A battery-operated ship-board remote control system for model ships

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A BATTERY - OPERATED SHIP - BOARD REMOTE CONTROL SYSTEM FOR MODEL SHIPS

-K. AYUKAWA, F. VACHON, AND W. FOSTER-

OTTAWA

JANUARY 1970

ANALYZED

ABSTRACT

This report describes the shipboard equipment which has been used since 1968 by the National Research Council. This equipment replaces the original ship-board equipment (ERB-808). Using integrated circuits in the digital portion of the system and analog servos for speed and rudder control, the equipment is more compact and easier to install and operate by the users. The radio link is pulse-code modulated as before.

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FIGURES

BATTERY-OPERATED REMOTE CONTROL OF MODEL SHIPS

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Introduction

This report contains a description of the *ship-board equipment* which was put into operation in mid-1968 and has been in use since that time. This equipment is more compact and lighter than the original ship-board equipment [1] which was in use till the end of 1967. The original system was powered by a gas-electric generator and used digital servo motors. The present system is powered from storage batteries and uses analog servos. Size, weight, and power have been reduced, largely through the use of integrated circuits and to some extent through the use of analog rather than digital servos. The main aim has been to reduce the size of the ship-board equipment and to make it simpler to install and operate by the user.

The transmitting equipment has not been modified nor has the main logic portion of the ship-board equipment. Details of this have been described before [1], and only that part which affects the operation of the analog servos will be described in detail in this report. However, a short review of the basic theory of operation will be given; this has not changed from the original system. Fig. 1 gives an over-all view of the situation.

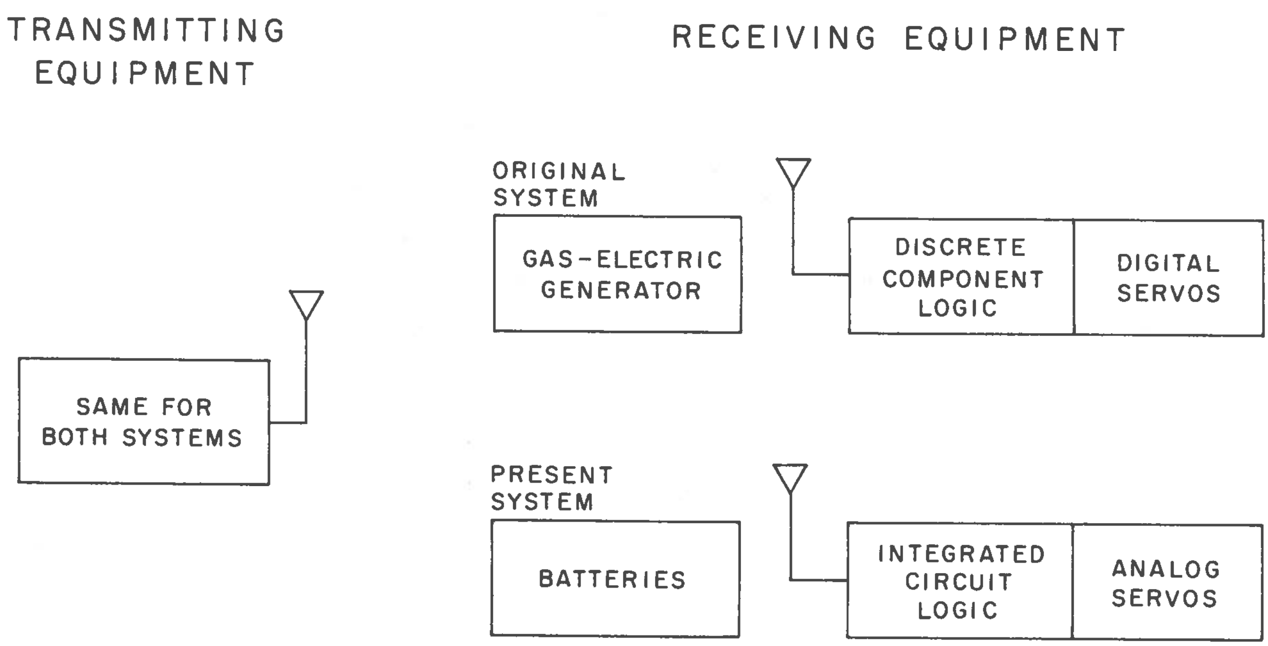
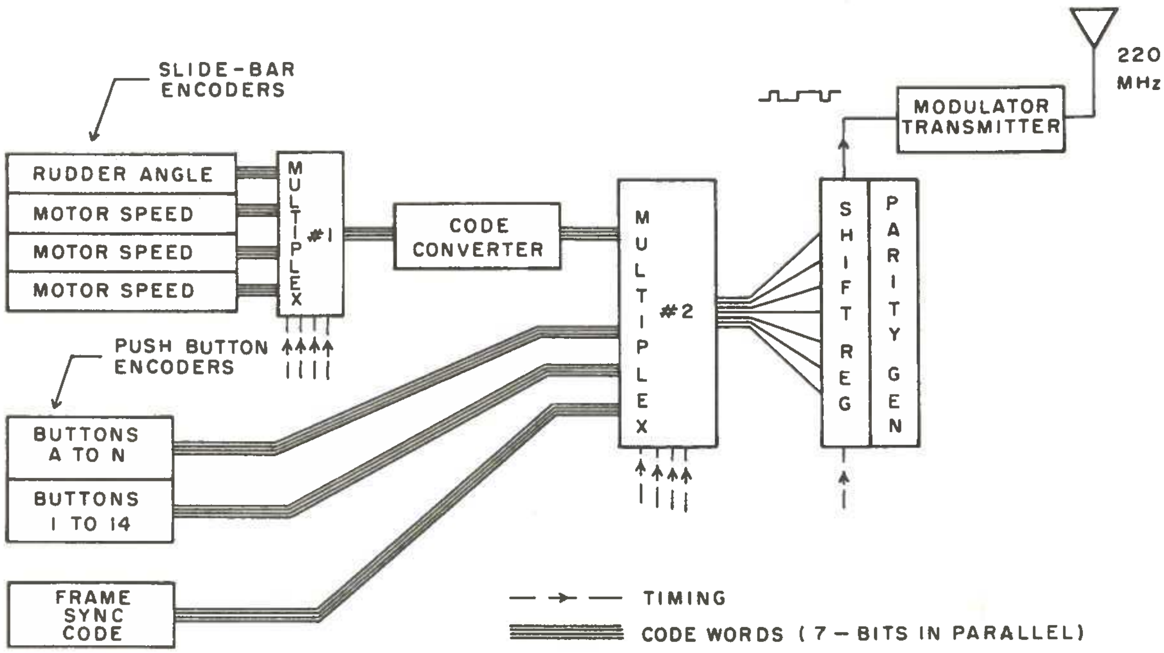
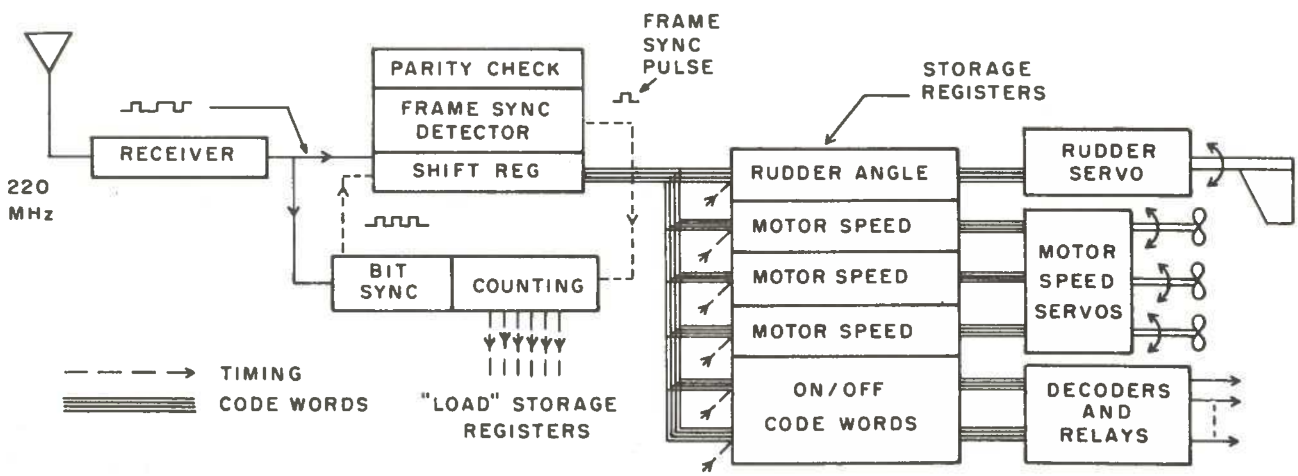


Figure 1 Block diagram of the two systems



(a) Sending end



(b) Receiving end

Figure 2 Radio control of model ship

Digital Signal Generation and Recovery

The major parts of the system are shown in Figs. 2*a* and 2*b*. The transmitting equipment will be described first. In Fig. 2*a*, four encoders (one for rudder-position control and three for motor-speed control) generate the commands desired by the operator. He merely slides the 'joy-sticks'. Each command consists of 6 bits plus a sign bit. This enables him to choose up to 128 rudder positions, 64 forward speeds and 64 reverse speeds for each of the propulsion motors (usually just two). In addition, he has a keyboard which allows him to select a number of output devices (MOTOR A, MOTOR B, RUDDER) and to select several functions (POWER ON/OFF, GO/STOP, X1/X2).

Each 7-bit code word (command) generated by the encoders is connected, 7-bits at a time, to the shift register in a sequential fashion, through the action of the multiplexers. Multiplexer 1 handles the code words from the rudder and motor speed encoders, and since these are gray-binary coded, they are converted to pure-binary by the code converter and then passed on to multiplexer 2. Code words from the push button encoders (keyboard) are connected directly to the second multiplexer, and similarly, two code words which make up the frame-synchronizing signal are connected to this multiplexer.

The two multiplexers are controlled by a timing generator, and all code words are loaded sequentially into the shift register, parity added, and shifted out serially. The resulting binary waveform modulates a 220-MHz carrier, simply turning the carrier ON for a binary '1' and turning it OFF for a binary '0'. One frame of the radio control signal is shown in Fig. 3. It consists of 6 commands, 8 bits each, prefaced by a frame sync code of 16 bits, a total of 64 bits. Each bit takes 30 microseconds and this gives a frame rate of 520 frames per second. Much of this redundancy enhances the noise immunity without too great a cost in bandwidth or coding complexity.

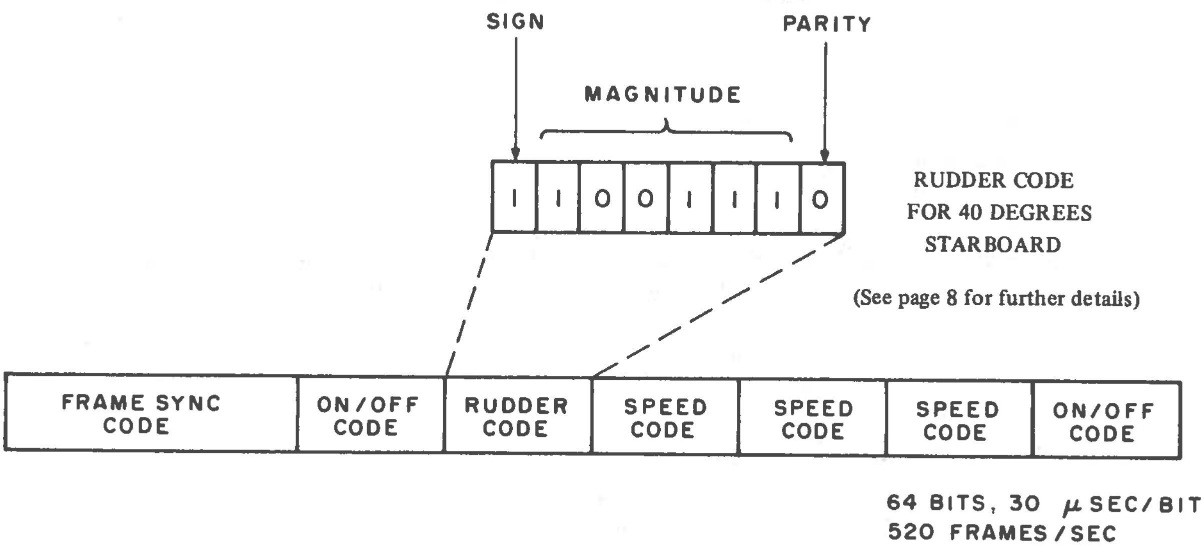


Figure 3 One frame of radio control signal

The receiving end is shown in Fig. 2*b*. It consists of a crystal-controlled, 220-MHz, AM receiver which has an envelope detector followed by a 'slicer' which strips off the binary modulation. The slicer's threshold is set automatically according to the strength of the received 220-MHz carrier. The binary signal now enters a shift register and a bit sync circuit, the latter recovering the bit-timing from the transitions in the signal by ringing a high-Q resonant circuit tuned to the bit rate ($33\frac{1}{3}$ kHz).

In order to start demultiplexing, the beginning of each frame must be identified. This is done by the frame sync detector producing a pulse once every frame. This pulse clears a modulo-64 counter and in so doing permits the word counter to start counting at the correct instant. Complete code words are extracted from the shift register and put into storage registers. Parity must check before storage occurs.

Up to this point, the present system is basically the same as the original system. Multiplexing of code words at the transmitting end and the demultiplexing of the code words at the receiving end are described fully in the previous report (ERB-808). The present system uses integrated circuits in the receiving equipment and details of the logic circuits are given in the following diagrams:

Bit timing and delay circuits (AF-12-88D)

Bit and word timing, frame sync. detector and shift register (AF-12-82D)

Timing logic waveforms (AF-12-96D)

Receiver 219.4 MHz (AF-12-90C)

Storage registers (AF-12-81D)

These are included in the appendix of this report.

Summary

Each command is sent as a code by the sending end, the codes being sent in a sequence. At the receiving end, the start of the sequence is found and each command is separated and stored. Output actuators respond to the stored commands to position the rudder, control motor speeds, and energize relays to select and control output devices.

The following section describes the process of converting the stored commands into an analog voltage suitable for driving the rudder and speed control servo motors, and the coding arrangement used to make this conversion compatible with the existing encoders.

Digital Analog Signal Conversion

Stored commands for rudder position and speed control consist of 7 binary digits or binary numbers (6 bits plus a sign bit) and the object is to convert these numbers into analog form. The conversion is illustrated by an example using only 3 bits, in Fig. 4.

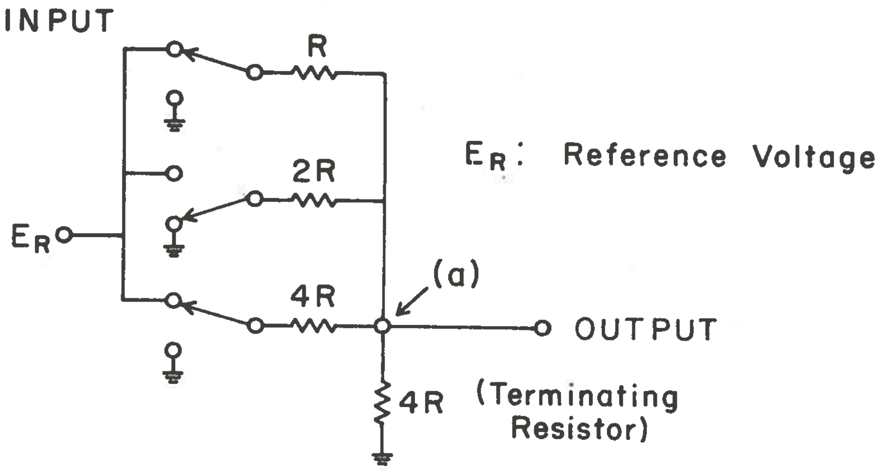


Figure 4 Example of a 3-bit digital to analog converter

The input ends of the three top resistors are connected to a reference voltage (E_R) or returned to ground, depending upon the binary number. In this case there will be 2^3 or 8 different combinations of connections, corresponding to the 8 possible input numbers. The greatest contribution to the output voltage comes from the uppermost resistor, while the others contribute lesser amounts. Evidently, the ratio of output voltage to the reference voltage is

$$\frac{E_0}{E_R} = \frac{\text{Resistance from pt. (a) to ground}}{\text{Resistance from pt. (a) to ground + resistance from pt. (a) to } E_R}$$

which is the same as

$$\frac{E_0}{E_R} = \frac{\text{Conductance from (a) to } E_R}{\text{Total conductance}} \qquad (1)$$

Taking a specific example with an input 101, the centre resistor ($2R$) goes to ground and the other two go to E_R. (The terminating resistor ($4R$) is permanently tied to ground).

$$\text{Conductance from (a) to } E_R = \frac{1}{R} + \frac{1}{4R} = \frac{1}{R}(1 + \frac{1}{4})$$

$$\text{Total conductance} = \frac{1}{4R} + \frac{1}{2R} + \frac{1}{R} + \frac{1}{4R} = \frac{1}{R}(\frac{1}{4} + \frac{1}{2} + 1 + \frac{1}{4})$$

Substituting into (1), gives

$$\frac{E_0}{E_R} = \frac{\frac{1}{R}\ (1\frac{1}{4})}{\frac{1}{R}\ (2)} = \frac{5}{8}$$

This ratio can be interpreted in the following way. Consider the numerator as having been formed from the whole binary number 101, with weights 4, 2, 1. The top resistor adds 4 units, the centre resistor adds nothing, and the third resistor adds 1 unit, a total of 5 units. The denominator is 2^3 or 8. (7, without the terminating resistor.) Other inputs will yield the following ratios of E_0 to E_R.

INPUT 4	2	1	E_0/E_R
0	0	0	0
0	0	1	1/8
0	1	0	2/8
0	1	1	3/8
1	0	0	4/8
1	0	1	5/8
1	1	0	6/8
1	1	1	7/8

where a '1' indicates a connection to E_R and a '0' indicates a connection to ground.

This interpretation is handy because 6 and 7 bit numbers (commands) can be converted into a voltage ratio, by inspection. The absolute voltage, E_0, is calculated and this is compared to the experimental value when checking the accuracy of conversion. In practice a 7-bit resistor network is used for the rudder commands and 6-bit resistor networks for the speed commands (AF-12-84D).

The following is a detailed description of the coding used in the commands for rudder and speed control.

At the transmitting end, the rudder and motor-speed encoders generate a gray-binary (GB) code, and this code is converted to pure-binary (PB) before transmission. The receiving equipment stores the PB code. The discussion which follows is concerned with a change in coding within the ship-board equipment for the rudder commands only; this change circumvents and simplifies several problems in going from digital to analog.

The desired input/output relationship for the rudder is shown in Fig. 5*a*. Also shown for comparison is the input/output relationship for the speed control commands in Fig. 5*b*. As mentioned previously, 7 bits are used to represent the commands; all 7 bits are used in PB form to get Fig. 5*a* (rudder) and only 6 bits are used to get Fig. 5*b* (speed), the 7th bit being used to reverse the motor and feed-back voltage. With this arrangement, only a single reference voltage supply is needed, a standard potentiometer can be used for rudder angle feedback and most important, the present ship-board equipment will be fully compatible with the original transmitting equipment.

