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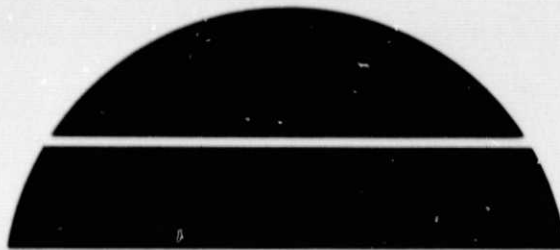
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SOLAR TRACKING CONTROL SYSTEM "SUN CHASER"

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16. ABSTRACT The solar tracking control system ('Sun Chaser') is believed to be an improved method of tracking the Sun in all types of weather conditions. The Sun Chaser will follow the Sun from east to west in clear or cloudy weather, and reset itself to the east position after sundown in readiness for the next sunrise. A description of the Sun Chaser hardware and its operation together with results is presented.					
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TECHNICAL MEMORANDUM

SOLAR TRACKING CONTROL SYSTEM "SUN CHASER"

I. INTRODUCTION

The utilization of solar energy from solar collectors has created a need for a simple and reliable solar tracking control system that can locate and track the Sun's position and consequently point concentrating type solar collectors toward the Sun in the presence of all normal atmospheric conditions such as clear, haze, cloudy, and partly cloudy skies. For maximum efficiency solar collectors should remain Sun oriented through any type of atmospheric condition. Other existing solar tracking control systems do not adequately follow the Sun in cloudy or partly cloudy weather and thus the performance of the collecting system has not operated as efficiently as expected.

The purpose of this report is to describe a simple solar tracking control system called the "Sun Chaser" designed to point toward the Sun in clear weather and to point in the near vicinity of the Sun when it is obscured by clouds or haze.

II. APPLICATION

The Sun Chaser components consist of a silicon solar cell light sensor module, a solid-state electronic control assembly module, and an electric motor (Fig. 1). The purpose of the Sun Chaser is to detect the sunrise, to initiate either tracking or pointing commands, to activate a motor, and to initiate a reset drive command at sunset. Tracking is defined as following the Sun's apparent movement by sensing light directly from the Sun generating an error signal, and mechanically driving the sensor in small discrete steps to reduce the error to zero. This in essence locks the sensor onto the Sun position. Pointing is defined as the capability of the Sun Chaser control system to follow the Sun position, even though obscured by clouds, utilizing timing pulses approximately the same duration as the tracking pulses used to drive the system, but with less accuracy than when tracking. Pointing is obtained by means of signals generated by an internal pulse generator. The solar flux level dictates the mode of operation, i.e., tracking, pointing, or nighttime reset is selected based on the instantaneous light intensity on the solar sensor cells. The Sun Chaser was

