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## DOE/NASA TECHNICAL MEMORANDUM

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### SOLAR TRACKING CONTROL SYSTEM "SUN CHASER"

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Solar Energy

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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. DESCRIPTION/APPLICATIONS

The purpose of the "Sun Chaser" Controller is: (1) to detect a daylight condition and initiate a tracking or pointing drive command to the gimbal motor, and (2) to detect an end-of-day condition and generate an east drive (reset) command. The components of the system are a silicon light sensor, an electronic control module (solid state), and an electric motor.

The system automatically operates in one of four control modes initiated by the instantaneous solar flux falling on the sensor. The modes are tracking, pointing, resetting, and parked. These modes are initiated only when both cells of the sensor simultaneously read the same predetermined light levels.

For example, if both cells detect a high level of flux, such as would result from a clear sunlight condition, the tracking mode is initiated. If one or both of the cells sees a lower threshold, indicating a cloud obstruction, etc., the system reverts to the pointing mode. When the light on both cells drop below a level predetermined to be twilight (dusk) the system will initiate a reset mode. In this mode the motor is driven until the sensor is aimed toward a sunrise position. At this time the east mechanical limit switch opens and the motor remains in the parked mode position until daylight arrives. The definition of tracking and pointing is as follows:

a) Tracking — That mode in which the controller sensor detects an angular difference between the Sun and the sensor and generates a proportional error signal. This error signal, when processed, becomes a motor drive command so as to reduce the error to zero. Thus, tracking is a Sun acquiring and locking mode.

b) Pointing — In the pointing mode an internal oscillator constantly generates a pulse train which, when released by the logic circuits, becomes motor drive commands. This pulse train is shaped to duplicate a typical tracking pulse train. Thus the system will, once synchronized, remain Sun oriented even though there may be cloud obscurations.

The circuitry instantaneously reverts from one mode to another as atmospheric conditions change.

The acquisition apertures of the Sun Chaser are designed to be relatively small angles, but once oriented the system should maintain a constant synchronized cycle with the Earth's rotation. For design reasons it is important to establish realistic threshold levels that initiate the early morning, tracking, pointing, and nite-time reset operate conditions. Since the drive motor and gear ratios are chosen for a specific system application, certain select-at-test components must also be chosen to create a final collector drive rate the same as that of the Earth's rotation ( $0.25^\circ/\text{min}$ ). These components are shown in Figure 2.

The circuitry contains two manual drive switches for initial collector orientation, etc. These are shown as the east and west reset switches on Figure 2.