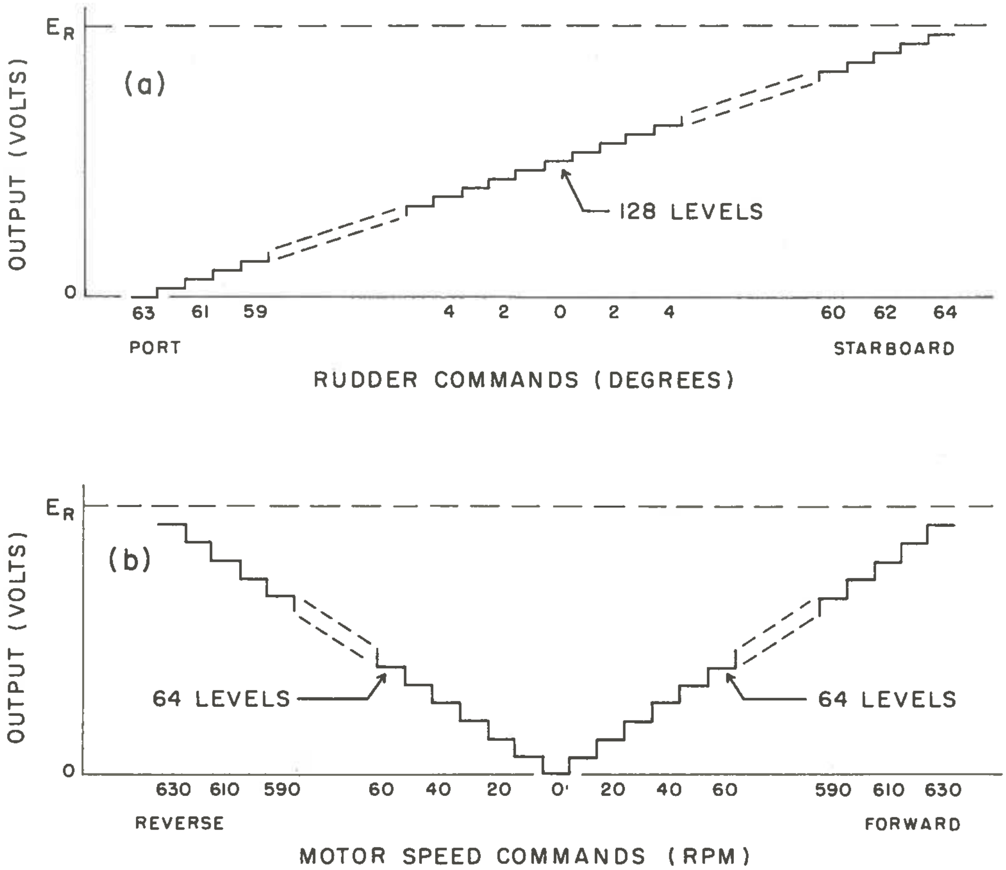


Figure 5 Input/output relationships for rudder and motor speed commands

A relatively simple scheme enables conversion from the existing code (6-bit GB code with a sign bit) to one that produces 128 levels as required for the rudder servo. This is illustrated by a 3-bit example, the 3 bits being made up of a sign bit, followed by a 2-bit gray-binary code. This is shown as code A below.

Rudder Commands		Code A	Code B	Code C	E_0/E_R
3°	Port	0 1 0	0 1 1	0 0 0	0
2°		0 1 1	0 1 0	0 0 1	1/8
1°		0 0 1	0 0 1	0 1 0	2/8
0°		0 0 0	0 0 0	0 1 1	3/8
1°	Starb'd	1 0 0	1 0 0	1 0 0	4/8
2°		1 0 1	1 0 1	1 0 1	5/8
3°		1 1 1	1 1 0	1 1 0	6/8
4°		1 1 0	1 1 1	1 1 1	7/8

Code A is generated by the rudder encoder. It is not a standard GB code as evident from the starting point (shown dotted). Code B is formed by converting the last two columns of code A into a PB code. Code B is the one that is transmitted and displayed on indicator lights in the receiver storage registers. Using code B, the rudder commands can be easily read out and compared with the transmitted commands. The weights for reading code B are as follows: The first column has a weight of one degree, and the remaining columns (in this case, just two) are weighted in powers of two, and decrease in weight as we go to the right, ending up with a weight of one for the right hand column. The first column (on the left) also indicates port (0) and starboard (1).

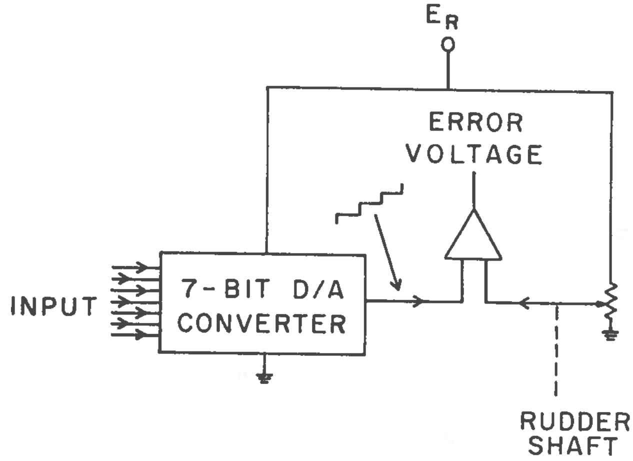
Code C drives the D/A converter. It is obtained by complementing the upper half of the 2nd and 3rd columns of code B. The lower half remains the same. Complementing or not complementing depends on whether the bit in the first column of code B is a '0' or a '1'. Code C is the desired result; it produces 8 levels in this case for 3 bits, and 128 levels for 7 bits. The weights assigned to code C are natural binary weights and the conversion of this code to analog uses the same weights, namely 4, 2, 1 in this example, and 64, 32, 16, 8, 4, 2, 1 in the actual case of 7 bits.

Logic circuits to convert from Code B to Code C are shown in drawing AF-12-81D, components 75 to 80 inclusive. The interpretation of code B and the final output, code C, are tabulated in drawing AF-12-77C. The complete 7-bit D/A converter, showing component values, layout, etc., is shown in drawing AF-12-84D.

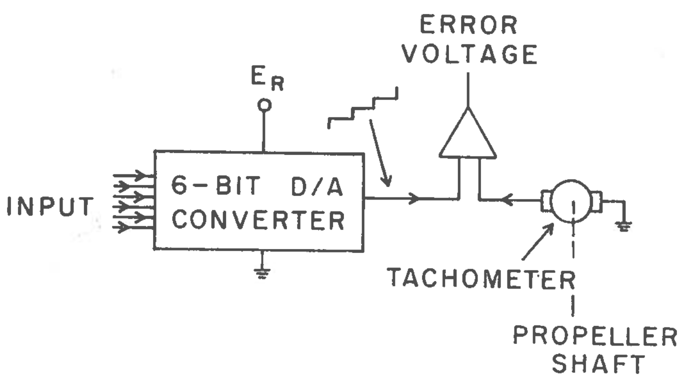
For the speed commands, code C is not required, but codes A and B, which have already been formed inside the transmitting equipment, are used. In the actual case, code B consists of a 6-bit PB code plus a sign bit and is received and indicated by indicator lights. The 6 bits yield 64 levels and hence 64 speeds; the sign bit controls the direction, forward or reverse, on the propulsion motors and no further significance is attached to it as it was for the rudder, where the sign bit took on a weight of one as well as indicating starboard. The 6-bit speed command is put directly into a D/A converter of the same design as that for the rudder. Three such 6-bit converters have been provided to handle three independent speed commands, although in most cases so far, just two motors have been controlled.

Diagram AF-12-77C shows the weights assigned to the speed commands. These range from 10 rpm for the least significant bit (LSB) up to 320 rpm for the most significant bit (MSB); these can be doubled (by halving the feedback voltage) so that the LSB represents 20 rpm and the MSB 640 rpm. These weights are selected by the operator through the keyboard, giving 'times one' (X1) or 'times two' (X2) on the three motors independently, or he can obtain other weights by appropriate scaling of the feedback voltage. Normally the scaling is pre-set to give X1 and X2.

One important point should be noted, and this is that the reference voltage must be held constant – within ± 0.1% on the D/A conversion network. This applies particularly to the speed control servos. For the rudder servo, this does not matter as the same reference voltage supply is fed to both D/A converter and the feedback



(a)



(b)

Figure 6 Error voltage for rudder servo is not affected by changes in E_R, but for the speed control servo, the error voltage is affected by changes in E_R.

potentiometer. This point is illustrated in Figs. 6*a* and 6*b*. Further details are given in the description of the servos, later in the report.

Experimental Results of Conversion of Rudder and Speed Commands to Analog Voltage

The experimental set-up is shown in Fig. 7. For these tests the contents of the storage registers were input via toggle switches and the output voltages were read on a differential voltmeter. Not all possible input words were tested. The demultiplexer selects the desired storage registers via input leads T_2, T_3, T_4, and T_5.

Results of checking the four D/A converters are shown in Fig. 8.

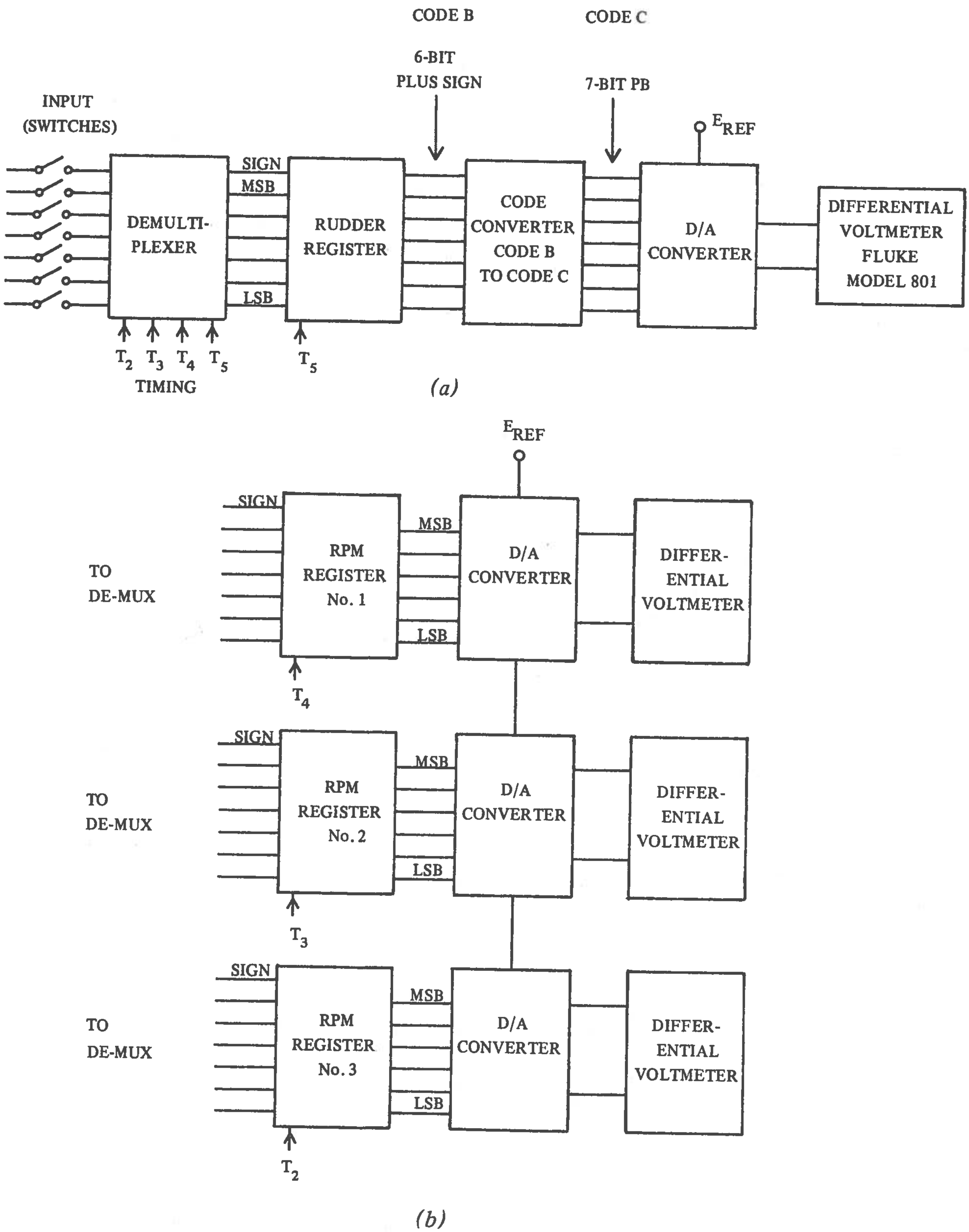


Figure 7 Test set up for checking D/A converters

Rudder Commands

INPUT (SWITCHES)

CODE B (Sign, MSB ...)	CODE C (MSB ... LSB)	OUTPUT (VOLTS) for (E_R = 5.120) CALC.	ACTUAL
0 1 1 1 1 1 0	0 0 0 0 0 0 1	0.040	0.0403
0 1 1 1 1 0 1	0 0 0 0 0 1 0	0.080	0.0804
0 1 1 1 0 1 1	0 0 0 0 1 0 0	0.160	0.1607
0 1 1 0 1 1 1	0 0 0 1 0 0 0	0.320	0.3210
0 1 0 1 1 1 1	0 0 1 0 0 0 0	0.640	0.6423
0 0 1 1 1 1 1	0 1 0 0 0 0 0	1.280	1.2839
1 0 0 0 0 0 0	1 0 0 0 0 0 0 *	2.560	2.5606
1 0 0 0 0 0 1	1 0 0 0 0 0 1	2.600	2.6010
1 0 0 0 0 1 0	1 0 0 0 0 1 0	2.640	2.6408
1 0 0 0 1 0 0	1 0 0 0 1 0 0	2.720	2.7207
1 0 0 1 0 0 0	1 0 0 1 0 0 0	2.880	2.8818
1 0 1 0 0 0 0	1 0 1 0 0 0 0	3.200	3.205
1 1 0 0 0 0 0	1 1 0 0 0 0 0	3.840	3.843

$$^*\text{Output (volts)} = \frac{5.120}{128}\left[64 \times 1 + 32 \times 0 + 16 \times 0 + 8 \times 0 + 4 \times 0 + 2 \times 0 + 1 \times 0\right]$$

$$= 2.560 \text{ volts.}$$

(See Fig. *7a* for test set-up.)

Speed Commands

INPUT (SWITCHES)

CODE B (Sign, MSB ... LSB)	OUTPUT (VOLTS), E_R = 5.120 volts CALC.	ACTUAL (1)	ACTUAL (2)	ACTUAL (3)
0 0 0 0 0 0 0	0.0	0.0	0.0	0.0
0 0 0 0 0 0 1	0.080	0.0801	0.0802	0.0801
0 0 0 0 0 1 0	0.160	0.1603	0.1605	0.1603
0 0 0 0 1 0 0	0.320	0.3202	0.3206	0.3206
0 0 0 1 0 0 0	0.640	0.6399	0.6406	0.6402
0 0 1 0 0 0 0	1.280	1.2795	1.2807	1.2813
0 1 0 0 0 0 0	2.560 *	2.5582	2.5568	2.5589

$$^*\text{Output} = \frac{5.120}{64}\left[32 \times 1 + 16 \times 0 + 8 \times 0 + 4 \times 0 + 2 \times 0 + 1 \times 0\right]$$

$$= 2.560 \text{ volts}$$

(see Fig. *7b* for test set-up.)

Figure 8 Check on the D/A converters for rudder and speed commands

Control of Rudder, Propulsion Motors, and Relays

This section describes the operation of the rudder and speed control servo motors, and a short description of how ON/OFF commands are sent and decoded to energize latching relays.

Analog Rudder Servo

A block diagram of the rudder servo is shown in Fig. 9 and the circuit diagram is shown in drawing AF-12-92D. This dc servo, also shown in plates XII and XIII can position the rudder over a range of 120 degrees with a maximum accuracy of ±0.05 degree. The input or position command is a 0 to 5 volt dc level. The 0 to 5 volt level can be obtained from an internal 1-kΩ potentiometer for local or manual positioning of the rudder or from the 7-bit digital-to-analog converter in the logic box for remote positioning.

The input voltage is compared in the SQ10A operational amplifier with the voltage on the moving arm of a 10-turn 5-kΩ potentiometer geared to the rudder. When the rudder turns 1 degree the potentiometer turns 30 degrees. The output of the SQ10A will assume values between ±10 volts depending on the difference between the input voltage and the feedback voltage on the moving arm of the 5-kΩ potentiometer.

The SQ10A output is connected to pins 8 and 10 of the MC889 integrated inverters. If the output is below +1 volt, both inverters will be OFF. If the output is greater than +1 volt but less than +8 volts, inverter 8-7 will be ON and inverter 10-5 will be OFF. If the output is greater than +8 volts, both inverters will be ON.

A 7-kHz oscillator comprising inverters 13-2 and 14-1 is used to strobe the outputs of inverters 10-5 and 8-7 into 2 JK flip-flops MC890. The 2 flip-flops thus contain the information necessary to control the rudder motor. Only 3 of the 4 possible states of the 2 flip-flops can actually exist except during power switch-on time. In any event only one state can exist at any one time. These 3 states are decoded and appear at pins 3, 14, and 5 of the MC824 gates. Pins 3 and 5 are used to drive the two windings (only one at a time) of the split field rudder motor, one winding will turn the motor clockwise and the other winding will turn it counterclockwise. Thus the rudder and the 5-kΩ feedback potentiometer will be turned in the demanded direction until the moving arm of the potentiometer is at the same voltage as the input level. At this point the servo is at a null and all power is removed from the motor. Pin 14 of the MC824 is used to drive a null indicator lamp. This red lamp is ON when the servo is turning and OFF when a null has been reached. Two limit switches are connected in series with the two motor windings to remove the power from the motor just before the 5-kΩ potentiometer reaches the end of its travel in either direction. This is to prevent damage to the potentiometer or to the rudder if the servo becomes uncontrolled due to radio link failure or for any other reason.

