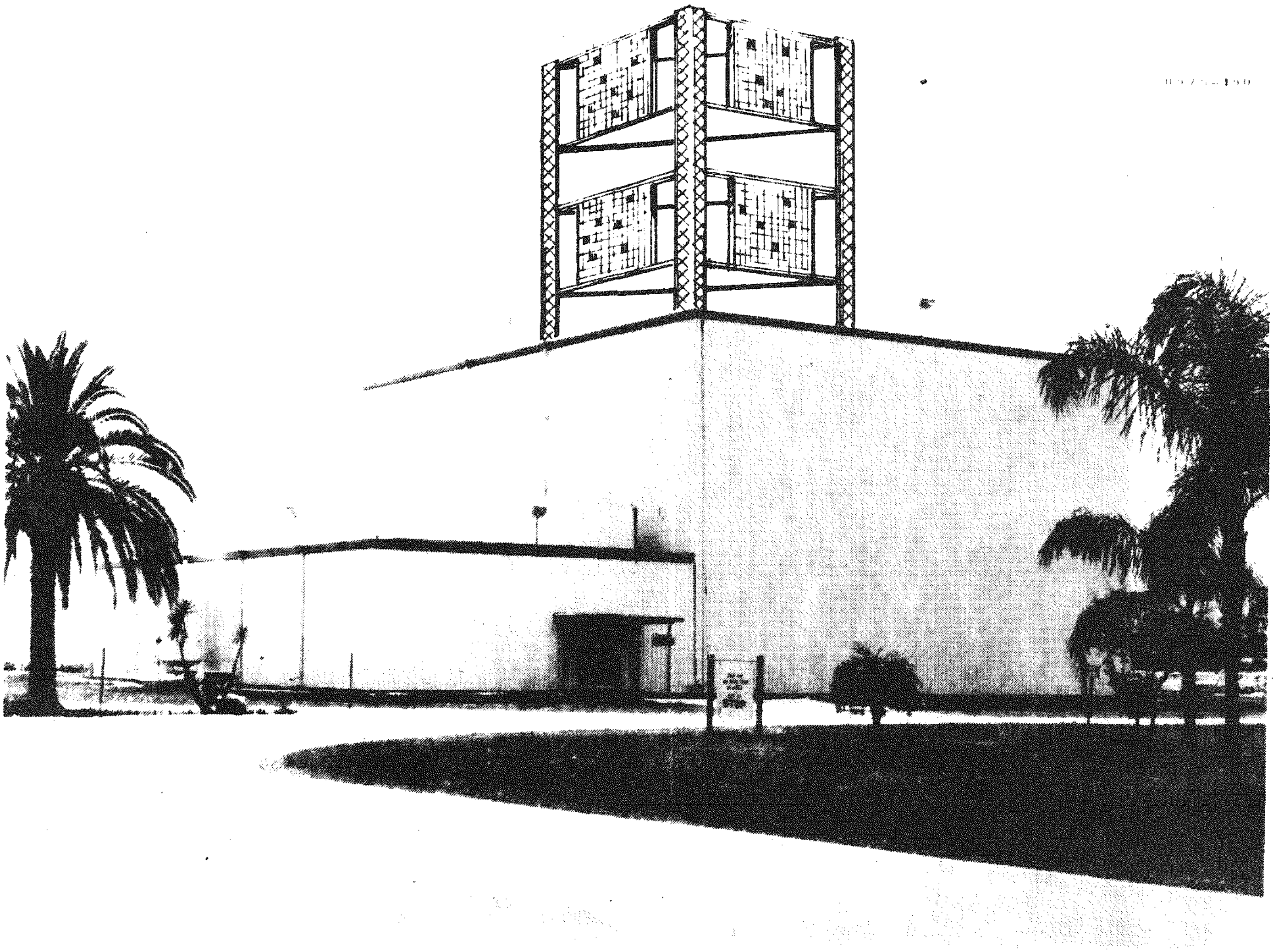
The Test Tower will be built on roof of Environmental Building No. 2 due to central location, building height, and structural stability.

The roof of Environmental Building No. 2 at 47 foot height is the highest point on the site. It is therefore, a logical location to build a tower addition to simulate the power tower.

The central location on the Honeywell site at Environmental Building No. 2 provides all direction access to focusing on the target and calibration test arrays. The stairway to the roof providing access to the tower would be equipped with a flashing warning sign or other safety devices to prevent entry to the roof when the computer is pointing heliostats to the tower.

It has been determined that a tower built with Radio/Television tower components provides the best overall design and stability for the least cost. A tower built of wood was determined not feasible due to affects of weather on bending, twisting and warping of the structure. A structural steel design tower was considered. It has the following disadvantages: The weight of the structure would be greater and therefore the costs would be greater. The components of a safety enclosed stairs and service catwalks would require more design costs. It should be recognized that Radio/Television type tower structures have been designed by fabricater/installers to provide the proper stability with the lightest and specially designed members with their resultant cost savings. These structures have predesigned stairs and catwalk planks to comply with OSHA and building codes.

The tower would be erected on the Northeast corner of the roof with connections to the building steel. The building has excellent stability against wind loads. Thus the tower can be built to take advantage of the stability and height.



ENVIRONMENTAL BUILDING WITH TEST TOWER

Collector Subsystem

Definition of Support Elements

PLAN FOR FACILITY MODIFICATION

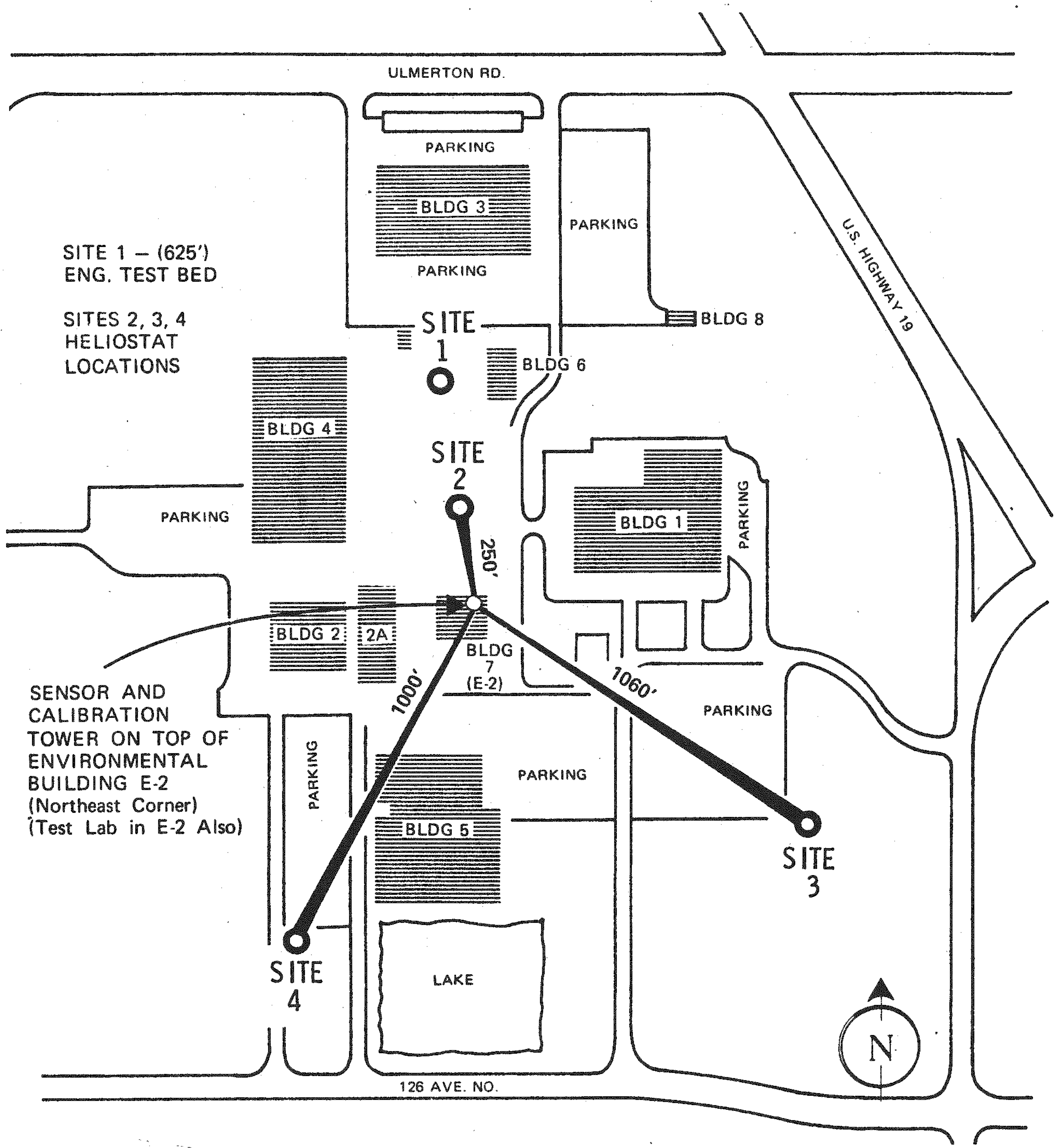
This facility site is good because it provides a central location of tower and test laboratory with multi-directional heliostat locations that can be protected.

This facility plan provides a central location for our test tower and test laboratory. There is an available laboratory space in the Northeast corner of Environmental Building No. 2.

The four heliostat locations as shown have been selected to provide an all direction aiming to the test tower. These locations are out of the normal facility pedestrian and vehicle traffic flow. Each location will be protected by a fence enclosure. A tarp backstop will be placed so mirrors can be pointed into the tarp in the process of stowing the mirrors in order to prevent the concentrated solar rays affecting passing pedestrians or driver's of vehicles.

