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Power Cable Carrier Control (PC^3) System

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POWER CABLE CARRIER CONTROL (PC^3) SYSTEM

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ABSTRACT

A control system has been developed that uses a carrier signal imposed on an existing ac power circuit to transmit commands. This system was specifically developed to control an entire solar collector field by sending sun-tracking information to the trough collectors or by commanding them to assume safe positions (STOW) if out-of-limit conditions were encountered. Objectives were to develop a control system that operates reliably and has enough functions to control an entire collector field, yet do it at less cost than for conventional approaches. We believe these objectives have been achieved. This report describes development, design, operating characteristics, and field testing and results of the new system, the Power Cable Carrier Control (PC^3) System.

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POWER CABLE CARRIER CONTROL (PC^3) SYSTEM

Executive Summary

Because of operational difficulties and hardware costs, we saw the need to improve the subsystem that controls the collector fields of solar thermal systems. In this report we describe development of such a subsystem with the potential to lessen both difficulties and costs: the Power Cable Carrier Control (PC^3) System. The system uses a carrier signal to transmit control data from a central transmitter to a receiver in the drive module of each solar collector.

The data transmission system (Figure 1) includes a multiplexer that transforms the incoming parallel-signal information into a series format, converts this information into Manchester code, and then supplies it to the frequency modulated (FM) transmitter through frequency shift keying (FSK). Over the power circuit, the transmitter supplies a carrier signal common to all collector drive modules. An FM receiver in each module receives the information and, with its shift register, converts it back to parallel format, checks it for error, and then stores it in memory until it is updated (which requires about 2/3 second) with new information. The entire system is synchronized with the 60-Hz utility power.

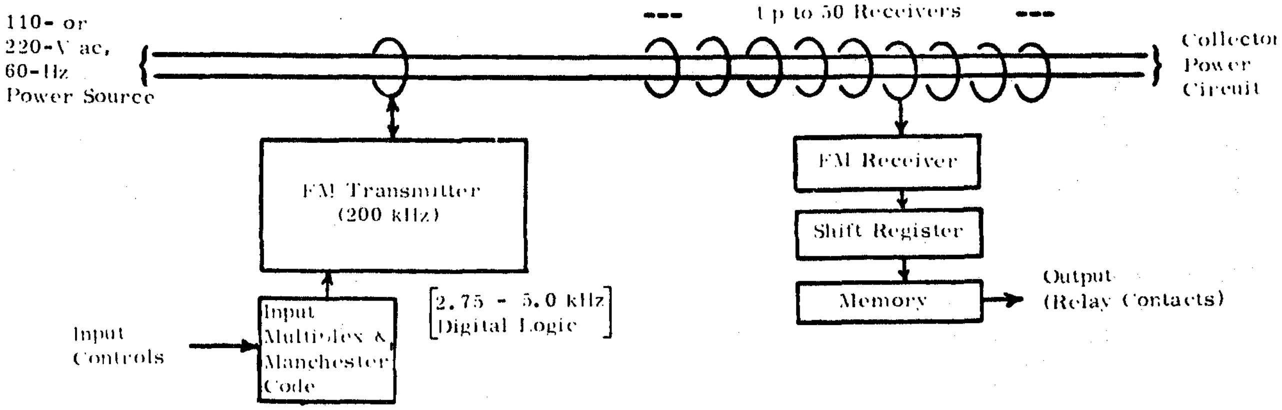

Figure 1. Solar Collector Control Data Transmission System

A complete data transmission system differs from the basic one in that it can completely control an entire field of parabolic, trough-type collectors when given an OPERATE or DO NOT OPERATE signal (Figure 2). Intelligence built into the transmitter informs each receiver of the position of the sun, within ±2-1/2 degrees, relative to its collector and depending on time of day, day of year, and latitude of the collector field. Each receiver has an analog-type, closed-loop control circuit that positions the collector within ±3 degrees of the sun's position. When there is

enough sunlight, a light-band* tracking system takes control and tracks the sun to within ±0.05 degrees. The same kind of circuit could control such parameters as valve position, outlet temperature of the collectors, or pumping speed of the heat transfer fluid. Other circuits in the receiver can detect whenever a particular parameter value is being exceeded (out-of-limits operation) and command the collector to assume a standby position (STOW). When this happens, a light goes on at the receiver and remains on until the receiver is manually reset (Figures 3 and 4).

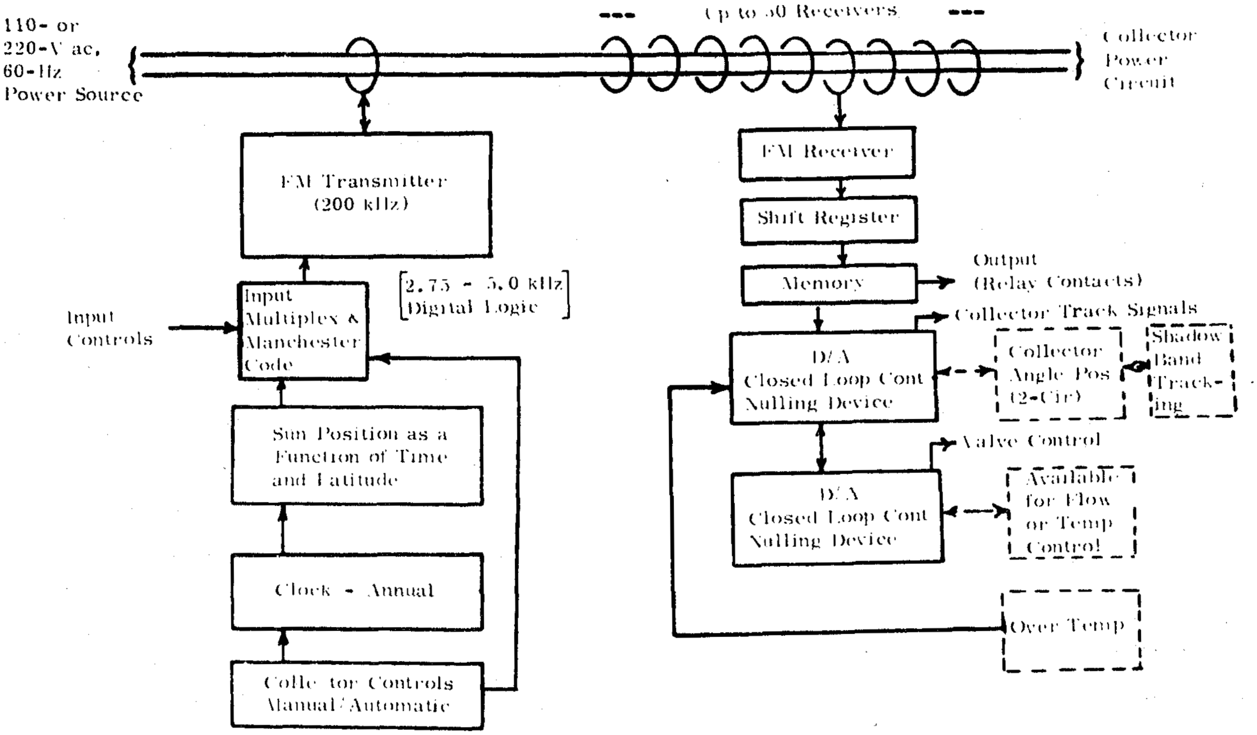

Figure 2. Additional Capabilities of Solar Collector Control Data Transmission Systems

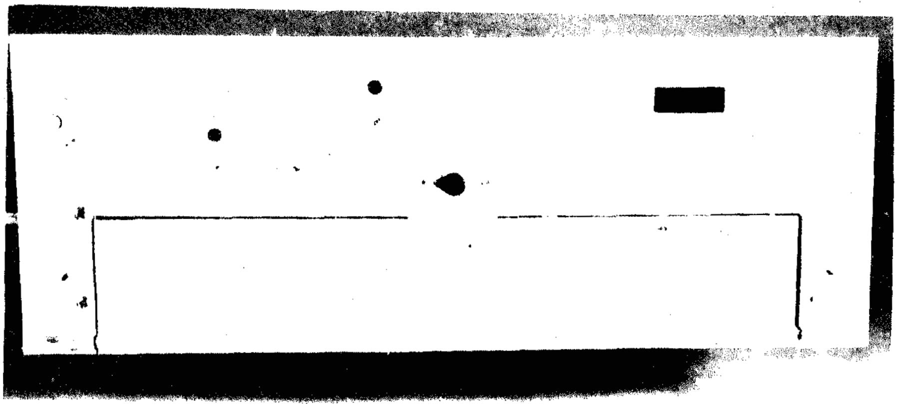

Figure 3. PC^3 Control

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* Opposite in design from the conventional shadow-band system

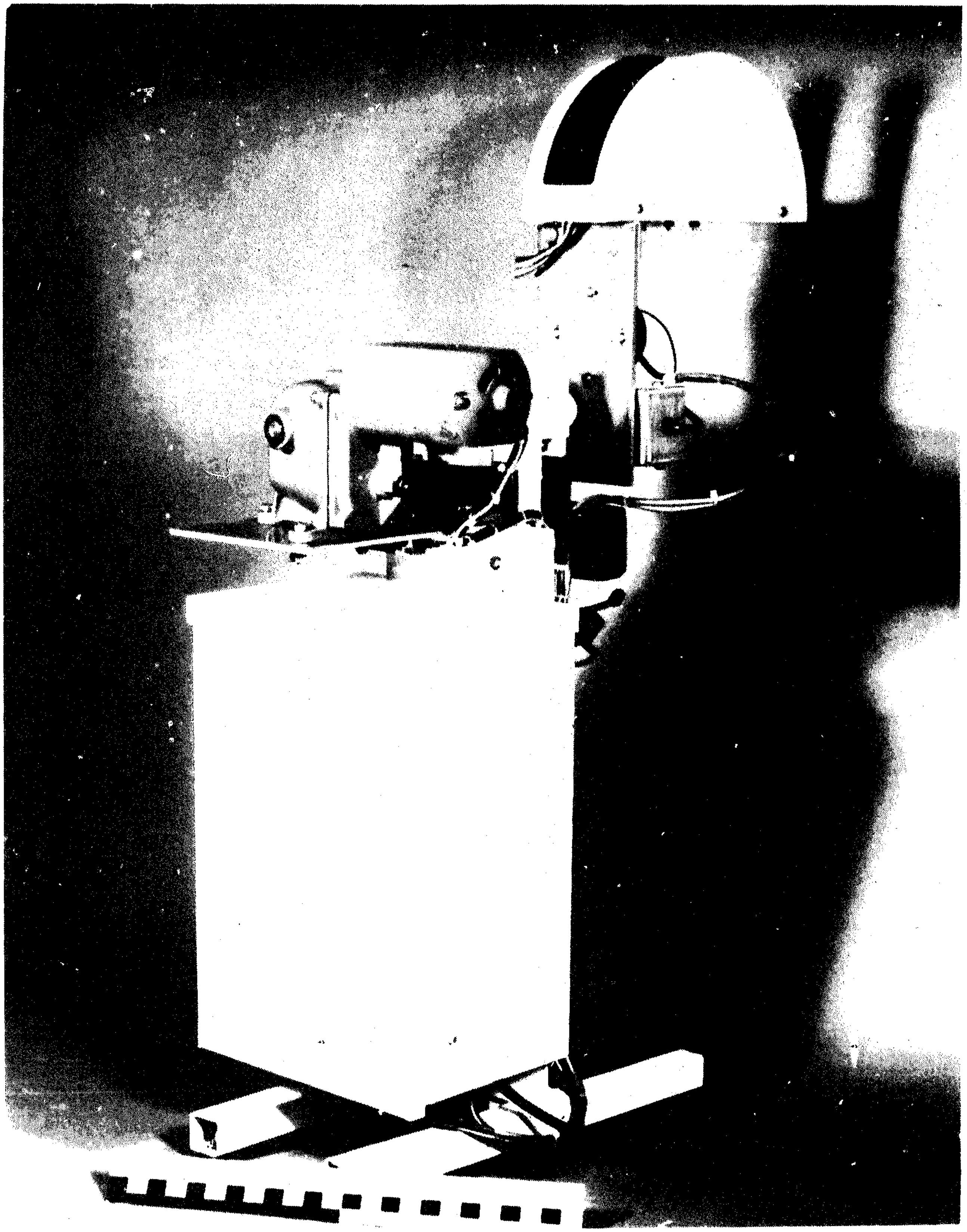


Figure 4. PC^3 Receiver and Light-Band Tracker

The purpose for developing the PC^3 was to have a system that was reliable in operation, had sufficient control capability, and would reduce the cost of installing a solar energy system. Environmental and operational tests verify that the system is reliable and has the desired capability. Costs are expected to equal, or be even less than, those of installing just the control circuits of conventional systems. The system requires no other tracking devices, can be connected to drive modules that operate either on ac or dc, can be expanded or contracted at will, and can work with a microprocessor to control 2-axis collectors.

We are including detailed design information on the PC^3 system. However, if anyone needs more information to manufacture or use the system, please contact the authors.

Background

Solar energy is being investigated by the Department of Energy (DOE) as an alternate to fossil-fuel energy. In some of the first DOE-sponsored experiments, solar energy was used to power irrigation pumps.[1, 2] Designs and hardware resulting from these early experiments indicated that concentrating-type collectors were desirable. These collectors, which have concentration ratios of 30 to 1, or more, required sun-tracking and -focusing controls. The technology for accurate tracking existed, but the cost was unacceptably high.

The irrigation experiments used parabolic trough collectors whose tracking axes parallelled the earth's rotational axis, which incorporated a shadow-band sun-tracking sensor, and whose controls were hard-wired. The control circuits consisted of POWER, STOW WEST, STOW EAST, and TRACK. Switches interrupted the drive power to determine the stow positions; there were no fail-safe systems for out-of-limits operation.

These early control systems did not measure up to expectations. For instance, at night the collectors were inverted in the stow position, and because the shadow-band sensor pointed downward, it could not direct the collector to a focus position next day. Also, problems arose with over-temperature, clouds interfering with tracking, and inability to limit rotation of the collectors. These situations could either damage or degrade the performance of the collector.

The cost of maintaining collectors is critical and is a sensitive parameter when analyzing the life-cycle cost of the system. Economically, these early systems did not measure up. Since their intelligence was minimal, they required an operator to keep the collectors operating properly. Even this was not satisfactory because sometimes receiver tubes overheated, damaging the collector. Cost of installing the system was also unexpectedly high. The average contractor willingly installs power cables but is reluctant to install control and instrumentation circuits; he subcontracts this work, thus increasing installation costs. Also, because of the sheer number of collectors and their control circuits, installing and checking out the circuits was a major expense. In fact, each channel of a conventional data circuit cost \$100 to \$300, 30% to 50% of which was simply for wiring.[3]

Because of the shortcomings of conventional systems, we needed a new approach for controlling collectors in the field. Such a control system had to be highly reliable in operation, able to operate unattended, incorporate fail-safe features, and cost as little as possible. The result was the PC^3 system described in this report.

Objectives

Objectives in developing a new control system were to improve data transmission and receiving, incorporate fail-safe features, improve tracking, and establish a system that would be highly reliable and easily serviced.

Data Transmission -- Data of interest to be transmitted are those that are required to control each solar collector in a field. Transmission should be reliable and its cost reasonable.

Reliability of hard-wired circuits has been good--after they have been checked out and signal crosstalk has been eliminated. However, cost of installation has been a major concern. Most general contractors can install electrical power circuits, but not control and instrumentation wiring, which they usually subcontract. This results in higher construction costs. Electrical codes and good design practices suggest that control circuits be separated from power circuits, that control circuits with a common function be grouped together, that common bundles of circuits run in conduits, and that the ends of each wire terminate at some sort of connector. This can cost more than $5.00 (1980) per running foot of 1/2-in. conduit. Therefore, depending on how extensive the collector field is, it can cost more than $300.00 to wire the drive module of each collector.

How much wiring or data transmission is needed to control a collector field is moot. Experience shows that the drive module should receive sufficient external control to operate satisfactorily, yet have enough internal control to reject inadequate or erroneous control information that could damage the collector. For example, one important problem would result if the collector were to be tracking the sun but the heat transfer fluid were not to be circulating.

We determined that the following data were enough to control line-focus solar collectors:

- Operate/Not Operate
- Track North/South
- Track East/West
- Sun Position
- Stow Clockwise
- Stow Counterclockwise
- Desired Output Temperature
- Change HTF Circulation Pump Speed (To conserve parasitic energy)
- Operate HTF Flow Valves
- Operate Automatic Collector Washing Systems

The approach we used for the PC^3 was to transmit the data on a carrier frequency added to the power circuit, thus eliminating conventional hard-wired circuits and saving the expense of installing and checking them out. This approach also allows the manufacturer to build in quality at the plant because no fabrication is necessary in the field. We arbitrarily set the number of information channels at 16 so that the system could interface directly with conventional microprocessors.

Since reliability in operation is the most desirable control quality, we reviewed several methods of transmission and adopted the following: The carrier system is FM and the data are transmitted in a logic format resulting from two distinct tones (FSK). The Manchester code (a system that uses data complements) further assures reliability by interrogating data sequences for Manchester code errors; if any are found, the data sequence containing the error is rejected. Memory storage retains the accepted data until a new sequence is received. The 60-Hz frequency of the power source is the clock and synchronizer for both the transmitter and receiver, eliminating usual clock problems. All components were chosen for stability over the temperature extremes expected. Figure 1 is a block diagram of the data-system approach that was chosen.

Collector Control -- The controller for a solar collector must receive the control data reliably and execute the commands properly. The collector itself must operate as a fail-safe device and detect its own limits of operation so as to protect itself from damage. These out-of-limit failures may result from erroneous or lost control data and from the collector overheating; such failures can and have occurred in actual operation. Since the safest condition for a solar collector is the STOW position, the collector is commanded into that position when a failure is detected.