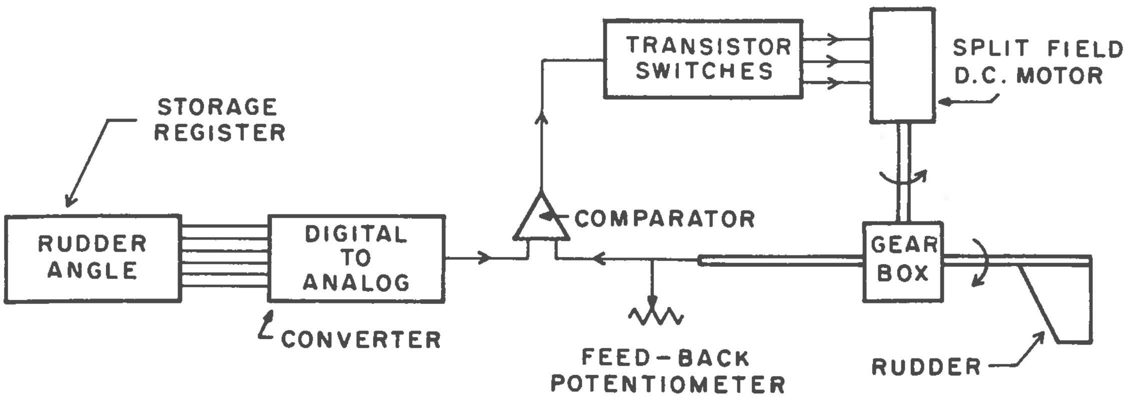


Figure 9 Analog rudder servo

If the servo has a tendency to hunt, the gain control on the SQ10A can be reduced until the hunting stops. This increases the dead zone or the error voltage required to drive the servo. The accuracy of the servo is of course also reduced. At maximum gain the servo accuracy will be ±0.05 degree. At minimum gain the accuracy will be ±0.12 degree.

The 20-kΩ potentiometer and the 5.6-kΩ resistor connected across the 5-kΩ feedback potentiometer is used to adjust the voltage span across the 5-kΩ potentiometer to calibrate the rudder. Before any calibration is done the rudder system must be checked to see that the output shaft of the rudder box as viewed from the top of the box gives a counterclockwise rotation (port-to-starboard rotation) when the rudder encoder is moved from left to right. If the rotation is the wrong way the coding bar in the rudder encoder must be taken out and changed end for end in the encoder to correct this. Calibration is done by setting correctly two points indicated by a pointer on the rudder angle scale. The first point is obtained by setting the rudder encoder on the tower to the 1° mark that produces the word 1000000 as indicated by the rudder lamps in the logic box (i.e., only the sign bit lamp is lit). The moving arm of the feedback potentiometer will then be at its electrical center. This point is chosen to adjust the rudder angle pointer to the correct reading on the scale because it is the only point on the feedback potentiometer that will not be affected by adjusting the calibration potentiometer. If the encoder (at 1000000) is at 1° port the pointer must also be adjusted to 1° port. The calibration can be completed by moving the encoder to some other point, say 45° port or starboard, and adjusting the calibration potentiometer to make the pointer give the correct reading. The box can then be installed on the model and with the encoder at 0° the rudder coupling can be secured with the rudder in the 0° position or pointing straight back.

The 24-V battery power is applied to the motor circuit and the null indicator lamp by a relay which can be operated remotely by a pushbutton command or by a local switch on the rudder box. A diode is connected in series with the relay winding to prevent it from operating if the batteries are connected in reverse.

The voltage across the 5-kΩ feedback potentiometer comes from a regulated power supply producing a 5-V stable reference. This same stable reference voltage is used in the digital-to-analog converter in the logic box. Thus the reference could drift drastically without affecting the positioning accuracy of the rudder servo.

The two J-K flip flops in this circuit are used to control the power to the motor in a very decisive manner. The power is fully ON or fully OFF. Without the flip flops, and under low (but not zero) error voltage conditions, a small amount of power would be applied to one motor winding. If this amount was insufficient to turn the motor, the servo would stand still and the power transistors would overheat. When the rudder is turning, the drain on the battery is 0.7 ampere.

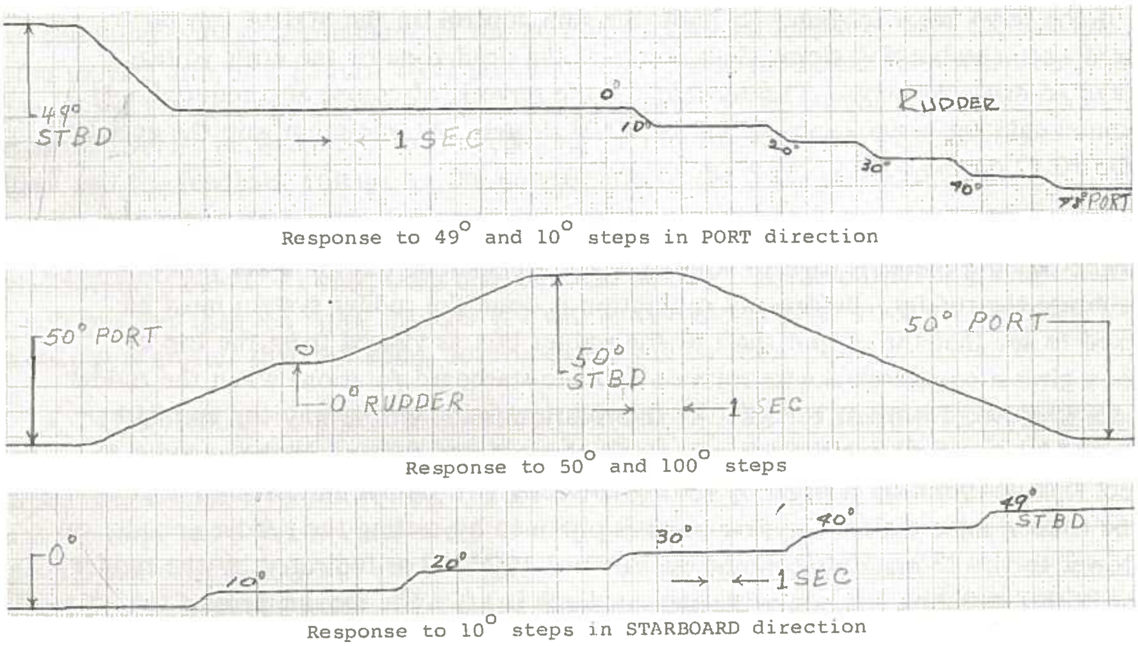


Figure 10 Response of rudder servo to encoder changes

Figure 10 shows the recorded response of an experimental rudder servo to various changes in encoder setting, during an actual run of the model in the turning basin. These recordings were made from information telemetered back to the control tower from a potentiometer connected to the output shaft of the rudder servo. Figure 11 shows the telemetry arrangement. The response possibly appears slightly worse owing to quantizing error in the telemetry link. The total quantizing interval is 0.3 degree. The experimental rudder servo takes 8 seconds to go from 50° starboard to 50° port. The final model of rudder servo shown in Plates XII and XIII takes about 1.6 seconds for the same movement.

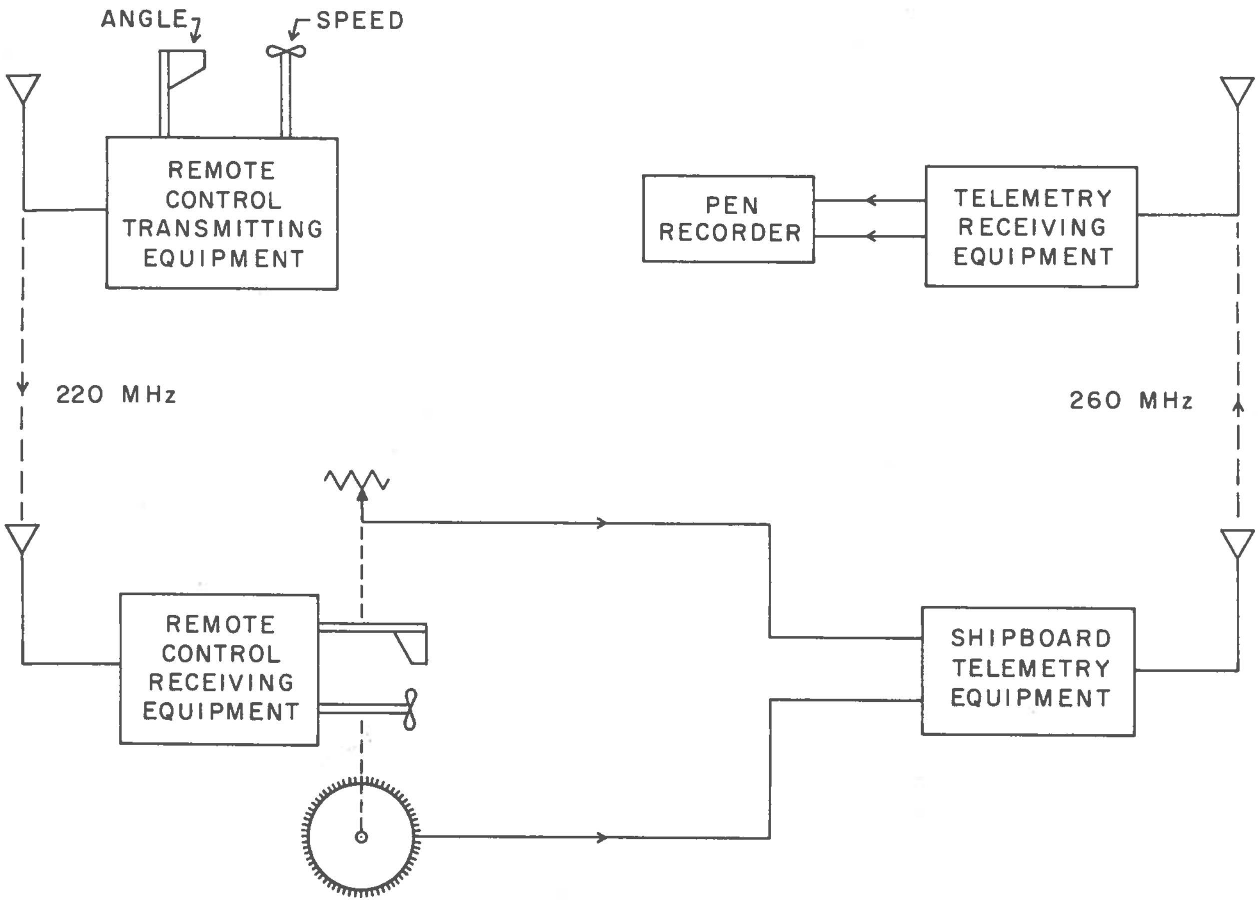


Figure 11 Telemetry equipment used to record the response of the remote control system

Battery Operated dc Motor Speed Control

A block diagram is shown in Fig. 12 and the circuit diagram is shown in drawing AF-12-89E. Plates XIV and XV show the actual control box. The speed of dc propulsion motors up to $\frac{1}{4}$ H.P. can be controlled without forced air cooling. For motors of higher ratings, up to $\frac{1}{2}$ H.P., forced air cooling of the power transistors should be provided. The transistors apply pulses of power to the motor armature from a storage battery. The pulse repetition frequency remains the same (about 2.5 kHz) but the pulse width is increased or decreased to control the amount of power going into the motor armature. Although the circuit diagram shows a shunt wound motor, series or compound wound motors could be controlled by a minor change in circuitry.

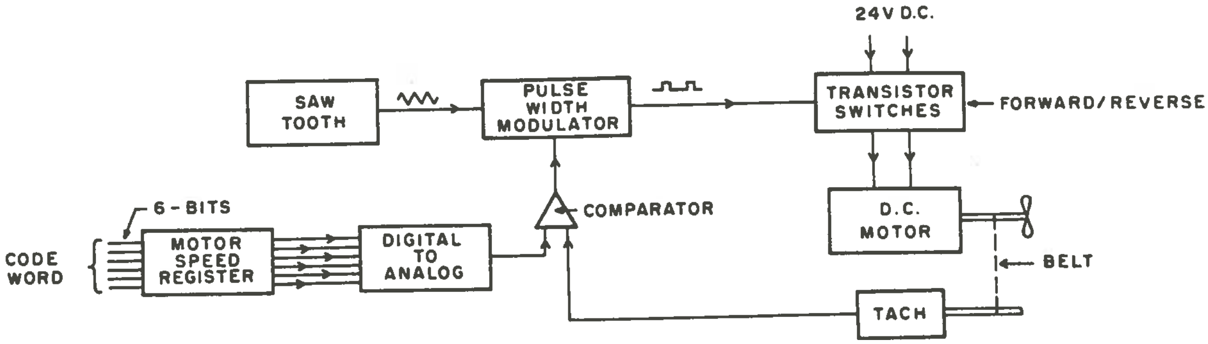


Figure 12 Rudder and speed control servos

The motor can be controlled locally by a DPDT center-OFF switch and a 5-kΩ potentiometer on the control box or remotely by the five following control signals from the logic box and the latching relay box:

1) a 0–5 volt level from a 6-bit digital-to-analog converter in the logic box, which determines motor speed;

2) a FORWARD or REVERSE command bit (sign bit) from a hold register in the logic box;

3) a GO or STOP command from the relay box;

4) an RPM X1 or RPM X2 command from the relay box;

5) a POWER ON or POWER OFF command from the relay box.

A 4PDT switch on the control box selects local (manual) or remote (automatic) operation.

The two operational amplifiers labeled *bistable multi* and *ramp generator* drive each other to produce a linear triangular waveform (ramp) with equal rise and fall time and with voltage limits of +6 and −6. The bistable multi has two stable states by virtue of positive feedback through the 12-kΩ resistor from its output to its positive input. The back-to-back 1N706 zener diodes prevent the AD111 from going into saturation. This makes the output less sensitive to power supply changes and also reduces delay in the AD111. The ramp generator time constant is decided by R1 and the 0.01-μF capacitor.

The ramp slicer produces pulses going from +6 to −6 V by slicing through the ramp. During the negative portion of this pulse train, power is applied to the motor armature. The width of the negative portion is determined by the level at which the ramp is sliced. This level is in turn decided by the voltage level at the output of the speed comparator. The speed comparator compares the RPM command voltage level from the 6-bit digital-to-analog converter (ladder) in the logic box or from the local rpm potentiometer with a portion of the voltage from a dc generator (tachometer) turning at the same speed as the propeller. A resistor—potentiometer network provides 2 different levels of feedback voltage from the tachometer. The higher level gives the lower speed and can be adjusted to give 0 to 630 rpm in 10-rpm steps. This is called the X1 or normal range. The lower level gives the higher speed and it can be adjusted to give 0 to 1260 rpm in 20-rpm steps. This is called the X2 range. The X1 or X2 ranges can be selected by a pushbutton command which operates latching relay 2 in the motor control box. The X2 range is also automatically selected if the local mode is switched in. The 10-kΩ potentiometer and 2.5-μF capacitor on the negative input of the speed comparator determine the slewing rate of the comparator to prevent hunting in the speed servo. If the slewing rate is too fast the propulsion motor cannot accelerate or decelerate fast enough to keep up with the speed change requested by the comparator and this results in full power or no power being applied to the motor rather than a gradual increase or decrease in power pulse width. The 1N457 diode across the 2.5-μF capacitor also prevents full power from being applied to the motor unless the ladder voltage is at maximum (5 V).

Latching relay number 3 and another 4PDT relay reverse the connections to the armature of both the tachometer and the propulsion motor to provide forward or reverse propulsion. These two relays are operated by latching relay number 1 via a DPDT switch which can be used to reverse the direction of propulsion if it happens to be different from the encoder. This is necessary because both right-hand and left-hand propellers may be used.

Relay number 1 is operated by the sign bit from one of the rpm registers in the logic box or from the local forward or reverse switch. However, a reverse or forward command can only operate relay number 1 if the propulsion motor is stopped or turning very slowly. This is done by a zero speed sensor which detects the presence or absence of voltage from the tachometer. If there is no voltage from the tachometer (this indicates zero RPM) the output of the zero speed sensor allows the forward reverse command to operate relay number 1 through MC824 unit 2. Thus, if the RPM encoder was moved quickly from, say, 500 rpm forward to 500 rpm in reverse, relay number 1 would not operate and the motor would keep on turning in the forward direction. To prevent this from happening, an 'exclusive-OR' circuit, MC824 unit 1, compares the actual position of relay number 1 (by looking at its contacts) with the forward or reverse command. If they are different, a transistor is turned off allowing the + input of the ramp slicer to rise slowly to 7V. This is higher than the ramp and no more slicing occurs. Thus the power pulses to the motor will be stopped and the motor will slow down until the zero speed sensor allows number 1 relay to be operated. At this point the transistor will be turned on and the + input of the ramp slicer will slowly return to 0 V, allowing the motor to speed up gradually until it reaches the requested speed, as determined by the speed comparator. This gradual application or removal of power to the motor also happens when the motor is started or stopped by using the GO or STOP pushbutton command.

The battery power for the motor is applied to the control circuitry by a relay, which is operated by the POWER-ON or -OFF pushbuttons on the tower. A green lamp

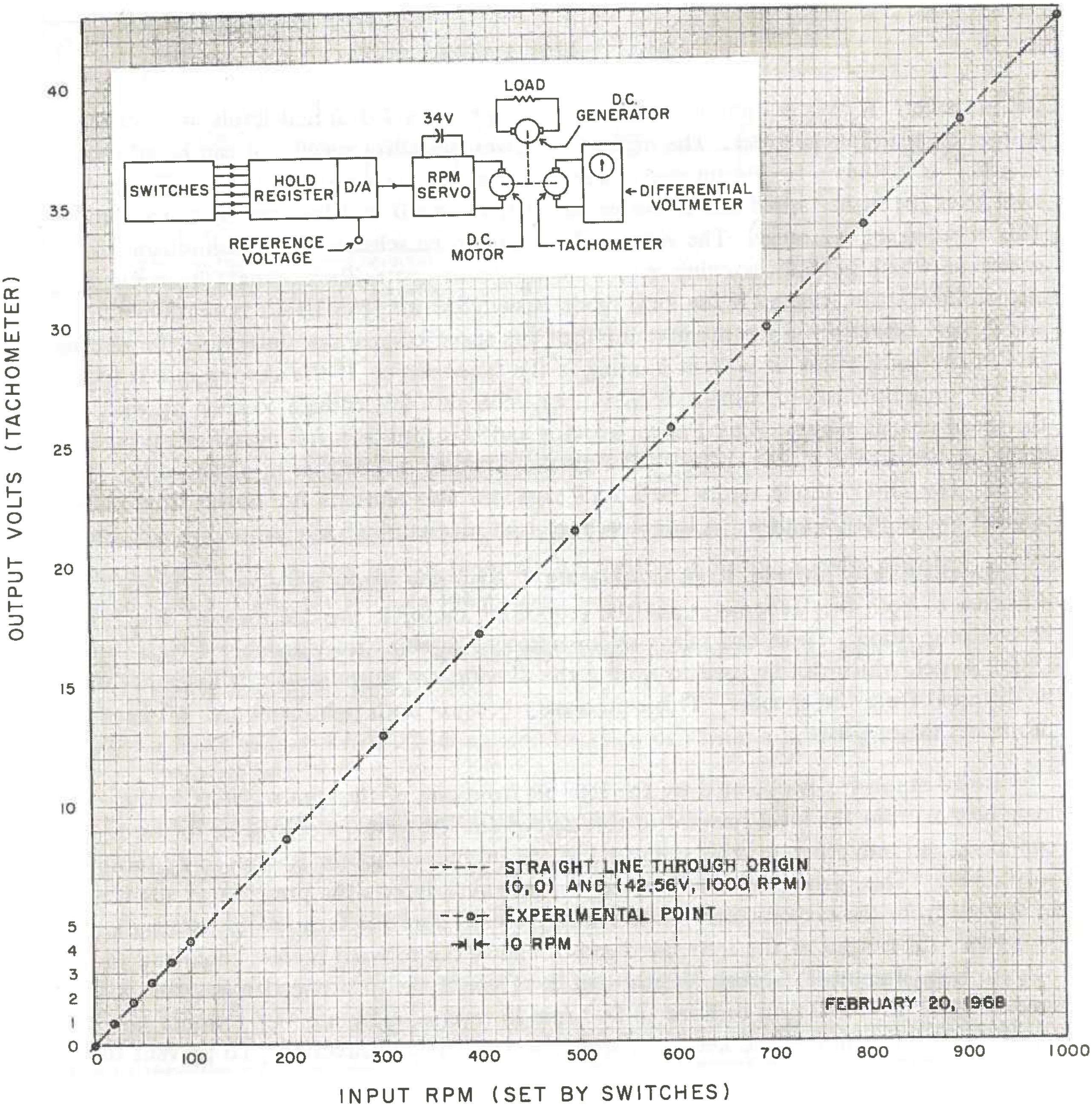
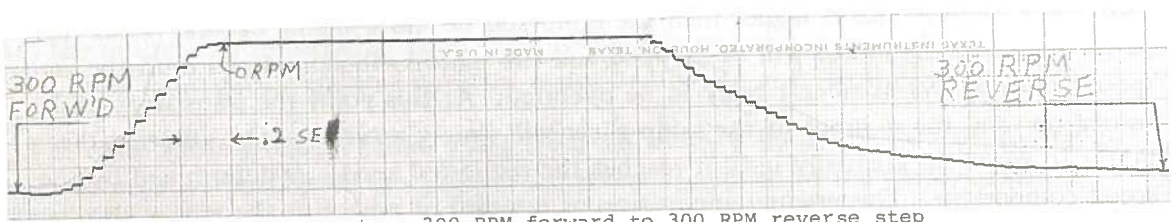
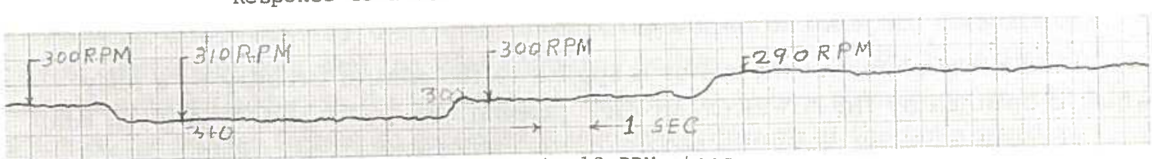