### 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.

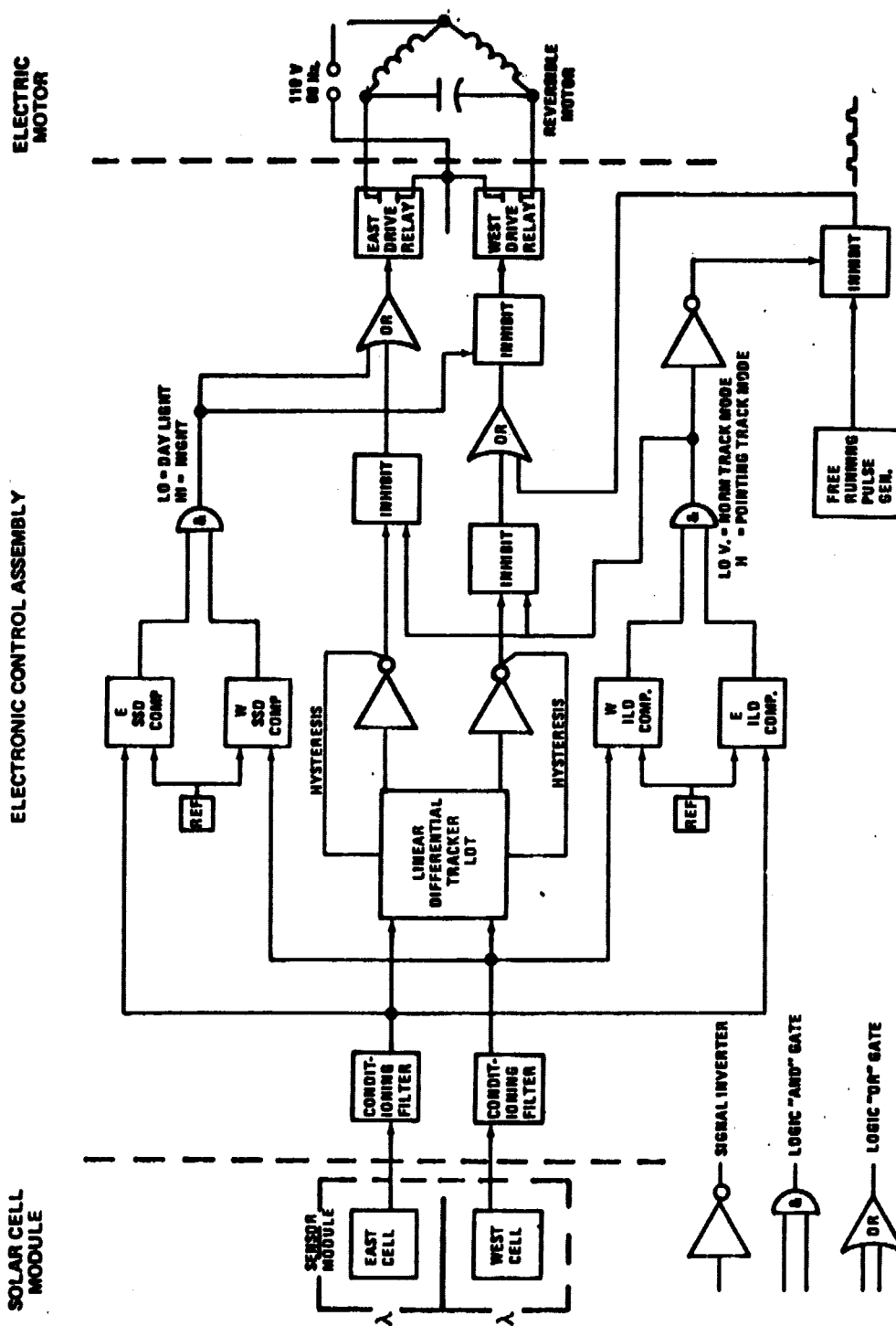


Figure 1. Sun Chaser solar tracker.

## IV. MODE OF OPERATION

### A. Sun Sensor

The Sun sensor consists of two  $0.5 \times 1.0$  cm silicon solar cells mounted in an enclosure and positioned in a plane normal to direct Sun rays. 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. The sensor module is designed to receive direct sunlight on exactly one-half the area of each cell when the sensor is centered on the Sun while the other half of each cell is shadowed. As the sensor is tilted, or as the Sun moves westward, the exposed area of the west cell increases and the east cell decreases simultaneously. This area change is directly proportional to the angular movement of the Sun. The arrangement of the cells is designed to obtain a linear output to  $\pm 5$  deg Sun angle.