Power distribution and communications will be provided between the heliostat and the computer, as well as between the target, calibration arrays and computer.

0975-251



PLOT PLAN

APPORTIONMENT OF TEST CONFIGURATION TRACKING ERRORS

An Error Budget must relate to the specifications, but it can be developed only after the experiment concept is established so that the budget of error allocations is meaningful.

The tentative budgeting of errors during the concept phase is based on the premise that error sources that can be controlled, must be. This leaves maximum margin for those error sources driven by environment which is less amenable to accurate prediction. It is also based on the premise that maximum cost effectiveness will be achieved by minimizing the structural stiffness requirements of each heliostat due to the massive cost leverage exerted by the large quantities involved. Hence computational budgets have been held rather tightly and those associated with individual heliostat structures and drive systems have been allotted the greater share.

Probable error sources associated with the budget items are listed below. This list will be adjusted as necessary during the detailed design.

- Computation Sun Vector
  - Time Standard
  - Temperature Input
  - Pressure Input
  - Algorithm Accuracy
  - LSB Limitations
- Computation Mirror Normal
  - Heliostat LOS Inputs
- Computation Axis Commands
  - Residual Calibration Error
  - Residual Drive Train Scale Factor Error
- Delivery Commands to Motor Controller
  - Δ Time delivered versus time for which computed
- Foundation
  - Initial Installation
  - Residual Stability
- Heliostat
  - (0,0) Gimbal Initialization
    - Initial Switch Alignment Errors
    - Repeatability
- Heliostat (Continued)
  - Motor and Drive System
    - Gear Train Backlash
    - Min Resolution/Step
    - Deviation from Nominal Drive Scale Factors
    - Initial Alignment Residual
    - Δ Wind Deflections
- Mirror Support Structure
  - Initial Alignment
  - Δ "g" Vector Changes
  - Thermal Effects
  - Δ Wind Deflections
- Boresight Normal
  - Basic Pointing Accuracy at RSS
- Non-Boresight Normals
  - Cross Axis Coupling - conservatively taken as additive
- Optics
  - Residual Focus Misalignment
  - Initial Alignment to Structure
  - Thermal Changes
  - Δ "g" Changes
  - Δ Wind Deflections
  - Aberations - mirror quality - Δ focus

In preparation for the research experiment, the question of central receiving simulator tower stability versus desired pointing accuracy monitoring came under consideration. Both optical plumbbob and sensitive level measurement were made on the appropriate portion of the Building No. E2 structure upon which it is planned to erect the tower. These measurements indicated that daily coning of the building due to varying sun load and motions due to wind project to less than ±0.5 inch motion at the top of the 90 ft tower from this cause. This plus predicted tower sway compares favorably with the resolution expected of the receiver simulator and the monitoring accuracies desired.

SPECIFICATION (RECOMMENDED)

0975-259

MIRROR NORMAL POINTING ± 2 MR 1σ EACH AXIS
OPTICS ONLY ± 1 MR 1σ TOTAL
HENCE, ASSUMING NORMAL DISTRIBUTION, $3\sigma = \pm 6$ MR POINTING

BUDGET

SOURCE	EACH AXIS		
COMPUTATION AND COMMUNICATION			
COMPUTATION SUN VECTOR	±0.15		
COMPUTATION MIRROR NORMAL	±0.3		
COMPUTATION COMMANDS	±0.15		
DELIVERY COMMANDS TO MOTOR CONT	±0.15		
	SUBTOTAL ±0.4 RSS 3σ		
FOUNDATION			
RESIDUAL MISALIGNMENT	±0.14		
UNCOMPENSATED DRIFT RATE	±0.14		
	SUBTOTAL ±0.2 RSS 3σ		
HELIOSTAT			
(0.0) GIMBAL INITIALIZATION	±0.3		
MOTOR AND DRIVE SYSTEM	±2.46		
MIRROR SUPPORT STRUCTURE	±2.46		
	SUBTOTAL ± 3.52 RSS 3σ		
BORESIGHT MIRROR NORMAL		TOTAL	± 3.55 RSS
NONBORESIGHT MIRROR NORMAL		TOTAL	± 2.45 ADDITIVE
MIRROR NORMAL POINTING BUDGET		GRAND TOTAL	± 6 MR 3σ
OPTICS (ONLY)		TOTAL	±3 MR 3σ

Collector Subsystem

Preparation for the Research Experiment

IDENTIFICATION OF LONG LEAD PARTS

Long lead parts are those which became pacing items either during the design phase or the build phase.

In all programs regardless of the magnitude, some of the component parts fall into the category of long lead items. There are, however, ways of minimizing the procurement problems of these long lead items. For the research experiment these are:

- Early identification of parts requirements.
- Adherence to the "commercial parts" philosophy.

To date, no long lead parts have been identified for the heliostat or calibration array. Four to six week delivery seems typical for the standard commercial parts. During the detail design phase, if a specific part becomes a pacing item, it will be identified so advance procurement can begin.

However, in the central processor, the Global has a 8 to 12 week delivery. The H-716 and peripherals have 10 to 16 week delivery. It is requested that action begin by 15 October to lease one Global, the H-716, ASR-35, and Magnetic Tape Unit for integration and software development.

Heliostat and calibration array	None identified - 4 to 6 weeks for standards parts
Signal distribution	Global - 8 to 12 weeks (order by Oct 30, 1975)
Computer and peripherals	H716 computer, ASR-35 teletypewriter, Magnetic tape unit } 10-16 weeks (Order by Oct 15, 1975)

LONG LEAD PARTS

Collector Subsystem

Preparation for the Research Experiment

DEFINITION OF FUNCTIONAL ELEMENT REQUIREMENTS

Included in the Appendix B through E are the Detail Specifications, Part I, which define the requirements for the Solar Collector Subsystem and its major elements sufficient to initiate the detail design diode.

Appendix A

MATHEMATICS OF SUN TRACKING

Appendix A-1

SUN'S MEAN ORBITAL ELEMENTS

1975 JAN 0^d 0^h E.T. J.D. 2442412.5

Julian Date at 0^h on 1975 Jan 0	= 2442412.5
Julian Date at epoch of tables	= 2415020.0
Interval in days (d)	= 27392.5
Fraction of Julian Century (T)	= 0.749966

ω_o = Mean longitude of perigee, mean equinox of date

$= 281.220833 + 0.0000470684d + 0.000453T^2 + 0.000003T^3$

= 282.51040 degrees

M_o = Mean anomaly

$= 358.475845 + 0.9856002670d - 0.000150T^2 - 0.000003T^3$

= 356.531056 degrees

i = Mean obliquity of the ecliptic

$= 23.452294 - 0.0130125T - 0.00000164T^2 + 0.000000503T^3$

= 23.442534 degrees

Y = Length of tropical year

$= 365.24219878 - 0.00000614T$

= 365.2422033 $\qquad 360/Y = 0.9856473232$

m = Mean light/time correction

= 20.47 arc seconds

= 0.005686 degrees

Ref: American Ephemeris and Nautical Almanac

Appendix A-2

COMPUTATION OF SUN'S POSITION IN ORBIT PLANE

Given:

$\omega = \omega_o + \dot{\omega}d = 282.51040 + 0.0000470684d$

$M = M_o - m + (360/Y)d = 356.531056 - 0.005686 + 0.985647d$

$i = 23.442534$

$e = 0.01672$

d = Number of days

Then:

E_{i+1} = Eccentric anomaly
$= M + e \sin E_i * 180/\pi$

Solve iteratively, three passes, $E_1 = 0$

Cos v = Cosine of true anomaly

$$= \frac{\cos E - e}{1 - e \cos E}$$

Sin v = Sine of true anomaly

$$= \frac{\sqrt{1-e^2} \sin E}{1 - e \cos E}$$

$$\text{Sun vector} = \begin{bmatrix} \cos v \\ \sin v \\ 0 \end{bmatrix}$$

Rotate Sun vector to equinox

$X = \cos v \cos \omega - \sin v \sin \omega$

$Y = \cos v \sin \omega + \sin v \cos \omega$

$Z = 0$

Rotate ecliptic to equatorial plane

$Eq = X$

$E = y \cos i$

$P = y \sin i$

We now have the unit Sun vector in equatorial, east, polar coordinates

To transform unit Sun vector in inertial coordinates to an Earth fixed UEN reference frame compute first

GHAγ 1975 0^d 0^h E.T.	=	6^h 36^m $9^s.628$
GMT_{DAYS} * 0.065709822 hrs/day	=	+
GMT_{HRS}		+ ______
Longitude		- ______
Longitude * 9.85654 arc sec/deg		+ ______