Figure 13 Laboratory check of RPM servo



Response to a 300 RPM forward to 300 RPM reverse step



Response to 10 RPM steps

Figure 14 Response of RPM servo to encoder changes on the motor control box indicates that the power is on. A diode is connected in series with the relay coil to prevent it from operating if the battery is accidentally reversed. When the STOP pushbutton command is given, a red lamp lights up on the motor control box. If the GO pushbutton command is then given, the red lamp goes out. If the green lamp is not on, then the red lamp cannot be on, even if the stop command is present, because there is no power available for the lamps.

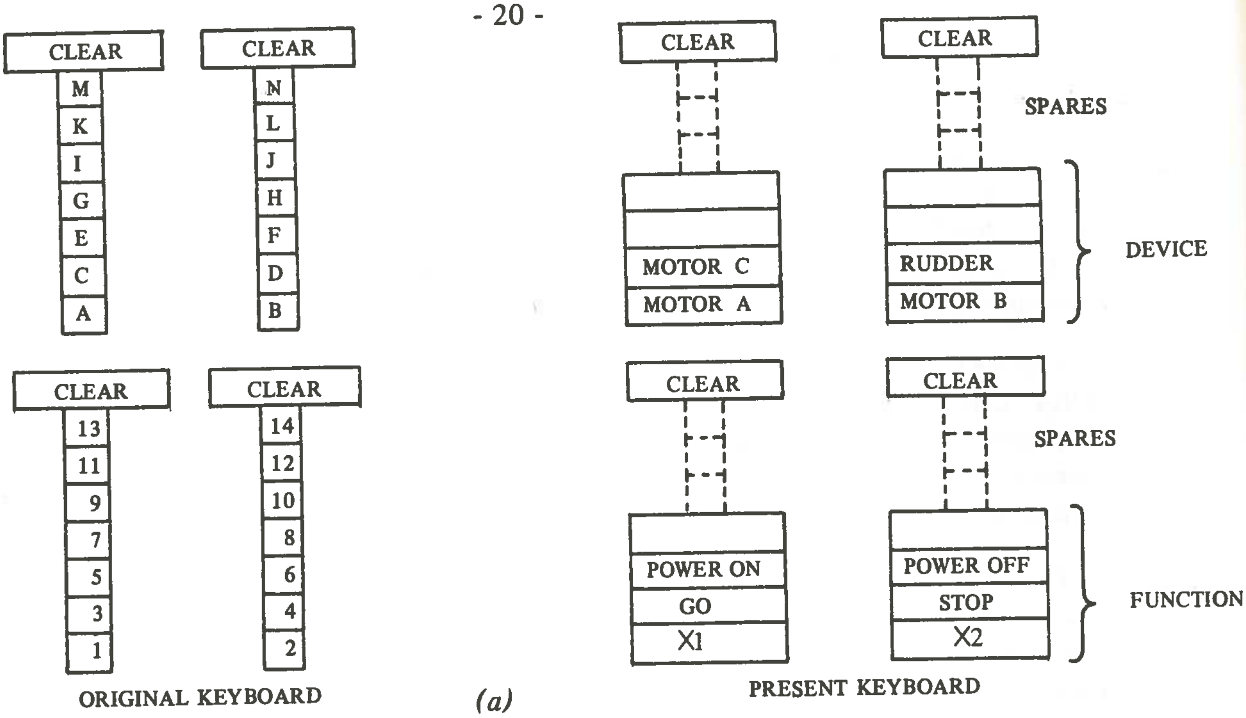
The 1N3210R power diode across the motor armature provides a path for the armature current during the interval between power pulses from the battery. This is current generated by the falling field in the armature due to its inductance. This prevents excessive voltage spikes across the armature at the end of each power pulse and the current thus produced is effectively added to the useful armature current.

The field winding of shunt motors is actually employed as a load resistor on one of the transistors used to drive the power transistors for the armature. Since the voltage across the transistor can only change by about 2 V, most of the battery voltage is applied to the field winding. If a series wound motor was used, the two jumpers shown by solid lines would have to be removed and replaced by the jumpers shown by dotted lines, as indicated by note 1 on the circuit diagram.

Two 2N3055 silicon power transistors are connected in parallel to drive the armature. Each of these is driven by a TIP14 silicon transistor connected in a Darlington configuration. A 0.1-ohm resistor is connected in series with the collector lead of each 2N3055. This helps to balance the currents in the two transistors and also provides a larger voltage across the TIP14 to drive the 2N3055.

Table I shows results of a laboratory check of the motor control box driving a $\frac{1}{2}$ H.P. shunt wound motor. The motor was driving the usual tachometer, and another $\frac{1}{3}$ H.P. motor used as a dc generator provided a load for the $\frac{1}{2}$ H.P. motor. Lamps were connected to the generator ($\frac{1}{3}$ H.P. motor) to provide further loading. The control box was in the remote mode and RPM commands were produced through input switches as in Fig. 7*b*. The tachometer output was measured to indicate speed. An evaluation is made of the deviations of the measured values from values calculated from a straight line through the 0 and 1000 rpm points. The maximum deviation shown is 1.41 rpm. Figure 13 shows the measurements of Table I in graphical form.

Figure 14 shows the recorded response of the rpm servo to various changes in encoder setting during an actual run of the model in the turning basin. These recordings were made from information telemetered back to the control tower from a digital pick-up connected to the propeller shaft of the model. Figure 11 shows the telemetry arrangement. The response possibly appears slightly worse owing to the quantizing interval (2.5 rpm) in the telemetry link.



(a)

	1 2	3 4	5 6	7 8	
A	(RELAY 1) MOTOR A X1 X2	(RELAY 2) MOTOR A GO STOP	(RELAY 3) MOTOR A POWER ON OFF	(RELAY 4)	RELAY BOX 1
B	(RELAY 5) MOTOR B X1 X2	(RELAY 6) MOTOR B GO STOP	(RELAY 7) MOTOR B POWER ON OFF	(RELAY 8) MOTOR B	RELAY BOX 1
C	(RELAY 9) MOTOR C X1 X2	(RELAY 10) MOTOR C GO STOP	RELAY 11) MOTOR C POWER ON OFF	(RELAY 12)	RELAY BOX 1
D	(RELAY 13)	(RELAY 14)	(RELAY 15) RUDDER POWER ON OFF	(RELAY 16)	RELAY BOX 2
E	(RELAY 17)	(RELAY 18)	(RELAY 19)	(RELAY 20)	RELAY BOX 2
F	(RELAY 21)	(RELAY 22)	(RELAY 23)	(RELAY 24)	RELAY BOX 2
G	(RELAY 25)	(RELAY 26)	(RELAY 27)	(RELAY 28)	RELAY BOX 2
H	(RELAY 29)	(RELAY 30)	(RELAY 31)	(RELAY 32)	RELAY BOX 2

(b)

Figure 15 Input/output chart showing the commands and associated output devices and functions which are actuated by each relay. Decoding has been wired for 32 latching relays or 64 commands.

TABLE I

Requested rpm	Tachometer output volts: measured	Tachometer output volts: calculated from line through 0 and 1000 rpm points	Deviations of measured values from calculated values: volts	Deviations of measured values from calculated values: rpm
0	0.06	0.00	+0.06	+1.41
20	0.90	0.851	+0.05	+1.18
40	1.76	1.702	+0.06	+1.4
60	2.60	2.55	+0.05	+1.18
80	3.45	3.405	+0.045	+1.06
100	4.30	4.256	+0.044	+1.01
200	8.57	8.512	+0.058	+1.36
300	12.83	12.77	+0.06	+1.41
400	17.08	17.02	+0.06	+1.41
500	21.33	21.28	+0.05	+1.18
600	25.59	25.54	+0.05	+1.18
700	29.79	29.79	0.0	0.0
800	34.04	34.05	- 0.01	- 0.235
900	38.30	38.30	0.0	0.0
1000	42.56	42.56		

Relay Outputs

The original system was designed for energizing many latching relays. A total of 14 X 14 = 196 commands were available for controlling 98 latching relays. In the present design the total number of commands permitted has been limited to 64, which is quite adequate. This allows 32 latching relays to be actuated.

A sketch of the keyboard and the functions are shown in Figs. 15*a* and 15*b*. Figure 15*a* shows the original keyboard with letters and numbers alongside the present keyboard which has the names of the devices and the functions labeled directly on the keys.

Figure 15*b* shows the relationship between the 'input' (letters and numbers on the original keyboard) and the 'output' (relays or devices and functions). This chart shows what commands have been used so far and what remain as spares. It also translates the information on the ship-board indicators, which show only letters and numbers, to the associated devices and functions, when this is needed for system checking. Ship-board indicators show letters A to H and numbers 1 to 8. For example, a complete command, such as POWER OFF MOTOR A is initiated by A6 or 6A (order does not matter). This energizes relay 3 which 'latches' (magnetically) and holds this state indefinitely. Commands such as MOTOR STOP and POWER OFF are stored in the latching relays before the system is shut down so that the start-up procedure will be safe.

Circuitry for decoding is shown in drawing AF-12-83D and circuit details of the drive and output connections to relays in drawing AF-12-78D. Basically, two 8-input gates decode a command, such as A6 and drive a transistor switch which in turn puts the relay into one of its two states. The letters and numbers are decoded separately and displayed on indicator lights.

During actual operation, the operator can see large indicator lights (auto turn indicators) which light up to show POWER ON/OFF, (GREEN) and MOTOR GO/STOP (RED). Also a rudder light warns the operator when the rudder servo is not at a null.

Miscellaneous

Construction

LOGIC UNIT

Most of the construction details can be seen from the photographs, Plates V and VI. Each circuit board measures $3\frac{3}{4}$ inches by 9 inches over all, with enough space for 40 dual in-line packages and solder terminals on one end. The seven boards are mechanically hinged and small flexible wires are used to go from one board to another.

Drawing AF-12-76D shows the ship-board equipment divided up according to functions and assigned to certain boards. The complete assembly, including power supplies was put in an enclosure measuring 7 inches *w* X 9 inches *h* X 12 inches *l* (14 lb). Output connectors are located at the back and the input connections, switches, and meters are located at the front (Plates X, XI).

RUDDER AND SPEED CONTROL SERVOS

Photographs XII, XIII, XIV, XV show the construction method. The control circuitry is mounted on a printed circuit card, hinged along one side, and put in a box measuring 13 X 9 X 7 inches (12 lb) for the rudder and 10 X 5 X 8 inches (7 lb) for speed control. In the latter case, power transistors are mounted on heat sinks attached to the exterior box.

'Manual/auto' switches and potentiometer shafts are brought out to allow manual (local) control of the servo units alone, before going to auto (remote) control.

RELAY BOX

This unit contains 16 latching relays and transistor drivers. All relay contacts are brought out to suitable terminals. The size is 12 X 8 X 3 and weighs 6 lb (plates XVI, XVII).

REMOTE CONTROL RECEIVER

This is a 220-MHz, crystal controlled AM receiver, completely transistorized; it measures 14 X $4\frac{1}{2}$ X $7\frac{1}{2}$ inches and weighs 9 lb with batteries (Plate III).

Power

A variety of voltages (+3.6, +12, and -12 V) are required for the circuitry in the logic box and servo boxes. All these voltages are supplied by one chopper in the bottom of the logic box. The chopper is shielded from the logic circuitry by a partition in the box. The complete power supply is built on a printed board, shown in Plate IX; the circuit diagram is shown in drawing AF-12-94D. The chopper transistors and the rectifiers for the logic box +3.6 V are mounted on heat sinks on the printed board. The toroidal transformer is wound for approximately 1 V per turn. There are 26 different filtered voltage outputs. This allows grounding of each voltage source close to where it is being used and thus prevents interacting ground currents. A 1N2071 diode, a 1-kΩ resistor and a 12-μF capacitor used in conjunction with the ON/OFF switch apply a positive pulse to the bases of the two chopper transistors when the power is turned on to start the chopper.

The 5-V reference supply uses a series transistor and a (Nexus SQ10A) operational amplifier for regulation. A portion of the reference voltage, obtained from wirewound resistors, is compared with a 1.35-V mercury cell by the SQ10A. The exact reference voltage is 5.149 ± 0.001 V.

The drain on the 24-V storage battery supplying the chopper is about 1.8 A. A 1N3210R rectifier, connected across the power input to the chopper, will make the fuse blow if the battery is accidentally reversed. Other 24-V storage batteries are needed to power the rudder motor and the propulsion motors. Each motor has its own battery. This, again, prevents interaction between circuits from common grounds, and also allows the user to replace or recharge only one discharged battery (usually the propulsion battery) in order to resume a test. There is also less danger of the model becoming completely uncontrolled due to low batteries.

Two 12-V, 90 A-hr storage batteries are used for each propulsion motor. Two 12-V, 30 A-hr storage batteries are used for the logic box chopper, and two more are used for the rudder servo. The 220-MHz receiver is powered by two dry cells supplying +12 and -12 V.

System Checking

The transmitting equipment, once installed on the control tower, needs little attention. All supply voltages are read out on meters, and abnormal conditions can be spotted by the operator. For further checks, a group of indicator lights can be uncovered for checking the outputs of the four encoders, keyboard (pushbuttons), code converter, multiplexer, and shift register. These checks are not done on site by the operator; they are intended primarily for initial alignment before installation, although the authors have used these indicators to verify the transmitting hardware. A single switch turns on the equipment and the checking of the signals or commands issued by the transmitter is done at the receiving end. It has been found that this is practical; only rarely does one have to go back to check the signal at its origin, i.e., inside the transmitting equipment.

On the ship-board equipment, a number of indicators both analog (meter) and digital (lights) are available for on-site checking, and in addition, a number of test points have been brought out for more comprehensive testing. The latter requires an oscilloscope.

Using the indicator lights, the commands sent down the link are verified. ON/OFF commands, such as POWER ON/POWER OFF, GO/STOP, on port and starboard motors are checked by means of the large indicator lamps. These commands can also be verified on the smaller indicator lights which show the result of decoding. In this case, a chart (Fig. 15*b*) is useful and a close-up view is necessary.

The rudder and speed control servo motors are checked manually before being put into 'auto'. This tests the servos and all the mechanical couplings to the final outputs, namely the rudder and propellers. Once this has been done, the system is put into auto (remote) control. An additional check point is provided by a switched meter which reads the result of digital-to-analog conversion. This analog read-out is the last check point before the control signals enter the servo motors, and thus provides a convenient 'partition' for fault finding.

More comprehensive tests on the receiving equipment are done in the laboratory, and for these tests a number of connectors (BNC) have been brought out to the front panel. These test points are labeled on drawings AF-12-82D and AF-12-88D. Waveforms for the first drawing are shown in drawing AF-12-96D.

Further details on how to install, calibrate, and check the ship-board equipment are covered in the publication, 'A manual for installation, operation and calibration of remote control system for model ships' [2].

Results

The present ship-board equipment is easier to install, calibrate, and put into operation by the user himself; previously the installation and checking was attended to by the authors. The present system is not restricted as much to the size of the model, as it was previously, where installations on some small models were difficult.

The present system is battery powered; (a gas-electric powered system was used before). While this limits the length of some model tests, it has not hindered most of the tests which run for a few hours at a time. Many batteries are used and these are distributed about the ship according to function and also to help the 'trim'. The three main functions are: 1) *Power for the logic unit.* This unit consumes 1.8 A at 24 V, a relatively light load and needs replenishing after a few days. 2) *Power for the rudder servo motor.* Again, the consumption is low. It is only during the time taken to go to a new rudder position that power is used. This is 0.7 A and lasts about 2 seconds to go from hard port to starboard. There is no drain when the servo is at a null. As in the first case, the rudder battery requires charging only infrequently. 3) *Power for the propulsion motors.* The consumption here depends greatly on the type of test and the rating of the motor. The small, fractional horsepower dc motors that have been in use so far consume about 5 A at full speed. Normally, two 12-V 90 A-hr batteries (lead-acid, automobile batteries) are used. In some cases, a third 6-V battery is used to boost the maximum propeller speed. No tests were made to determine the maximum running time for the propulsion batteries under a continuous load. A rule of thumb has been to keep another set of batteries under charge if long tests are anticipated or to charge overnite. This simple procedure, although a nuisance, ameliorates the battery problem.

Battery operation has proved a smooth, quiet running system with more reliability. Logic and rudder power, being supplied by a separate battery, is uninterrupted by power surges caused by the propulsion motors. Control is retained in spite of run-down propulsion motor batteries. As mentioned earlier, a single chopper power supply, powered from the logic unit's battery, supplies all the voltages necessary for the control circuits in both servo systems. It is only the final motors (rudder and propulsion) that take currents from their own batteries.