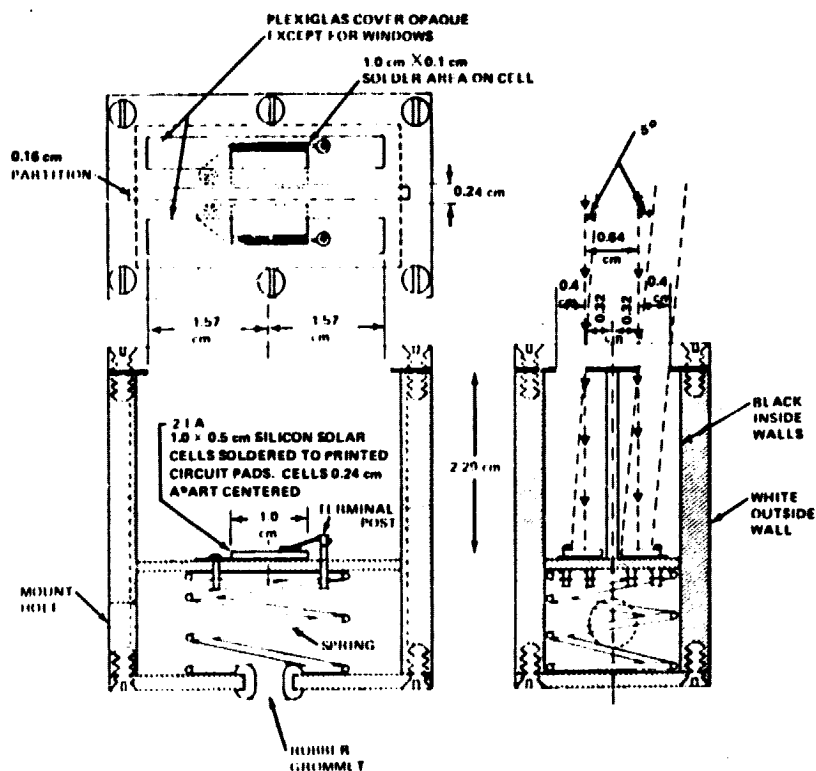


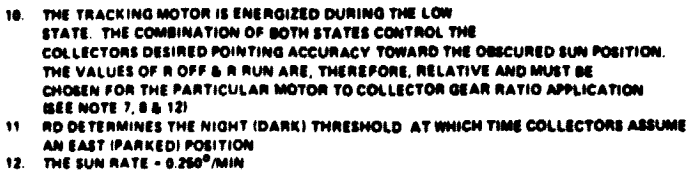
Figure 2. Sun Chaser sensor.

A solar cell is a current generating device and its output is proportional to the exposed area and the light flux on the area. The voltages across the cells are a nonlinear function of the light intensity, and, thus, these currents must be converted to voltages for the devices to be used as linear light position sensors. In this system, the conditioning of the current is done by input amplifiers A1 and A2 (Fig. 3).



7. \* VALUES MUST BE SELECTED FOR PARTICULAR MOTOR TO COLLECTOR GEAR RATIO APPLICATION
8. ALL COMPONENT VALUES SHOWN ON THIS DRAWING ARE FOR A SYSTEM WITH  $\approx 6$  SEC. RUN TIME,  $\approx 65$  SEC PAUSE TIME, WITH A 3200 RPM MOTOR, AND 448,000 1 MOTOR TO COLLECTOR GEAR RATIO
9. SELECT RT SO THAT AT DESIRED SUN OBSURATION THE SYSTEM WILL POINT BY RELEASING THE GENERATED PULSE TRAIN TO THE MOTOR

FIGURE 3 "SUN CHASER" TRACKER MODEL ONE ELECTRICAL  
ENGR. PAUL WHITE'D SCOTT



TRACKER MODEL ONE ELECTRICAL SCHEMATIC  
BY PAUL WHITEID SCOTT

The sensor module is designed to receive only incident light, and for purpose of acquisition, the window opening is such that a  $\pm 5$  deg Sun angle (away from the plane of the partition) will still impinge on 100 percent of the respective cell area. A further increase in Sun angle will decrease the area until at  $\pm 15$  deg the cell will be totally shadowed.

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  $\pm 5$  Vdc), printed circuit board, and miscellaneous components (resistors, diodes, capacitors, wires, and fuses) integrated together to perform the following functions:

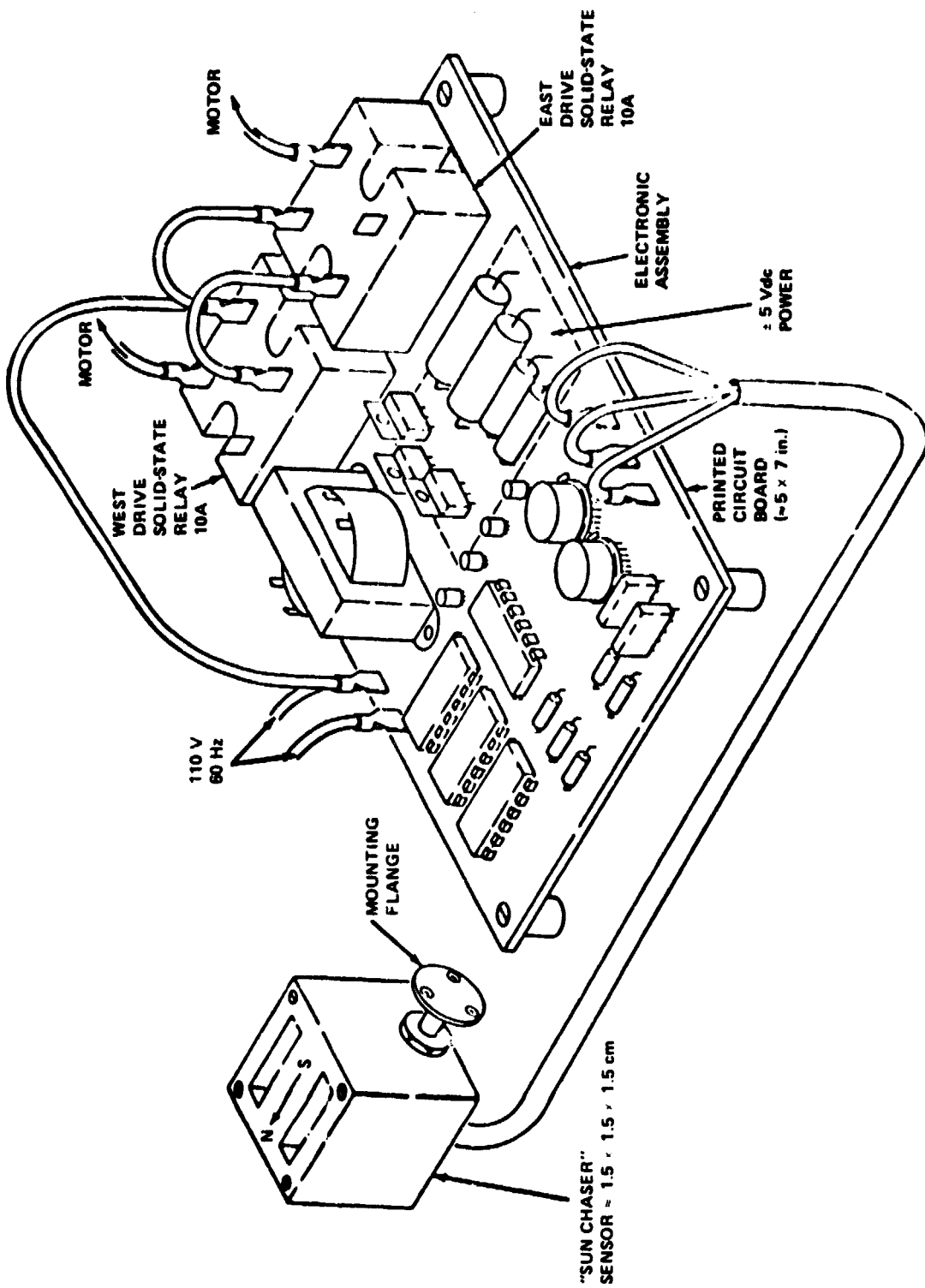


Figure 4. Sun Chaser assemblies.

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

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 ( $I_{\text{cell}}$ ) 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  $0.5 \times 1.0$  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

"NO1." 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 (mil 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.