Even though overall control is automatic, manual control of the collectors at their drive modules is essential. Manual control is not only convenient for maintenance personnel, but also absolutely necessary for their safety. It allows one drive assembly to be out of operation while the rest of the field continues operating.

All operating collectors receive the following identical control data automatically and simultaneously:

- OPERATE/NOT OPERATE -- Supplies or does not supply power to the tracking controls; in NOT OPERATE, power remains only for manual operation.
- TRACK (Single or double axis) -- This command enables the trough to collect solar energy by focusing the insolation on the receiver. In early systems, once the collector obtained the sun, a shadow-nulling device kept the collector focused on the sun. However, if the collector was not pointing at or near the sun to begin with, it did not have the intelligence to find it. In later designs, the collector traversed from STOW LEFT to STOW RIGHT and stopped whenever the shadow band sensed the sun. Although this was an improvement, it unduly exercised the drive mechanism. In the PC^3, a reference voltage corresponding to the sun's position is transmitted to the collector, which then nulls to this voltage with an inclinometer reading; accuracy is ±3 degrees. A light-band sensor and an insolation detector with a ±9-degree field of view assume control when insolation exceeds a preselected value; accuracy can be as good as 0.05 degree.

- STOW (East or West)/NOT STOW -- In STOW, the trough is as inverted as practical, either clockwise or counterclockwise. Some recent designs can be stowed in only one direction, but completely inverted. In a conventional system, the collector is driven until it trips a switch that stops its rotation. If the switch fails, power continues until the collector meets a mechanical stop. In the PC^3, the inclinometer determines the STOW position; the limit switches and mechanical stops are for back-up and fail-safe reasons only.

- Temperature Limits -- Depend on the capability of the collector materials or on the desired results. These limits can be determined before the collector field is installed. The PC^3 uses any kind of switch that closes or opens at preset receiver temperature limits, generating a signal that overrides all other data and commands the collector to STOW. A light on the control board indicates the problem with the collector. The drive module must then be manually reset to return the collector to normal operation; manual reset is a precaution that is necessary because an out-of-limit condition has occurred and the collector must be inspected and perhaps repaired before it can be restored to operation.

Reliability and Servicability -- Reliability is the single most important consideration for solar energy systems; maintenance is a sensitive parameter in life-cycle costing and unscheduled repairs in the field are difficult and expensive. Therefore, it is best to service a system by replacing a component and sending the defective one to a central location for repairs.

The PC^3 controller was designed so that the operating and maintenance personnel can observe its status without additional instrumentation or equipment. For instance, if a major component fails, a light on the control board indicates the type of failure. The system is then returned to operation by replacing a complete module within the system and sending the defective one to the repair center.

Much study has gone into the reliability and serviceability of the PC^3, contributing significantly to the decision to use FM, the Manchester code, FSK, and memory storage, and to interface the drive module with a conventional microprocessor. Sufficient light-emitting-diode (LED) indicators were included so that no auxiliary instrumentation would be needed to operate the system or to determine failure modes. Most maintenance personnel should have little difficulty in maintaining the PC^3 system by this replacement technique.

Description

Basically, the main components of the PC^3 are a centrally located controller and a slave control module at the drive mechanism of each collector. The central controller includes a data transmitter and a data generator that tracks the sun from east to west. Each field collector drive module includes a receiver.

Central Controller and Transmitter

The transmitter (Figures 3, 5, and 6) connects the 120-V ac, 60-Hz power line with the data bit-generator. Input to the transmitter is 16 bits, or channels, of parallel information. A multiplexer converts the parallel data to a serial format, generates the complement of each bit (Manchester Code), and combines the complements with a group of fixed data bits at the end of the message, producing a 40-bit word. Since the 60-Hz line parallels the serial conversion frequency, it requires approximately 2/3 second to transmit the 40-bit (1 bit/Hz) word. The serial word is then applied to a frequency shift keying (FSK) generator that produces a 2.75-kHz tone for logic "1" and a 5.0-kHz tone for logic "0". The FSK output modulates the FM oscillator. The FM carrier frequency is 200-kHz (adjustable) and is modulated with approximately 1 V peak-to-peak to produce a frequency deviation of ±3%. The FM signal is coupled to the ac power line through an amplifier, transformer, and capacitors.

The bit generator produces parallel data on the position of the sun from stored sun-position information and the following external inputs:

- EXT DISABLE - Prevents the system from tracking if it is in the automatic operation mode (AUTO) and puts the collector field in STOW. This input may come from an insolation intensity sensor, wind, rain, flow monitors, or any other system sensor that detects a fault in the field and informs the central controller.
- AUTO/MANUAL - In AUTO, the system will activate automatically in the morning, track the sun, and return to STOW at night; in MANUAL the position of the collectors is controlled by the STOW or COLLECTOR POSITION switches.
- STOW - Stows the entire field clockwise (CW) or counterclockwise (CCW).
- COLLECTOR POSITION - Puts the entire field at any position, from CCW horizon to CW horizon, in approximately 30-degree increments; can be overridden by the STOW switch.

The approach we took when designing the sun-position generator was to activate (wake-up) the field at the appropriate time, and when the sun-tracking system sensed a predetermined intensity of insolation, it would start following the sun. If it could not sense insolation because of cloudiness, it would position the collectors, in 3-degree increments, at constant time intervals using stored sun position information. It would continue this movement until it detected the sun or until the fields were sent to stow at the end of the day. The sun-position data-bit generator contains a 24-hour clock, a day counter, and latitude selector to determine the proper wake-up time and track-segment interval.

Data bits 1 through 9 have been assigned certain functions and 10 through 16 are presently spares (Table 1). Characteristics for the transmitter are listed in Table 2 and those of the bit generator in Table 3.

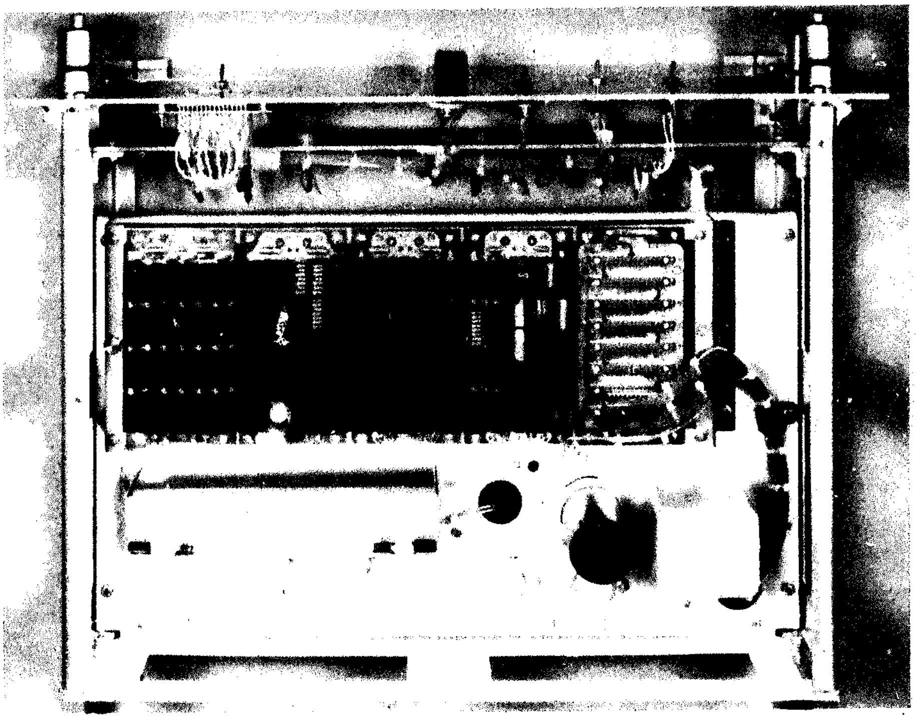


Figure 5. PC^3 Control - Top View

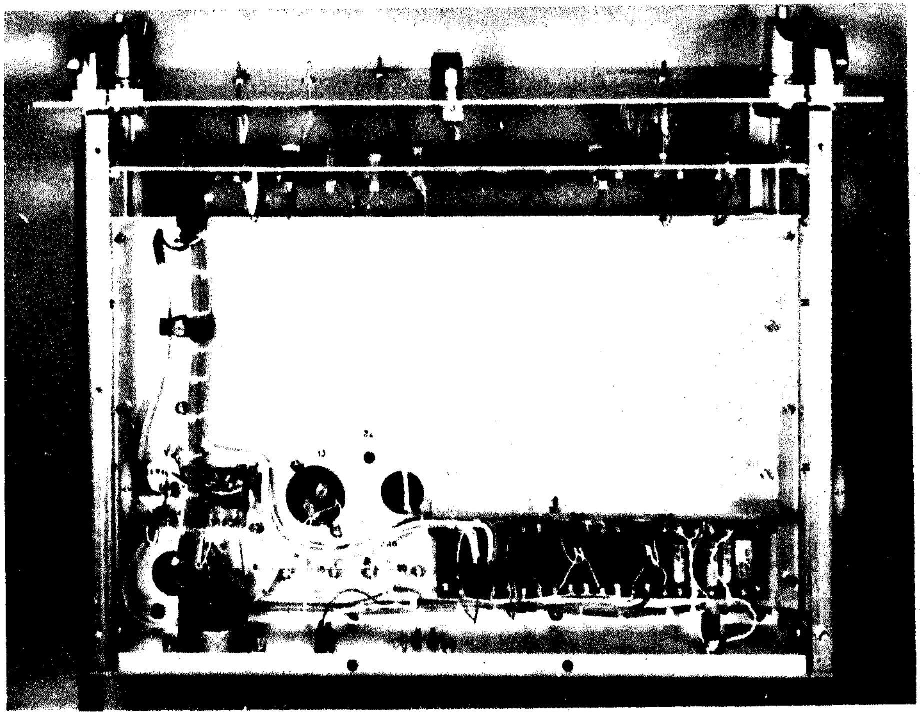


Figure 6. PC^3 Control - Bottom View

Table 1

Data-Bit Assignments

Bit No.	Function
1	AUTO/MANUAL Switch (AUTO=1)
2	STOW CCW
3	STOW CW
4 - 9	Sun Position
10 - 16	Spares (Can be used for tracking a second axis or for additional external controls)

Table 2

PC^3 Transmitter Characteristics

Function	Specifications
Power Requirement	120 V ac, 60 Hz, 5 W
DC Power	Internal, 15 V, 200 mA
Data Input	16 Channels (0 to 0.5 V = logic "0"; 12 to 15 V = logic "1"); external driving: 10 kΩ at 15 V)
Word Length	40-bit (16 data bits and their complements, plus 8 end-of-word bits)
Type Transmission	FM/FSK; FM carrier averages 200 kHz but can be adjusted from 100 to 300 kHz; FSK frequency: 2.75 kHz = logic 1 5.0 kHz = logic 0
RF Power Output	40 mW across a 1.5-Ω load

Table 3

Bit Generator Characteristics

Function	Specifications
DC Power	12-V Gell-Cell, 1.5 Ah with charger. Without charger, operates 5 days.
Internal Clock	3.58 MHz divided down to 60 Hz, ±0.01%. Output can be selected with switch.
Display	24-hour clock; day and state counter. Clock and day counter can be set manually with external switches.
Latitude Selector	Internal switches for latitudes of 32° to 34°; 34° to 42°; and 42° to 48°.
Data Output	6 bits; based on east-to-west tracking of the sun (000001 = east horizon; 100000 = zenith, 111111 = west horizon); 3 control bits (AUTO/MANUAL, STOW CCW, and STOW CW)

Control Module Receiver

The collector control module consists of two printed-circuit boards (PCBs): one for receiver and one for analog control; they are mounted in a 6- x 8- x 10-in. NEMA3R enclosure (Figures 4, 7 through 10). The receiver PCB has a built-in ±15-V dc supply for powering both boards. The receiver detects the FM information on the ac power line and converts it to digital information. The analog control PCB positions the collector properly by using the received digital information and generates control information local to the collector, from flow, temperature, insolation, and sun position data.

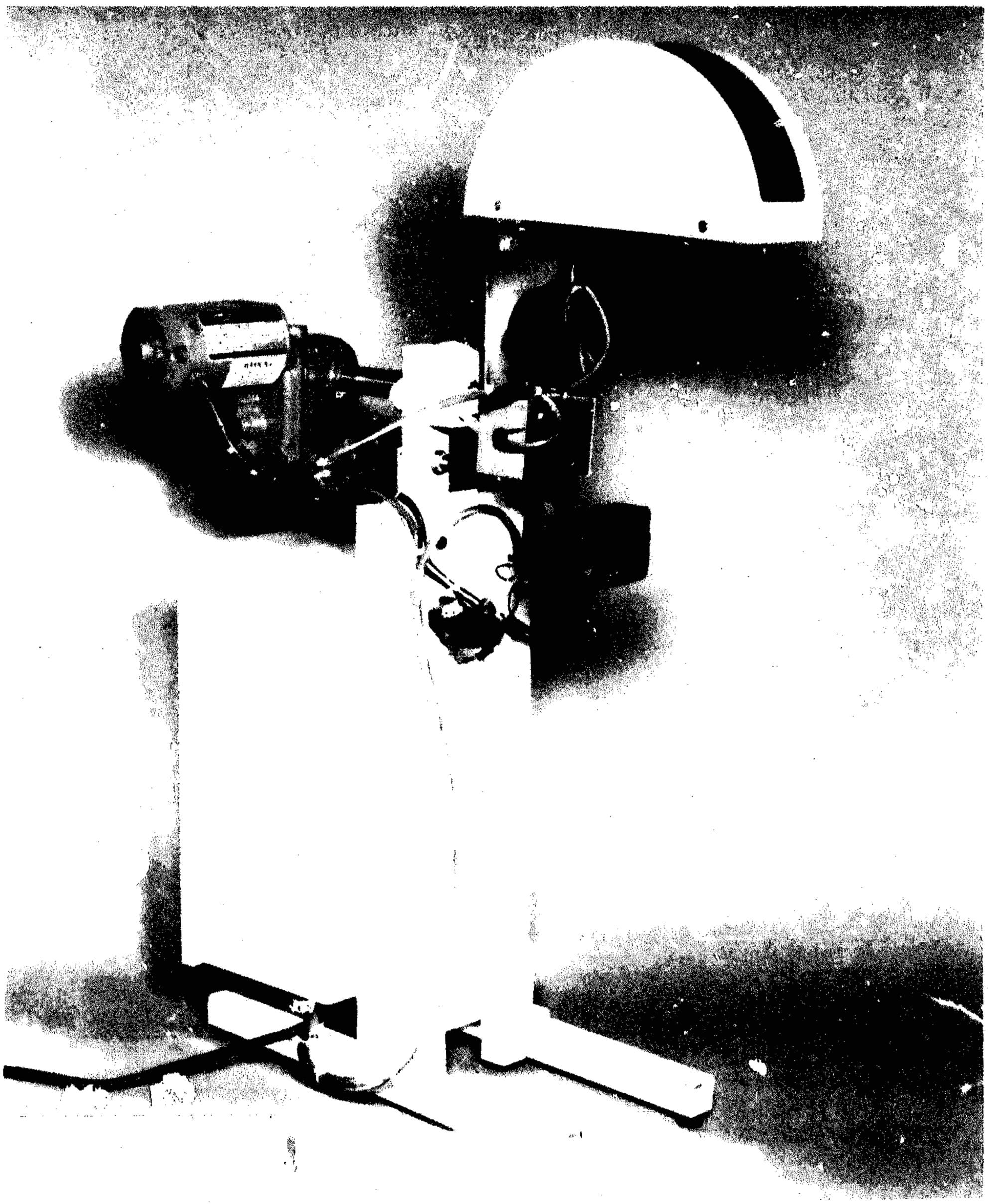


Figure 7. Receiver Showing Light Band, Inclinometer, and Display Fixture

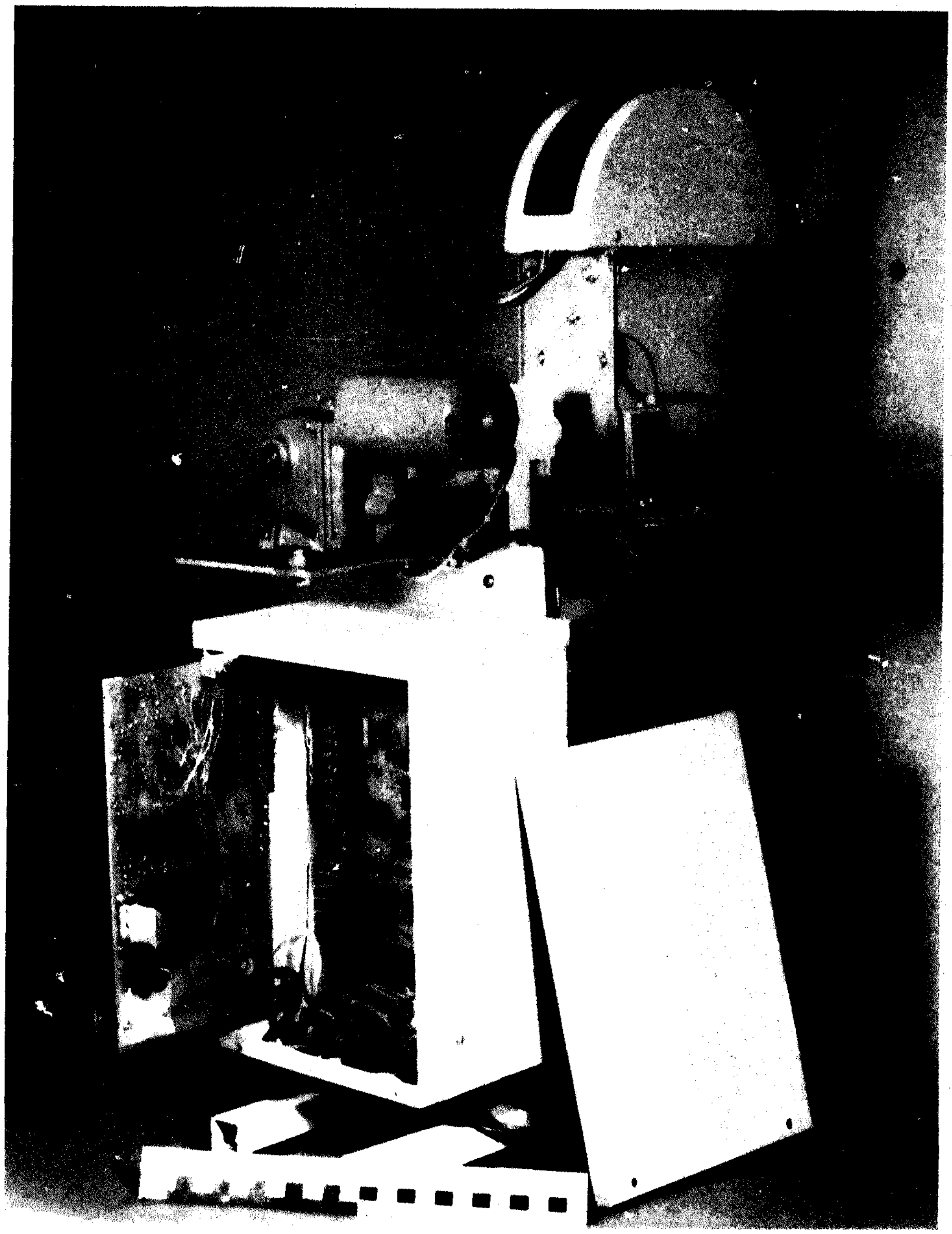


Figure 8. Receiver Showing Receiver PC Board Folded Out and Control PC Board in Rear of Enclosure