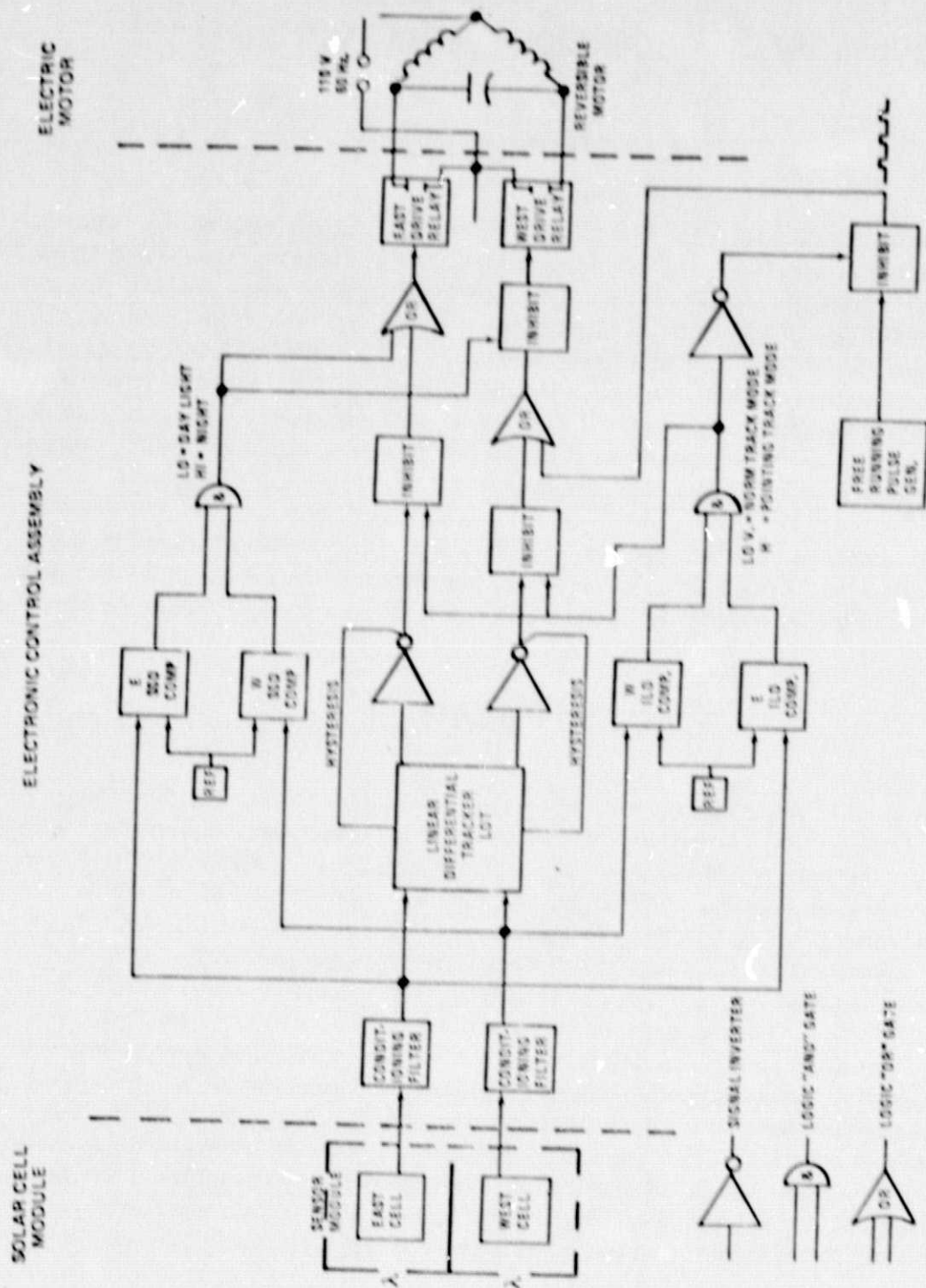


Figure 1. Sun Chaser solar tracker.

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designed specifically to provide the drive control logic and voltages necessary to maintain an accurate Sun orientation of tracking solar collectors and may be used in any solar tracking application with the following requirements:

- a) Automatically acquire and track the Sun with an accuracy of typically 0.25 deg.
- b) Continual automatic pointing toward the Sun even though the Sun may be obscured by clouds or haze with automatic reacquisition to the Sun tracking mode when the Sun is not obscured.
- c) Automatic nighttime "reset to east" capability.

The Sun Chaser may be utilized to track the Sun in either elevation or azimuth.

III. DISADVANTAGES OF PRESENT SUN TRACKERS

Sun trackers presently used include solar cell sensors, electronic circuitry, and electric motors. These trackers are generally similar to the Sun Chaser described herein. They perform well in very clear skies with a bright Sun, but will not continue to point toward the Sun under cloudy conditions. A wide field-of-view (FOV) of approximately 180 deg is necessary on these Sun trackers because they are continually acquiring or reacquiring the Sun following a period of haze or cloud cover. The required wide FOV makes the sensor overly sensitive to variations in scattered light levels, especially from bright clouds within its FOV. This characteristic can cause the tracker to acquire and track the cloud and especially to be led away from the Sun by a cloud that has passed the Sun (i.e., the Sun track gives way to a cloud track). These trackers will also acquire and track holes in cloud coverage.