Heat sinks and louvres in the shipboard equipment have been adequate for cooling. The logic and servo units require no forced air cooling as in most cases, these units are mounted so that air can circulate freely. This has led to a problem of another nature – corrosion. After over a year's operation, there is evidence of this and although it is not a serious problem it is being monitored and checked at the present time.

Experience with actual testing procedures with the original system indicated that the accuracy and calibration-free feature of the digital-type servos were not and would not be used to good advantage in most cases. The original system had a considerable number of ship-board logic circuits to implement the rudder and speed control servos. These have been replaced by analog servos which are simpler to operate and service. With the digital controllers, the *initial* adjustments of the digital-type feedback transducers (gray-coded discs for rudder angle and incremental pulse-counting disc for motor speed) were tedious, but once having been set no further calibration was required. With the present system, the initial adjustment of feedback potentiometers and tachometers for rudder and speed control are less tedious but they do require calibration. This turns out to be fairly straightforward. The net result of changing from digital to analog servos has been a size reduction and a simpler system for the user. What has been lost is the calibration-free feature inherent in the digital servo systems.

In retrospect it can be said that the original ship-board equipment was designed to meet the requirements existing at that time and in the process of defining the user's requirements, over-specification resulted. The present system using batteries cannot run as long as the gas-electric powered system, but is adequate for most tests. It is not completely calibration free, but calibration is straightforward. It is much easier and simpler to install and put into operation *by the user*. It is compatible with the original transmitting equipment so that he can choose either system – the large, more complex unit for long-term tests and the smaller unit described here for most others.

Acknowledgments

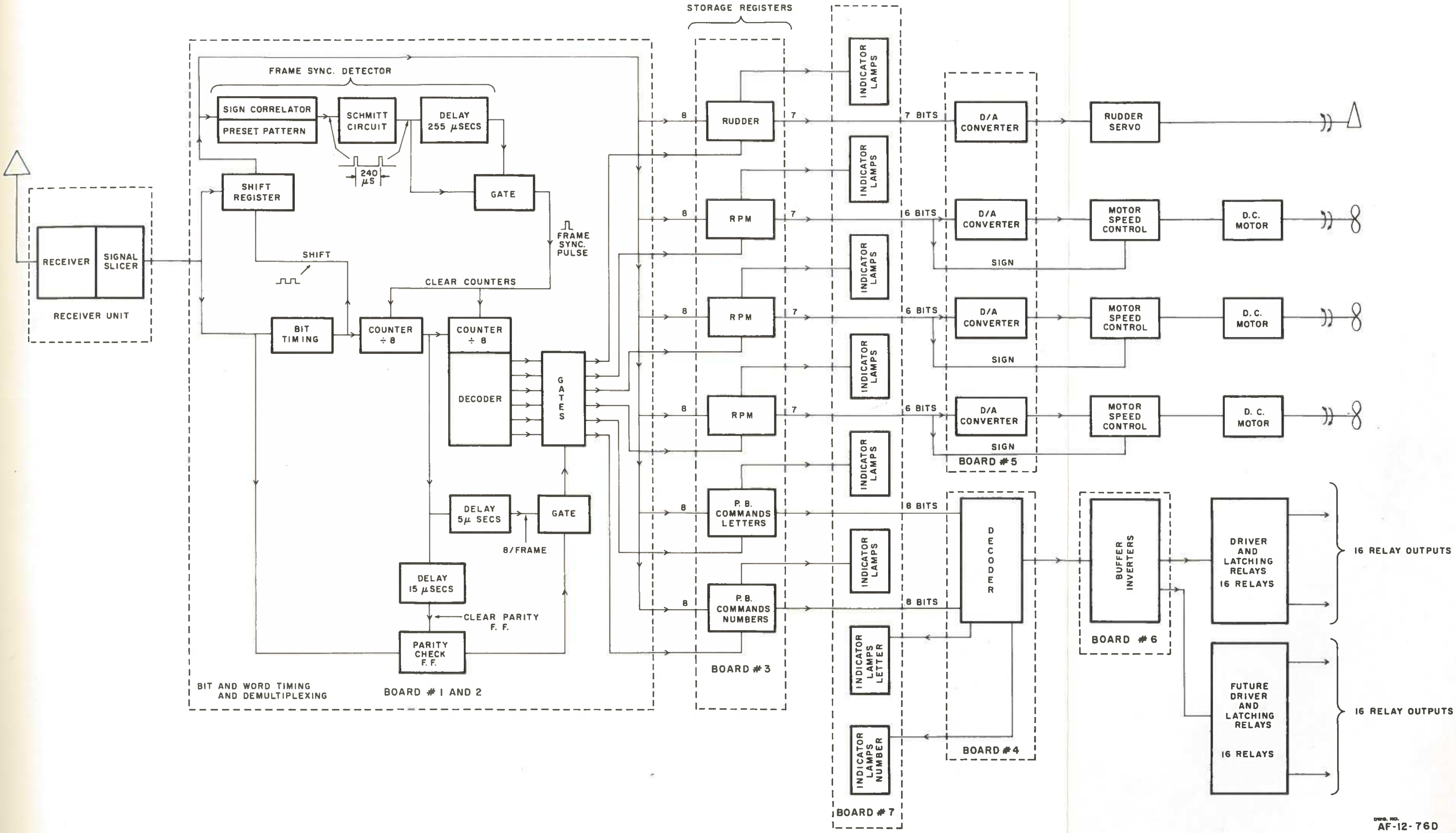
The authors were assisted in this work by Mr. W. Johnson (summer student) and Mr. R. Peters of the Ship Laboratory.

Photographs were taken by Mr. D. Phinney.

References

1. Remote control of model ships. NRC Report, ERB-808, December, 1968.
2. A manual for installation, operation and calibration of remote control system for model ships. NRC Report, ERB-841, 1970.

APPENDIX A – CIRCUIT DIAGRAMS



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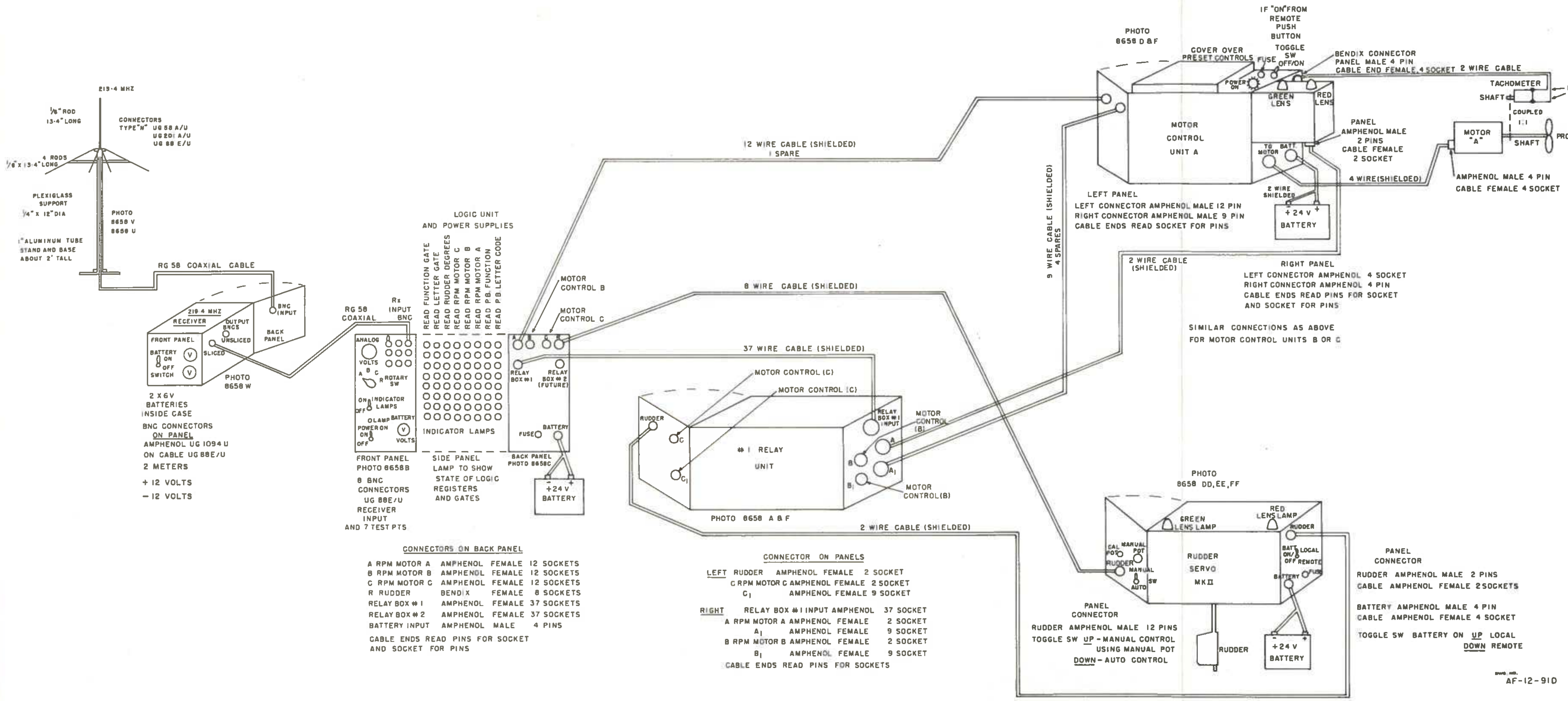
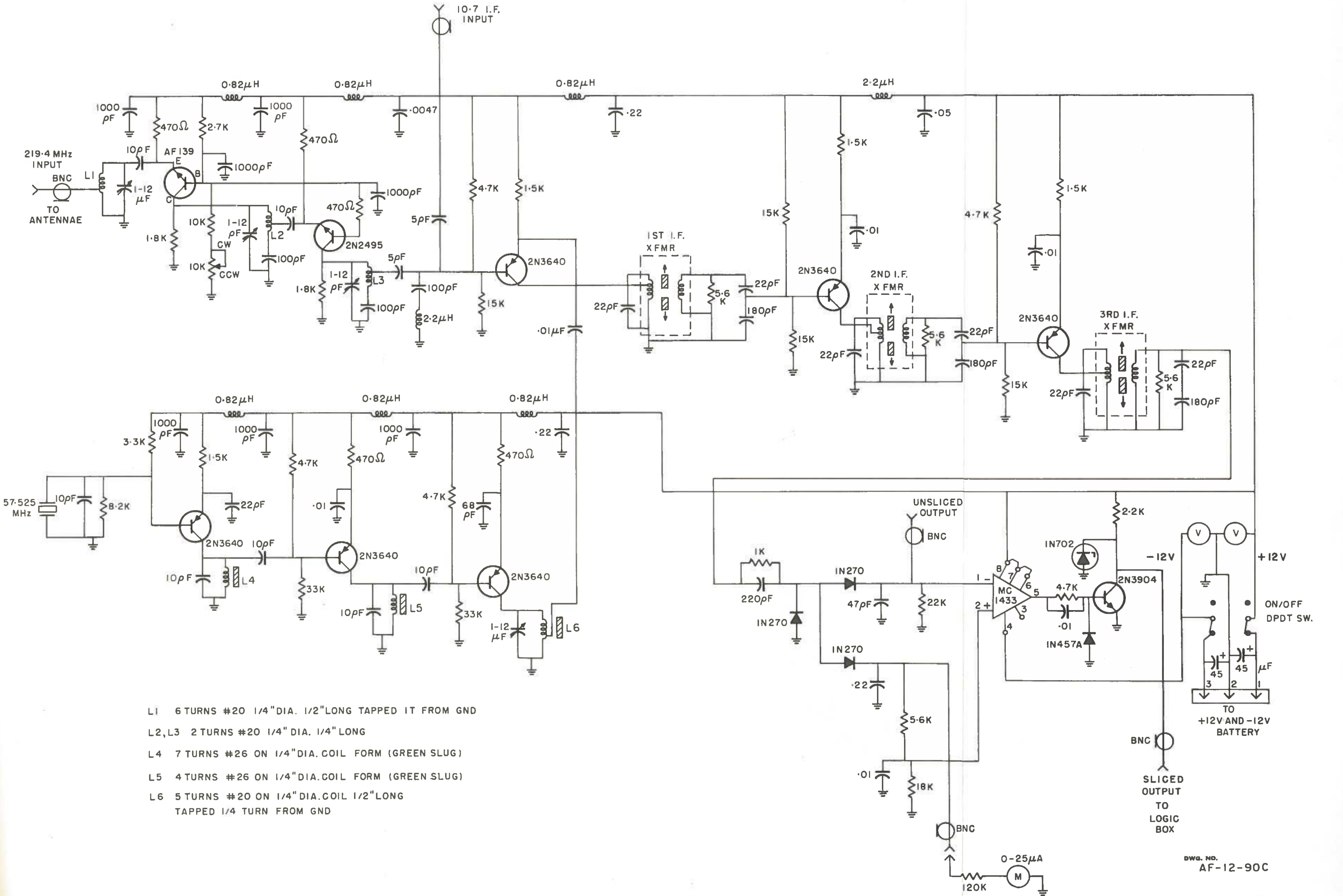


219·4 MHZ
1/8" ROD 13-4" LONG
CONNECTORS TYPE "N" UG 58 A/U UG 201 A/U UG 88 E/U
4 RODS 1/8" X 13-4" LONG
PLEXIGLASS SUPPORT 1/4" X 12" DIA
PHOTO 8658 V 8658 U
1" ALUMINUM TUBE STAND AND BASE ABOUT 2' TALL
RG 58 COAXIAL CABLE
219.4 MHZ RECEIVER
OUTPUT BNCS
UNSLICED
SLICED
BNC INPUT
BACK PANEL
FRONT PANEL
BATTERY ON OFF SWITCH
PHOTO 8658 W
2 X 6V BATTERIES INSIDE CASE
BNC CONNECTORS ON PANEL AMPHENOL UG 1094 U ON CABLE UG 88E/U
2 METERS
+ 12 VOLTS
− 12 VOLTS
RG 58 COAXIAL
Rx INPUT BNC
ANALOG VOLTS
A B C R ROTARY SW
ON OFF INDICATOR LAMPS
POWER ON OFF
LAMP BATTERY VOLTS
FRONT PANEL PHOTO 8658B
8 BNC CONNECTORS UG 88E/U RECEIVER INPUT AND 7 TEST PTS
LOGIC UNIT AND POWER SUPPLIES
READ FUNCTION GATE
READ LETTER GATE
READ RUDDER DEGREES
READ RPM MOTOR C
READ RPM MOTOR B
READ RPM MOTOR A
READ P.B. FUNCTION
READ P.B. LETTER CODE
INDICATOR LAMPS
SIDE PANEL LAMP TO SHOW STATE OF LOGIC REGISTERS AND GATES
MOTOR CONTROL B
MOTOR CONTROL C
RELAY BOX #1
RELAY BOX #2 (FUTURE)
FUSE
BATTERY
BACK PANEL PHOTO 8658C
+24 V BATTERY
12 WIRE CABLE (SHIELDED) 1 SPARE
8 WIRE CABLE (SHIELDED)
37 WIRE CABLE (SHIELDED)
MOTOR CONTROL (C)
MOTOR CONTROL (C)
RUDDER
C
C1
#1 RELAY UNIT
RELAY BOX #1 INPUT
MOTOR CONTROL (B)
A
A1
B
B1
MOTOR CONTROL (B)
PHOTO 8658 A & F
2 WIRE CABLE (SHIELDED)
9 WIRE CABLE (SHIELDED) 4 SPARES
2 WIRE CABLE (SHIELDED)
PHOTO 8658 D & F
COVER OVER PRESET CONTROLS
FUSE
POWER ON
IF "ON" FROM REMOTE PUSH BUTTON
TOGGLE SW OFF/ON
BENDIX CONNECTOR PANEL MALE 4 PIN CABLE END FEMALE, 4 SOCKET
2 WIRE CABLE
GREEN LENS
RED LENS
MOTOR CONTROL UNIT A
TO MOTOR
BATT
2 WIRE SHIELDED
+24 V BATTERY
PANEL AMPHENOL MALE 2 PINS CABLE FEMALE 2 SOCKET
TACHOMETER
LUGS ON CABLE
SHAFT
COUPLED 1:1
MOTOR "A"
SHAFT
PROP
4 WIRE (SHIELDED)
AMPHENOL MALE 4 PIN CABLE FEMALE 4 SOCKET
LEFT PANEL
LEFT CONNECTOR AMPHENOL MALE 12 PIN
RIGHT CONNECTOR AMPHENOL MALE 9 PIN
CABLE ENDS READ SOCKET FOR PINS
RIGHT PANEL
LEFT CONNECTOR AMPHENOL 4 SOCKET
RIGHT CONNECTOR AMPHENOL 4 PIN
CABLE ENDS READ PINS FOR SOCKET AND SOCKET FOR PINS
SIMILAR CONNECTIONS AS ABOVE FOR MOTOR CONTROL UNITS B OR C
PHOTO 8658 DD, EE, FF
GREEN LENS LAMP
RED LENS LAMP
CAL POT
MANUAL POT
RUDDER
MANUAL AUTO SW
RUDDER SERVO MK II
RUDDER
BATT ON/OFF
LOCAL REMOTE
BATTERY
FUSE
PANEL CONNECTOR
RUDDER AMPHENOL MALE 12 PINS
TOGGLE SW UP - MANUAL CONTROL USING MANUAL POT
DOWN - AUTO CONTROL
RUDDER
+24 V BATTERY
PANEL CONNECTOR
RUDDER AMPHENOL MALE 2 PINS
CABLE AMPHENOL FEMALE 2 SOCKETS
BATTERY AMPHENOL MALE 4 PIN
CABLE AMPHENOL FEMALE 4 SOCKET
TOGGLE SW BATTERY ON UP LOCAL
DOWN REMOTE
CONNECTORS ON BACK PANEL
A RPM MOTOR A AMPHENOL FEMALE 12 SOCKETS
B RPM MOTOR B AMPHENOL FEMALE 12 SOCKETS
C RPM MOTOR C AMPHENOL FEMALE 12 SOCKETS
R RUDDER BENDIX FEMALE 8 SOCKETS
RELAY BOX #1 AMPHENOL FEMALE 37 SOCKETS
RELAY BOX #2 AMPHENOL FEMALE 37 SOCKETS
BATTERY INPUT AMPHENOL MALE 4 PINS
CABLE ENDS READ PINS FOR SOCKET AND SOCKET FOR PINS
CONNECTOR ON PANELS
LEFT RUDDER AMPHENOL FEMALE 2 SOCKET
C RPM MOTOR C AMPHENOL FEMALE 2 SOCKET
C1 AMPHENOL FEMALE 9 SOCKET
RIGHT RELAY BOX #1 INPUT AMPHENOL 37 SOCKET
A RPM MOTOR A AMPHENOL FEMALE 2 SOCKET
A1 AMPHENOL FEMALE 9 SOCKET
B RPM MOTOR B AMPHENOL FEMALE 2 SOCKET
B1 AMPHENOL FEMALE 9 SOCKET
CABLE ENDS READ PINS FOR SOCKETS
DWG. NO. AF-12-91D