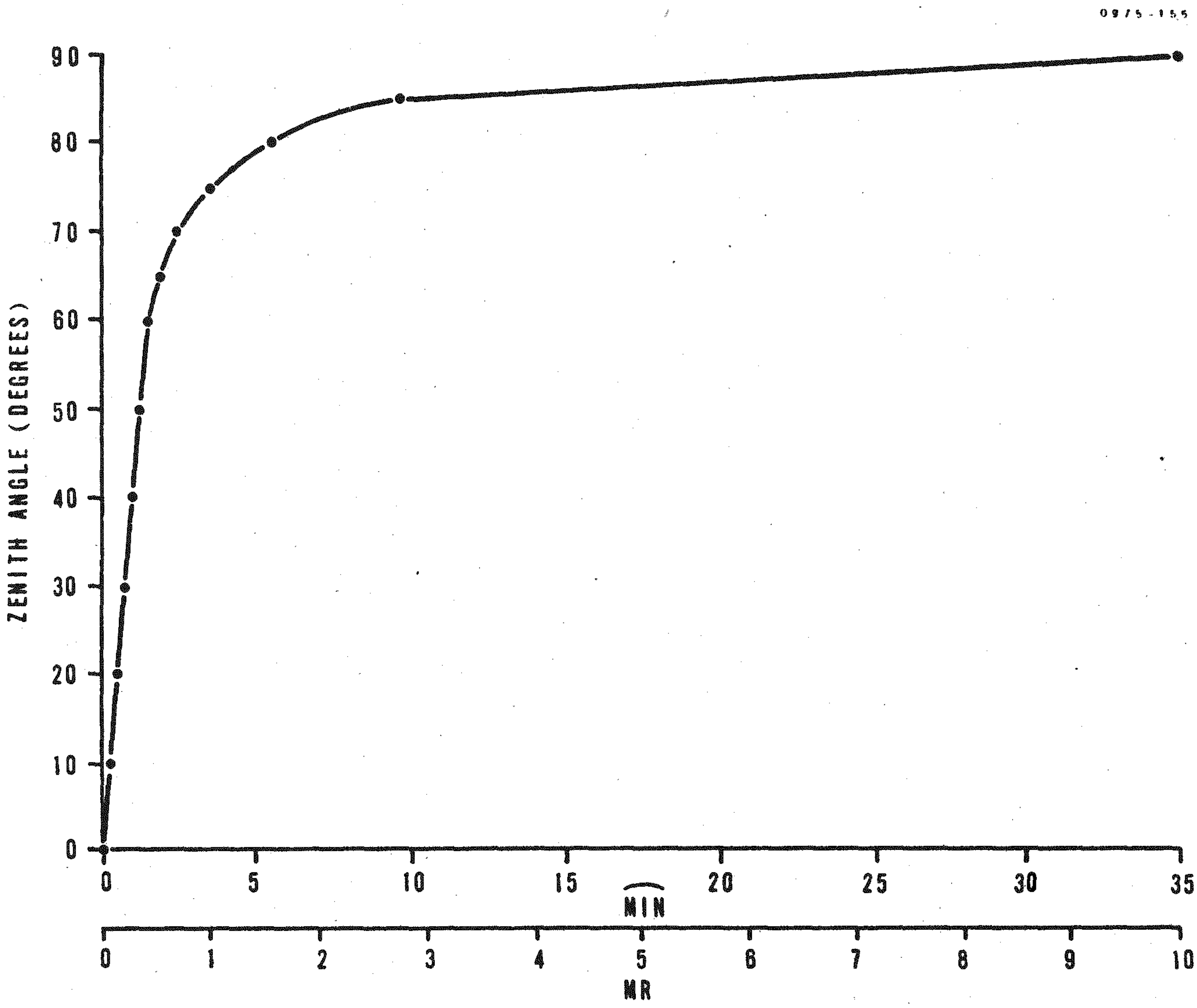
Convert time to angle Ω =

Now make the following transformations:

$$\begin{bmatrix} U \\ E \\ N \end{bmatrix} = \begin{bmatrix} \cos\lambda & 0 & \sin\lambda \\ 0 & 1 & 0 \\ -\sin\lambda & 0 & \cos\lambda \end{bmatrix} \begin{bmatrix} \cos\Omega & \sin\Omega & 0 \\ -\sin\Omega & \cos\Omega & 0 \\ 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} Eq \\ E \\ P \end{bmatrix}$$

λ = local geodetic latitude

We now have a unit Sun vector in local UEN coordinates



Appendix C

REFRACTION CORRECTION FOR ZENITH ANGLES AT SEA LEVEL
0°C 76 CM HG

$$R_{\widehat{sec}} = 206 \frac{P_{cm}}{T_K} \tan z$$

		-4°		32°		68°		104°			F
z°	-30	-20	-10	0	10	20	30	40	50	60	70°C
0	0	0	0	0	0	0	0	0	0	0	0
10	11	11	11	10	10	9	9	9	9	8	8
20	23	23	22	21	20	19	19	18	18	17	17
30	37	36	34	33	32	31	30	29	28	27	26
40	54	52	50	48	46	45	43	42	41	40	38
50	77	74	71	68	66	64	62	60	58	56	54
60	112	107	103	99	96	93	90	87	84	82	79
70	177	170	164	158	152	147	142	138	133	129	126
75	240	231	222	214	206	199	193	187	181	176	170
80	366	351	338	326	314	303	293	284	275	267	259
85	736	708	680	655	632	611	591	572	555	538	522

at 76 cm Hg

z°	73	76	79
0	0	0	0
10	9	9	9
20	18	19	20
30	29	30	31
40	42	43	45
50	59	62	64
60	86	90	93
70	137	142	148
75	185	193	200
80	282	293	305
85	568	591	615

73 cm = 28.74 in Hg
76 cm = 29.92 in Hg
79 cm = 31.10 in Hg

at 30°C

APPENDIX B

DETAIL SPECIFICATION

PART I

SOLAR COLLECTOR SUBSYSTEM

HONEYWELL INC.
Aerospace Division

DETAIL SPECIFICATION PART I OF I

DS YG 8112A1

THIS DETAIL SPECIFICATION IS FOR

CONTRACT No. LC 403127

SOLAR COLLECTOR SUBSYSTEM

SIGNATURES	DATE
ORIGINATOR S. K. STEPHENSON	9/12/75
ACCEPTOR S. K. STEPHENSON	
APPROVED BY R. S. PARKER	

REVISIONS

LTR.	DESCRIPTION	APPROVAL	DATE

F12. PT-0135 (973)

DETAIL SPECIFICATION NUMBER YG 8112A1

SOLAR COLLECTOR SUBSYSTEM

1.0 SCOPE

This specification establishes the performance, design, development, and test requirements for the Solar Collector Subsystem (SCS). The SCS is an experimental system of computer controlled tracking reflectors used to determine focusing and pointing capabilities. A calibration array is included along with computer software and peripherals.

2.0 APPLICABLE DOCUMENTS

The following documents, of latest issue form a part of this specification to the extent specified herein. In the event of conflict between the documents referenced herein and the contents of this specification, the contents of this specification shall be considered a superseding requirement.

a. Interstate Commerce Commission Shipping Standards and Regulations.

b. Standards of the American Institute of Steel Construction.

c. Specifications for Aluminum Structures of the Aluminum Association.

d. American Concrete Institute Standards

e. Standards of the National Electrical Manufacturing Association.

3.0 REQUIREMENTS

3.1 Solar Collector Subsystem Definition

The Solar Collector Subsystem shall consist of an array of heliostats to reflect the solar rays to a specified elevated receiver of the receiver subsystem. The basic heliostat design requires a reflective surface which is mounted on a tracking support such that solar rays may be reflected onto a specified fixed receiver continuously during sunlight hours.

The heliostat may employ sensors, electronics, and drive mechanisms to direct the reflected rays of the sun onto the receiver as well as provide auxiliary functions for other modes of operation and non-operational positionings. A design goal is that all heliostats be interchangeable regardless of position in the concentrating field.

A central computer controller, software, and associated peripherals provides computation of apparent sun position, heliostat command instructions, mode control, and control of communications to the heliostat field.

Grid mounted photo-cell calibration arrays provide for periodic calibration of each heliostat by relaying re-directed beam pointing coordinates to the control computer. Included in the calibration arrays are high-intensity sources of modulated light for use in initial focus and mirror alignment or subsequent rechecks, as necessary.

Items to be developed are as follows:

a. LG 8016A1 - Heliostat - An assembly of tracking solar reflectors mounted on a common set of two degree-of-freedom gimbals with drive trains, motors, and motor control electronics.

b. BG 8251A1 - Computer, Heliostat Control - A central processor with associated peripheral equipment used to command heliostats to specified pointing vectors.

c. LG 8015A1 - Calibration Array - A set of light detectors mounted on a grid framework and used to measure pointing accuracies of heliostats.

d. QG 8172A1 - Software, Heliostat Control - A set of computer programs and subroutines used to command heliostats and provide interface for operator and other equipment.

3.1.1 Solar Collector Subsystem Diagram

Figure 1 shows a functional diagram of heliostats of the Solar Collector Subsystem and its interfaces with the other subsystems.

3.1.2 Interface Definition

The interfaces between the Solar Collector Subsystem and other subsystems are as follows:

3.1.2.1 Collector Positioning/Sun Movement/Receiver

Heliostat positioning during normal operations shall continuously or incrementally follow the sun and adjust the attitude of the reflective surfaces to position the reflected image on the receiver. Normal operations are defined as operation in the tracking mode during the time interval between one-half hour after true sun-rise and one-half hour before true sun-set.

3.1.2.2 Collector Controls/Master Controls

Heliostat controls shall be responsive to signals from a master control system.

3.1.2.3 Collector Foundation/Site

Heliostat support structure/foundations shall be designed and installed to minimize overall cost and yet not degrade the Sollar Collector Subsystem performance, Paragraph 3.2.1., while operating in environments of Paragraph 3.2.5.

3.1.2.4 Collector Subsystem/Prime Power

The Solar Collector Subsystem shall be supplied with 120V rms, 60 Hz, single phase prime power.