IV. MODE OF OPERATION

A. Sun Sensor

The Sun sensor consists of two 0.5×1.0 cm silicon solar cells mounted in an enclosure and positioned in a plane normal to direct Sun rays when the sensor is being used. The cells are positioned on each side of a partition under translucent windows (Fig. 2). The translucent windows are sized and positioned over the cells to form the acquisition and tracking apertures of the detector.

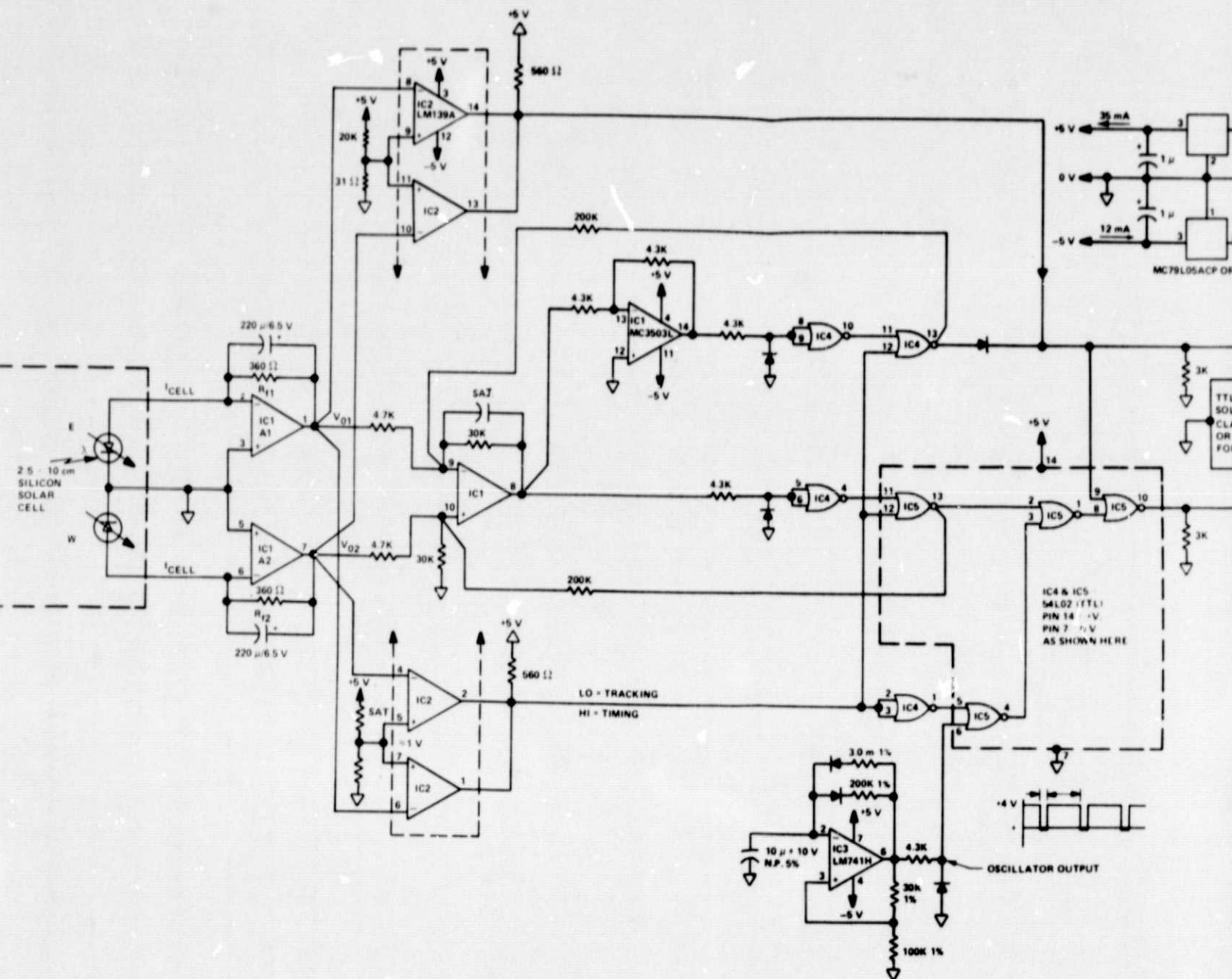
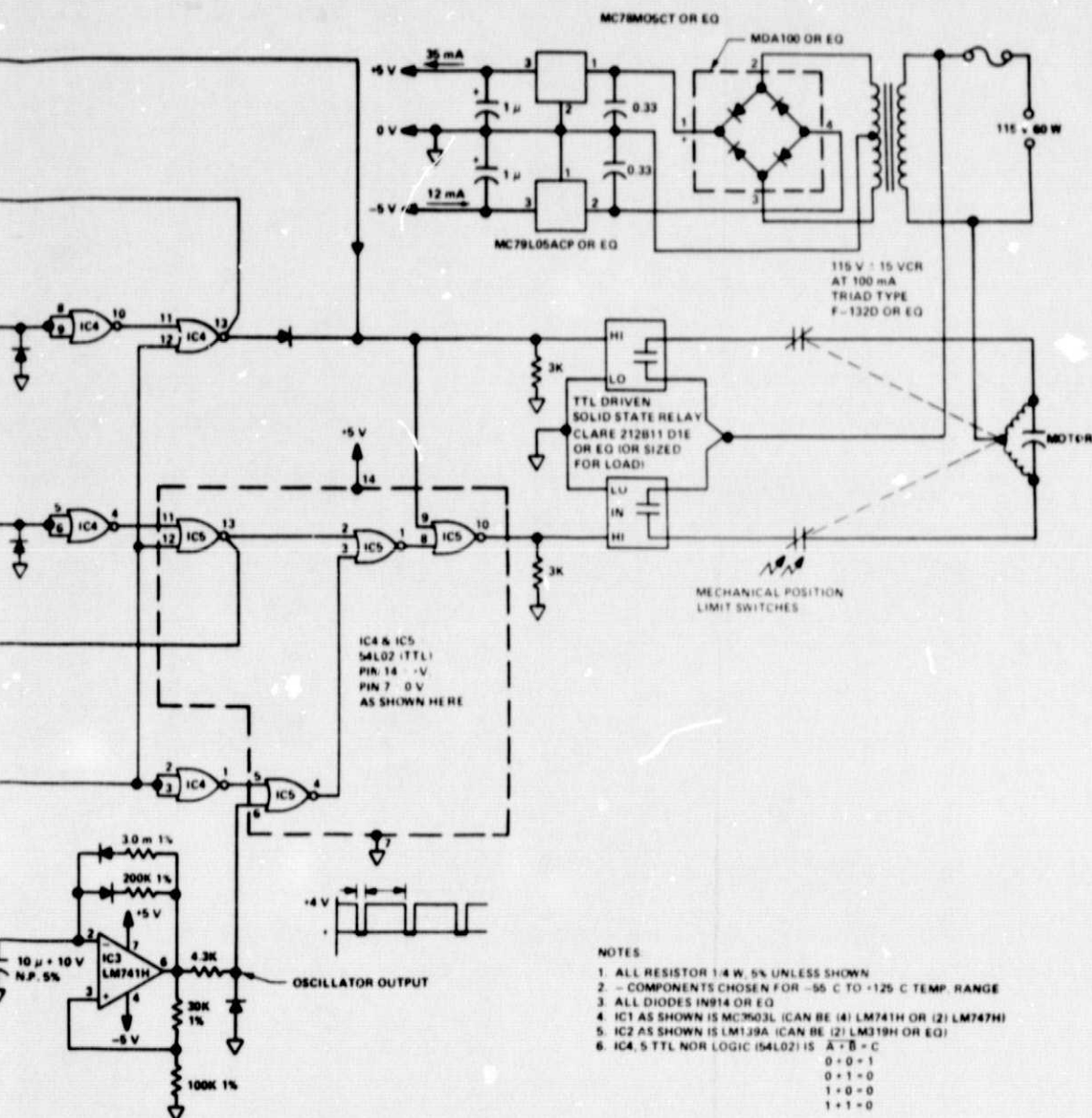


Figure 3. Sun Chaser solar tracker electrical schematic.



cal schematic.