L1 6 TURNS #20 1/4"DIA. 1/2"LONG TAPPED 1T FROM GND

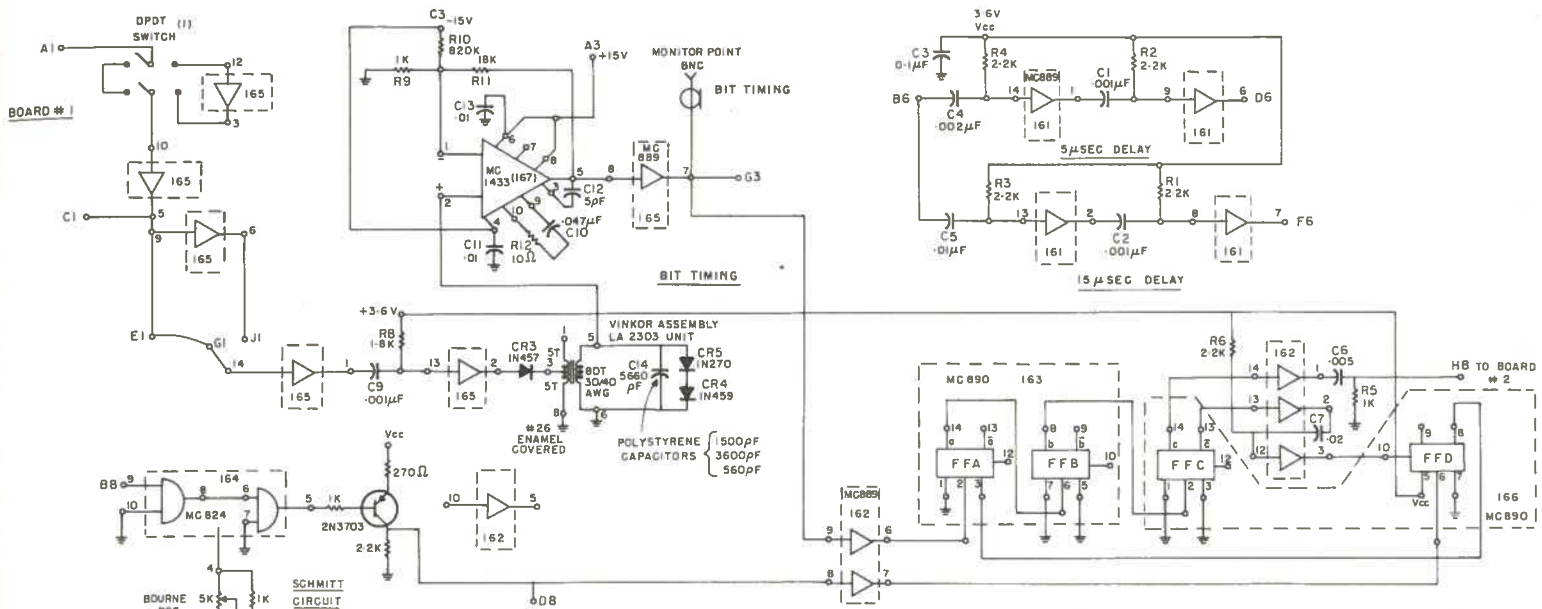
L2, L3 2 TURNS #20 1/4" DIA. 1/4" LONG

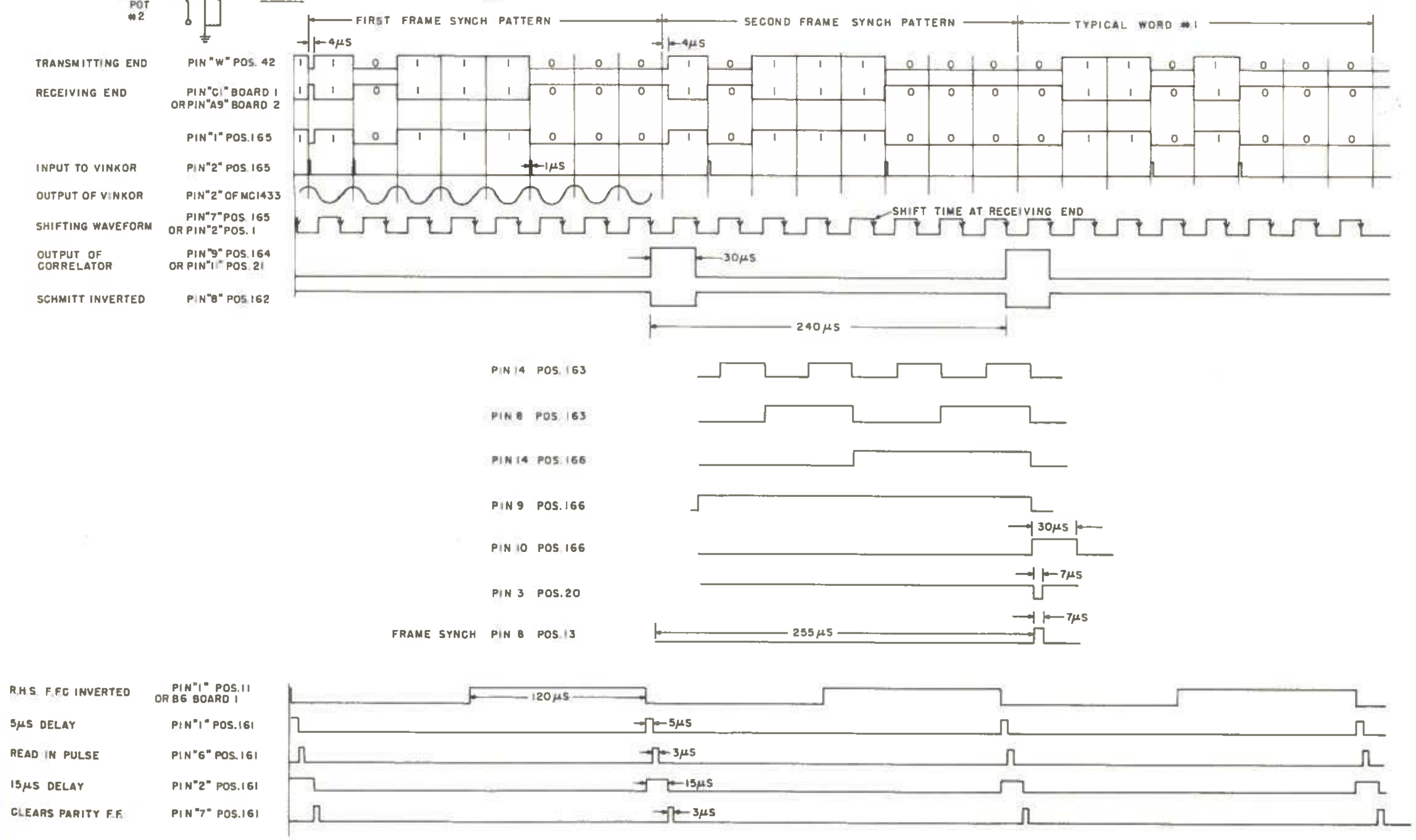
L4 7 TURNS #26 ON 1/4"DIA. COIL FORM (GREEN SLUG)

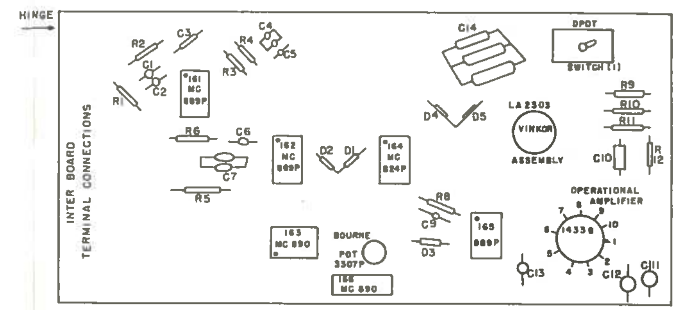
L5 4 TURNS #26 ON 1/4"DIA. COIL FORM (GREEN SLUG)

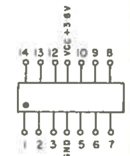
L6 5 TURNS #20 ON 1/4"DIA. COIL 1/2"LONG TAPPED 1/4 TURN FROM GND

DWG. NO. AF-12-90C







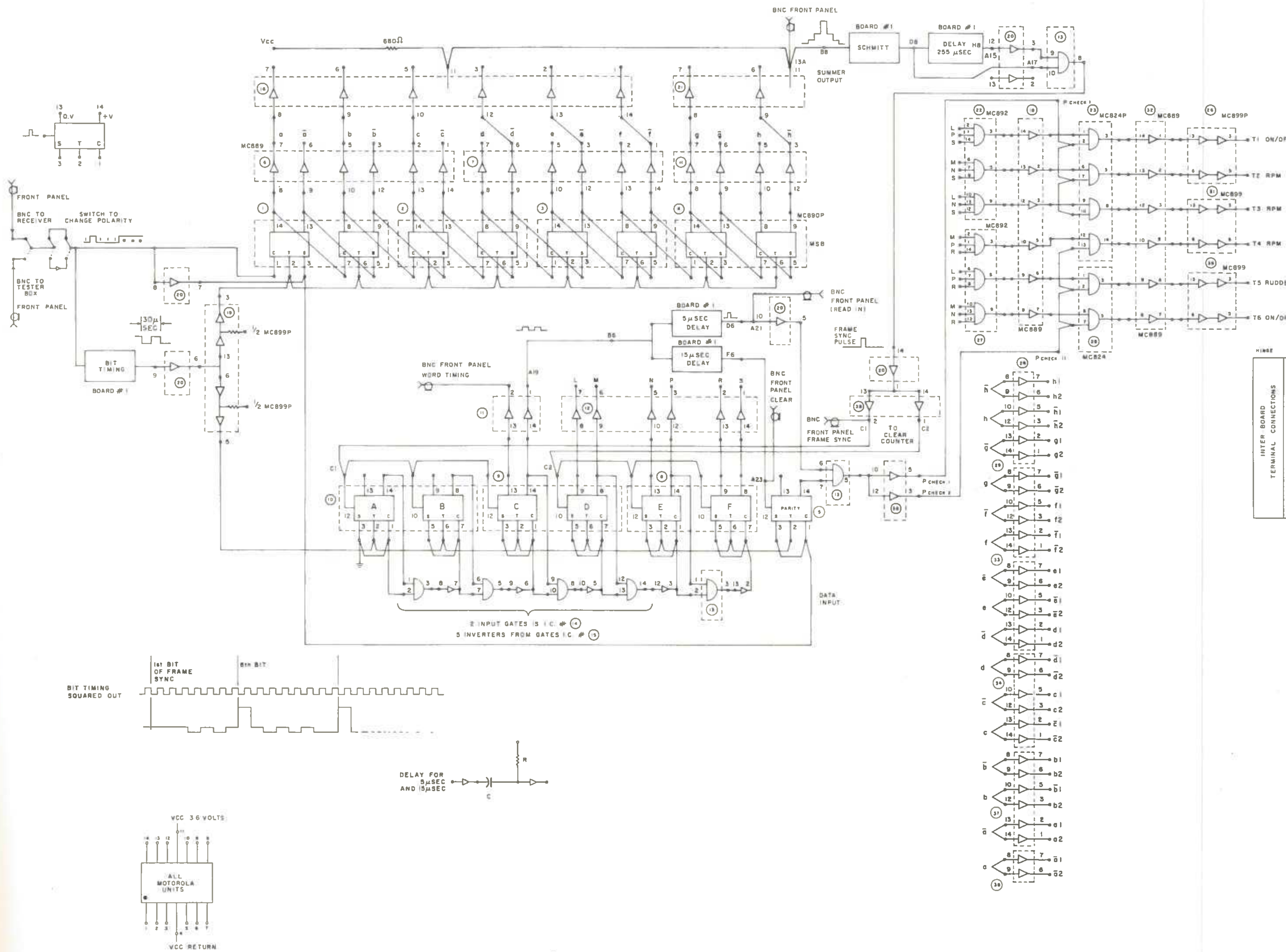


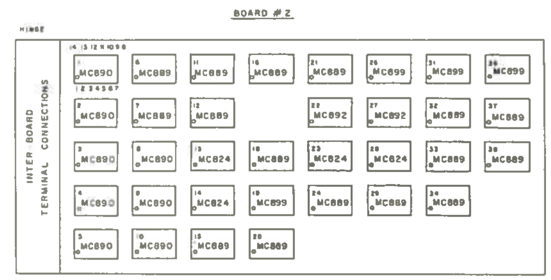
INTERBOARD TERMINAL TO IC UNIT AND PIN NUMBER

COLUMN NUMBER	A	B	C	D	E	F	G	H	J
	—	—	—	—	—	—	—	—	—
1	DPDT SWITCH		165, 5		165,9		165,14		165,6
2	—								
3	166,6&8		820K & 166,4				165,7		
4	—								
5	—								
6		INPUT TO DELAYS		161,6		161,7			
7	—								
8		164,9		C OF 2N3703				162,1	
9	—								
10				Vcc		GND			

MOTOROLA UNITS PIN 11 Vcc
4 GND

DWG. NO. AF-12-880D

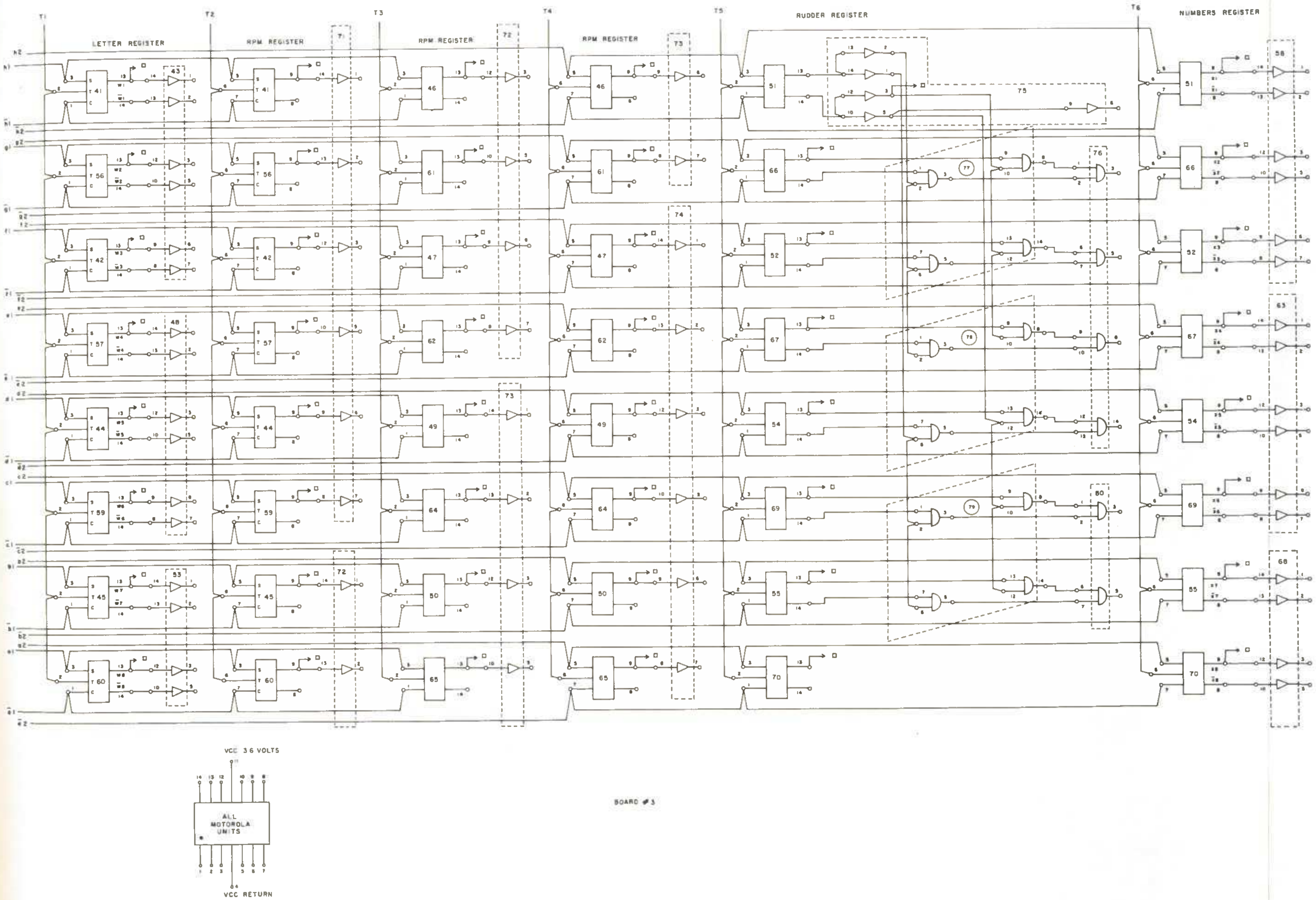


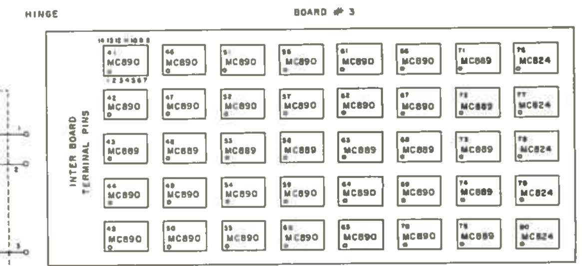


INTER BOARD TERMINAL TO I.C UNIT & PIN NUMBERS

COLUMN NUMBER	A	B	C	D	E	F	G	H	J
	-	-	-	-	-	-	-	-	-
1	-	-	-	-	-	-	-	-	-
2	-	-	-	-	-	-	-	-	-
3	-	-	-	-	-	-	-	-	-
4	-	-	-	-	-	-	-	-	-
5	-	-	-	-	-	-	-	-	-
6	-	-	-	-	-	-	-	-	-
7	-	-	-	-	-	-	-	-	-
8	-	-	-	-	-	-	-	-	-
9	20,8 1,1	-	-	-	24,7	-	33,7	-	37,7
10	-	-	-	-	-	-	-	-	-
11	20,9	-	-	-	24,6	-	33,6	-	37,6
12	-	-	-	-	-	-	-	-	-
13	21,11 16,11	-	-	-	24,5	-	33,5	-	37,5
14	-	-	-	-	-	-	-	-	-
15	20,12	-	-	-	24,3	-	33,3	-	37,3
16	-	-	-	-	-	-	-	-	-
17	13,10	-	-	-	24,2	-	33,2	-	37,2
18	-	-	-	-	-	-	-	-	-
19	11,1	-	-	-	24,1	-	33,1	-	37,1
20	-	-	-	-	-	-	-	-	-
21	20,10	-	25,3	-	28,7	-	34,7	-	38,7
22	-	-	-	-	-	-	-	-	-
23	5,12	-	24,5	-	28,6	-	34,6	-	38,6
24	-	-	-	-	-	-	-	-	-
25	-	-	31,3	-	28,5	-	34,5	-	-
26	-	-	-	-	-	-	-	-	-
27	-	-	31,8	-	28,3	-	34,3	-	-
28	-	-	-	-	-	-	-	-	-
29	-	-	36,3	-	28,2	-	34,2	-	-
30	-	-	-	-	-	-	-	-	-
31	GND	-	36,6	-	28,1	-	34,1	-	-
32	-	-	-	-	-	-	-	-	-
33	VCC	-	-	-	-	-	-	-	SIGNAL GND
34	-	-	-	-	-	-	-	-	-
35	-	-	-	-	-	-	-	-	-