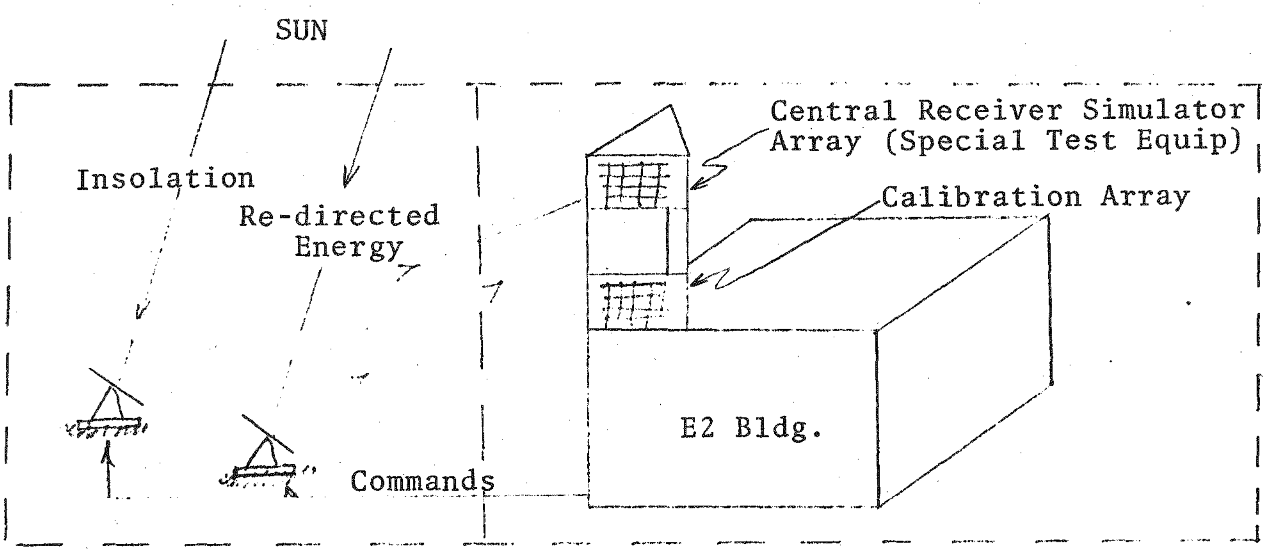


FIGURE 1

MAJOR COMPONENTS AND INTERFACES OF HELIOSTAT SUBASSEMBLY OF THE COLLECTOR SUBSYSTEM IN THE RESEARCH EXPERIMENT

3.2 Characteristics

3.2.1 Performance

The heliostats shall reflect the direct insolation as projected on the heliostat onto the central receiver in such a manner as to permit optimizing the system operation, shall permit modifications to adjust power loads, and shall be rapidly controllable for emergency defocusing or stowage in the event of need.

a. Reflective surfaces shall direct 95% of the redirected insolation into the receiver cavity with a (TBD) pattern measured perpendicular to the beam. The reflectance of the surface shall be as high as practical and in no case less than 80% of the direct reflectance when measured by Cary Model 14 reflectometer or equivalent equipment. A surface life of 30 years is required and surface degradation rate shall be minimized. The optical spreading due to surface irregularities shall be less than one milliradian, 1 sigma. Total heliostat reflector area shall be approximately 30 m^2.

b. Structural support shall be consistent with the requirements of Paragraph 3.2.5.

c. The drive system shall adjust the position of the reflective surfaces to achieve specified receiver solar flux pattern throughout daily and seasonal variations. The per axis pointing, tracking, or following accuracy shall be two milliradians (1σ) in the presence of the environmental disturbances defined in Paragraph 3.2.5. The drive shall have capability for survival, defocusing and maintenance operations that will allow reflective surfaces to be placed in stowage within 12 minutes and remove solar flux from the receiver within 12 seconds.

d. The Control System shall provide for all required operating modes which may include but are not necessarily limited to:

Initialization
Offset pointing
Tracking or following
Emergency shutdown
Manual control of single units
Fail safe
Return to stowage
Limit control
Calibration and check-out

e. The local heliostat controls shall meet applicable standards and be installed in suitable weathertight enclosure. These controls shall include detection of loss of AC power or communications, limit of gimbal travel, and gimbal initialization attitude, as well as the logic to self command the emergency defocus mode, the stowage mode, and gimbal drive inhibit.

f. A suitable foundation design shall be provided for the proper stable support of the components of all heliostats.

g. Further provision shall be added to the basic calibration array to permit initial in field mirror focus and alignment and subsequent rechecks using high intensity sources of modulated light. The approach shall provide for a mechanical control box for heliostats undergoing alignment, and remote readout of re-directed modulated mirror pattern, possibly by RF multi-plexer link.

h. Suitable allocation of potential error sources is shown in Appendix entitled "Collector Subsystem-Error Budget".

3.2.2 Physical Characteristics

a. The maximum heliostat weight shall be governed by cost, transportation and servicing constraints, structural requirements, and power consumption of the drive components.

b. Shape limitations will be constrained only by the collector field layout, shadowing and blocking restraints, and servicing functions.

c. The heliostat shall require a specified stored or "safe" position(s) which may be used during periods of maintenance, high winds, at night, in stormy weather, or in case of loss of receiver working fluid.

3.2.3 Reliability

Consideration shall be given in the heliostat design to achieving high reliability by providing operating margins and utilizing standard parts and conservative design practice.

3.2.4 Maintainability

a. The reflective surfaces shall be readily cleaned without degradation. Water, ice, dust, or other degrading conditions such as bird droppings on the reflective surfaces should cause no permanent damage to the reflective characteristics. The entire heliostat should be designed such that potential maintenance points can be easily reached and components such as electronic units, motors, drives, etc., readily replaced.

b. Elements subject to wear or damage should be easily inspected, serviced or replaced, or shall be designed for long life.

c. The heliostats should be serviceable by personnel of normal skills and should require a minimum of specialized equipment and tools.

3.2.5 Environmental Conditions

Heliostats shall withstand normal ambient conditions of temperature variations from -20 degrees C to 60 degrees C (goal), 0 degrees C to 60 degrees C (requirement) humidity, rain, snow, ice, hail, sand storms, and earthquakes of (to be furnished) intensity. Electrical and control components shall not be damaged by electrical disturbances or by currents expected during severe thunder storms. The heliostats shall withstand sustained winds up to 13.5 m/s and gusts with rms velocity of TBD m/s in an operational mode, and withstand sustained winds of 25 m/s and gusts with rms velocity of TBD m/s in a non-operational mode.

3.2.6 Transportability

Transportation of the heliostats to the test facility site shall be subject to all pertinent federal and state transportation regulations.

3.3 Design and Construction

Design and construction standards compatible with the end use shall be employed.

3.3.1 Materials, Processes, and Parts

To the maximum extent possible, standard materials and processes shall be employed. Avoidance of highly stressed components and unusual materials is desired. As far as practical, off-the-shelf components used in industry should be employed.

3.3.2 Electrical Transients

The heliostat operation shall not be adversely affected by external or internal electrical transients. Components of the collector subsystem shall be protected, as required, against environments as specified in Paragraph 3.2.5.

3.3.3 Nameplates and Product Marking

The major elements in the heliostats shall be marked with suitable identifying nameplates permanently attached.

3.3.4 Workmanship

The heliostat and all associated items shall be fabricated and assembled in accordance with the best modern engineering, shop and field practices consistent with cost and performance requirements.

3.3.5 Interchangeability

Components with standard tolerances, where available, shall be used to permit interchangeability for servicing. Satisfactory replacement parts shall be available for the period of the contract.

3.3.6 Safety

The heliostats shall be designed to minimize safety hazards to operating and service personnel and the public. Electrical supplies shall be adequately insulated and grounded. Moving elements shall be shielded to avoid entaglements and safety override controls available for service.

3.4 Documentation

3.4.1 Characteristics and Performance

Equipment functions, normal operating characteristics, limiting conditions, test data, and performance curves, where applicable shall be documented.

3.4.2 Instructions

Instructions shall cover assembly, installation, alignment, adjustment, checking, lubrication, and maintenance. Operating instructions shall be prepared for startup, routine and normal operations, regulation and control, shutdown, and emergency conditions. A guide to "troubleshooting" instruments and controls shall be prepared.

3.4.3 Construction

Engineering and assembly drawings shall be prepared to show the equipment construction, including assembly and disassembly procedures. Engineering data, wiring diagrams, and parts lists shall be prepared.

3.5 Logistics

3.5.1 Maintenance

3.5.2 TBD

3.5.2 Supply

TBD

3.5.3 Facilities and Facility Equipment

TBD

3.6 Personnel And Training

3.6.1 Personnel

TBD

3.6.2 Training

TBD

3.7 Major Component Characteristics

3.7.1 Heliostat Functional Characteristics

TBD

3.7.2 Computer-Heliostat Control Functional Characteristics

TBD

3.7.3 Calibration Array Functional Characteristics

a. Operational Calibration

b. Heliostat Reflective Surface Alignment

3.7.4 Software, Heliostat Control Functional Characteristics

3.8 Precedence

The order of precedence regarding importance of heliostat characteristics for this development is as follows:

a. Performance

b. Capability to withstand natural environmental conditions.

c. Cost (dollars/square meter) of heliostat. (While the cost of prototype mirror modules is not of overriding importance, it is desirable that the design be such that comparable units could eventually be mass-produced in large numbers at low cost.)

4.0 QUALITY ASSURANCE PROVISIONS

4.1 General

A test program at system level shall be conducted to validate the design for the solar pilot plant. System level testing will be conducted at Aero Florida. The system will consist of three (3) heliostat subassemblies, a tower structure including target and calibration arrays, and an H716 computer with associated peripherals.

4.2 Responsibility for Tests

Honeywell Aero will be responsible for conducting the system tests. Detail test procedures shall be prepared to ensure that the system conforms to the requirements of this specification and the Master Test Plan.

4.3 Quality Conformance

Inspections and testing shall be used as methods of verification that the system specification requirements are complied with.

4.3.1 Inspection

Examination of the system shall be conducted to verify that it meets with applicable workmanship standards, identifying nameplates are attached and correct, and documentation is available and correct as identified in the Master Test Plan.