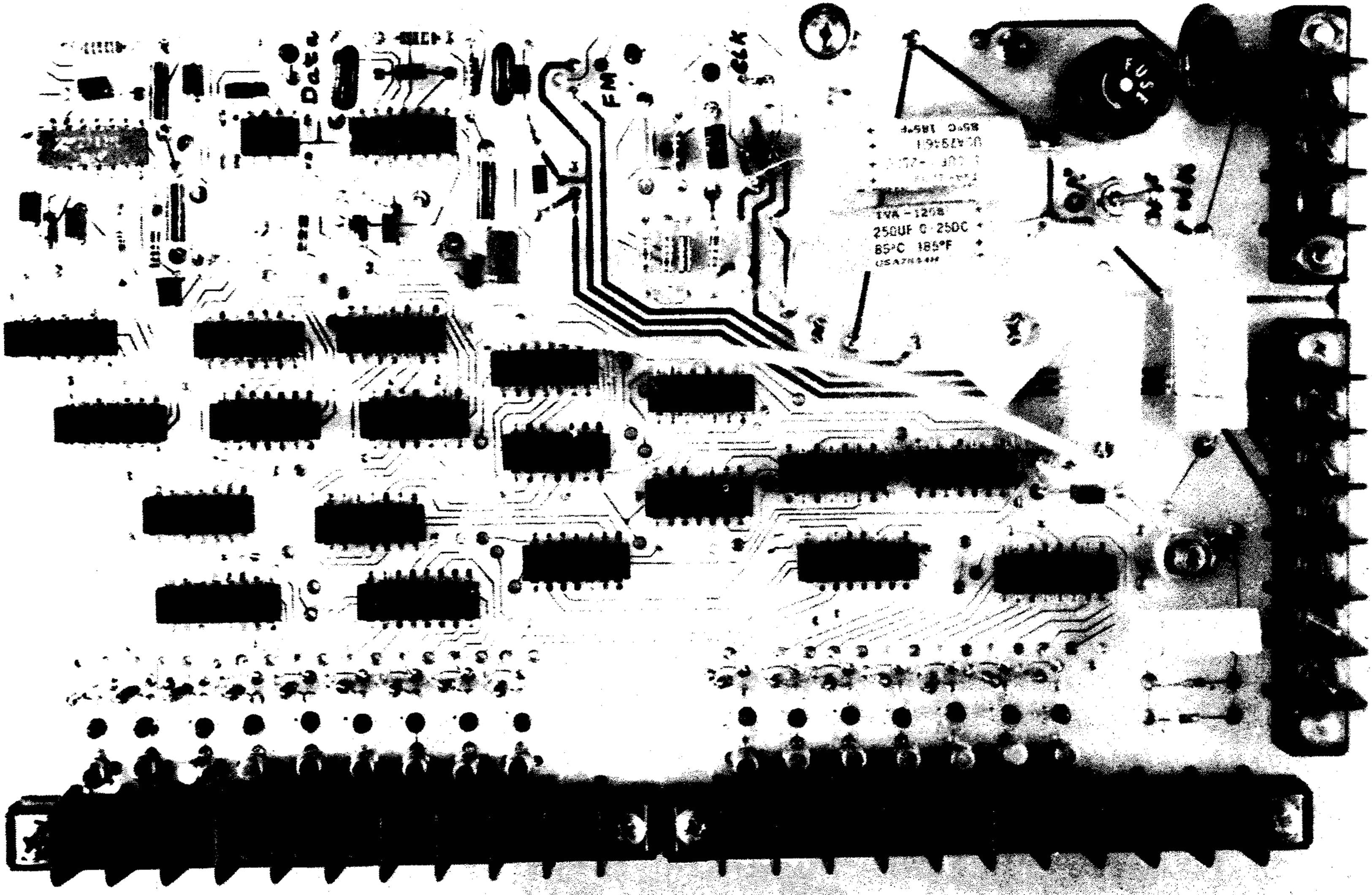


Figure 9. Receiver Board

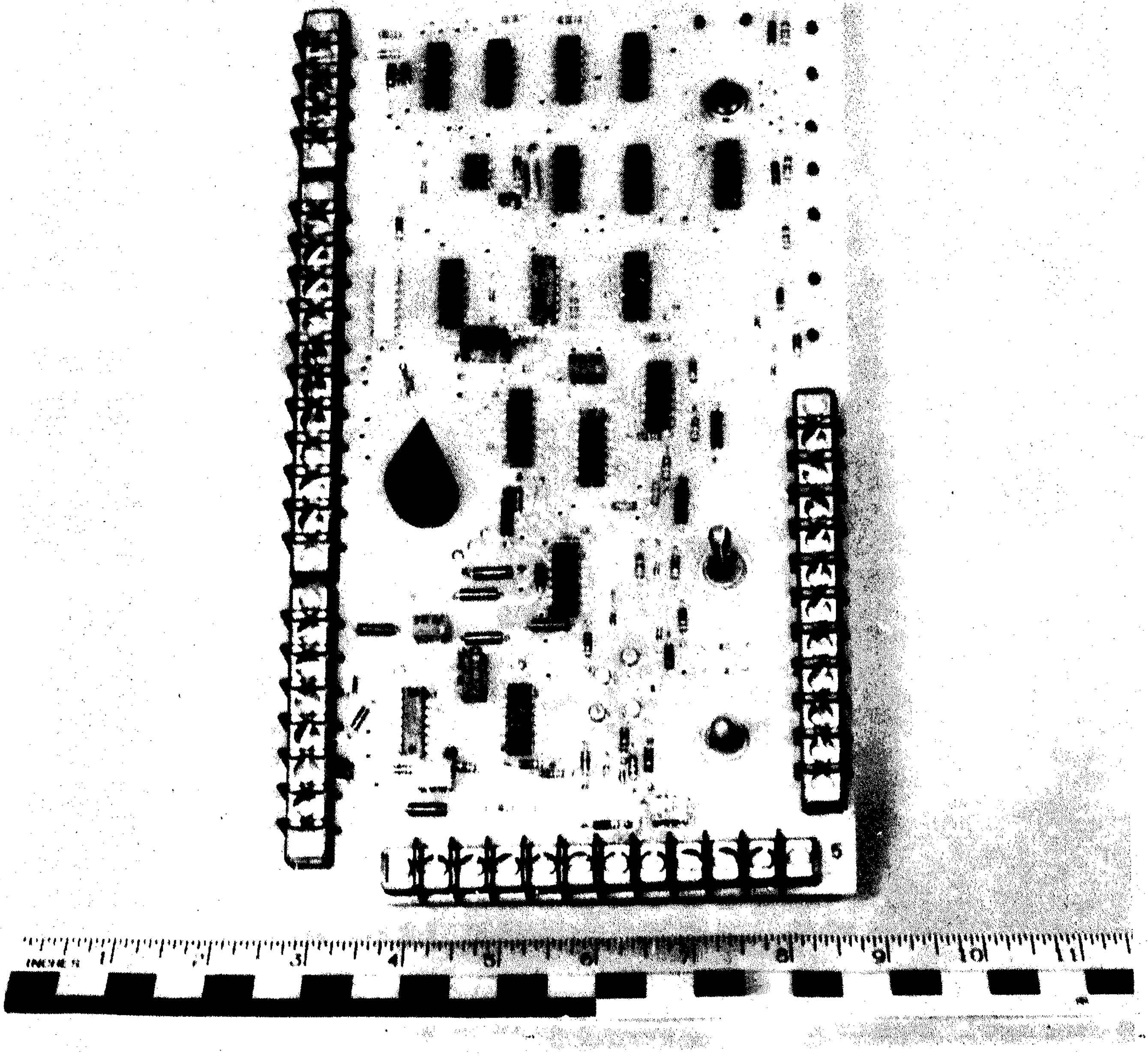


Figure 10. Analog Control Board

At the receiver, coupling capacitors and a transformer obtain the FM carrier from the 60-Hz ac line. The output of the transformer is applied to an FM detector chip (U1)* that produces the FSK signal and a CLEAR (CLR) signal if the FM carrier is not present or when applying ac power to reset the system. The FSK signal is buffered with an operational-amplifier (op-amp) (U18) and is applied to the FSK detector (U2) to produce the serial data which is loaded into a 40-bit shift register (U9-U13). The data are then shifted through the register with the positive-going edge of the 60-Hz clock derived from T1, R17, C19, and U3. When the end of the message bit-pattern (011111) reaches the last register (U13), the decode logic gates (U4, U7, and U8) detect this condition and activate the error detection logic. If the information bit and its complement are of the same value, ie, both true or both false, because of a transmission error, the logic will detect the error and not use the message in the shift register. If errors are not detected, the STORE DATA line will be true when the clock goes low. The STORE DATA signal will transfer the information bits in the shift register to the storage register (U14-U17), whose outputs are buffered by transistors Q1-Q16. The logical output state of the transistor can be selected with a jumper inserted on the card between the Q or $\overline{Q}$ and the base resistor of each transistor. Each transistor is connected to a LED (CR10-CR25) that indicates when its output transistor is on. The data in the output storage are updated after each correct message is received (every 0.75 second). The output storage is reset by the CLR signal during ac power application and also when the FM carrier is not detected. Characteristics of the receiver are listed in Table 4.

Table 4

Receiver Characteristics

Function	Specification
Power requirement	120 V ac, 60 Hz, 10 W
DC power	Internal ±15 V, 250 mA
Temperature capability	-18°C to 68°C (0° to 150°F)
FM: sensitivity	50 mV, peak-to-peak; capture range 190 to 210 kHz
Data output	16 open collector transistors capable of sinking 75 mA at 30 V (Logic state can be selected with jumpers on the card).
Input/output connectors	Barrier strips
PCB size	8 x 10 in.

The analog control board (Figure 10) is connected to the data output of the receiver. These digital data are decoded and combined with local information of sun position and insolation to position the collector properly. The analog control board consists of command decoding logic, a digital-to-analog converter (D/A), an analog-to-sensor interface, and an output drive circuit.

---

*Items such as U1, C1, R2, T1, Q4, and U3, and CLR are reference designations on the schematics in Appendix A.

The command decoding logic determines the proper output command from the transmitted digital information and local input status signals. The inputs are:

- 3 transmitted control bits: AUTO, STOW CW, and STOW CCW
- 2 system-disable lines
- sun-level detector
- status of LOCAL-REMOTE switch

The possible outputs are:

- TRACK
- NOT TRACK
- D/A select
- STOW CW select
- STOW CCW select

The system-disable inputs allow each collector to detect out-of-limits conditions such as loss of heat transfer fluid (HTF) flow or too high HTF temperature. With the LOCAL-REMOTE switch (S2), control can be transferred from the field controller to a local position control (R35) on the analog control board. The sun-level detector (SUN) is true when insolation is above a predetermined level of intensity.

The output lines of the combined decoder control six analog switches (U14, U16). TRACK output is the condition where the system has found the sun and is following it with the sun sensor; to produce it, AUTO, SUN, and REMOTE are true while STOW CW, STOW CCW are not true; both system disables are not true. The NOT TRACK output is true if any of the conditions for TRACK are not met. The D/A select is true for input REMOTE true and STOW CW, STOW CCW, and system disables all not true. This output selects the D/A to control the position of the collector. The STOW CW select output is true for inputs REMOTE and STOW CW true and STOW CCW and system disables not true. This output allows the collector field to be stowed CW from the main controller. The STOW CCW select is true for inputs REMOTE and STOW CCW true and STOW CW not true, or where REMOTE and either system disable is true. This output causes the collector to go to STOW CCW from either the collector field controller or from a local system disable.

The D/A (U11) converts 6 bits of digital information to a voltage (Table 5). The D/A full-scale output can be adjusted with R43 and zero with R29.

Table 5

Conversion of Digital Data to Voltage

Data Bits	dc Output to Voltage	Collector Trough Position
HHHHHL (111110)	-5	CCW Horizon
LHHHHH (011111)	0	Noon (Straight Up)
LLLLLL (000000)	+5	CW Horizon

The analog-to-sensor interface consists of a buffer amplifier (U12) for the inclinometer, a comparator for the sun-level detector, and a differential amplifier for the sun-tracking sensors. The inclinometer is mounted directly on the hardware of the collector trough and produces a dc output corresponding to the collector's position. The sun-level sensor is a photo-transistor whose output is connected to the positive input of a comparator (U13). The negative input of this comparator is an adjustable reference voltage (R15) and its output (SUN) is true (positive) when the insolation is above the reference level.

The sun-tracking sensors are also mounted on the trough hardware. They consist of two photo transistors in an enclosure that is shaded when the collector is in focus. As the sun appears to move, one transistor is exposed to it, and the other remains in the shade. The transistor outputs are applied to a differential amplifier (U12) whose output is approximately zero when the collector is in focus, positive when the collector is lagging the sun, and negative when leading the sun.

The output drive circuits consist of a ± voltage reference, two voltage comparators, a time delay, and transistor switching logic. The comparator (U17) compares a common input signal against the ± reference (TP7, TP8). The comparator outputs are negative if the input signal is between the (+) and (-) reference voltage. The positive referenced comparator output (U17 pin 10) will go positive when the input signal exceeds the (+) reference voltage at TP7 and activates the CW drive transistors (Q1 and Q2). When pin 10 returns to a negative voltage, it starts the 13-second delay (U8). The negative referenced comparator output (U17 pin 12) will go positive when the input signal is less than the negative reference voltage at TP8. The negative comparator output is logically anded with the inverse of the negative comparator output and when the time delay expires. If all the above conditions are true simultaneously, the CCW drive transistors (Q3, Q4) will turn on. The 13-second delay is to prevent the logic from responding too fast, forcing the solar collector drive to oscillate.

Assume that the STOW CCW, AUTO, REMOTE inputs are true and system disables are false. The command decoding logic generates NOT TRACK and STOW CCW select. The output from STOW CCW select closes analog switch S2 of U14, connecting the negative output of the voltage divider (R30 and R31) to the positive input of U15 differential amplifier; the inclinometer output is connected to the negative input of U15. The NOT TRACK signal operates analog switch S2 of U16 which connects the differential amplifier output to the output of the drive circuit comparators (U17). When the differential output is more negative than the negative reference voltage, the collector will drive CCW until it reaches the STOW CCW position, at which time the inclinometer output will equal the negative divider output and the drive unit will stop.

Now assume the collector is commanded to go to the CCW horizon. The input data line would be AUTO true; both STOWS and system disables would be false. The D/A data would be HHHHHL (-5 V). The command decoding logic outputs would be NOT TRACK, and D/A select. The output of D/A, being true, would be connected to the positive input of U15 through analog switch S1 of U14. The D/A output will be compared with the inclinometer output (-8 V for STOW CCW), and the difference applied as an input to the output of the drive comparators (U17), which will drive the collector CW until it reaches the CCW horizon, at which time the inclinometer input (now -5V) will equal the D/A output and stop the drive unit.

If at this time, the insolation is above the preset level of R15, the SUN signal will be true and will cause the command decoding logic to produce TRACK and to remove NOT TRACK. This will switch the output drive comparators that were input from D/A inclinometer difference to the sun-tracking differential output of U12. As the sun moves, the output of U12 pin 10 will increase and overcome the (+) reference of the output drive comparator and the collector will move CW until the output is less than the + reference, at which time the drive unit will stop. If, at any time, the insolation drops below the preset level, the D/A will take control and possibly move the collector either CW or CCW. However, it will always remain within range of the sun-tracking transistors. When the sun reappears, the system will switch back to sun tracking and return the collector to focus.

The collector field can be taken out of focus by moving the AUTO-MANUAL switch on the collector field controller to MANUAL and setting the COLLECTOR POSITION switch to the desired position. At the collector, with the AUTO now cancelled, the system will switch to NOT TRACK and use the D/A output to position the collector. This procedure could be useful for collector maintenance or washing. Analog control characteristics are listed in Table 6.

Table 6

Analog Control Characteristics

Function	Specifications
DC power requirements	+15 V at 150 mA; - 15 V at 50 mA
Operating temperature range	-18° to 68°C (0° to 150° F)
D/A output range	±5 V ±0.5%
D/A output vs collector angle	55.6 mV/degree of rotation
Sun-tracking accuracy	±0.05 degree of rotation
System disables input	2, with logic level selectable with jumper on card
Output drive	NPN transistors capable of sinking 75 mA at 30 V dc
Input-output connections	Barrier strip
PCB size	8 x 10 in.