DWG. NO.
AF-12-82D





INTER BOARD TERMINAL TO I C UNIT AND PIN NUMBER

COLUMN NUMBER	A	B	C	D	E	F	G	H	J
	-	-	-	-	-	-	-	-	-
1	-	-	-	-	-	-	-	-	-
2	-	44,3	-	73,6	-	58,1	-	-	-
3	41,3	-	71,1	-	43,1	-	41,2	-	-
4	-	54,5	-	73,7	-	58,2	-	-	-
5	51,5	-	71,2	-	43,2	-	41,6	-	-
6	-	44,1	-	74,1	-	58,3	-	-	-
7	41,1	-	71,3	-	43,3	-	46,2	-	-
8	-	54,7	-	74,2	-	58,5	-	-	-
9	51,7	-	71,5	-	43,5	-	46,6	-	-
10	-	59,3	-	74,3	-	58,6	-	-	-
11	56,3	-	71,6	-	43,6	-	51,2	-	-
12	-	69,5	-	74,5	-	58,7	-	-	-
13	66,5	-	71,7	-	43,7	-	51,6	-	-
14	-	59,1	-	74,6	-	63,1	-	-	-
15	56,1	-	72,1	-	48,1	-	-	-	-
16	-	69,7	-	74,7	-	63,2	-	-	-
17	66,7	-	72,2	-	48,2	-	-	-	-
18	-	45,3	-	75,6	-	63,3	-	-	-
19	42,3	-	72,3	-	48,3	-	-	-	-
20	-	55,5	-	76,3	-	63,5	-	-	-
21	52,5	-	72,5	-	48,5	-	-	-	-
22	-	45,1	-	76,5	-	63,6	-	-	-
23	42,1	-	72,6	-	48,6	-	-	-	-
24	-	55,7	-	76,8	-	63,7	-	-	-
25	52,7	-	72,7	-	48,7	-	-	-	-
26	-	60,3	-	76,14	-	68,1	-	-	-
27	57,3	-	73,1	-	53,1	-	-	-	-
28	-	70,5	-	80,3	-	68,2	-	-	-
29	67,5	-	73,2	-	53,2	-	-	-	-
30	-	60,1	-	80,8	-	68,3	-	-	-
31	57,1	-	73,3	-	53,3	-	-	-	-
32	-	70,7	-	-	-	68,5	-	-	-
33	67,7	-	73,5	-	53,5	-	-	-	-
34	-	VCC	-	GND	-	-	-	-	-

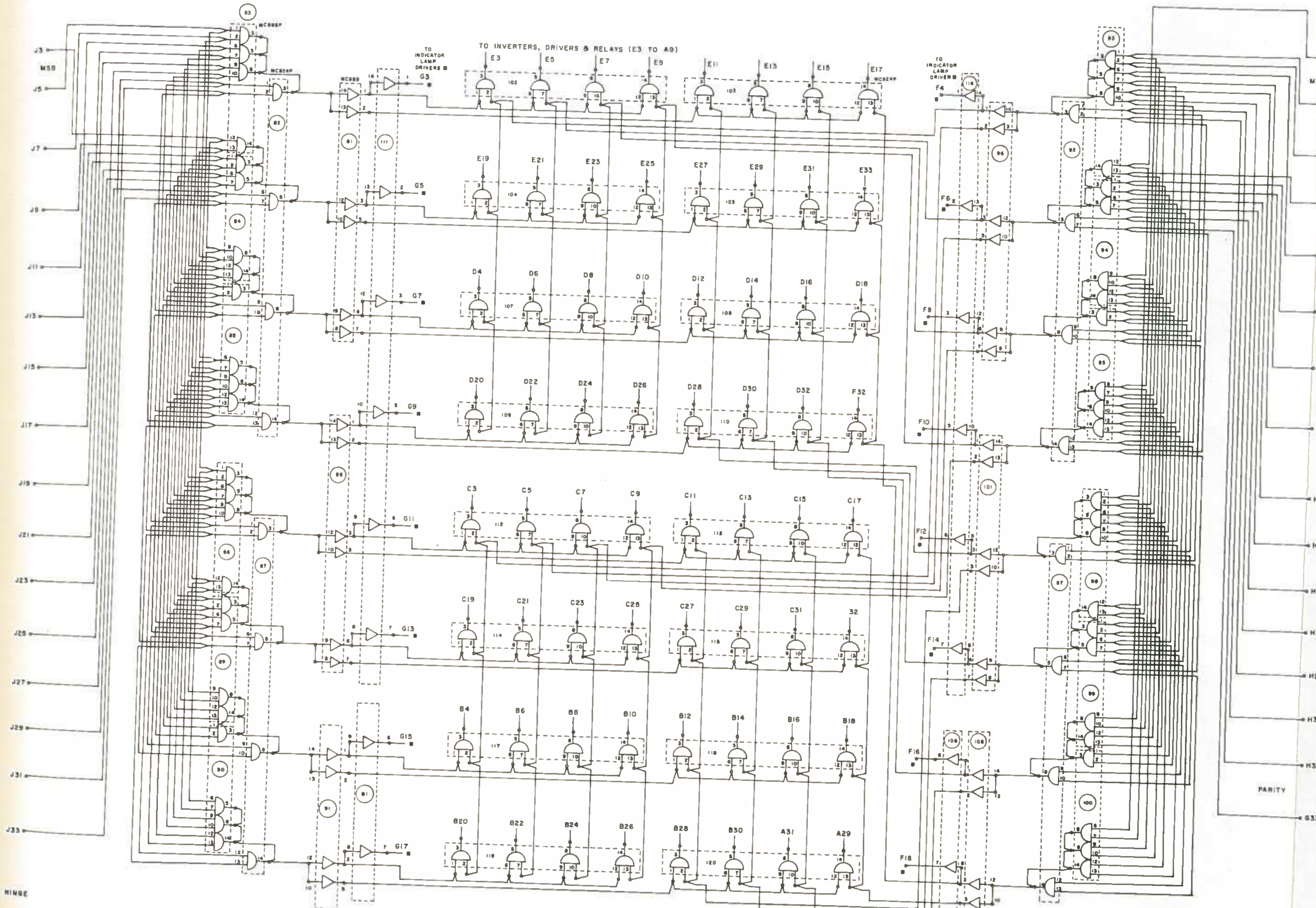
INDICATOR LAMPS (□)

BOARD # 3 UNITS TO BOARD # 7 INTERBOARD PINS

IC # 41, 13 TO A1	IC # 41,9 - B1	IC # 46,9 - C1
56, 13 - A2	56,9 - B2	61,9 - C2
42, 13 - A3	42,9 - B3	47,9 - C3
57, 13 - A4	57,9 - B4	62,9 - C4
44, 13 - A5	44,9 - B5	49,9 - C5
59, 13 - A6	59,9 - B6	64,9 - C6
45, 13 - A7	45,9 - B7	50,9 - C7
60, 13 - A8	60,9 - B8	65,9 - C8
51, 9 - A9	46,13 - B9	76,6 - C9
66, 9 - A10	61,13 - B10	66,13 - C10
52, 9 - A11	47,13 - B11	52,13 - C11
67, 9 - A12	62,13 - B12	67,13 - C12
54, 9 - A13	49,13 - B13	54,13 - C13
69, 9 - A14	64,13 - B14	69,13 - C14
55, 9 - A15	50,13 - B15	55,13 - C15
70, 9 - A16	65,13 - B16	70,13 - C16

BOARD # 3

DWG. NO. AF-12-81D

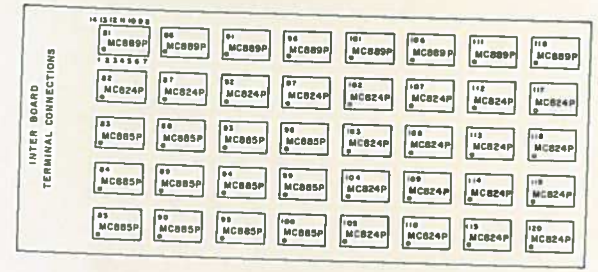


PACKAGES USED - QUAD 2 - INPUT GATE - MC824P = 20
QUAD 2 - INPUT EXPANDER - MC885P = 12
HEX INVERTER - MC889P = 4 + 2/6
38 UNITS

BOARD # 4

HINGE

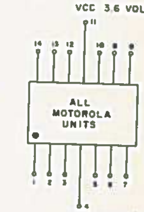
BOARD # 4



INTER BOARD TERMINAL TO I.C. UNIT AND PIN NUMBER

COLUMN NUMBERS	A	B	C	D	E	F	G	H	J
	-	-	-	-	-	-	-	-	-
1	-	-	-	-	-	-	-	-	-
2	-	-	-	-	-	-	-	-	-
3	-	-	112, 3	-	102, 3	-	111, 1	-	83, 12
4	-	117, 3	-	107, 3	-	116, 1	-	93, 12	-
5	-	-	112, 5	-	102, 5	-	111, 2	-	83, 1
6	-	117, 5	-	107, 5	-	116, 2	-	93, 1	-
7	-	-	112, 8	-	102, 8	-	111, 3	-	83, 2
8	-	117, 8	-	107, 8	-	116, 3	-	93, 2	-
9	-	-	112, 14	-	102, 14	-	111, 5	-	83, 13
10	-	117, 14	-	107, 14	-	116, 5	-	93, 13	-
11	-	-	113, 3	-	103, 3	-	111, 6	-	83, 6
12	-	118, 3	-	108, 3	-	116, 6	-	93, 6	-
13	-	-	113, 5	-	103, 5	-	111, 7	-	84, 1
14	-	118, 5	-	108, 5	-	116, 7	-	94, 1	-
15	-	-	113, 8	-	103, 8	-	91, 6	-	84, 2
16	-	116, 8	-	108, 8	-	106, 6	-	94, 2	-
17	-	-	113, 14	-	103, 14	-	91, 7	-	83, 7
18	-	118, 14	-	108, 14	-	106, 7	-	93, 7	-
19	-	-	114, 3	-	104, 3	-	-	-	83, 9
20	-	119, 3	-	109, 3	-	-	-	93, 9	-
21	-	-	114, 5	-	104, 5	-	-	-	84, 6
22	-	119, 5	-	109, 5	-	-	-	94, 6	-
23	-	-	114, 8	-	104, 8	-	-	-	84, 7
24	-	119, 8	-	109, 8	-	-	-	94, 7	-
25	-	-	114, 14	-	104, 14	-	-	-	83, 10
26	-	119, 14	-	109, 14	-	-	-	93, 10	-
27	-	-	115, 3	-	105, 3	-	-	-	82, 6
28	-	120, 3	-	110, 3	-	-	-	92, 6	-
29	120, 14	-	115, 5	-	105, 5	-	-	-	82, 1
30	-	120, 5	-	110, 5	-	-	-	92, 1	-
31	120, 8	-	115, 8	-	105, 8	-	-	-	82, 2
32	-	115, 14	-	110, 8	-	110, 14	-	92, 2	-
33	VCC	-	GND	-	105, 14	-	92, 7	-	82, 7
34	-	-	-	-	-	-	-	-	-

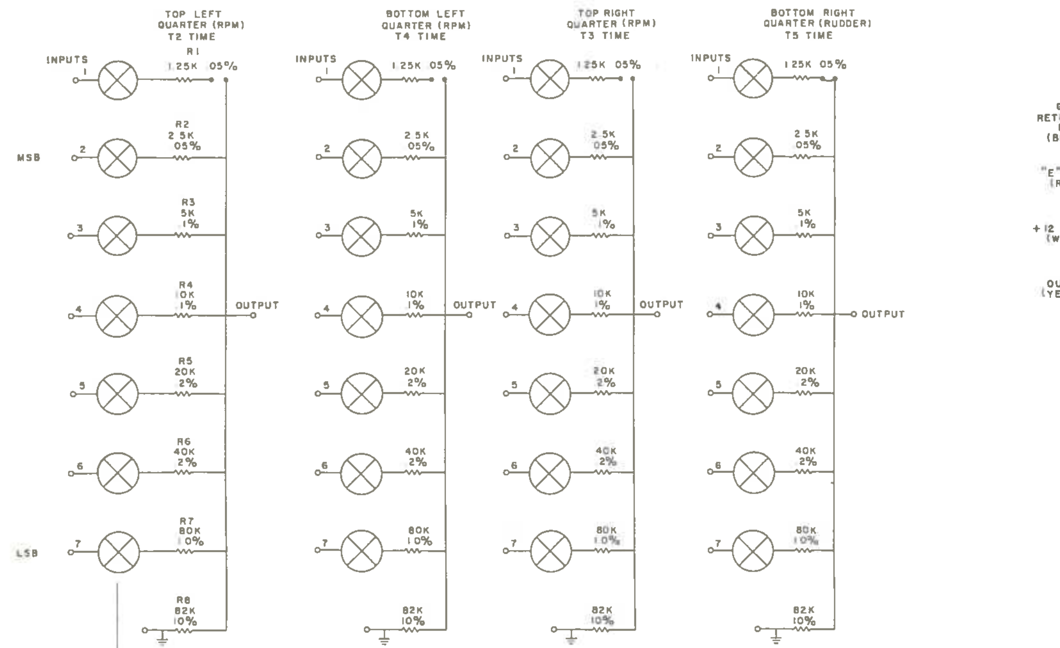
VCC 3.6 VOLTS

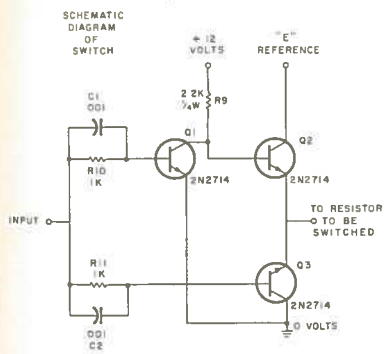


VCC RETURN

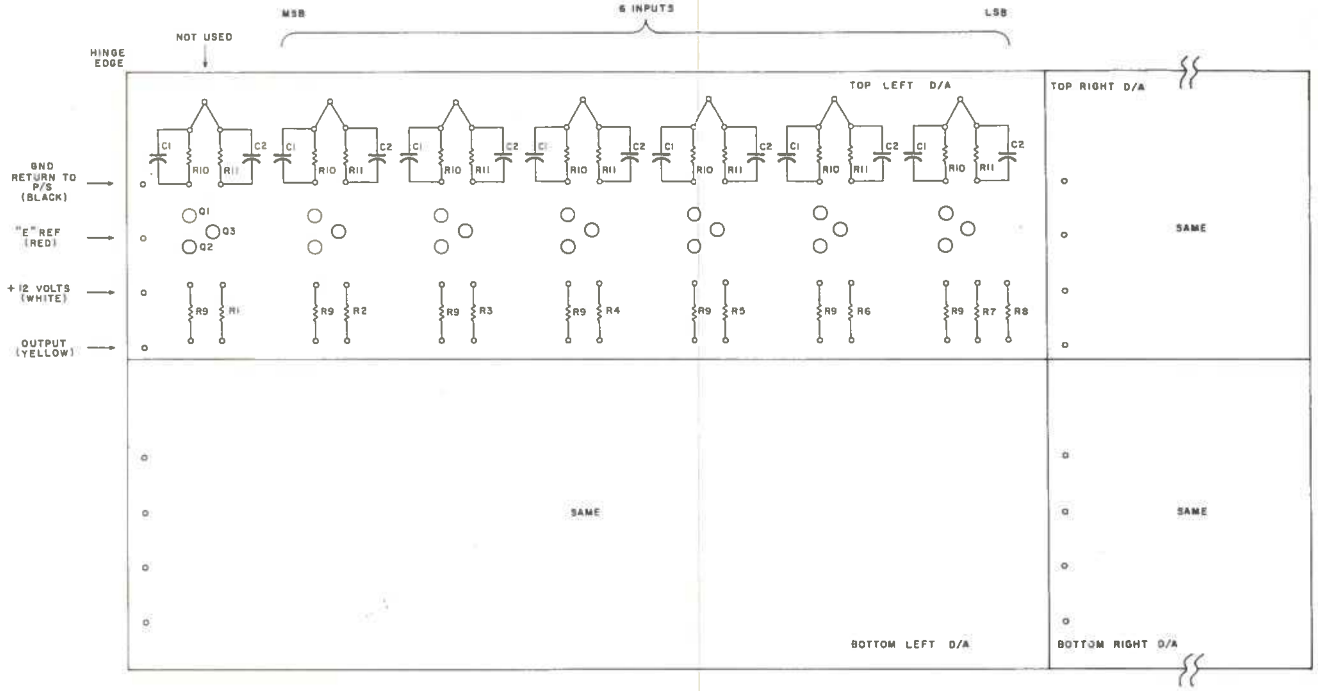
DWG. NO. AF-12-83D

BOARD # 5





NOTES
1) ALL RESISTORS 1/4 WATT EXCEPT FOR R1 - R8
2) OUTPUT OF LADDER FOR 6 BITS IS - $E_0 = \frac{E_{REF}}{64}(32+16+8+4+2+1)$
3) OUTPUT OF LADDER FOR 7 BITS IS - $E_0 = \frac{E_{REF}}{128}(64+32+16+8+4+2+1)$



INPUTS TO D/A CONVERTER

TOP LEFT D/A CONVERTER
(RPM) T2 TIME

PAGE 3
C5 TO INPUT # 2 (MSB) PAGE (5)
C7 " " 3
C9 " " 4
C11 " " 5
C13 " " 6
C15 " " 7 (LSB)

TOP RIGHT D/A CONVERTER
(RPM) T3 TIME

PAGE 3
C21 TO INPUT # 2 (MSB) PAGE 5
C23 " " 3
C25 " " 4
C27 " " 5
C29 " " 6
C31 " " 7 (LSB)

BOTTOM LEFT D/A CONVERTER
(RPM) T4 TIME

PAGE 3
D4 TO INPUT # 2 (MSB) PAGE (5)
D6 3
D8 4
D10 5
D12 6
D14 7 (LSB)

BOTTOM RIGHT D/A CONVERTER
(RUDDER) T5 TIME

PAGE 3
D18 TO INPUT # 1 (MSB) PAGE 5
D20 2
D22 3
D24 4
D26 5
D28 6
D30 7 (LSB)