4.3.2 Testing

The pilot plant design shall be tested by using a system configuration consisting of three heliostats placed on the Honeywell Aero property at distances from a tower to represent the minimum, mid, and maximum distances of the pilot plant configuration. A H716 computer will be used as the central controller for the system. The system testing will be conducted over a period of months to demonstrate system performance under natural environmental conditions.

4.3.2.1 Structural Integrity

Static and dynamic loading of the foundation and structure shall be used to test the stability, strength, and the ability of the drive system to handle the additional loads due to wind or ice.

4.3.2.2 System Performance

Operational tests at system level shall be performed to demonstrate that the operational requirements as stated in this specification are complied with. Weather data shall be provided to obtain a daily weather profile for use in the analysis of operational data. Testing shall be in accordance with detailed test procedures that demonstrate that the system complies with the tracking error requirements, defocusing requirements, emergency responses, and ability to maintain tracking integrity under natural environmental and operating conditions.

5.0 PREPARATION FOR DELIVERY

TBS

6.0 NOTES

TBS

10.0 APPENDIX I

TBS

SPECIFICATION (RECOMMENDED)

0975-259

MIRROR NORMAL POINTING ±2 MR 1σ EACH AXIS
OPTICS ONLY ±1 MR 1σ TOTAL
HENCE, ASSUMING NORMAL DISTRIBUTION, 3σ = ± 6 MR POINTING

BUDGET

SOURCE	EACH AXIS
COMPUTATION AND COMMUNICATION	
COMPUTATION SUN VECTOR	±0.15
COMPUTATION MIRROR NORMAL	±0.3
COMPUTATION COMMANDS	±0.15
DELIVERY COMMANDS TO MOTOR CONT	±0.15
	SUBTOTAL ±0.4 RSS 3σ
FOUNDATION	
RESIDUAL MISALIGNMENT	±0.14
UNCOMPENSATED DRIFT RATE	±0.14
	SUBTOTAL ±0.2 RSS 3σ
HELIOSTAT	
(0.0) GIMBAL INITIALIZATION	±0.3
MOTOR AND DRIVE SYSTEM	±2.46
MIRROR SUPPORT STRUCTURE	±2.46
	SUBTOTAL ±3.52 RSS 3σ
BORESIGHT MIRROR NORMAL	TOTAL ±3.55 RSS
NONBORESIGHT MIRROR NORMAL	TOTAL ±2.45 ADDITIVE
MIRROR NORMAL POINTING BUDGET	GRAND TOTAL ±6 MR 3σ
OPTICS (ONLY)	TOTAL ±3 MR 3σ

APPENDIX C

DETAIL SPECIFICATION

PART I

HELIOSTAT

HONEYWELL INC.
Aerospace Division

DETAIL SPECIFICATION PART I OF I

DS LG 8016A1

THIS DETAIL SPECIFICATION IS FOR

CONTRACT No. LC 403127

HELIOSTAT

SIGNATURES	DATE
ORIGINATOR R. E. YOUNSKI/R. R. SNYDER	9/13/75
ACCEPTOR R. E. YOUNSKI/R. R. SNYDER	
APPROVED BY R. S. PARKER	

REVISIONS

LTR.	DESCRIPTION	APPROVAL	DATE

PAGE 1 OF 12

DS LG 8016A1

F12. PT-0135 (973)

HONEYWELL INC.

Aerospace Division

DETAIL SPECIFICATION NUMBER | LG 8016A1

HELIOSTAT

1.0 SCOPE

This specification defines the performance, environmental, and design requirements for the Heliostat, LG 8016A1, a portion of the Solar Collector Subsystem YG 8112A1. The heliostat consists of mirrors mounted on a two-axis gimbal system with the required drive systems and electronics to track the sun and direct the reflected solar energy to a fixed target.

2.0 APPLICABLE DOCUMENTS

The following documents, of exact issue shown, form a part of this specification to the extent specified herein.

Specifications:

Federal (TBD)
Military MIL-D-1000
Honeywell (TBD)

Standards:

Federal (TBD)
Military (TBD)
Honeywell (TBD)

Drawings:

LG 8016A1 Heliostat

Other Publications:

Manuals (TBD)
Regulations (TBD)
Handbooks (TBD)

3.0 REQUIREMENTS

3.1 Item Definition

The Heliostat shall be designed to accept digital data in serial form from the Heliostat control computer and, by means of appropriate electrical signals to two gimbal motors, cause the reflective surfaces to track the sun and direct the reflected solar energy to a fixed target.

Major heliostat components are:

Mirror Module (4)
Mirror Module Drive
- Dual Worm Reducer
- Stepper Motor

Outer Gimbal Frame Assembly
Outer Gimbal Drive
- Ball Bearing Screw Drive (2)
- Worm Reducer
- Stepper Motor

Foundation Assembly
Electronics
Battery Pack

3.2 Characteristics

3.2.1 Performance Characteristics

3.2.1.1 Electrical Input

3.2.1.1.1 Power

3.2.1.1.1.1 Voltage: 110V rms ± 10%

3.2.1.1.1.2 Current: (TBD) ma rms max.

3.2.1.1.1.3 Frequency: 60 ± TBD Hz

3.2.1.1.2 Communications

3.2.1.1.2.1 Input Form: Serial Data, 2 Bytes per instruction, 12-Bits per Byte arranged as an Address Byte followed by a Data Byte.

3.2.1.1.2.2 Address Byte Format: Start Bit, ID Bit, 7 Data Bits, Parity Bit, 2 Stop Bits for a total of 12-Bits.

3.2.1.1.2.3 Data Byte Format: Start Bit, ID Bit, 7 Data Bits, Parity Bit, 2 Stop Bits for a total of 12-Bits.

3.2.1.1.2.4 Baud Rate: 4800-Bits/second

3.2.1.1.2.5 Data Trans. Level: 12 Volt differential

3.2.1.1.2.6 Input Imp.: 4700 Ohm minimum

3.2.1.2 Emergency Reserve Power

3.2.1.2.1 Capacity: (TBD) watt hours

3.2.1.2.2 Voltage: 30V DC ± 10%

3.2.1.2.3 Current Capability: 3.2 Amps for 14 minutes @ $0^{o}C$

3.2.1.3 Optical Surface Reflectance

Total normal solar spectral reflectance of mirror surfaces shall be 80% minimum as measured by a Cary Model 14 reflectometer.

3.2.1.4 Mirror Module Focusing

3.2.1.4.1 Initial Contour

Reflective surface normals at all areas on a mirror shall be parallel to those defined by a parabaloid of revolution with focal length of (TBD) within (TBD) milliradian (1σ). The above requirement applies at the mirror module level with mirror surface vertical (mirror axis horizontal). The axis of the parabaloid is defined as perpendicular to the mirror module axis of rotation.

3.2.1.4.2 G-Sensitivity

Mirror surface contour will not deviate more than (TBD) MR (1σ) when the mirror module is rotated from vertical to horizontal.

3.2.1.4.3 Wind Load Sensitivity

Mirror surface contour will not deviate more than (TBD) MR (1σ) when the mirror module is exposed to (TBD) m/s winds gust at worst-case attach angle.

3.2.1.4.4 Temperature Sensitivity

Mirror surface contour will not deviate by more than (TBD) MR (1σ) when temperature is varied ± 40°C from a baseline of 20°C.

3.2.1.4.5 Focal Length Adjustment

Each mirror module assembly shall have provision for fine adjustment of focal length in the field.

3.2.1.5 Heliostat Focusing

3.2.1.5.1 Initial Adjustment

The heliostat design shall contain provision for relative angular adjustment of each mirror module to allow converging all mirror module beams into one.

Resolution of these adjustments shall be .05 milliradians or better referenced to the mirror surface.

3.2.1.5.2 Variation With Angular Travel

Variations in relative angle between mirror modules shall not exceed 0.2 MR over the range of ± 60° from the initial alignment position.

3.2.1.6 Pointing Accuracy

3.2.1.6.1 Total Error

Pointing accuracy of the heliostat over the range of operating conditions and environments shall be 2 milliradian (1σ) about each axis.

3.2.1.6.2 Error Budget

Pointing error contributions (1σ) shall be limited to the values specified for the items listed below:

Error Source	Outer Axis	Inner Axis
Drive System Resolution	TBD	TBD
Backlash	TBD	TBD
Initial Alignment	TBD	TBD
Drive System Non-Linearities	TBD	TBD
Gimbal Imbalance	TBD	TBD
Stiction	TBD	TBD
Electronics	TBD	TBD
Wind	TBD	TBD
Temperature	TBD	TBD

3.2.1.7 Dynamic Response

3.2.1.7.1 Maximum Command Rate

The heliostat gimbals shall maintain pointing accuracy per Paragraph 3.2.1.6.1 after continuous torquing of (TBD) minutes minimum at (TBD) pulses/sec motor command rate.

3.2.1.7.2 Frequency Response

The heliostat gimbals shall maintain pointing accuracy per Paragraph 3.2.1.6.1 after continuous torquing of (TBD) minutes at (TBD) heliostat resonances below (TBD) Hz.

3.2.1.8 Drive Torque

The heliostat drive units shall be capable of torquing the gimbals to any position in the range specified in Paragraph 3.2.2.2 d. and e. in the presence of sustained winds of (TBD) m/s minimum.

3.2.1.9 Reinitialization

The heliostat shall have indicators on each axis to show when the gimbals have reached the following positions:

Outer Gimbal - (TBD)

Inner Axis - (TBD)

3.2.2 Physical Characteristics

3.2.2.1 Electronics

The interface electronics and energy storage shall be enclosed in a weathertight enclosure.