Qualification Tests

Several system and subsystem tests have been conducted with the PC^3 to verify its performance over a wide range of temperatures and operating conditions.

Environmental Tests

The PC^3 design was first fabricated in two "breadboard" models (Figures 11 and 12). Both models were placed in an environment chamber and tested to determine how the individual circuits would perform in different temperatures. When their response to temperature extremes was determined to be within tolerance, the entire systems were tested. They operated satisfactorily at the design temperature limits of from -18° to 68°C. Although humidity tests were not conducted, ice formed on the system when the chamber was being cooled down.

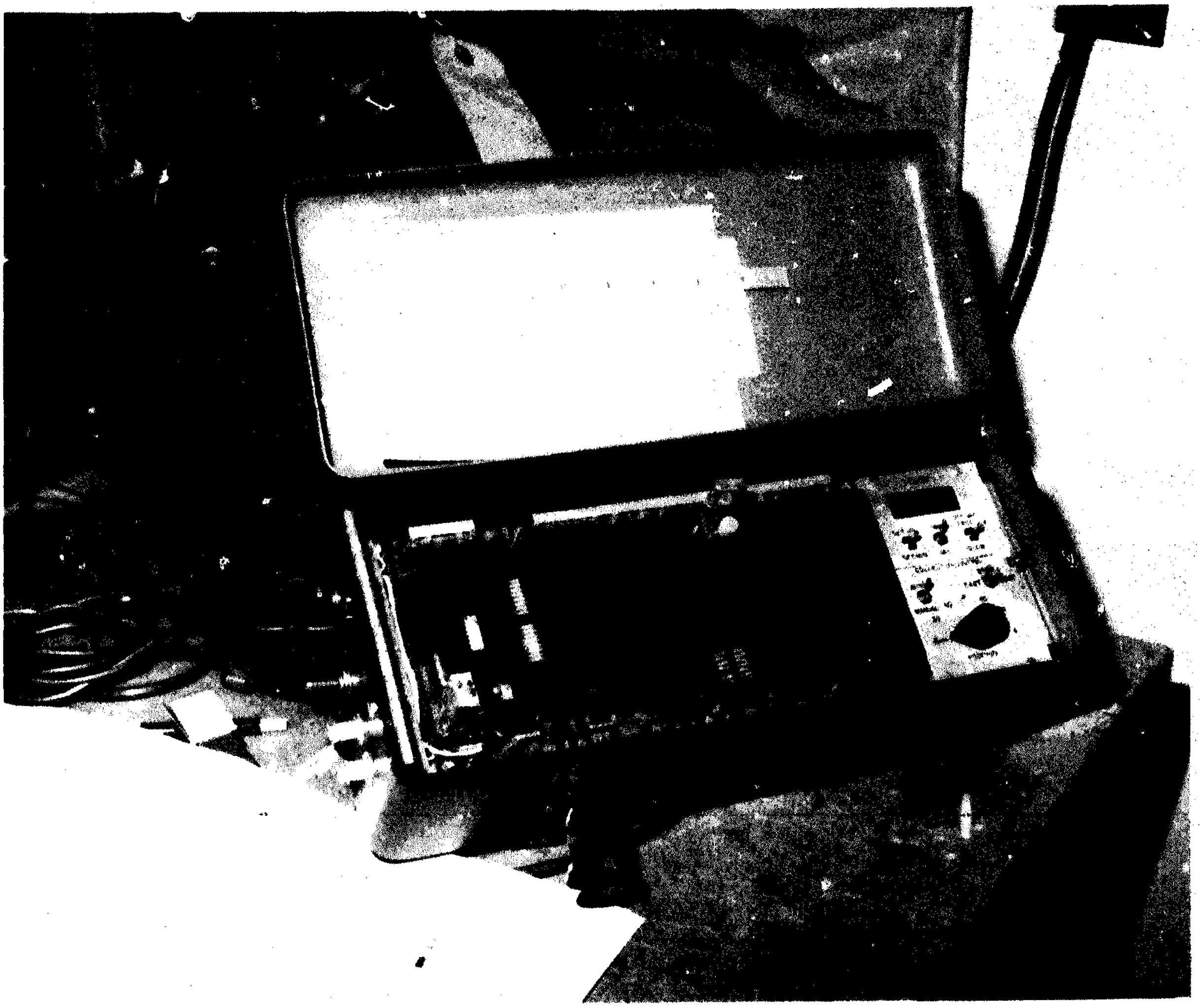


Figure 11. PC^3 Breadboard Model Controller

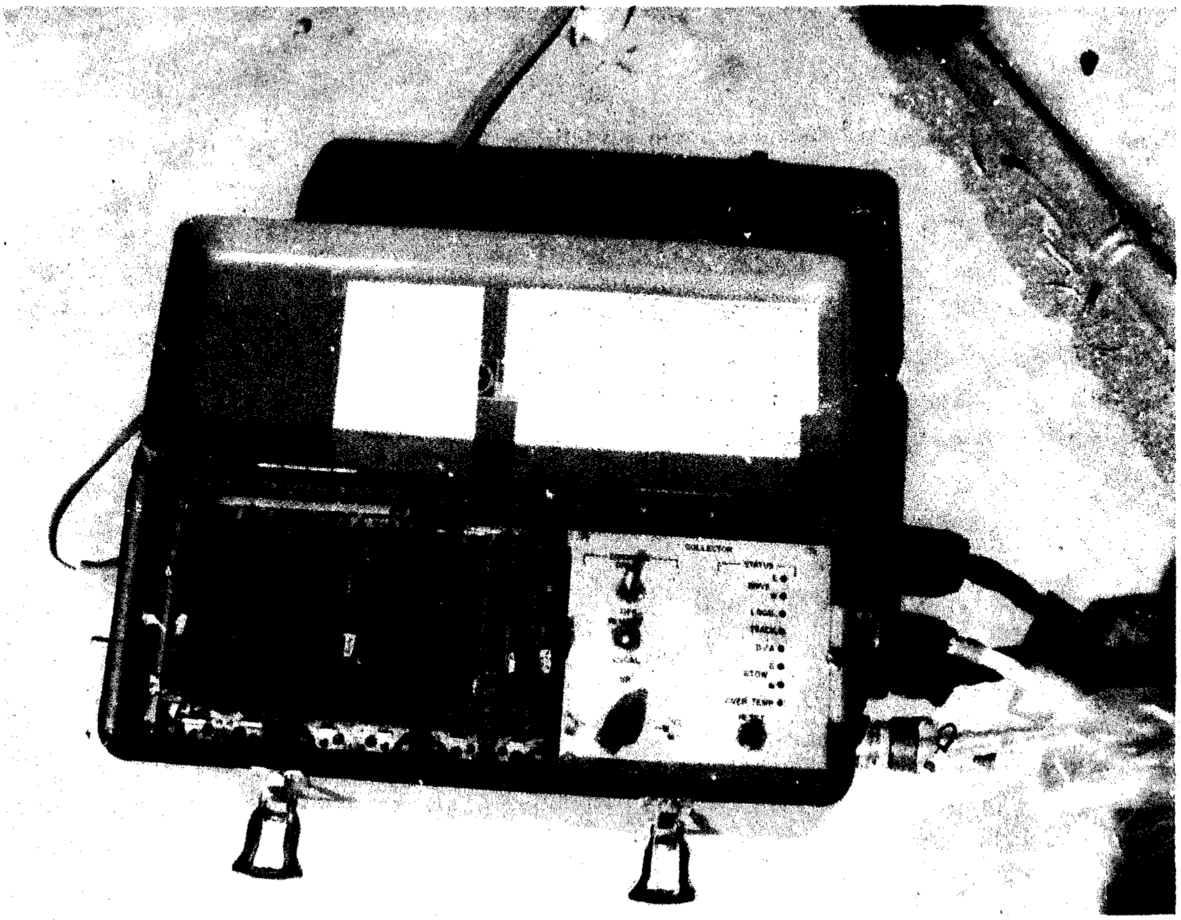


Figure 12. PC^3 Breadboard Model Receiver

System Tests

System tests were conducted with the PC^3 and solar collector drive units at the Sandia Midtemperature Solar System Test Facility (MSSTF). The first test was conducted with the Del collector drive system (Figure 13), which consists of a dc shunt-wound motor and gear drive. The dc power is supplied from batteries recharged automatically by the ac power line. The PC^3 system controlled the drive unit and accurately tracked the sun. For approximately 1 month we monitored its operation with strip chart recorders and obtained several surprising results. For instance, sharp shadows that fell on the light band from adjacent structures around sunrise and sunset caused the system to give oscillatory drive commands. When the shadow crossed the insolation detector, the sun-position intellignece became biased in its direction. When it tried to return to the sun position given by control, the detector would be illuminated by sunlight and the light band would resume control. The alternating sun-detector control and sun-position command caused the behavior. We modified the PC^3 circuit to correct the malfunction.

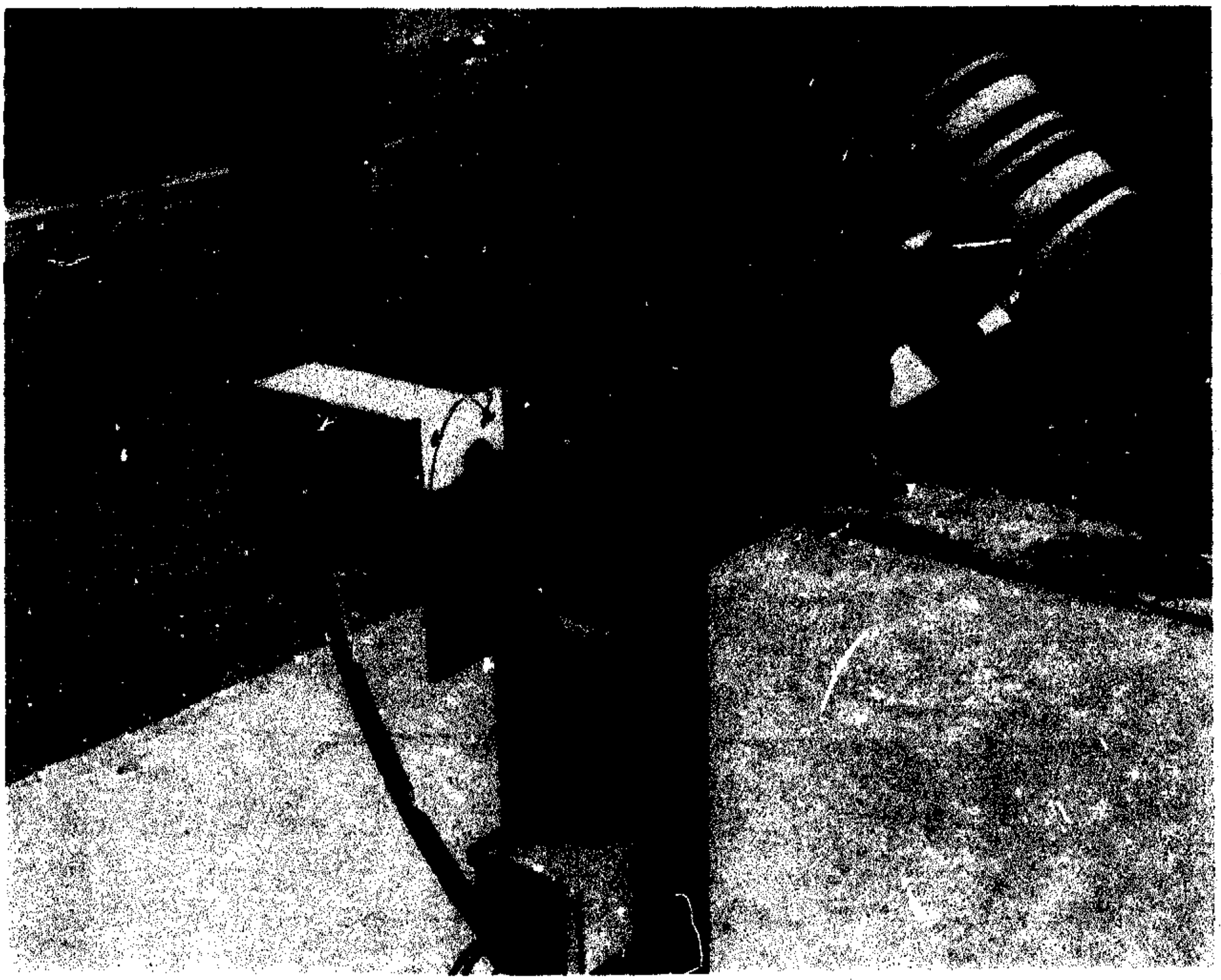


Figure 13. Breadboard PC^3 Tracker With Del Collector Drive

The Del drive system did not have enough inertia to really represent a solar collector drive unit of the kind we needed. An Acurex collector drive string that had its axis of rotation in the plain to that of the earth axis was available. The PC^3 breadboard system was moved to the Acurex collector and we resumed testing for approximately 2 months. Play in the gearing, coupled with the inertia of the collectors, tended to cause oscillatory drive commands. Although it was the drive gearing that was at fault, the situation was indicative of what a gear system could become after years of wear. We modified the design of the PC^3 circuit to prevent a drive CCW from occurring within 13 seconds after a drive CW had been executed. This eliminated fast oscillations that could ultimately damage the collector.

We also found that a signal from another transmitter could prevent a receiver from operating properly; this happened when a wireless intercom system was used simultaneously with the PC^3. During each test, the controller was located in the MSSTF office, and the collector being tested was located up to 50 m away. Although the noise on the power line was always very high, the receiver never failed to detect the PC^3 signal. However, when the intercom was operated nearby, its signal overpowered that of the PC^3 controller and the receiver could not decipher it, commanding the collector to drive the STOW. Tuning the PC^3 away from the intercom's 200-kHz frequency did not help. From this experience we determined that only one carrier frequency system should be operated at any given time in any one collector control group. A collector field, however, can be divided into as many groups as desired by using insolation transformers which will prevent interference. The phase of the ac power does not interfere with the operation of the PC^3 as long as all phases are coming from the same side of a power transformer.

Field Tests

After testing the breadboard models, prototypes of the PC^3 system were fabricated (Figures 3 and 4). Actual solar operation was desired, so we decided to place a controller and enough receivers (6) to control one ΔT loop of Acurex collectors at the Coolidge, AZ irrigation experiment. We installed the units on October 14, 1980.

The PC^3 receiver shown in Figure 14 was installed in parallel with the existing tracking system; a toggle switch allowed the experimenters to select one or the other system. We decided on this option because the PC^3 had not been proven and we did not want it to interfere with the solar experiment in case it performed poorly.

The controller was placed in the control building, and the system OPERATE signal was connected to the experiment HTF flow switch. When set in AUTO, the PC^3 automatically places those collectors it controls into a track condition, or within 3 degrees of track if insolation is low when the HTF starts flowing. It also automatically places the collectors in STOW position at night or if HTF stops flowing.

We placed the receivers on the most distant ΔT string, in the northeast corner of the collector field. This string consists of six drive modules. There are two receivers on each power phase and the controller is connected to one of these phases in the control building.

At this time (January 1981), the PC^3 system has operated without needing adjustment or repair. Since it operated satisfactorily during the winter solstice, when the angle of the sun is greatest on the light band detector, we believe the system will continue to operate satisfactorily. We do not plan to move the PC^3 from Coolidge, so anyone seeking more information may talk to the experiment operators directly or visit the site.

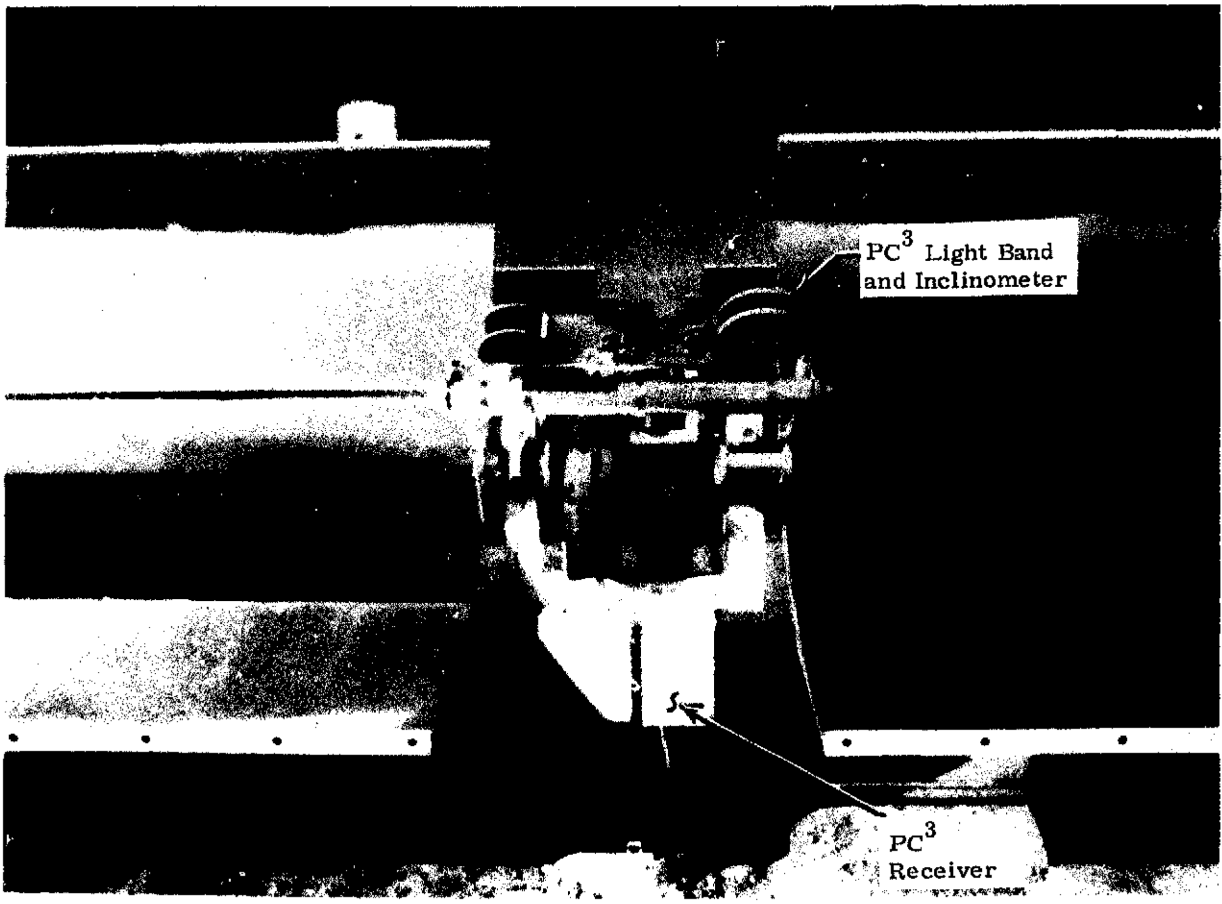


Figure 14. PC^3 Installation at the Coolidge Solar Experiment

Cost Estimates

The cost of fabricating the PC^3 system cannot be firmly determined because such cost depends on the number of units fabricated and the type of personnel assembling the system. The authors constructed the prototype system and bought the components from distributors. The parts for one controller and one receiver cost \$333 and \$388, respectively. If 100 or more components were purchased at a time, this cost would probably drop to \$264 and \$240, respectively. If many of these units are to be fabricated, however, it could be possible to fabricate much of the system on integrated chips.