The greatest angle required for acquisition will occur between the time the morning light passes the daylight threshold and the time the flux intensity is high enough for acquisition and track to begin. This time can range from a few minutes (very clear early morning light) to all day (no Sun). Normally a full day of pulsing (no acquisition) will create less than a 5 deg error angle. This will be a function of the winter/summer temperatures and its effect on the repeatability of the drive system.

The inside of the module is black to increase the sensors selectivity to incident light. Scattered or nondirectional light raises the level of the sensors outputs but cannot be used in direction determinations. Since the magnitude of the light is used to determine the mode of operation, it is important that the scattered light be kept to a minimum. The small apertures reduce the scattered light effect from bright clouds near the Sun. This type cloud in the vicinity of the Sun can create an unbalance in the sensor output which would result in erroneous pointing if the electronic circuit did not recognize and discriminate against these false targets (Section IV.B).

The outside of the module is white to reduce the Sun's heat on the module. Silicon cells were chosen for their wide light bandwidth and their stability in extreme temperature environments.

The cell sizes were chosen because of their commercial availability and because they are the largest size a standard operational amplifier (LM 741) can load into. (The cells are power generating devices.)

A clear window material is used as a cover to the enclosure to protect the wiring and to prevent atmospheric contamination of the cells. This window can also be a polarized or infrared filter to increase the light wavelength selectivity of the cells.

B. Electronic Control Assembly

The electronic control circuitry module (Fig. 4) contains microelectronic components (amplifiers, comparators, oscillators, and TTL logic gates), two solid-state relays (TTL to 115 V, 60 Hz), power supply (115 V, 60 Hz to ± 5 Vdc), printed circuit board, and miscellaneous components (resistors, diodes, capacitors, wires, and fuses) integrated together to perform the following functions:

- 1) Condition the solar cell output signals to compatible levels and linearize the voltage for the rest of the assembly.