3.2.2.2 Mechanical

a. The heliostat shall have an outer gimbal whose axis is horizontal and aligned to heading (TBD).

b. The heliostat shall have four mirror modules which comprise a set of inner gimbals driven by a common motor.

c. Overall size of the heliostat shall be approximately 10 feet wide x 52 feet long and (TBD) high at max. gimbal angle of (TBD).

d. The outer gimbal shall have minimum free travel of $\pm 65^{o}$.

e. The mirror modules shall have free travel of $\pm 18^{o}$ from a position of mirror normal up.

f. The mirror modules shall have a maximum imbalance about their axes of 15 lb-ft.

g. The completed heliostat shall have a maximum imbalance of 60 lb-ft.

h. Mechanical stops are required on the outer gimbal damage to the frame or foundation.

i. Shading of incoming roofs and blockage of reflected rays by heliostat drive components, frame, etc. shall be minimized.

3.2.3 Reliability

Heliostat design life shall be 30 years minimum.

3.2.4 Maintainability

a. The reflective surfaces shall be readily cleaned without degradation. Water, ice, dust, or other degrading conditions such as bird droppings on the reflective surfaces should cause no permanent damage to the reflective characteristics. The entire heliostat should be designed such that potential maintenance points can be easily reached and components such as electronic units, motors, drives, etc., readily replaced.

b. Elements subject to wear or damage should be easily inspected, serviced or replaced, or shall be designed for long life.

c. The heliostats should be serviceable by personnel of normal skills and should require a minimum of specialized equipment and tools.

3.2.5 Environmental Conditions

3.2.5.1 Operating Environments

Heliostats shall meet the performance requirements of Paragraph 3.2.1 while operating in the following environments.

Temperature: -20 to +60°C (goal)
(-4 to +140°F)
0 to +60°C (requirement)
(+32 to 140°F)

Wind sustained 13.5 m/s (30 mph)
gusts (TBD) m/s (TBD)

3.2.5.2 Non-Operating Environments

Heliostats shall meet the performance requirements of Paragraph 3.2.1 after exposure to the following environments.

Temperature: -20 to +60°C
(-4 to +140°F)

Wind sustained 25 m/s (56 mph)
gusts (TBD) m/s (TBD mph)

Humidity per TBD
Rain per TBD
Snow per TBD
Ice per TBD
Hail per TBD
Sand Storms per TBD
Earthquakes of TBD intensity

3.2.6 Transportability

Transportation of the heliostats to the plant or test site shall be subject to all pertinent federal and state transportation regulations.

3.3 Design and Construction

TBD

3.4 Documentation

TBD

3.5 Logistics

TBD

3.6 Precedence

TBD

4.0 QUALITY ASSURANCE PROVISIONS

4.1 General

A test program shall be conducted on the Heliostat to verify and analyze the design prior to integration into the system. The testing will be conducted at Aero Florida.

4.2 Responsibility for Tests

Honeywell Aero will be responsible for conducting the Heliostat tests. Detail test procedures shall be prepared to ensure that the Heliostat conforms to the requirements of this specification and the Master Test Plan.

4.3 Quality Conformance

Inspections and testing shall be used as methods of verification that the Heliostat specification requirements are complied with.

4.3.1 Inspection

Examination of the Heliostat and the parts of the Heliostat shall be conducted to verify that it meets with applicable workmanship standards, identifying nameplates are attached and correct as identified in the Master Test Plan.

4.3.2 Testing

Testing of the Heliostat will be performed on the various subassemblies to ensure that the specification requirements are complied with. The subassemblies that constitute a Heliostat assembly are the foundation, frame assembly, mirror assembly, drive system, computer interface, and battery.

4.3.2.1 Foundation

Structural testing and stability testing will be performed on the foundation to ensure that the foundation complies with all the requirements stated in this specification.

4.3.2.2 Frame Assembly

The frame assembly shall be tested for structural integrity to ensure compliance with the requirements stated in this specification.

4.3.2.3 Mirror Assembly

The mirror assembly shall be tested for structural integrity, reflectance of the mirrors, focusing techniques, pointing, and tracking accuracy to ensure compliance with the requirements stated in this specification.

4.3.2.4 Drive System

The heliostat drive system shall be tested for power consumption, electrical noise interference between circuits, driving rates while being subjected to environmental disturbances, pointing, and tracking accuracy. The drive system shall demonstrate compliance with all the electrical and accuracy requirements of this specification.

4.3.2.5 Computer Interface

The computer interface shall be tested for signal characteristics, drive capability, and signal integrity and shall demonstrate compliance with all the signal requirements of this specification.

4.3.2.6 Battery

The battery shall be tested for discharge rates under difference load conditions and environmental disturbances. The battery shall demonstrate ability to comply with the power requirements of this specification.

5.0 PREPARATION FOR DELIVERY

TBD

6.0 NOTES

TBD

10.0 APPENDIX

TBD

APPENDIX D

DETAIL SPECIFICATION

PART I

HELIOSTAT CONTROL SOFTWARE

HONEYWELL INC.
Aerospace Division

DETAIL SPECIFICATION PART I OF I

DS QG 8172A1

THIS DETAIL SPECIFICATION IS FOR

CONTRACT No. LC 403127

SOFTWARE, HELIOSTAT CONTROL

SIGNATURES	DATE
ORIGINATOR JOHN R. SCHMID	9/12/75
ACCEPTOR JOHN R. SCHMID	
APPROVED BY ROBERT S. PARKER	

REVISIONS

LTR.	DESCRIPTION	APPROVAL	DATE

F12. PT-0135 (973)

HONEYWELL INC.

Aerospace Division

DETAIL SPECIFICATION NUMBER QG 8172A1

SOFTWARE, HELIOSTAT CONTROL

1.0 SCOPE

The software described in this specification will be designed to operate on a TBD computer having 32K of memory, a reasonable instruction set, and add and multiply times of 2 and 8 microseconds, respectively. The computer must have at least 16 DMA channels capable of simultaneous independent operation. This computer with its associated software will be used to control the heliostat arrays of the Solar Collector Subsystem, YG 8112A1.

1.1 Identification

The approved identification number for this program is QG 8172A1. Additional nomenclature and authorized abbreviations will be defined by cognizant personnel as the program develops per Honeywell Aerospace Division Design Procedure No. 3.3.

1.2 Functional Summary

This program will provide control for the heliostats by computing the line of site unit vector to the sun, adding it to the known line of site unit vector from each heliostat to the receiver, and extracting, formatting, and sending gimbal commands to the heliostats, all in real time. The program will also provide calibration, status, and emergency action functions as defined in the system analysis concept.

2.0 APPLICABLE DOCUMENTS

The following documents of exact issue shown, form a part of this specification to the extent specified herein.

Honeywell Aerospace Division Design Procedures No. 3.3
Honeywell Software Standards Procedure E.O. 21627
Applicable Manuals describing the target computer

3.0 REQUIREMENTS

The computer program shall be constructed in such a fashion that 1000 heliostats can be controlled, calibrated, and monitored in a real time application. Design goals will be to service each heliostat in 0.5 milliseconds in a normal tracking mode to a gimbal command accuracy of ± 1/2 bit (± 10 arc seconds). Evidence of satisfactory system performance will be interpreted as evidence of satisfactory software operation. Documentation shall consist of high level flow charts and well documented assembly listings. No intermediate level documentation is required.

3.1 <u>Program Definition</u>

The major functions of the computer programs are.

3.1.1 Mode Control to include normal tracking, periodic calibration, offset pointing, initialization, turn-over, status, and operator interface.

3.1.2 Computation of the unit line of site vector to the sun with appropriate corrections for atmospheric refraction.

3.1.3 Heliostat command generation will compute the mirror normal vector by adding the sun vector to the heliostat unit LOS vector, normalizing, and rotating to heliostat radial coordinates. An arctangent routine will be used to extract the gimbal command angles.

3.1.4 Heliostat control angles will be generated by differencing the new command angle from the integral of the previously issued control angles. Any difference angle will be formulated into a command word to the heliostat and summed into the computers memory of control angles.

3.1.5 The calibration flow will consist of sequentially commanding each heliostat to the calibration array by first, computing the unit line of site vector based on the geometrical displacement of the calibration array from the receiver and second, use this new LOS to command the heliostat onto the array. The calibration array will be interrogated, after a suitable time delay, for the error displacement in azimuth and elevation. These errors will be projected back to the receiver and then used to update the reference LOS.

3.1.6 Offset pointing will be handled by computing a new LOS to the desired point and commanding the heliostats to direct their reflected energy there.

3.2 Detailed Functional Requirements

3.2.1 Inputs

3.2.1.1 Analog inputs consisting of:

- Ambient temperature
- Ambient pressure
- Wind speed
- Wind direction
- Solar insolation

3.2.1.2 Digital inputs consisting of:

- Operator keyboard inputs, parallel byte
- Calibration array inputs, serial data
- Plant controller inputs, serial data
- Greenwich Mean Time input, parallel BCD

3.2.2 Processing

3.2.2.1 Memory requirement is 32K 16-Bit words

3.2.2.2 Add time is ≤ 2 microseconds

3.2.2.3 Multiply time is ≤ 8 microseconds

3.2.2.4 Single precision arctangent routine with 360^{o} resolution, ≤ 100 microseconds. Two arguments will be supplied.

3.2.2.5 Single precision square root routine with a double precision input argument, ≤ 150 microseconds.

3.2.2.6 Single precision sine and cosine routine which returns both results from a single angle input in $\leq$120 microseconds.

3.2.3 Outputs

3.2.3.1 Data to operator via CRT or printer or both

3.2.3.2 Address and command word to each heliostat

3.2.4 Special Requirements

3.2.4.1 A minimum of 16 DMA channels capable of simultaneous independent operation.

3.2.4.2 An Analog-to-Digital converter suitable for converting 0 to +5 VDC signal inputs.

3.3 Adaptation

3.3.1 This software operates in a low cost, non-high rel, commercial ground power station environment.

3.3.2 System parameters, other than what have already been stated, are undefined at this writing.

3.3.3 System capacities are adequate for the stated purpose.

4.0 QUALITY ASSURANCE PROVISIONS

4.1 General

The program software shall be subjected to the following controls, examinations, and tests to assure compliance with the requirements specified in Section 3.0 herein. The testing will be conducted at Aero Florida.