As we stated at the beginning, we expect the PC^3 to more than pay for itself with the savings on the cost of installing the collector system. The PC^3 should cost substantially less than a conventional system.

Conclusions

The PC^3 system was developed to control an entire field, up to 5000 m^2, of solar trough collectors. Although it is potentially more economical than the conventional approach, it offers more control capability. In actual application, it has operated adequately and reliably.

The PC^3 approach to controlling solar collector systems has several important advantages that are inherent in its design. Quality can be assured by manufacturing the system completely in the factory and thoroughly checking it out before installing it in the field, which is done by simply plugging it into the ac power outlet. If maintenance is required, the problem can be detected by non-specialist electricians, without expensive instruments; the defective part can then be replaced and sent to the manufacturer's plant or an authorized representative to be repaired. These attributes are beneficial for economical and reliable field operation.

We recommend that a microprocessor, instead of the discrete component programmer, be used with the controller. This would save a significant cost, yet add more system capability. Most of the cost of a PC^3 system is that of the receivers. Considerable additional savings may be possible by developing most receiver electronics into an electronic chip, depending on the number of units to be fabricated.

References

[1] Robert L. Alvis and Jerry M. Alcone, Solar Powered Irrigation System, SAND76-0358 (Albuquerque, NM: Sandia Laboratories, September 1976).

[2] G. Alexander et al, The Modification and 1978 Operation of the Gila Bend Solar-Powered Irrigation Pumping System (Columbus, OH: Battele Columbus Laboratory, December 29, 1978).

[3] Skip Osgood, Jr, "Distributed Microcomputers Cut Time, Costs in Data Acquisition/Control," DESIGN NEWS, March 24, 1980, pp 86-90.

APPENDIX A

Schematics of the PC^3

DESIGN AGENCY PART NO.	REV		DESCRIPTION	DATE		
533600-000	A		M. O'BRYANT, 2458 / J. ROSBOROUGH, 2166.			
	B		M. O'BRYANT, 2458 / J. ROSBOROUGH, 2166.	12/16/80	[illegible]	[illegible]

NOTES:

1. DESIGNATIONS ARE FOR REFERENCE ONLY AND ARE NOT TO APPEAR ON THIS PART.
2. SOLDER ALL ELECTRICAL CONNECTIONS PER 9913000. METHOD OPTIONAL.
3. MARK DESIGN AGENCY PART NUMBER, PER 9919100, CLASS N-1.
4. ORIENT COMPONENTS APPROXIMATELY AS SHOWN.
5. BOND COMPONENT TO BOARD USING ADHESIVE PER 2149029.
6. IC's DO NOT HAVE SOCKETS; HARD-MOUNT THEM.
7. DOT INDICATES CATHODE END OF DIODE AND/OR POSITIVE END OF POLARIZED CAPACITORS.

SCHEMATIC ON SHEET 2

8. LANDS DESIGNATED WITH NUMBERS LIKE (1804) AND (2011) REQUIRE A HARD WIRE, ITEM 3, CONNECTED BETWEEN THEM. THE NUMBERS SPECIFIED IN THOSE LANDS ARE A CODE INDICATING THE ELECTRICAL CONNECTION BEING MADE; FOR EXAMPLE, 1804 REPRESENTS BUG 18, PAD 4 AND 2011 INDICATES BUG 20, PAD 11 BEING CONNECTED PER THIS CODING SYSTEM. ROUTE THE HARD WIRES, ITEM 8, PER THE FOLLOWING TABLE:

LAND TO LAND	LAND TO LAND
1205 - 1405	1604 - 2005
2205 - 1404	1605 - 2013
1212 - 1413	1613 - 2006
2202 - 1412	2113 - 1505
1713 - 1906	2105 - 1504
1704 - 1905	2106 - 1513
1705 - 1913	2102 - 1512
1712 - 1902	1109 - 0601
1612 - 2002	0706 - 0411
0306 - 0402	0705 - 0303
0303 - 1609	

9. MAKE THE FOLLOWING ELECTRICAL CONNECTIONS ON THIS PWB ASSEMBLY WITH HARD WIRE, ITEM 9, PER THE SCHEMATIC AND WITH REFERENCE TO THE FOLLOWING TABLE:

COMPONENT TO COMPONENT	
F1-A	TB4-ACH
F1-B	S1-C
T1-1	S1-NC

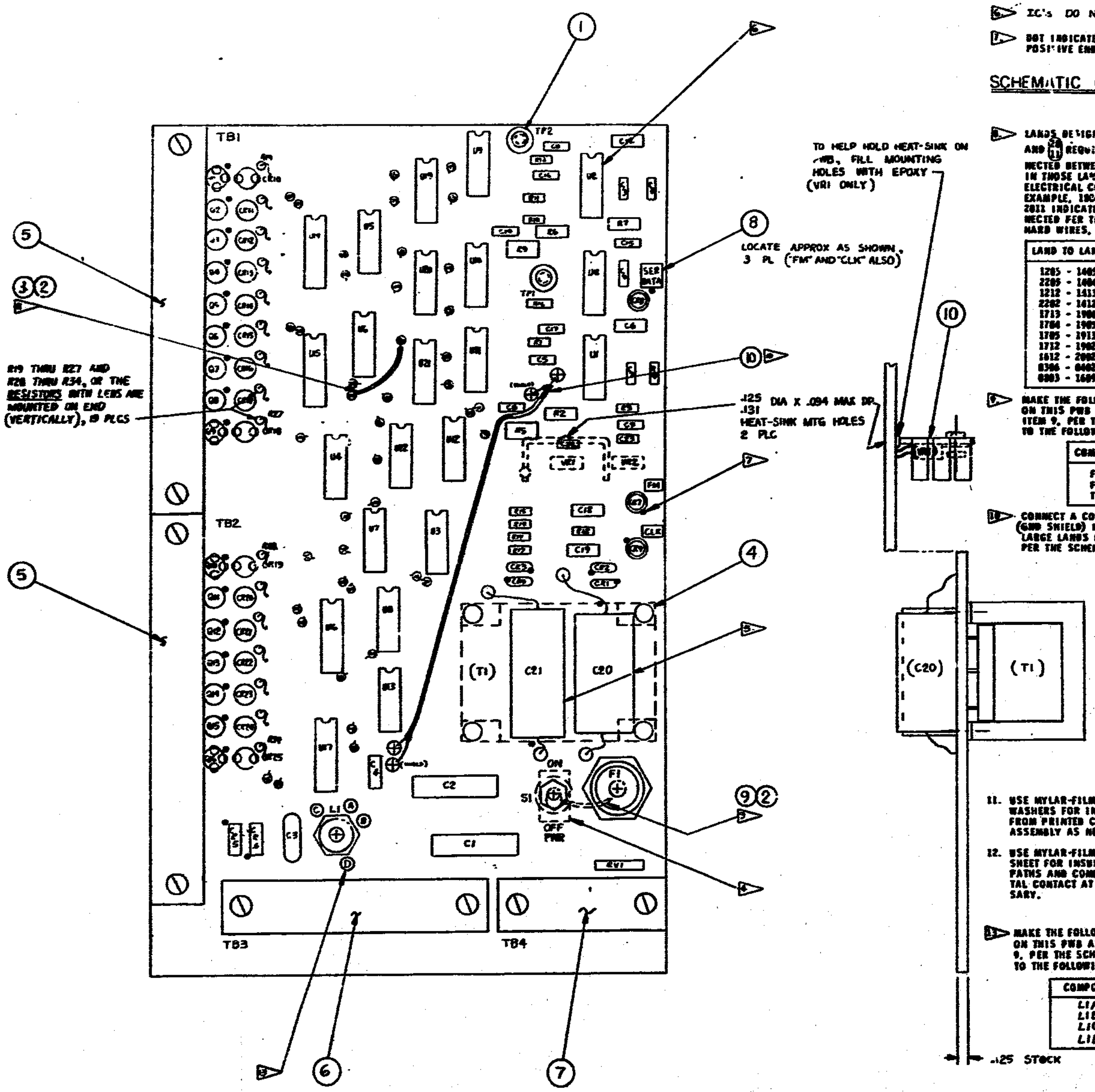
10. CONNECT A COAXIAL LEAD (CENTER CONDUCTOR) (GND SHIELD) ITEM 10 FROM C4 TO U1-2 AT THE LARGE LANDS PROVIDED NEAR THESE COMPONENTS; PER THE SCHEMATIC AND THIS ILLUSTRATION.

11. USE MYLAR-FILM PIECES AND FIBER WASHERS FOR INSULATING COMPONENTS FROM PRINTED CIRCUIT PATHS AT ASSEMBLY AS NECESSARY.

12. USE MYLAR-FILM PIECES AND LUCITE SHEET FOR INSULATING HIGH-VOLTAGE PATHS AND COMPONENTS FROM ACCIDENTAL CONTACT AT ASSEMBLY AS NECESSARY.

13. MAKE THE FOLLOWING ELECTRICAL CONNECTIONS ON THIS PWB ASSEMBLY WITH HARD WIRE, ITEM 9, PER THE SCHEMATIC AND WITH REFERENCE TO THE FOLLOWING TABLE:

COMPONENT TO *LAND*	
L1A	*A*
L1B	*B*
L1C	*C*
L1D	*D*



R19 THRU R27 AND R28 THRU R34, OR THE RESISTORS WITH LEDS ARE MOUNTED ON END (VERTICALLY), 19 PLCS

LOCATE APPROX AS SHOWN, 3 PL ("FM" AND "CLK" ALSO)

.125 DIA X .094 MAX DP. .131 HEAT-SINK MTG HOLES 2 PLC

TO HELP HOLD HEAT-SINK ON VR1, FILL MOUNTING HOLES WITH EPOXY (VR1 ONLY)

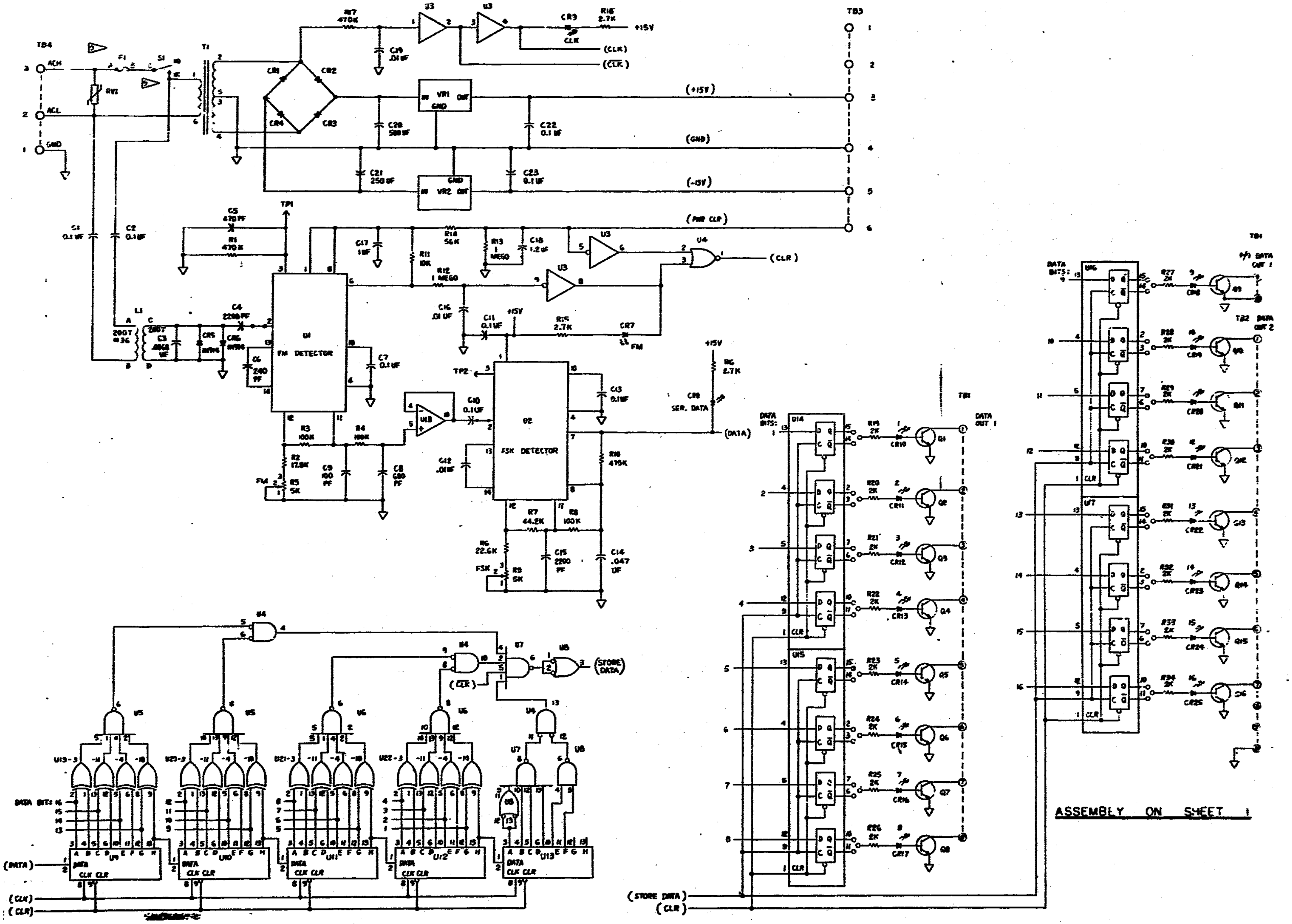
.125 STOCK

Figure A-1. Printed Wiring Assembly for Receiver

1	[illegible]	FUSEHOLDER, 3AG TYPE, LITTLEFUSE			XF1
1	[illegible]-15	VOLTAGE REGULATOR			VR2
1	MC7805CT	VOLTAGE REGULATOR			VR1
4	74C86	INTEGRATED CIRCUIT, DIP, 14-PIN		U09 -	U12
1	741	INTEGRATED CIRCUIT, DIP, 14-PIN			U08
4	74C175	16-PIN		U04 -	U07
5	74C164	14-PIN		U9 -	U13
1	74C00	14-PIN			U6
3	74C20	14-PIN		U5 -	U7
1	74C02	14-PIN			U1
1	74C14	14-PIN			U3
2	XR2211	INTEGRATED CIRCUIT, DIP, 14-PIN			U1, U2
1	PC4400	TRANSFORMER, 6 PINS, MICROTRAN ± 15V @ 250mA			T1
1	[illegible]	SWITCH, TOGGL, SD, [illegible] CH			S1
1	V130LA20A	VARISTOR, GE			RV1
16	[illegible]	RESISTOR, FIXED, [illegible], 2K, 1/4W, 2%		R19 -	R36
1	[illegible]	2.7K, 1/4W, 2%	R35,	R16,	R18
1	[illegible]	[illegible], 1/4W, 2%			R16
2	[illegible]	[illegible], 1/4W, 5%		R12,	R13
1	[illegible]	[illegible], 1/4W, 2%			R33
2	[illegible]	FIXED, 470K, 1/4W, 5%		R17,	R18
1	[illegible]	FIXED, 100K, 1/4W, 2%		R8,	
1	[illegible]	RESISTOR, FIXED 44.2K, 1/4W, 1%			R7
1	[illegible]	FIXED 22.6K, 1/4W, 1%			R6
2	[illegible]	VARIABLE — 5K, [illegible]		R5,	R9
2	[illegible]	FIXED 100K, 1/4W, 1%		R3,	R4
1	[illegible]	17.8K, 1/4W, 1%			R2
1	[illegible]	RESISTOR, FIXED, COMP, 47K, 1/4W, 5%			R1
16	[illegible]	TRANSISTOR, 2N2222		Q1 -	Q16
1		COILFORM, .375 x 1.0, MILLER 64A024-1			L1
1	[illegible]	FUSE, 1 AMP, LITTLEFUSE			F1
10	[illegible]	DIODE, LIGHT-EMITTING, HP [illegible] REF)		CR7 -	CR25
2	[illegible]	SEMICONDUCTOR DEVICE, DIODE, 1N914		CR5,	CR6
4	[illegible]	SEMICONDUCTOR DEVICE, DIODE, [illegible]		CR1 -	CR4
1	6030B	HEAT-SINK, THERMALOY			HS
1	[illegible]	CAPACITOR, FIXED, [illegible] UF, 25V			C21
1	[illegible]	[illegible] UF, 25V			C20
1	[illegible]	1.2 UF ±10%, 20V TANT			C18
1	[illegible]	6.8 UF, 10%, 35V			C16
1	[illegible]	.047 UF, 10%, 20V			C14
2	[illegible]	CAPACITOR, FIXED, 0.01 UF, 10%, 50V		C13,	C12
1	[illegible]	[illegible] PF, 10%, 200V			C8
7	[illegible]	0.1 UF, 10%, 20V	C12,	C7, C10, C11,	C17, C19, C23
2	[illegible]	[illegible] PF, 10%, 500V MICA		C6,	C9
1	[illegible]	470 PF, 10%, 200V			C5
2	[illegible]-152	2200 PF, 10%, 100V		C4,	C15
1	[illegible]	.[illegible] UF, 10%, 400V			C3
2	[illegible]	CAPACITOR, FIXED, 1 UF, 10%, 400V			C1, C2
ARS		WIRE, SOLID STRAND, SOFT-DRAWN, ANNEALED, BARE COPPER [illegible]			9
ARS	[illegible]	I.D. TAPE, EMBOSSABLE, 1-SIDED CONTRASTING COLOR			8
1	72000-3	CONNECTOR, TERMINAL STRIP, VERNITRON			7
1	72000-5	CONNECTOR, TERMINAL STRIP, VERNITRON			6
2	72000-10	CONNECTOR, TERMINAL STRIP, VERNITRON			5
1	PC[illegible]-FR	BRACKET, TRANSFORMER, MICROTRAN			4
ARS		WIRE, SOLID STRAND, SOFT-DRAWN ANNEALED, BARE COPPER [illegible]			3
ARS	221[illegible]	SLEEVING, INSULATION, ELECTRICAL			2
2	[illegible]	TERMINAL STUD, TURRET TYPE, MINIATURE			1
ARS	[illegible]	CABLE, COAXIAL			10
NA	[illegible]	MARKING, GENERAL METHODS			
NA	533[illegible]-000	PRINTED WIRING BOARD, RECEIVER			
NA	[illegible]	SOLDERING SPEC, PWB'S			
NA	[illegible]	FABRICATION, PRINTED WIRING BOARDS			