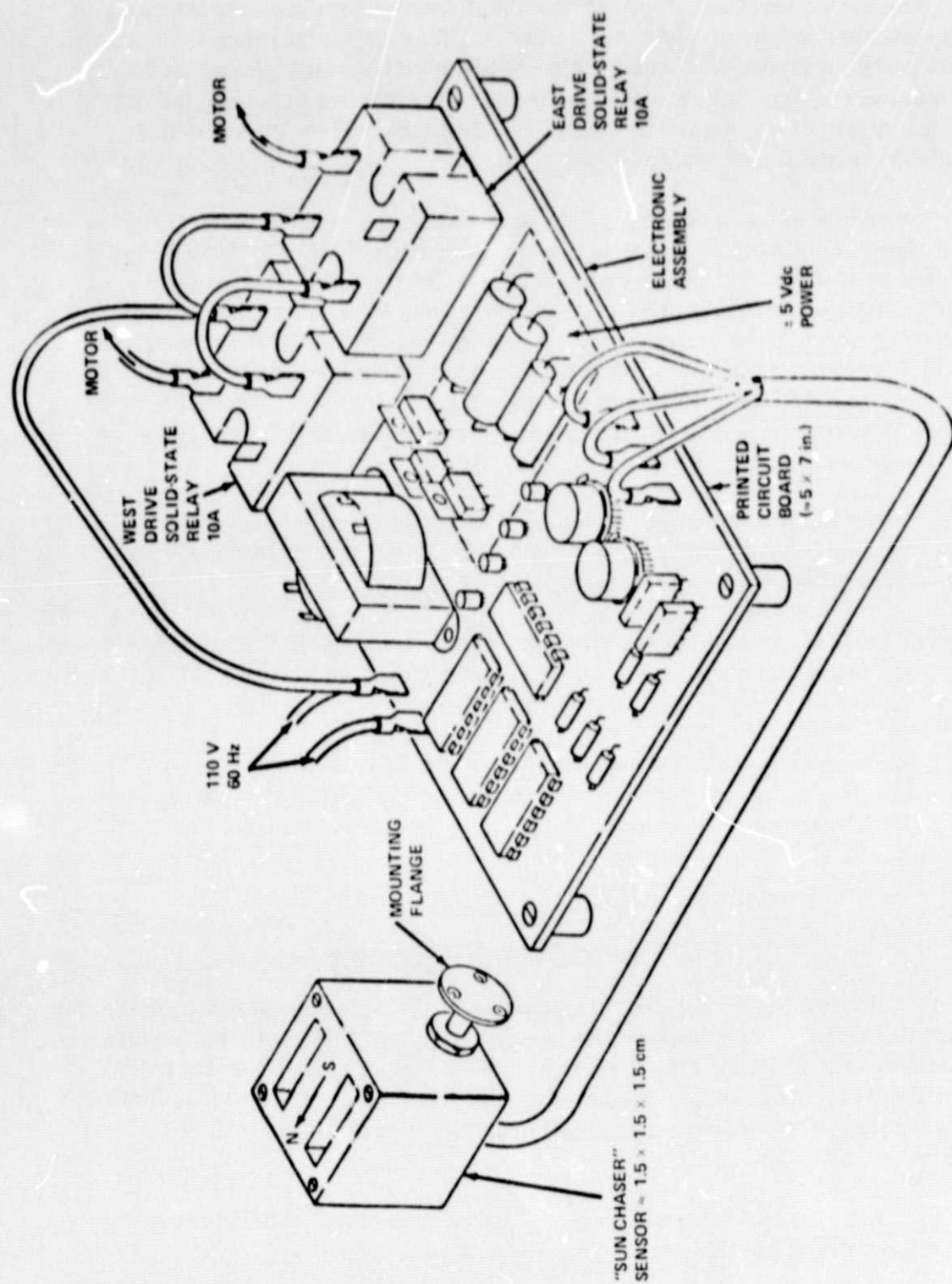


Figure 4. Sun Chaser assemblies.

2) Determine when the sensed light levels are for a nighttime, a cloudy or haze daytime, or a bright sunny condition and initiate necessary corresponding commands. For example, when the light level on both cells drops below a predetermined level indicating night, the circuit initiates a "reset to east" drive command. When the light intensity rises above the night threshold (indicating low-daylight), the circuitry responds by generating a timing sequence in which the motor is pulsed in approximately the same timed intervals as though tracking the Sun. When the sunlight on both cells increases to a track level (high-daylight), the circuit changes to a linear drive state and the system will drive east or west until Sun acquisition is attained and then pulse periodically as necessary to track the Sun thereafter. The circuitry will create drive commands only as necessary to maintain an error angle less than 0.25 (typical) deg between the tracker and the Sun and will not track cloud movement.

C. Circuit Operation

The signal conditioning amplifiers A1 and A2 invert, linearize, and amplify the solar cell outputs to levels compatible with those needed by the other circuit functions. This is done by selecting the feedback resistor (R_f) to give the desired output voltage swing (V_o) for the greatest anticipated solar flux incident on the full area of each cell; i.e., $V_o = I_{\text{cell}} R_f$ (Fig. 3). Since the amplifier must deliver the cell current (I_{cell}) through the feedback resistor R_f , the amplifier and its power supply must be chosen to adequately handle the power generated by the cells to achieve linear operation. The 0.5×1.0 cm cells were the largest silicon solar cell area recommended to be power compatible with conventional operational amplifiers of the LM741 type.

The outputs of A1 and A2 are each fed to three circuit functions: (1) sunset detector (SSD), (2) intermediate light detectors (ILD), and (3) linear differential tracking circuit (LDT).

The SSD circuit is a dual comparator connected to compare the linearized cell voltages, V_o , of each cell with a fixed voltage level. The fixed voltage level (approximately 10 mV) simulates a level of light representing sunset or nighttime. The dual comparators are connected in a manner that requires light levels on both solar cells to be below the threshold for the output to go into a high voltage state. When this condition is met, a constant east motor drive is initiated through the solid-state power relay and all other circuit functions are inhibited by the TTL

"NOR" gates. The motor then drives the collectors and sensor back to the east direction until a mechanical actuated limit switch opens the motor circuit. The system is then in a "sunrise" orientation. There is also a mechanical limit switch on the extreme west side of the drive to open the circuit and stop the west drive at about the sundown position for safety purposes.