4.2 Responsibility For Tests

Honeywell Aero will be responsible for conducting the software tests. Test procedures shall be prepared to ensure that the software conforms to the requirements of this specification.

4.3 Quality Conformance

The software shall be inspected and tested to verify compliance with the specification requirements.

4.3.1 Inspection

Examination of the documentation will be conducted for compliance with the specification requirements.

4.3.2 Testing

Testing will be conducted to demonstrate that the software complies with the requirements of this specification.

5.0 PREPARATION FOR DELIVERY

TBD

6.0 NOTES

TBD

10.0 APPENDIX 1

TBD

APPENDIX E

DETAIL SPECIFICATION

PART I

CALIBRATION ARRAY

HONEYWELL INC.
Aerospace Division

DETAIL SPECIFICATION PART I OF I

DS LG 8015A1

THIS DETAIL SPECIFICATION IS FOR

CONTRACT No. LC 403127

CALIBRATION ARRAY

SIGNATURES	DATE
ORIGINATOR R. E. YOUNSKI/R. R. SNYDER	9/12/75
ACCEPTOR R. E. YOUNSKI/R. R. SNYDER	
APPROVED BY R. S. PARKER	

REVISIONS

LTR.	DESCRIPTION	APPROVAL	DATE

F12. PT-0135 (973)

HONEYWELL INC.

Aerospace Division

DETAIL SPECIFICATION NUMBER | LG 8015A1

CALIBRATION ARRAY

1.0 SCOPE

The purpose of this specification is to provide the optical, electrical, and mechanical requirements for the design of the Calibration Array, LG 8015A1, a part of the Solar Collector Subsystem, YG 8112A1. The array will be used to provide a means of measuring certain characteristics of a re-directed beam of solar energy. The measurements will be used to provide calibration data to the Heliostat control system.

2.0 APPLICABLE DOCUMENTS

The following documents, of exact issue shown, form a part of this specification to the extent specified herein.

Specifications:

Federal (TBD)
Military (N/A)
Honeywell (TBD)

Standards:

Federal (TBD)
Military (N/A)
Honeywell (TBD)

Drawings:

TBD

Bulletins:

TBD

Other Publications:

Manuals (TBD)
Regulations (TBD)

3.0 REQUIREMENTS

The equipment shall provide the means to make a measurement of the energy centroid of a concentrated beam of re-directed solar energy. The equipment will be exposed and mounted to a tower some 80 feet in the air. Equipment design life is expected to be 30 years.

3.1 Item Definition

The calibration array shall accept a beam of concentrated solar energy and provide two outputs corresponding to a measurement of the horizontal and vertical energy centroid with respect to the array mid-point. The outputs shall be in serial digital form.

Major components are:

a. Light sensors

b. Interface electronics

c. Support structure

3.2 Characteristics

3.2.1 Performance Characteristics

3.2.1.1 Input Flux Requirements

3.2.1.1.1 Incident Signal Level Range: (TBD) to (TBD) mw/cm^2

3.2.1.1.2 Incident Background Level Range: (TBD) to (TBD) mw/cm^2

3.2.1.1.3 Incident Signal-To-Background Ratio: (TBD) minimum

3.2.1.1.4 Maximum Incident Input Level: (TBD) mw/cm^2

3.2.1.1.5 Spectrum Of Incident Power: Typical Solar Spectrum

3.2.1.1.6 Input Spot Shape: Irregular

3.2.1.1.7 Input Spot Area: (TBD) square feet maximum at 50% sig.

3.2.1.1.8 Maximum Energy Displacement From Center Of Array: 6 feet maximum

3.2.1.1.9 Input Level Intensity Profile: (TBD)

3.2.1.2 Input Power Requirements

3.2.1.2.1 Voltage: +15 VDC ± 3% @ 100 ma maximum

3.2.1.2.2 Voltage: +5 VDC ± 3% @ 250 ma maximum

3.2.1.2.3 Voltage: -12 VDC ± 3% @ 100 ma maximum

3.2.1.3 Output Signal Requirements

3.2.1.3.1 Number Of Outputs: Two, representing a measurement of the enery centroid about the horizontal and vertical axes

3.2.1.3.2 Centroid Axis Reference: Center of array

3.2.1.3.3 Output Form: Digital Serial

3.2.1.3.4 Data Word Length: 7-Bits + Sign.

3.2.1.3.5 Output Level: 5V Differential

3.2.1.3.6 Load: Twisted shielded pair loaded with line receiver

3.2.1.4 Dimensional Stability

The mechanical support of the array shall not allow movement of sensors from an initial location defined as (TBD) by more than the values stated below in the presence of the operating environments of Paragraph 3.2.5.

Vertical	± 0.5 inch
Horizontal	± 0.5 inch*
Radially from Tower	± 1.0 inch

*in plane of array

3.2.1.5 Structural Integrity

The mechanical support shall not move more than the values stated in Paragraph 3.2.1.4 after exposure to the non-operating environments of Paragraph 3.2.5.

3.2.2 Physical Characteristics

3.2.2.1 Size

The calibration array shall be 12 x 12 feet.

3.2.2.2 Sensor Location

Each array shall contain (TBD) sensors mounted (TBD) centers.

3.2.2.3 The axes of the sensors shall be oriented per (TBD).

3.2.2.4 Tower Interface

The mechanical support shall provide means for attachment to the tower to meet the requirements of Paragraph 3.2.1.4 and Paragraph 3.2.1.5.

3.2.3 Reliability

TBD

3.2.4 Maintainability

3.2.5 Environmental Conditions

3.2.5.1 Operating Temperature

$-20^{o}C$ to $+60^{o}C$

3.2.5.2 Non-Operating Temperature

$-20^{o}C$ to $+60^{o}C$

3.2.5.3 Operating Wind

0 - 30 mph

3.2.5.4 Non-Operating Wind

0 - 120 mph

3.2.5.5 Operating Solar Flux Intensity

TBD $\left(\frac{\text{Watts}}{\text{Sq. Meter}}\right)$

3.2.5.6 Earthquake Of Intensity

TBD (as modified by tower frequency response)

3.2.6 Transportability

TBD

3.3 Design And Construction

TBD

3.4 Documentation

TBD

3.5 Logistics

TBD

3.6 Precedence

TBD

4.0 QUALITY ASSURANCE PROVISIONS

4.1 General

The Calibration Array shall be subjected to the following controls, examinations, and tests to assure compliance with the requirements specified in Section 3.0 herein. The testing will be conducted at Aero Florida.

4.2 Responsibility For Tests

Honeywell Aero will be responsible for conducting the Calibration Array tests. Detail test procedures shall be prepared to ensure that the Calibration Array conforms to the requirements of this specification and the Master Test Plan.

4.3 Quality Conformance

The Calibration Array shall be inspected and tested to verify compliance with the specification requirements.

4.3.1 Inspection

Examination of the Calibration Array will be conducted for compliance with all mechanical requirements in this specification.

4.3.2 Testing

Testing will be conducted to demonstrate that the Calibration Array complies with the electrical requirements in this specification.