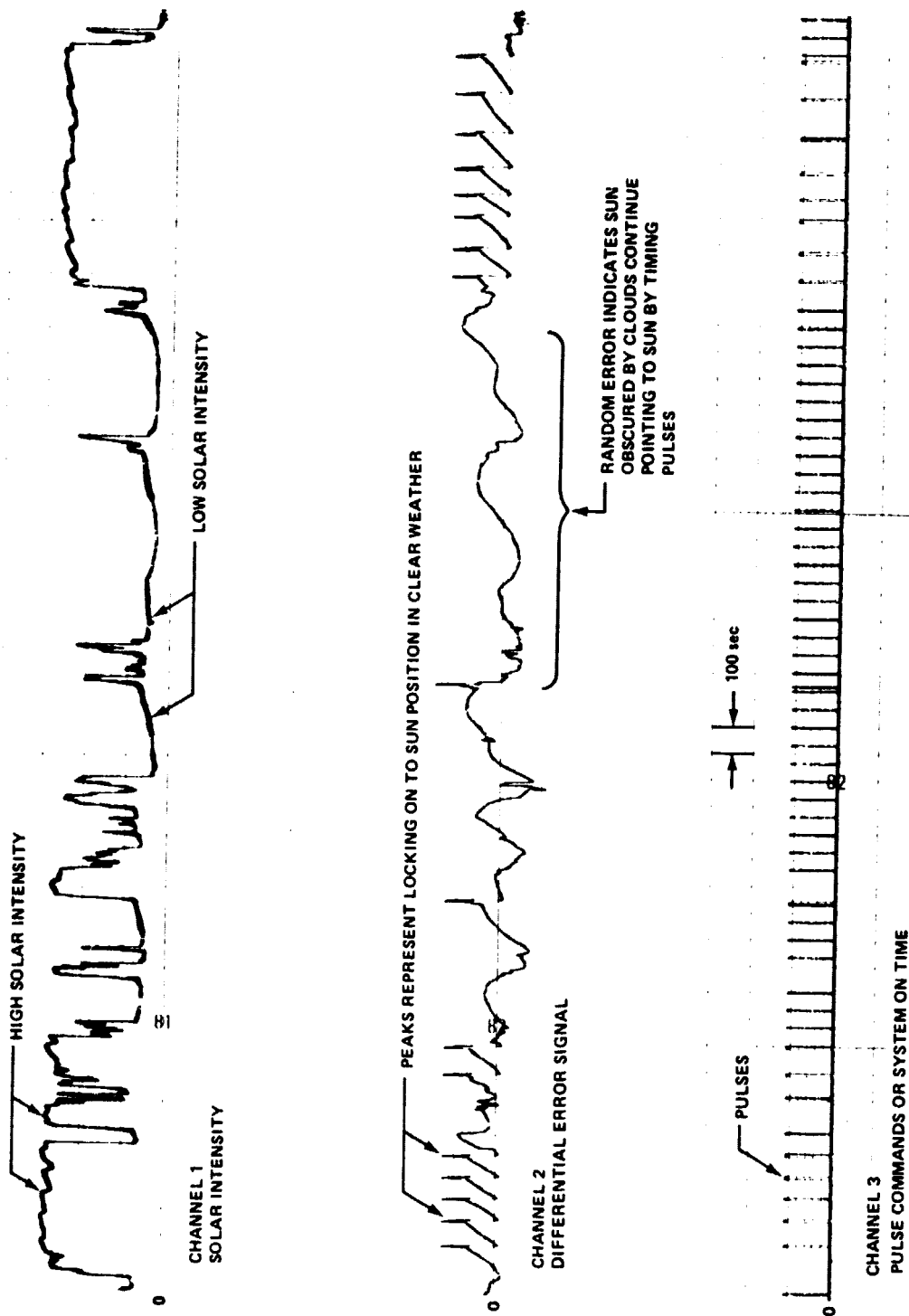


Figure 5. Test results.

## APPROVAL

### SOLAR TRACKING CONTROL SYSTEM "SUN CHASER"

By D. R. Scott and P. R. White

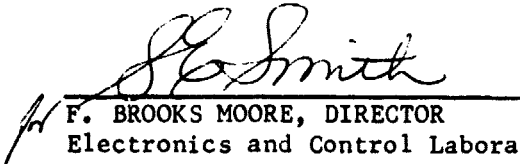
The information in this report has been reviewed for technical content. Review of any information concerning Department of Defense or nuclear energy activities or programs has been made by the MSFC Security Classification Officer. This report, in its entirety, has been determined to be unclassified.



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