The ILD circuit is activated when the light intensity is above night and below a high daytime intensity. When the morning light increases above the toggle point of the SSD comparators, its output changes state (back to low) and the normal low daytime ILD threshold is passed. At this time both sensors are below a light level required for track and are, thus, in the area designated as "intermediate." In this area, the ILD circuit inhibits the linear west and night drive signals and releases the pulse generator output to the west drive motor relay. The motor will be pulsed by the internal generator at essentially the same rate (Earth's rate) as though it were locked to the Sun. This will continue until both cells are receiving tracking level incident light. At this time (day high), the ILD circuit output goes to a high state, the pulse generator output is inhibited, and the linear drive inhibit is released. Since the Sun will be well within the acquisition angle of the detector, the system will then drive in the direction (east or west) necessary to acquire and null on the Sun. The circuit will continue locked on the Sun unless interrupted by clouds or nightfall.

In the LDT operation, the motor drives in pulsed intervals. The circuit is designed to pulse only long enough to reduce the error voltage to zero and, consequently, the Sun error to zero. The off time, which is a function of light intensity, represents the time it takes the Sun to move approximately 0.25 deg and is approximately 1 min. The circuit has hysteresis to optimize the motor on/off time to prevent rapid on/off cycling and unnecessary wear on the motor. Since the comparators are comparing the light level of both cells simultaneously, the system discriminates against following a bright cloud that may pass the Sun. This occurs because the passing cloud may cause one cell level to drop its output below the ILD threshold and, thus, will cause the system to instantly change from a tracking to a pointing mode. In this mode the motor is, as stated previously, time-pulsed westward until the clouds are clear of the Sun.

D. Power Supply and Motor

The 115 V, 60 Hz power circuit consist of TTL logic and compatible solid-state relays sized for the motor load. This type relay was chosen due to the large number of on/off power switches to the inductive motor load.

The ac motor is sized for load requirement and its ability to operate in outside winter/summer environment.

Wide temperature range (mill spec) electronic components must be selected if they are to be operated in an outside uncontrolled temperature environment.

V. TEST RESULTS

Figure 5 shows a typical response of the Sun Chaser control system to both clear and cloudy conditions. Channel 1 represents solar intensity, Channel 2 the differential error signal from the solar sensor, and Channel 3 the pulsing or command to the electric motor which is generated by a timing pulse or by the error signal. The data for the figure were taken on May 24, 1978 in the afternoon.

Note the periodic error signal to the extreme left and right of the chart on Channel 2. This corresponds to high solar intensity (see Channel 1), i.e., no clouds over the Sun and the control system in the tracking mode. The area in between indicates mostly low solar intensity, clouds covering the Sun, which is recognized by the Sun Chaser and the pointing mode takes over. In the pointing mode, the timing pulses continue to point the sensor toward the Sun as evidenced by the small error signal on Channel 2.

VI. CONCLUSION

Much of the world's atmosphere consists of combinations of clear, hazy, solid cloud, and broken cloudiness with intermittent sunshine. It is desirable to have a solar tracker/pointing system that will always point in the direction of the Sun regardless of cloud cover. The Sun Chaser accomplishes this by locking on the Sun in clear weather, continuing to point in the Sun's direction based on an internal timer when the Sun is obscured by clouds, and then automatically relocking on the Sun when it is visible again. The system automatically resets to the east at sundown to wait for the next sunrise. It is believed that the Sun Chaser offers the best alternative solutions to the heretofore unsolved problems of solar tracking control systems, especially for those used on concentrating collectors in solar heating and cooling systems.

In addition to its improved tracking capability, the Sun Chaser would be very competitive from the standpoint of economics, size, and operation compared with presently used trackers.