5.0 PREPARATION

TBD

6.0 NOTES

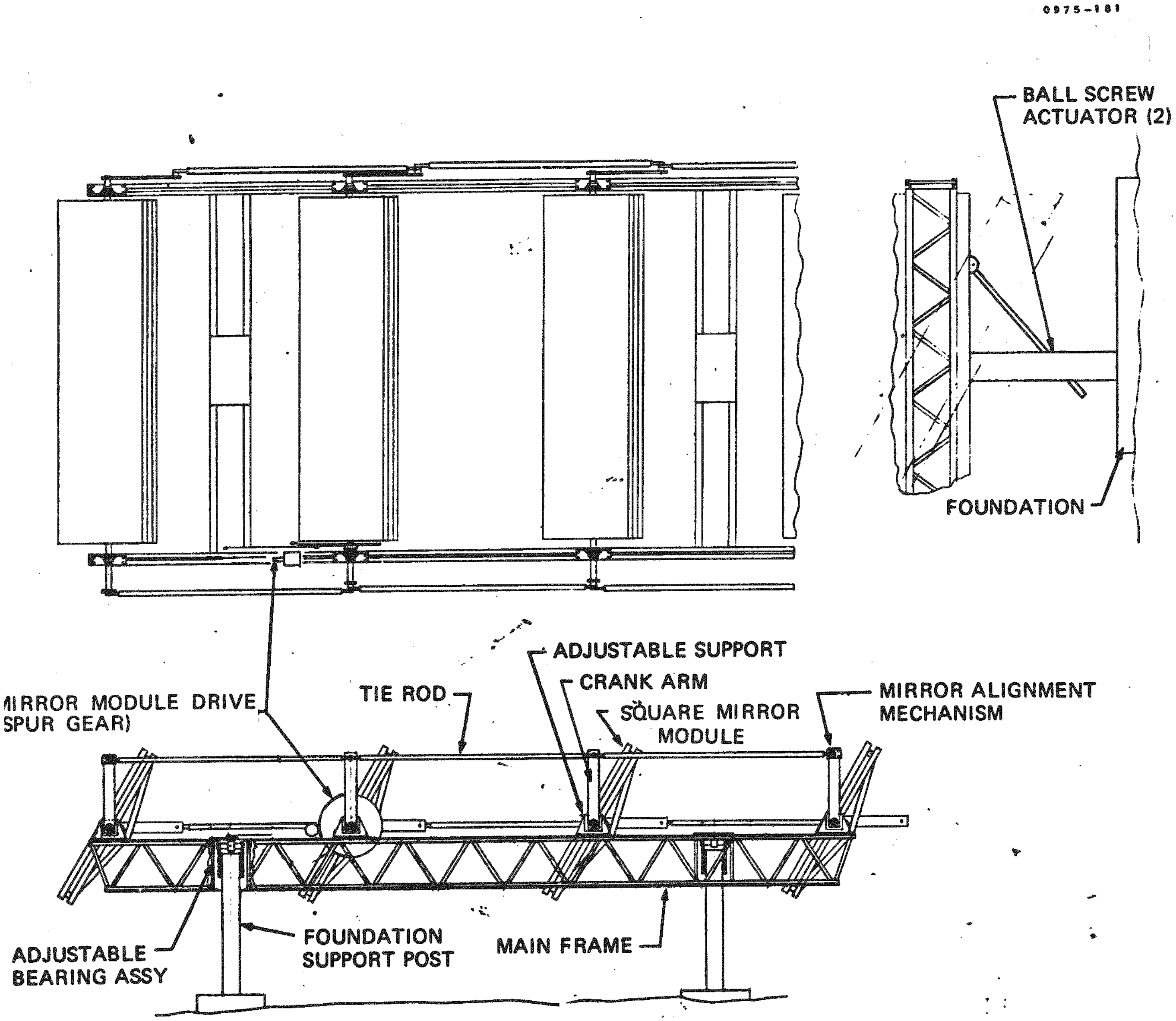
TBD

10.0 APPENDIX 1

TBD

Appendix F

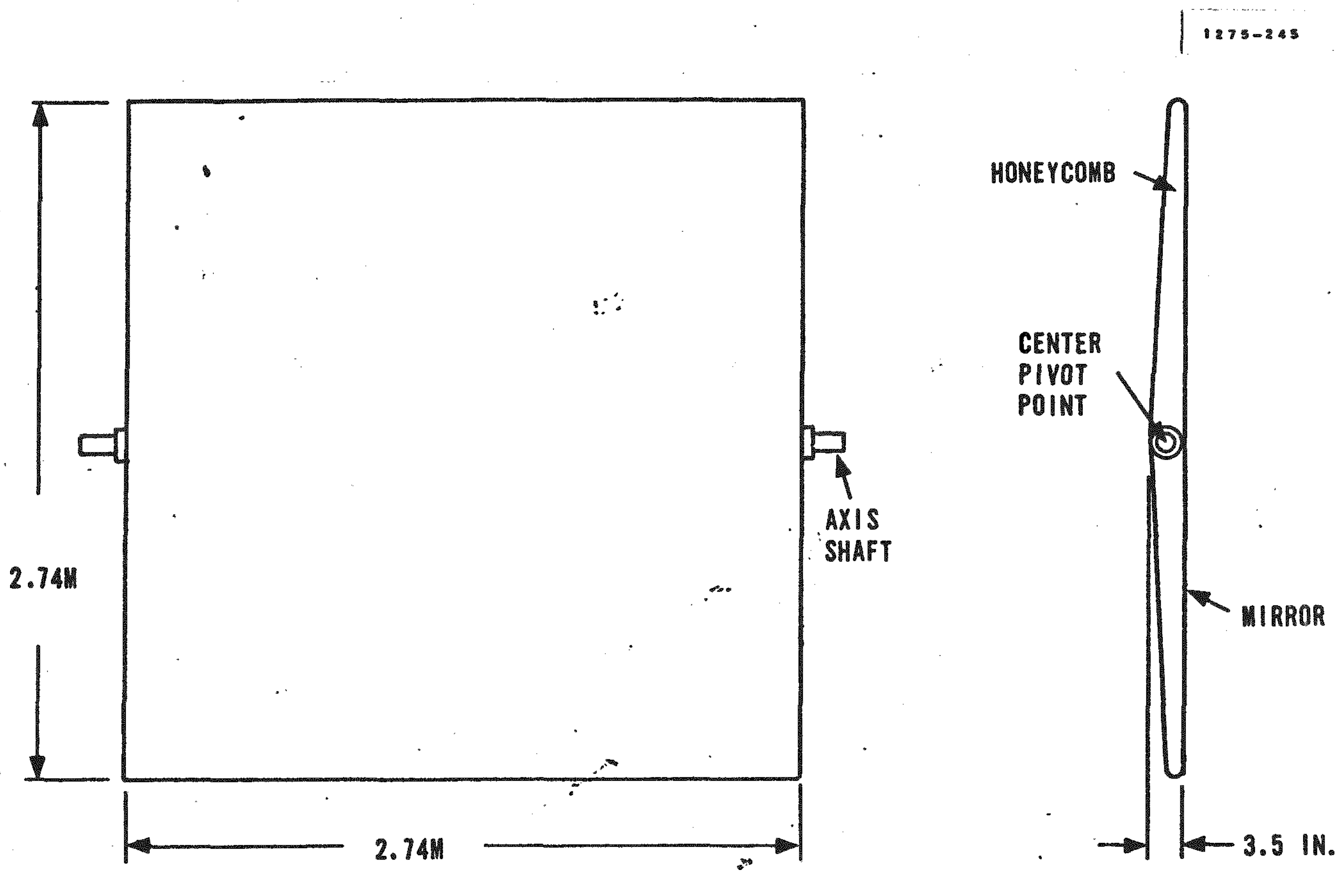
OUTER GIMBAL AND DRIVE ASSEMBLY.



PRELIMINARY CONFIGURATION HELIOSTAT CONCEPT

Appendix G

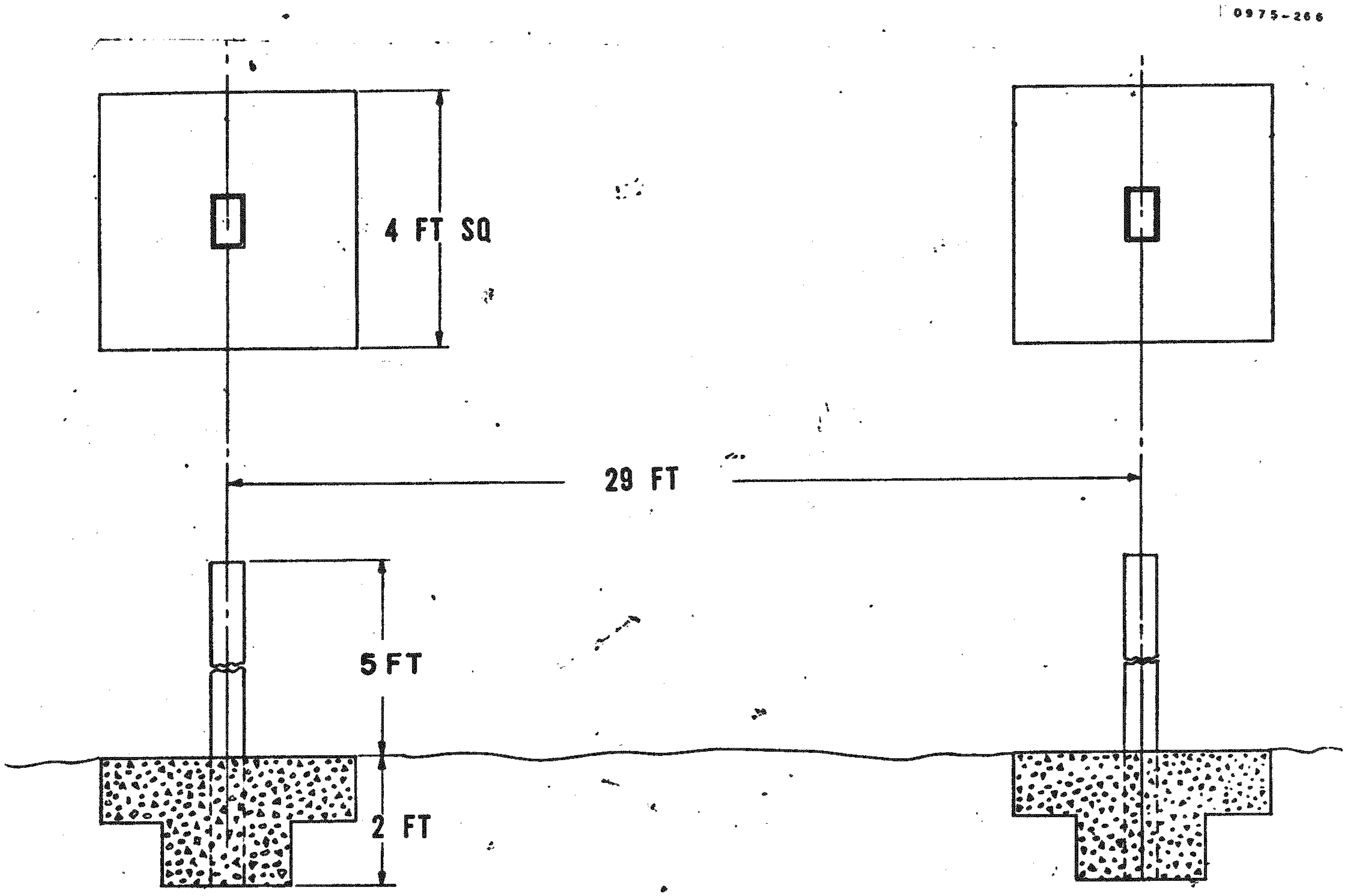
MIRROR MODULE ASSEMBLY



PRELIMINARY CONFIGURATION MIRROR MODULE

Appendix H

HELIOSTAT FOUNDATION



PRELIMINARY CONFIGURATION HELIOSTAT FOUNDATION