LIST OF MATERIAL

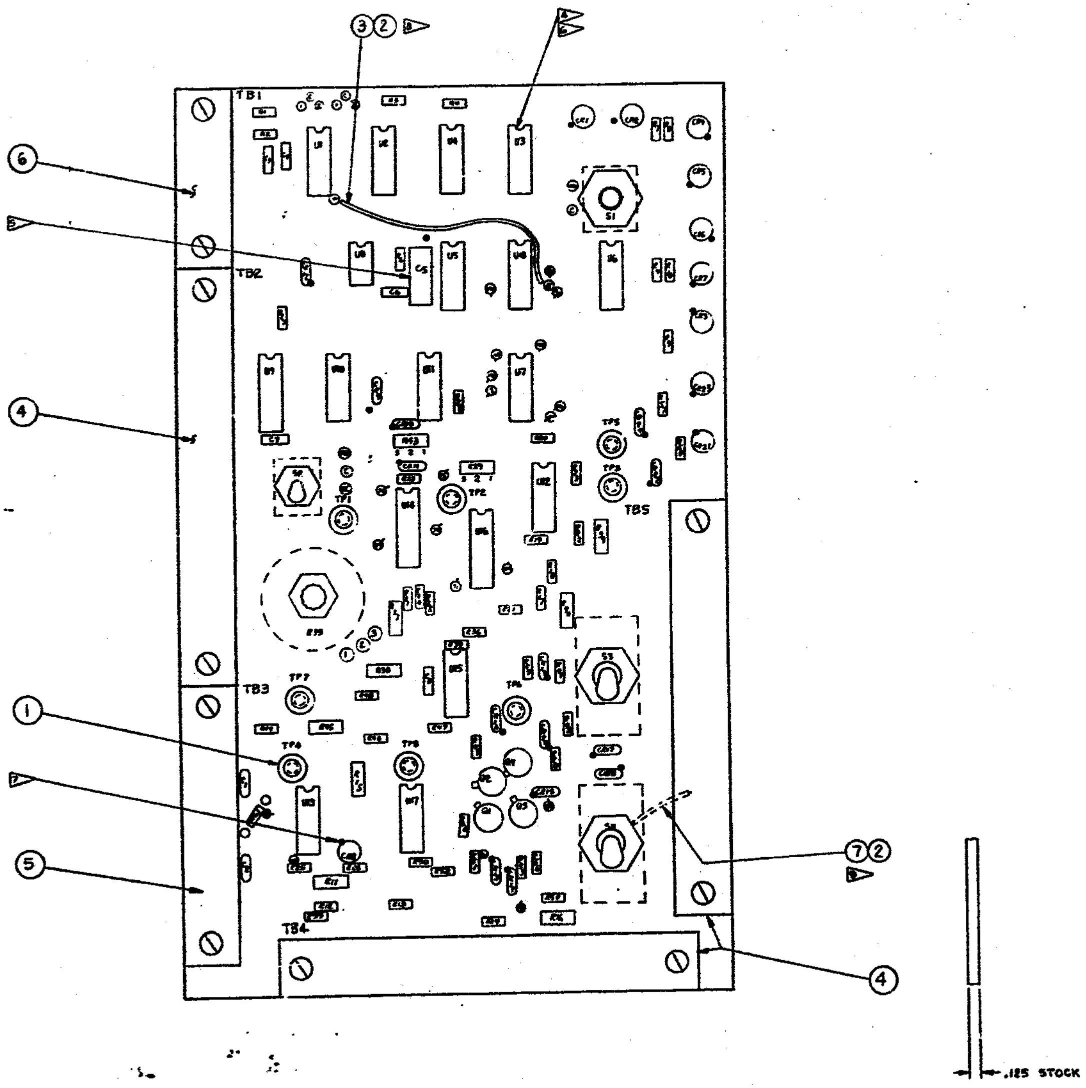
DWG. No. 533600



ASSEMBLY ON SHEET 1

Figure A-2. Schematic for Receiver

533765-000	A		M. O'BRYANT, 2458/ J. ROSBOROUGH, 2166.
	B		M. O'BRYANT, 2458/ J. ROSBOROUGH, 2166.



NOTES:

1. DESIGNATIONS ARE FOR REFERENCE ONLY AND ARE NOT TO APPEAR ON THIS PART.
2. SOLDER ALL ELECTRICAL CONNECTIONS PER 9913000, METHOD OPTIONAL.
3. MARK DESIGN AGENCY PART NUMBER, PER 9919100, CLASS N-1.
4. ORIENT COMPONENTS APPROXIMATELY AS SHOWN.
5. BOND COMPONENT TO BOARD USING ADHESIVE PER 2149029.
6. IC'S DO NOT HAVE SOCKETS; HARD-MOUNT THEM.
7. DOT INDICATES CATHODE END OF DIODE AND/OR POSITIVE END OF POLARIZED CAPACITORS.

SCHEMATIC ON SHEET 2

8. LANDS DESIGNATED WITH NUMBERS LIKE ⑱④ AND 20/11 REQUIRE A HARD WIRE, ITEM 3, CONNECTED BETWEEN THEM. THE NUMBERS SPECIFIED IN THOSE LANDS ARE A CODE INDICATING THE ELECTRICAL CONNECTION BEING MADE; FOR EXAMPLE, 1804 REPRESENTS BUG 18, PAD 4 AND 2011 INDICATES BUG 20, PAD 11 BEING CONNECTED PER THIS CODING SYSTEM. ROUTE THESE HARD WIRES, ITEM 3, PER THE FOLLOWING TABLE:

LAND TO LAND	LAND TO LAND
1809 - 0208	610 - 1310
1609 - 0713	
1608 - 0701	
1409 - 0709	
1416 - 0705	
1401 - 0711	
1408 - 0703	

9. MAKE THE FOLLOWING ELECTRICAL CONNECTIONS ON THIS PWB ASSEMBLY WITH HARD WIRE, ITEM 7, PER THE SCHEMATIC AND WITH REFERENCE TO THE FOLLOWING TABLE:

COMPONENT	TO	COMPONENT
S3-NC	—	TB5-5
S3-C	—	TB5-6
S3-NO	—	S4-C
S4-A	—	TB5-7
S4-B	—	TB5-8
COMPONENT	**TO**	**LAND**
S1-C	-	C
S1-NO	-	NO
S2-C	-	C
S2-NO	-	NO
R56	-	1806
R61	-	CR13
CR14	-	1811

10. USE MYLAR-FILM PIECES AND FIBER WASHERS FOR INSULATING COMPONENTS FROM PRINTED CIRCUIT PATHS AT ASSEMBLY AS NECESSARY.
11. USE MYLAR-FILM PIECES AND LUCITE SHEET FOR INSULATING HIGH-VOLTAGE PATHS AND COMPONENTS FROM ACCIDENTAL CONTACT AT ASSEMBLY AS NECESSARY.

1	74C10N	INTEGRATED CIRCUIT, DIP, 14 PIN		[illegible]
2	LF13201N	INTEGRATED CIRCUIT, DIP, 16 PIN	U4,	U6
1	[illegible]	INTEGRATED CIRCUIT, DIP, 14 PIN		U13
3	[illegible]	INTEGRATED CIRCUIT, DIP, 14 PIN	U2, U15,	U17
1	DAC-[illegible]	16 PIN		[illegible]
1	[illegible]	16 PIN [illegible]		U9
1	[illegible]	8 PIN		U8
2	74C[illegible]	16 PIN	U7,	U10
1	74C[illegible]	14 PIN		U5
1	74C[illegible]	14 PIN	[illegible]	
2	74C[illegible]	14 PIN	U3,	U5
1	74C74N	14 PIN		U2
1	74C14N	INTEGRATED CIRCUIT, DIP, 14 PIN		U1
2	440018-340	RESISTOR, FIXED, 10K, 1/4W, 2% MF	[illegible],	[illegible]
1	228501-196	RESISTOR, FIXED, 1K, 1/8W, 1% MF		R50
1	MS25306-222	SWITCH, TOGGLE, BAT HANDLE [illegible] REF)		S4
1	MS25306-232	TOGGLE, BAT HANDLE [illegible] REF)		S3
1	[illegible]	MIN. TOGGLE, [illegible] REF)		S2
1	2P[illegible]-12	SWITCH, PB, HONEYWELL [illegible] REF)		S1
1	[illegible]-304	RESISTOR, FIXED, [illegible], 1/4W, 2% MF		[illegible]
1	[illegible]-340	RESISTOR, FIXED, 10K, 1/4W, 2% MF		[illegible]
1	440006-368	1 MEG, 1/4W, 5% CC		[illegible]
1	440015-308	1K, 1/4W, 2% MF		[illegible]
3	[illegible]-676	FIXED, [illegible], 1/4W, 1% MF	[illegible] -	[illegible]
1	3299W1-502	VARIABLE, 5K, 1[illegible], BOURNS		[illegible]
1	[illegible]-642	RESISTOR, FIXED, [illegible], 1/4W, 2% MF		[illegible]
1	3299W1-[illegible]	VARIABLE, 20K, 1[illegible], BOURNS		[illegible]
2	[illegible]	FIXED, 20K, 1/4W, 1% MF	[illegible],	[illegible]
2	[illegible]	FIXED, 10K, 1/4W, 1% MF	[illegible],	[illegible]
1	440018-316	FIXED, 3.3K, 1/4W, 2% MF		[illegible]
1	[illegible]	VARIABLE, 10K, 2W		[illegible]
1	3299W1-[illegible]	VARIABLE, 500, 1[illegible], BOURNS		[illegible]
1	[illegible]	FIXED, 470K, 1/4W, 5% CC		[illegible]
4	[illegible]-306	2K, 1/4W, 2% MF	[illegible], [illegible],	[illegible]
5	[illegible]-312	2.7K, 1/4W, 2% MF	[illegible], [illegible]	[illegible]
2	[illegible]	1 MEG, 1/4W, 5% CC	[illegible],	[illegible]
1	[illegible]	RESISTOR, FIXED, [illegible], 1/4W, 2% MF		[illegible]
1	[illegible]	FIXED, 24K, 1/4W, 2% MF		[illegible]
1	[illegible]	FIXED, 10K, 1/4W, 2% MF		[illegible]
1	3299W1-[illegible]	VARIABLE, 50K, 1[illegible], BOURNS		[illegible]
6	[illegible]	FIXED, 2K, 1/4W, 2% MF	[illegible]	[illegible]
4	[illegible]	FIXED, 100K, 1/4W, 2% MF	[illegible],	[illegible]
1	[illegible]	FIXED, 5.1K, 1/4W, 2% MF		[illegible]
1	3299W1-[illegible]	RESISTOR, VARIABLE, 5K, 1[illegible], BOURNS		[illegible]
1	[illegible]-275	FIXED, 2 MEG, 1/4W, 5% CC	[illegible]	[illegible]
8	[illegible]-282	FIXED, 2.7K, 1/4W, 2% MF	[illegible]	[illegible]
3	[illegible]-340	RESISTOR, FIXED, 10K, 1/4W, 2% MF	[illegible]	[illegible]
1	[illegible]-296	RESISTOR, FIXED, 1.2K, 1/4W, 2% MF		[illegible]
4	[illegible]	TRANSISTOR, 2N[illegible]	Q1 -	Q4
1	[illegible]	RESISTOR, FIXED, [illegible], 1/4W, 2% MF		[illegible]
1	[illegible]-322	RESISTOR, FIXED, 4.3K, 1/4W, 2% MF		[illegible]
1	[illegible]	SEMICONDUCTOR DEVICE, DIODE, 1N[illegible]		[illegible]
15	[illegible]	SEMICONDUCTOR DEVICE, DIODE, [illegible]	[illegible] -	[illegible]
8	5082-4[illegible]	DIODE, LIGHT-EMITTING, HP [illegible] REF)	CR1 -	CR8
ARS		WIRE, SOLID STRAND, SOFT DRAWN ANNEALED, BARE COPPER #[illegible]		7
1	[illegible]	CAPACITOR, FIXED, [illegible], [illegible], [illegible]		C6
1	[illegible]	CAPACITOR, FIXED, [illegible], [illegible], 20V		C5
5	[illegible]	CAPACITOR, FIXED, [illegible], [illegible], [illegible]	C1-C4,	C7
1	7[illegible]-3	CONNECTOR, TERMINAL STRIP, VERNITRON		6
1	7[illegible]-6	CONNECTOR, TERMINAL STRIP, VERNITRON		5
3	7[illegible]-10	CONNECTOR, TERMINAL STRIP, VERNITRON		4
ARS		WIRE, SOLID STRAND, SOFT-DRAWN ANNEALED, BARE COPPER #22		3
ARS	[illegible]-00	SLEEVING, INSULATION, ELECTRICAL		2
8	[illegible]	TERMINAL STUD, TURRET TYPE, MINIATURE		1
NA	[illegible]	MARKING, GENERAL METHODS		
NA	[illegible]-000	PRINTED WIRING BOARD, COLLECTOR CONTROL		
NA	[illegible]	SOLDERING SPEC, PWBS		
NA	[illegible]	FABRICATION, PRINTED WIRING BOARDS		

533765

Figure A-3. Printed Wiring Assembly, Collector Control

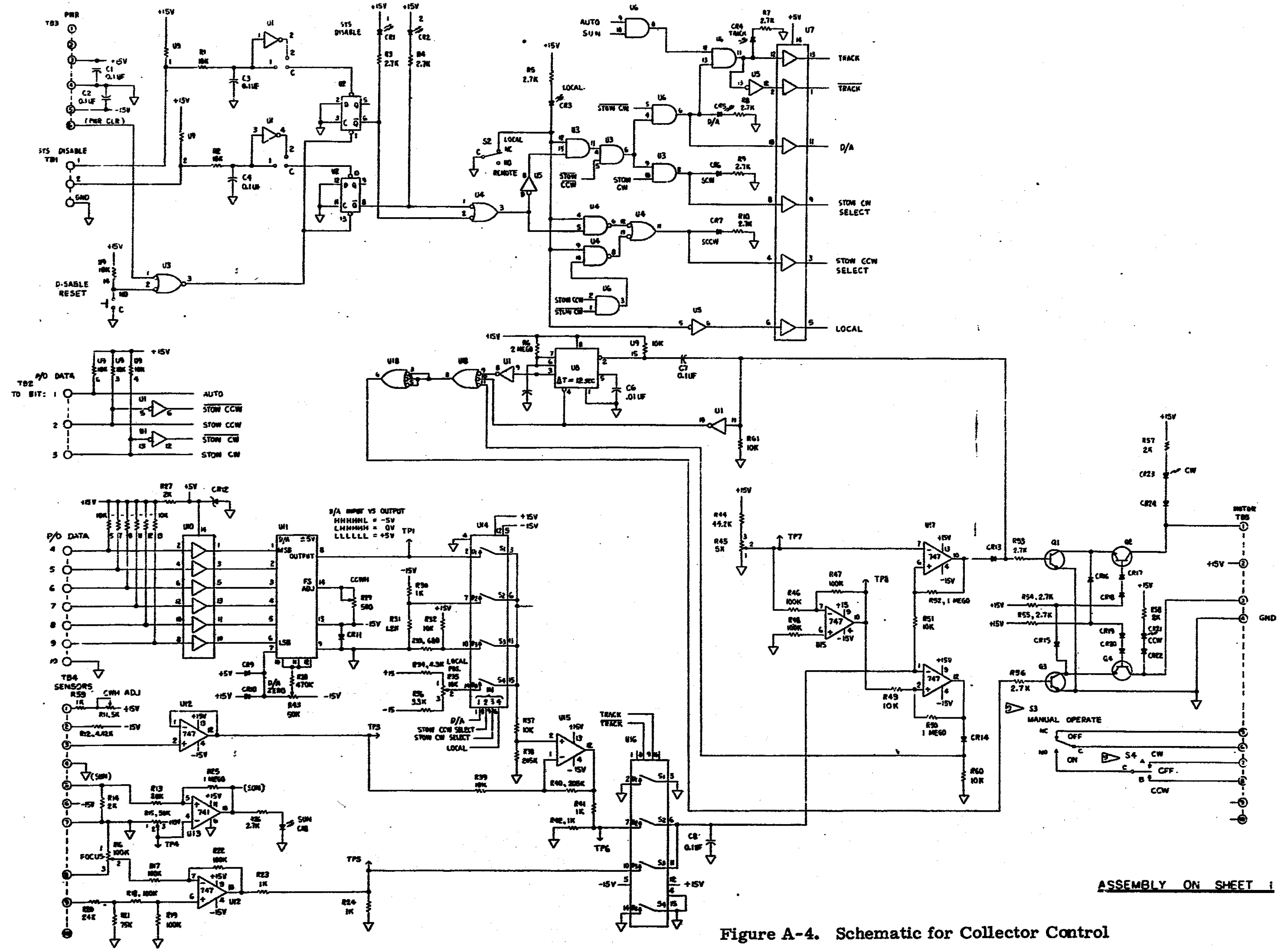


Figure A-4. Schematic for Collector Control

ASSEMBLY ON SHEET 1

NOTE:

1. CASE, COVER AND BRACKETS TO BE PAINTED REFLECTIVE, BRIGHT WHITE.
2. BOX IS HOFFMAN A-12R86.

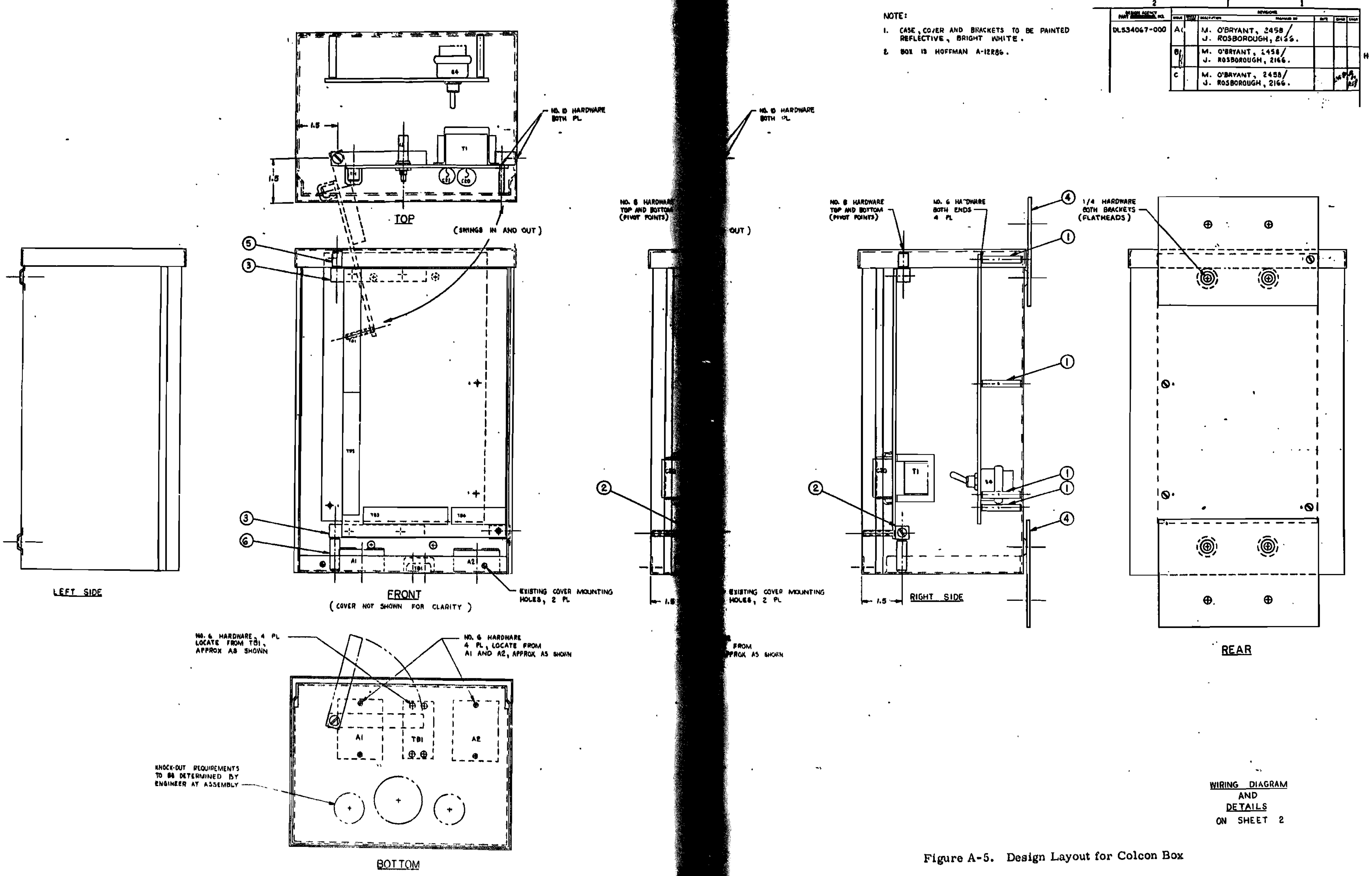
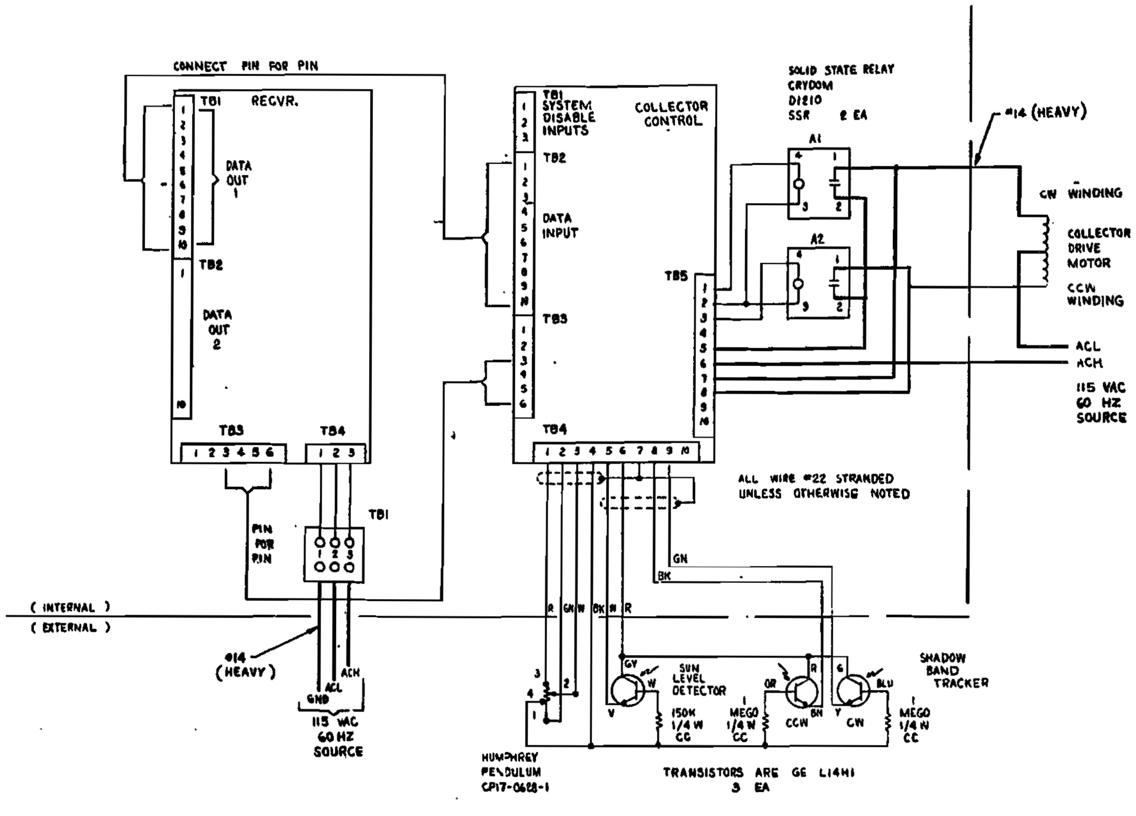
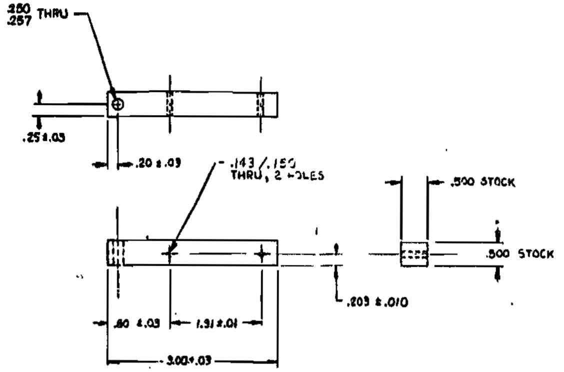


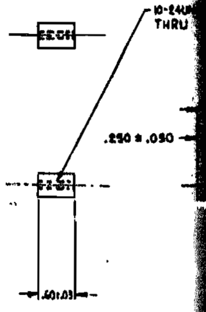
Figure A-5. Design Layout for Colcon Box



WIRING DIAGRAM



ITEM 3 (2 REQD) ALUM, 6061-T6, ANODIZE



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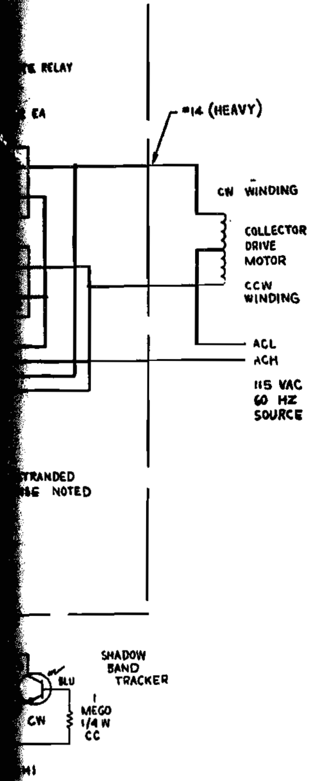

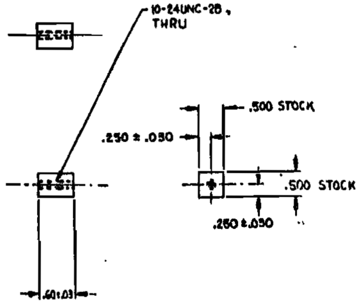

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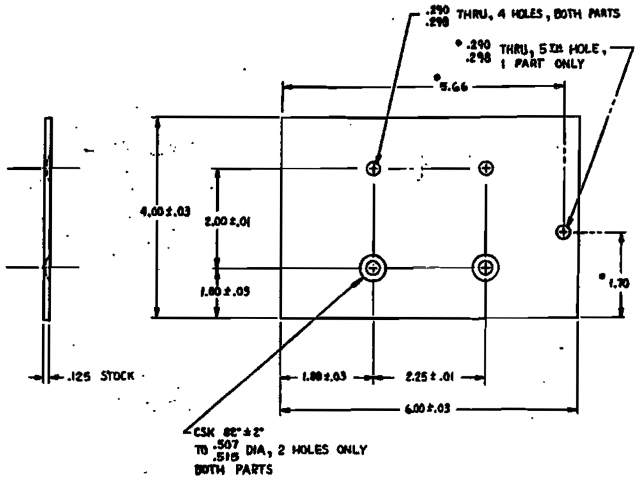

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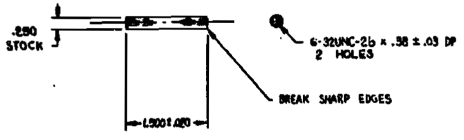
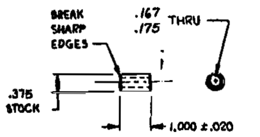


ITEM 1 (4 REQD) ALUM, 6061-T6, ANODIZE



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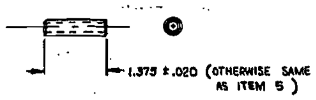
ALUM, 6061-T6 ANODIZE



ITEM 6 (1 REQD) ALUM, 6061-T6 ANODIZE

ASSEMBLY ON SHEET 1

Figure A-6. Schematic for Colcon Box

533790-000	A	M. O'BRYANT, 2458 / J. ROSBOROUGH, 2166.
	B	M. O'BRYANT, 2458 / J. ROSBOROUGH, 2166.

NOTES:

1. DESIGNATIONS ARE FOR REFERENCE ONLY AND ARE NOT TO APPEAR ON THIS PART.
2. SOLDER ALL ELECTRICAL CONNECTIONS PER 9913000. METHOD OPTIONAL.
3. MARK DESIGN AGENCY PART NUMBER, PER 9919190, CLASS N-3.
4. ORIENT COMPONENTS APPROXIMATELY AS SHOWN.
5. BOND COMPONENT TO BOARD USING ADHESIVE PER 2149079.
6. IC'S DO NOT HAVE SOCKETS, HARD-MOUNT THEM.
7. DOT INDICATES CATHODE END OF DIODE AND/OR POSITIVE END OF POLARIZED CAPACITORS.

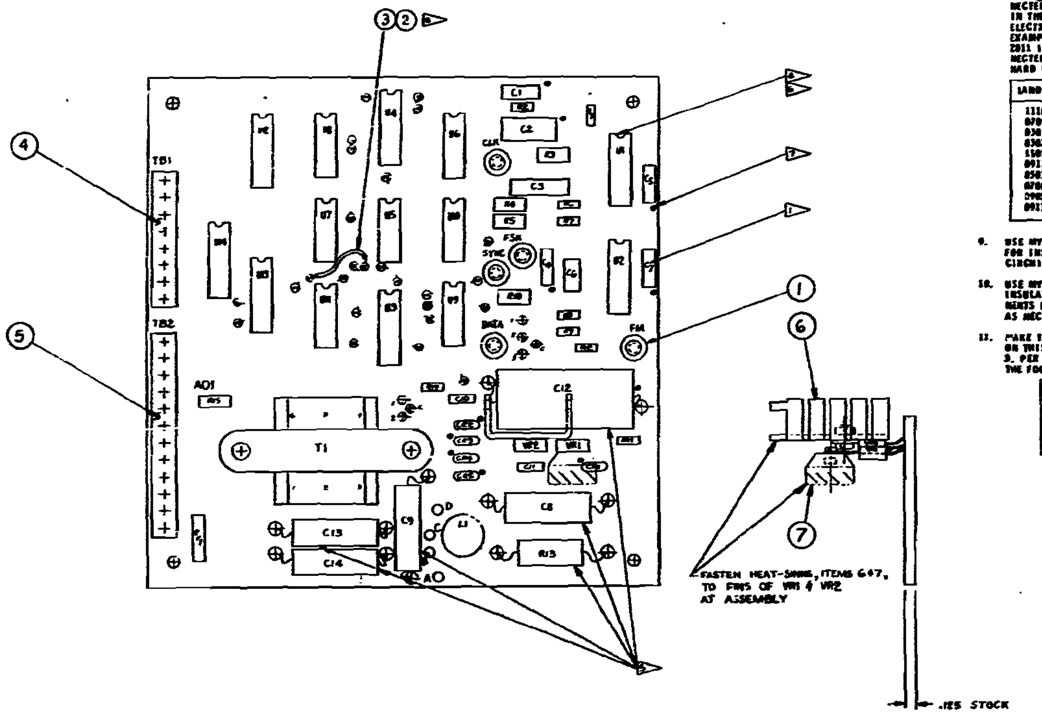
SCHEMATIC ON SHEET 2

8. LANDS DESIGNATED WITH NUMBERS LIKE (1004) AND (20 11) REQUIRE A HARD WIRE, ITEM 3, CONNECTED BETWEEN THEM. THE NUMBERS SPECIFIED IN THESE LANDS ARE A CODE INDICATING THE ELECTRICAL CONNECTION BEING MADE; FOR EXAMPLE 1004 REPRESENTS BUG 10, PAD 4 AND 2011 INDICATES BUG 20, PAD 11 BEING CONNECTED PER THIS CODING SYSTEM. ROUTE THE HARD WIRES, ITEM 3, PER THE FOLLOWING TABLE:

LAND TO LAND	LAND TO LAND
1110 - 0812	1009 - 0901
0709 - 0811	1010 - 0906
0301 - 0801	0505 - 214
0307 - 0415	
1501 - 0413	
0911 - 1305	
0503 - 1106	
0706 - 1307	
0905 - 0502	
0913 - 0504	

9. USE MYLAR-FILM PIECES AND FIBER WASHERS FOR INSULATING COMPONENTS FROM PRINTED CIRCUIT PATHS AT ASSEMBLY AS NECESSARY.
10. USE MYLAR-FILM PIECES AND LUCITE SHEET FOR INSULATING HIGH-VOLTAGE PATHS AND COMPONENTS FROM ACCIDENTAL CONTACT AT ASSEMBLY AS NECESSARY.
11. MAKE THE FOLLOWING ELECTRICAL CONNECTIONS ON THIS PWB ASSEMBLY WITH HARD WIRE, ITEM 3, PER THE SCHEMATIC AND WITH REFERENCE TO THE FOLLOWING TABLE:

COMPONENT	TO LAND
L1A	A
L1B	B
L1C	C
L1D	D



1	7815	VOLTAGE REGULATOR		VR2
1	LM317	VOLTAGE REGULATOR		VR1
1	[illegible]	INTEGRATED CIRCUIT, DIP, 16-PIN		[illegible]
2	[illegible]	INTEGRATED CIRCUIT, DIP, 16-PIN	[illegible]	[illegible]
1	[illegible]	16-PIN		[illegible]
2	[illegible]	16-PIN		[illegible]
3	[illegible]	16-PIN	[illegible]	[illegible]
1	[illegible]	16-PIN		[illegible]
2	[illegible]	16-PIN		[illegible]
2	[illegible]	INTEGRATED CIRCUIT, DIP, 16-PIN		[illegible]
1	[illegible]	TRANSFORMER, [illegible]		T1
1	V130LA20A	VARISTOR, GE		[illegible]
1	440008-244	RESISTOR, FIXED, [illegible], 1/4W, 5%		R14
1	440021-165	51 OHMS, 2W, 5%		R13
2	440008-220	1K, 1/4W, 5%	R11,	R15
1	356410	5.11K, 1/8W, 1% MF		R9
1	440008-236	4?K, 1/4W, 5%		R8
1	357192	17.8K, 1/8W, 1% MF		R7
1	356497	FIXED, 10.2K, 1/8W, 1% MF		R6
3	[illegible]	VARIABLE, 5K, [illegible], BOURNS	[illegible]	[illegible]
1	[illegible]	VARIABLE, [illegible], BOURNS		[illegible]
3	440008-326	RESISTOR, FIXED, 5.1K, 1/4W, 5%	R1, R2,	R12
1	[illegible]	INDUCTOR, [illegible], .375 x 1.0		L1
5	[illegible]	SEMI-CONDUCTOR DEVICE, DIODE	CR1-	CR5
1	[illegible]	HEAT-SINK, WAKEFIELD ENGINEERING		7
1	[illegible]	CAPACITOR, FIXED, [illegible], 400V MYLAR		C9
2	[illegible]	0.1 UF, ±10%, 50V	C8,	C10
1	[illegible]	[illegible] PF, ±10%, 50V		C6
1	[illegible]	[illegible] UF, ±10%, 50V		C3
1	[illegible]	10 UF, ±10%, 50V		C2
4	[illegible]	CAPACITOR, FIXED, 1 UF, ±10%, 50V	C1,C4,C5	C7
1	60308	HEAT-SINK, THERMALOY		6
1		CONNECTOR, TERMINAL STRIP, 12-PIN		5
1		CONNECTOR, TERMINAL STRIP, 8-PIN		4
A/R		WIRE, SOLID STRAND, SOFT-DRAWN [illegible] COPPER, 22		3
A/R	[illegible]	SLEEVING, INSULATION, ELECTRICAL		2
5	[illegible]	TERMINAL, STUD, TURRET TYPE, MINIATURE		1
NA	[illegible]	MARKING, GENERAL METHODS		
NA	[illegible]	PRINTED WIRING BOARD, TRANSMITTER		
NA	[illegible]	SOLDERING SPEC, PWBS		
NA	[illegible]	FABRICATION, PRINTED WIRING BOARDS		

LIST OF MATERIAL

533790

Figure A-7. Printed Wiring Assembly for Transmitter

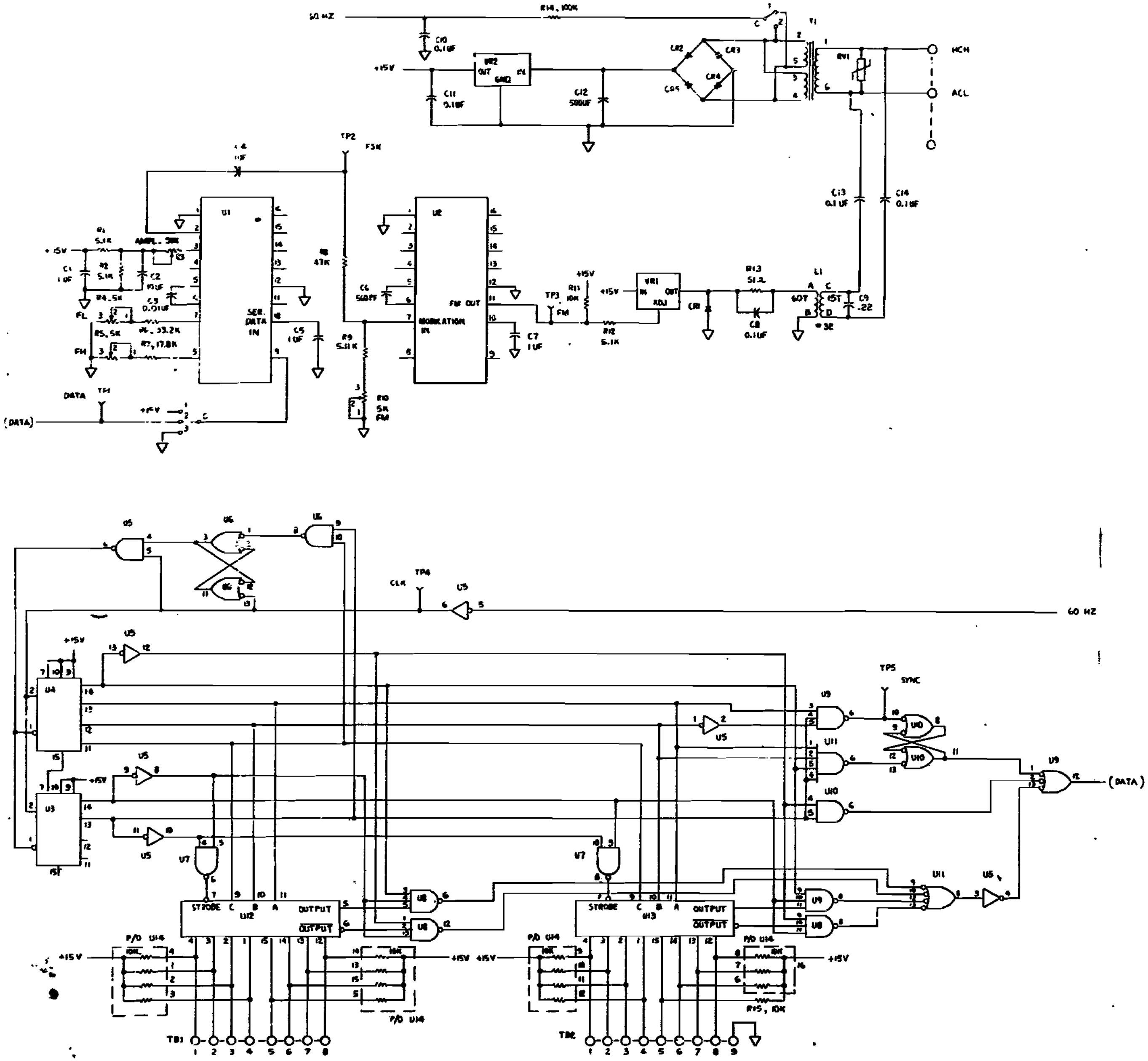


Figure A-8. Schematic for Transmitter

ASSEMBLY ON SHEET 1

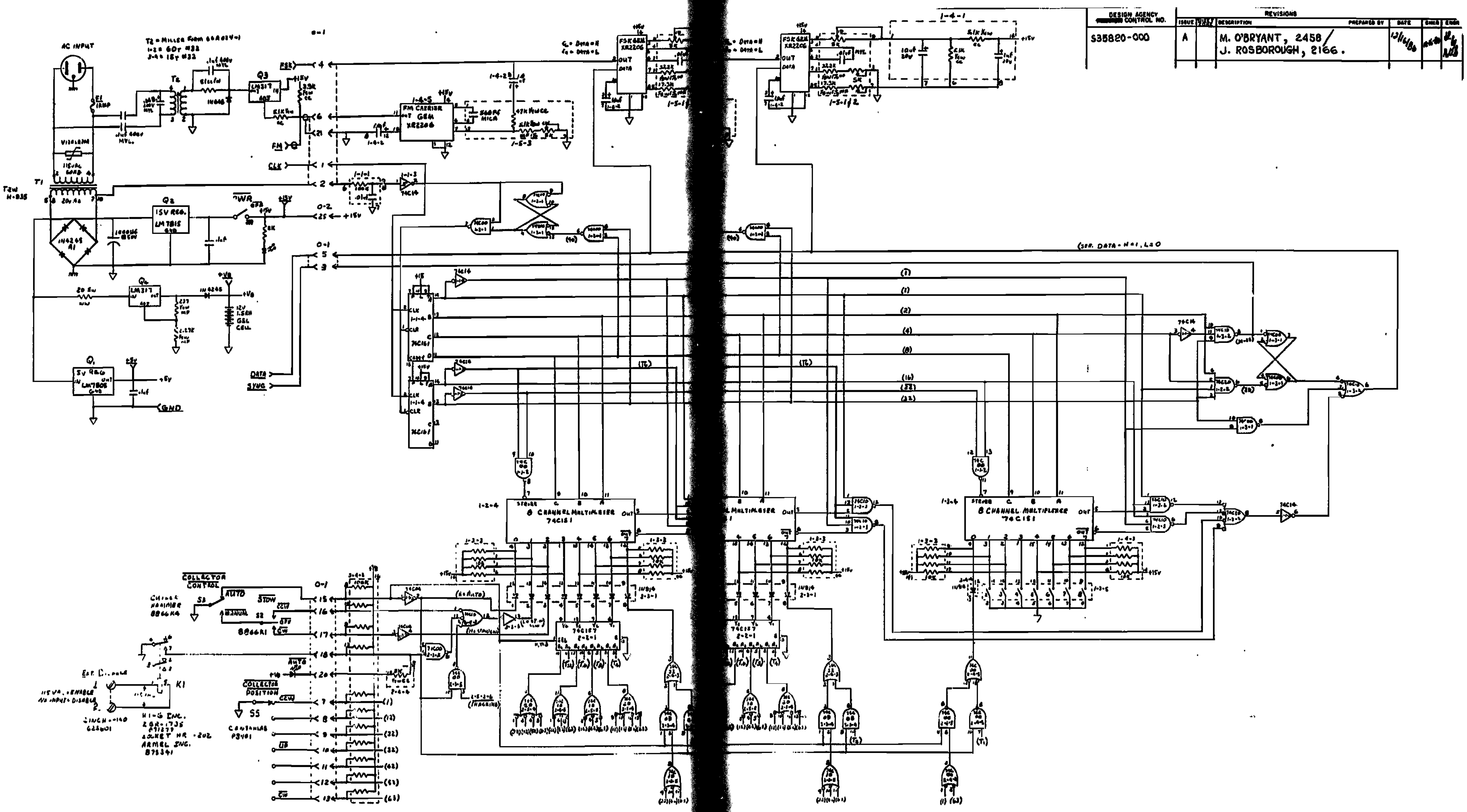


Figure A-9. Schematic for Carrier Collector Control

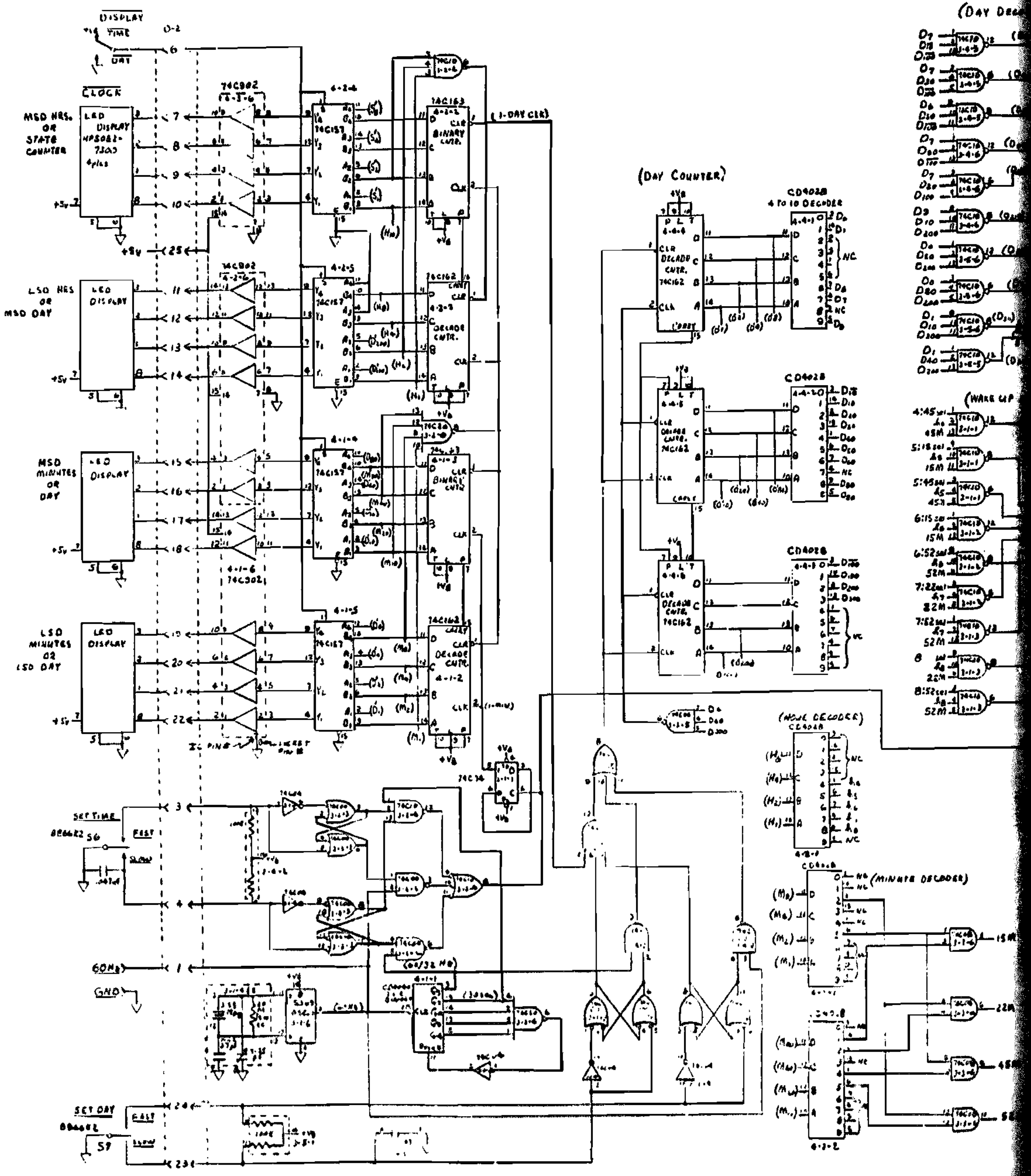


Figure A-9 (continued

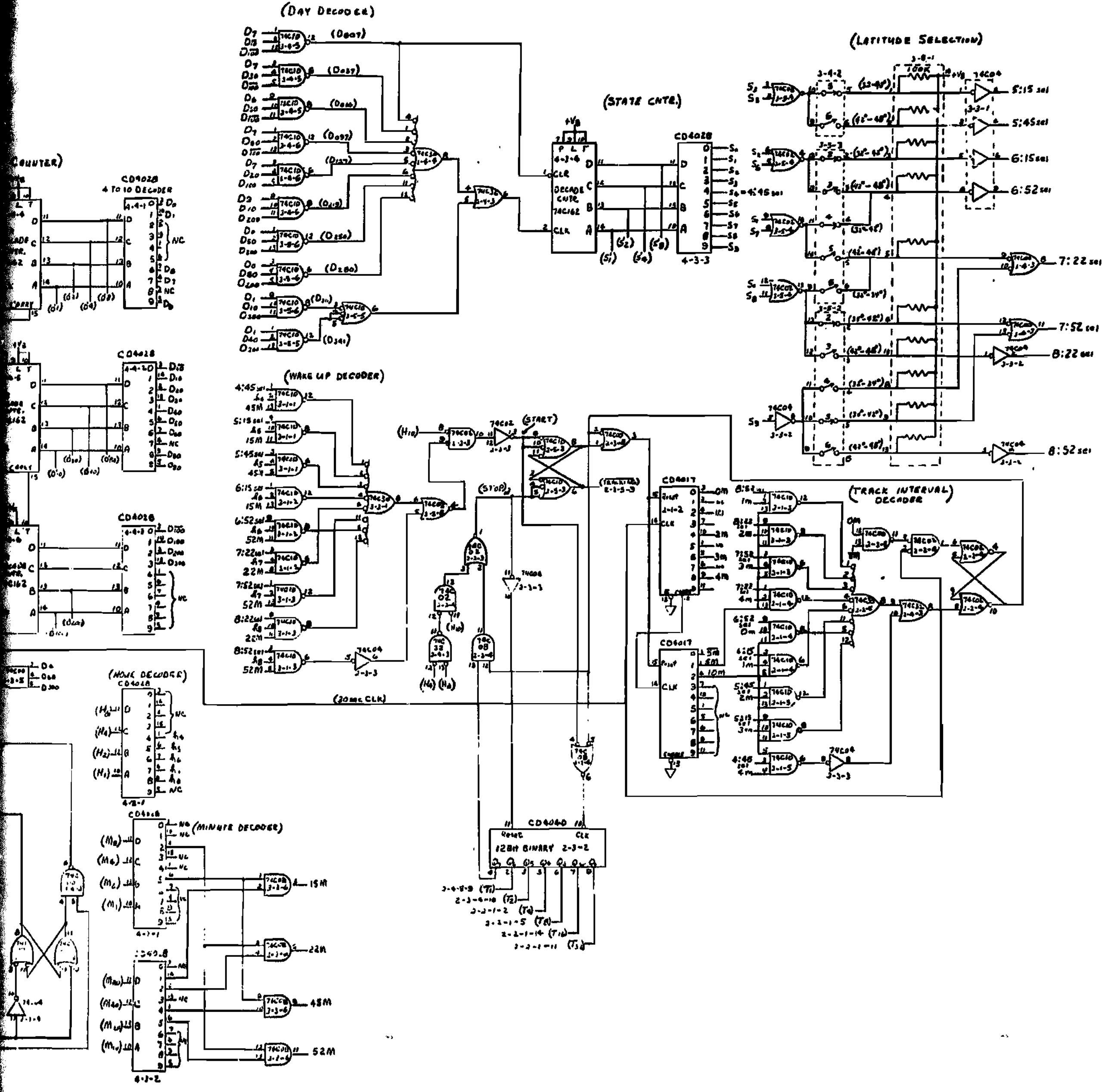


Figure A-9 (continued)

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5523	R. C. Reuter
5810	R. G. Kepler
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5830	M. J. Davis
5833	J. L. Jellison
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8450	R. C. Wayne
8452	A. C. Skinrood
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