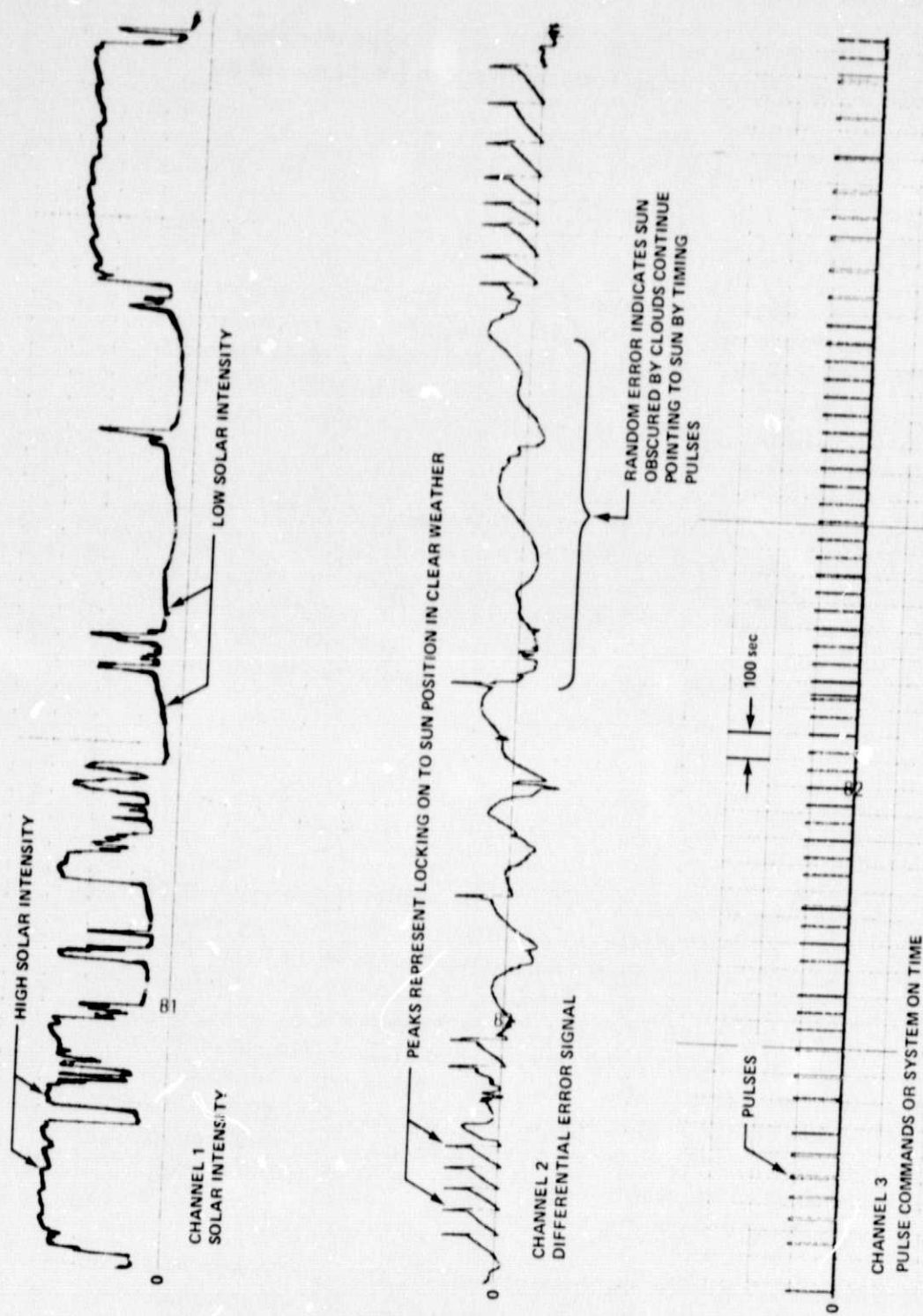


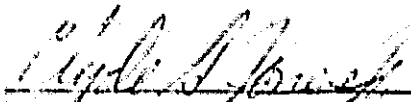
Figure 5. Test results.

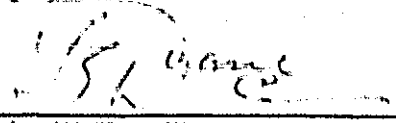
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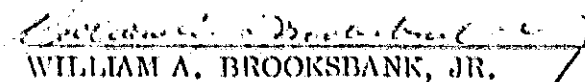
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