OUTPUT OF D/A CONVERTERS TO CONNECTORS

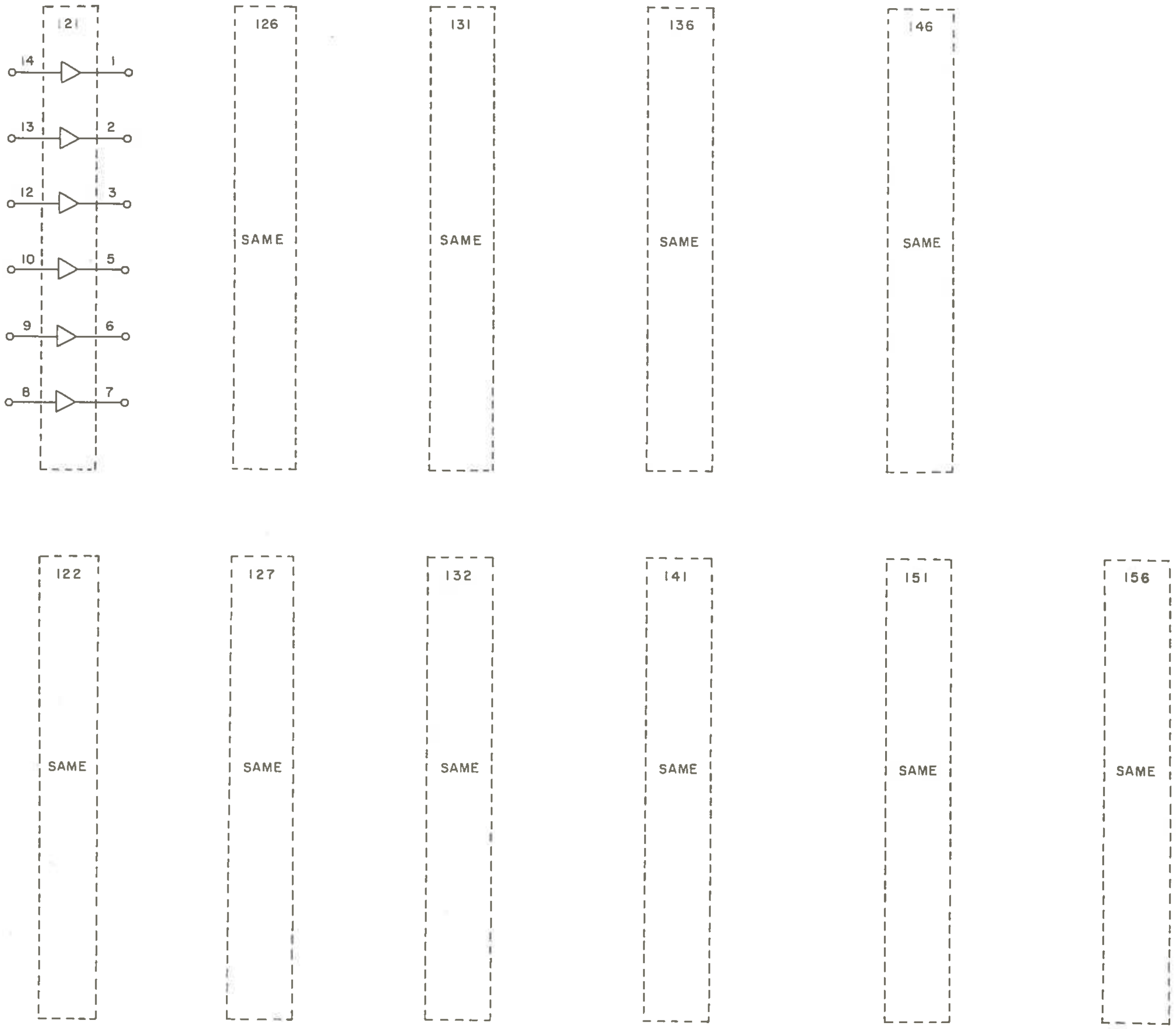
			CONNECTOR 165 - 11
TOP LEFT	OUTPUT	TO #1	CONNECTOR ON PANEL PIN E
(RPM)(T2)	GROUND	TO #1	" " " PIN F
BOTTOM LEFT	OUTPUT	TO #3	CONNECTOR ON PANEL PIN E
(RPM)(T4)	GROUND	TO #3	" " " PIN F
TOP RIGHT	OUTPUT	TO #2	CONNECTOR ON PANEL PIN E
(RPM)(T3)	GROUND	TO #2	" " " PIN F
			CONNECTOR PT02A - 16 - 8S
BOTTOM RIGHT	OUTPUT	TO	CONNECTOR ON PANEL PIN E
(RUDDER)	GROUND		" " " PIN F

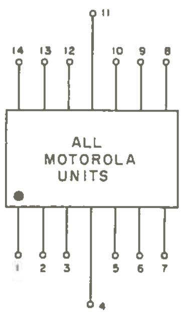
DWG. NO.
AF - 12 - 84D

BOARD # 6

BUFFER INVERTERS FOR

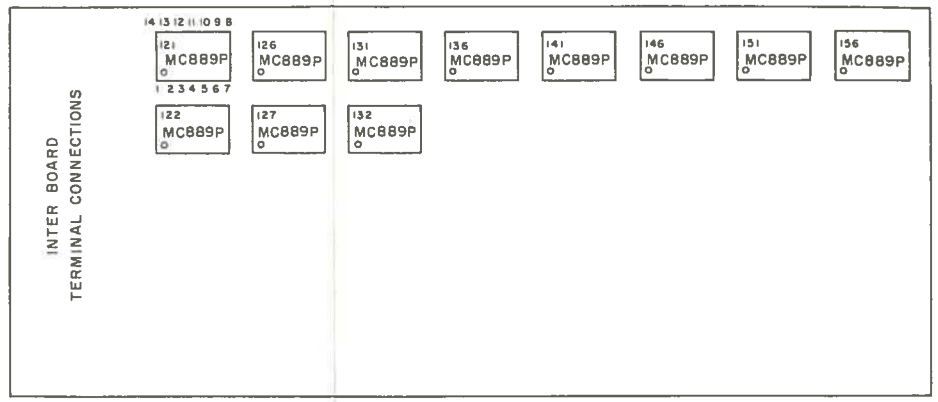
DECODER GATE BOARD # 4 TO LATCHING RELAY BOX





BOARD # 6

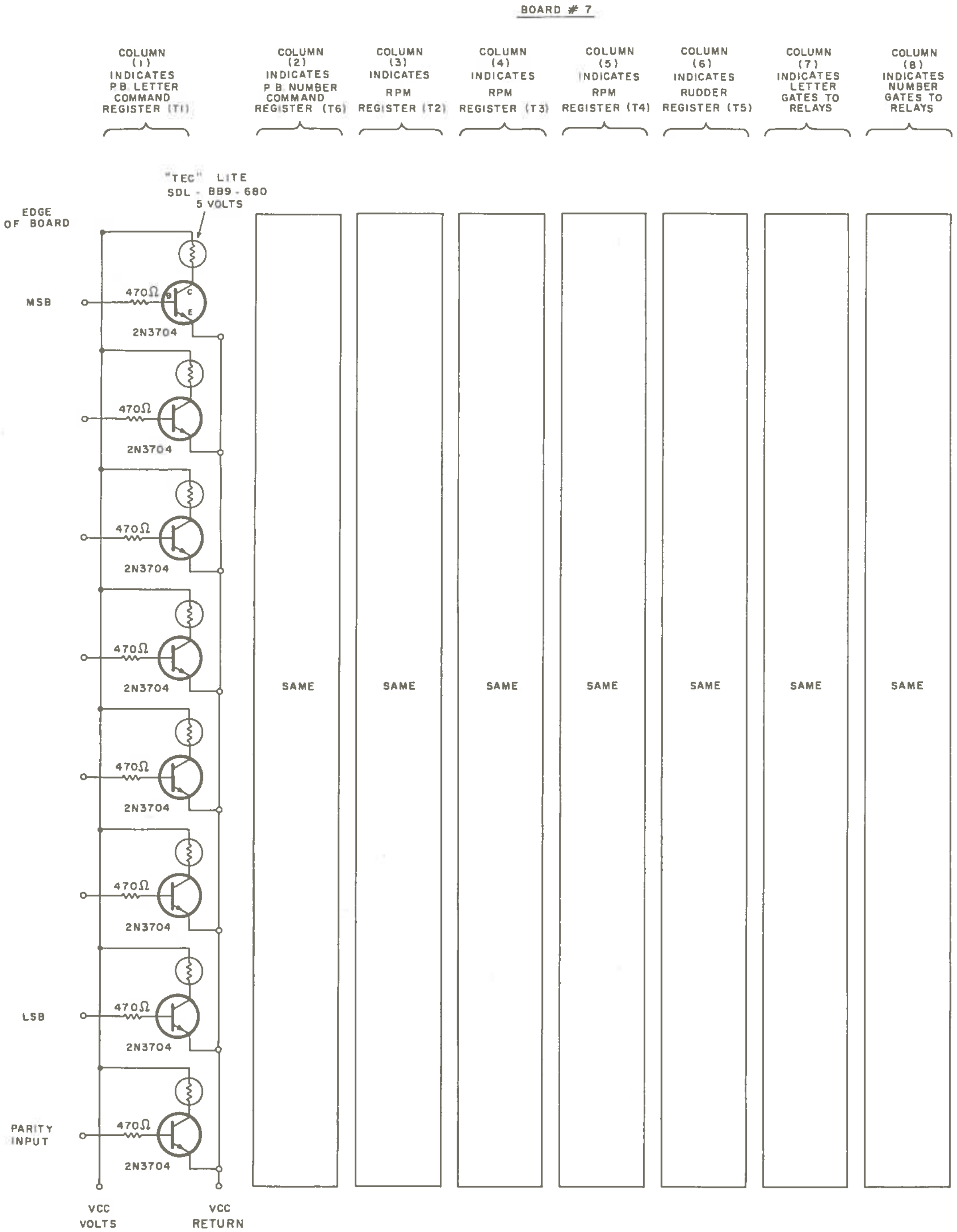
HINGE

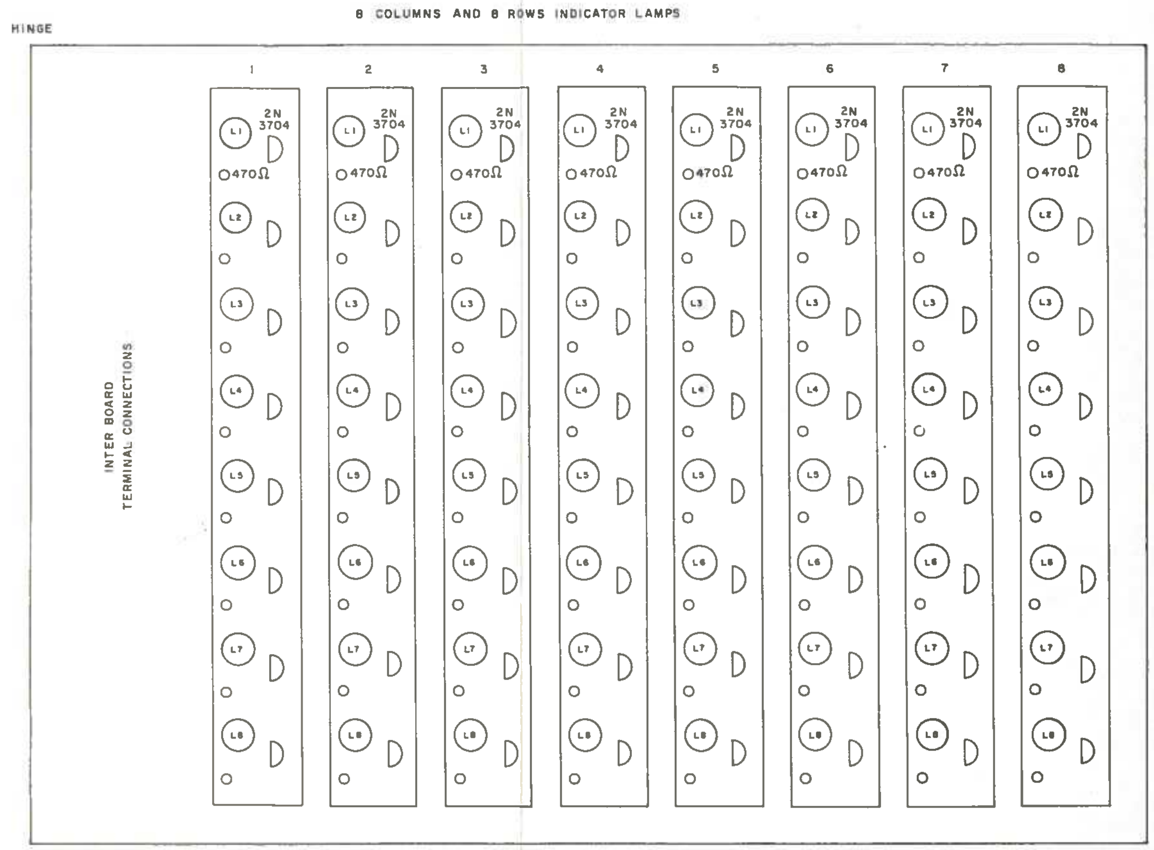


INTER BOARD TERMINAL TO I.C. UNIT AND PIN NUMBER

COLUMN NUMBER	A	B	C	D	E	F	G	H	J
	-	-	-	-	-	-	-	-	-
1	-	-	-	-	-	-	-	-	-
2	-	-	-	-	-	-	-	-	-
3	121,14	-	146,12	-	121, 1	-	146, 3	-	-
4	-	131, 9	-	122,14	-	131, 6	-	122, 1	-
5	121, 13	-	146,10	-	121, 2	-	146, 5	-	-
6	-	131, 8	-	122, 13	-	131, 7	-	122, 2	-
7	121, 12	-	146, 9	-	121, 3	-	146, 6	-	-
8	-	136,14	-	122, 12	-	136, 1	-	122, 3	-
9	121, 10	-	146,8	-	121, 5	-	146, 7	-	-
10	-	136,13	-	122,10	-	136, 2	-	122, 5	-
11	121, 9	-	151,14	-	121, 6	-	151, 1	-	-
12	-	136,12	-	122,9	-	136,3	-	122,6	-
13	121, 8	-	151,13	-	121,7	-	151, 2	-	-
14	-	136,10	-	122,8	-	136,5	-	122,7	-
15	126,14	-	151,12	-	126,1	-	151, 3	-	-
16	-	136, 9	-	127,14	-	136,6	-	127, 1	-
17	126,13	-	151,10	-	126,2	-	151,5	-	-
18	-	136, 8	-	127, 13	-	136,7	-	127, 2	-
19	126,12	-	151, 9	-	126,3	-	151,6	-	-
20	-	141,14	-	127,12	-	141, 1	-	127,3	-
21	126,10	-	151,8	-	126,5	-	151,7	-	-
22	-	141, 13	-	127,10	-	141,2	-	127,5	-
23	126, 9	-	156,14	-	126, 6	-	156, 1	-	-
24	-	141,12	-	127, 9	-	141,3	-	127,6	-
25	126, 8	-	156,13	-	126,7	-	156,2	-	-
26	-	141, 10	-	127,8	-	141,5	-	127,7	-
27	131,14	-	156,12	-	131, 1	-	156,3	-	-
28	-	141, 9	-	132,14	-	141,6	-	132, 1	-
29	131,13	-	156,10	-	131,2	-	156,5	-	-
30	-	141, 8	-	132,13	-	141,7	-	132, 2	-
31	131,12	-	156,9	-	131,3	-	156,6	-	VCC
32	-	146,14	-	132,12	-	146,1	-	132,3	-
33	131,10	-	156,8	-	131,5	-	156,7	-	GND
34	-	146,13	-	132,10	-	146,2	-	132,5	-

DWG. NO.
AF - 12 - 85D

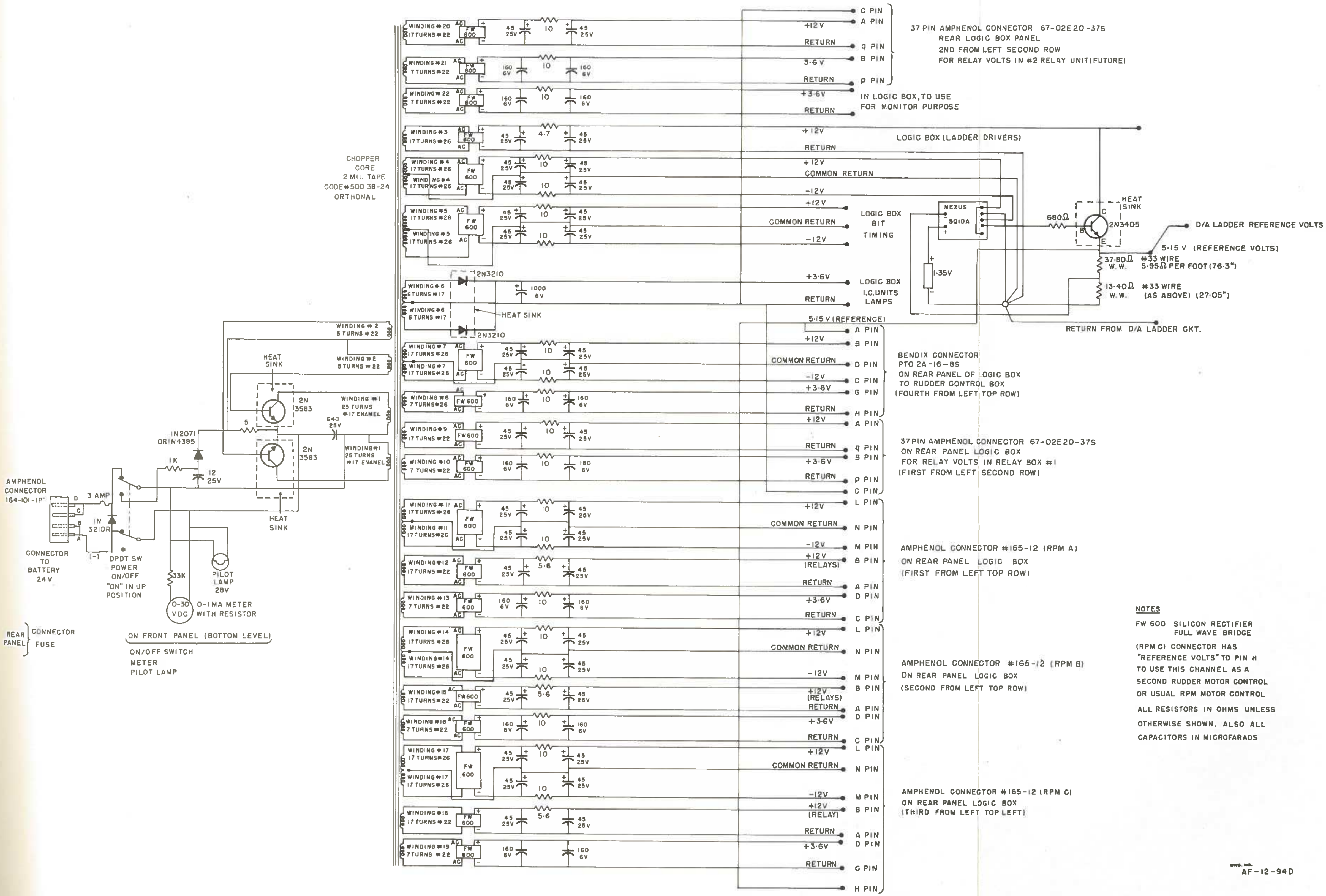


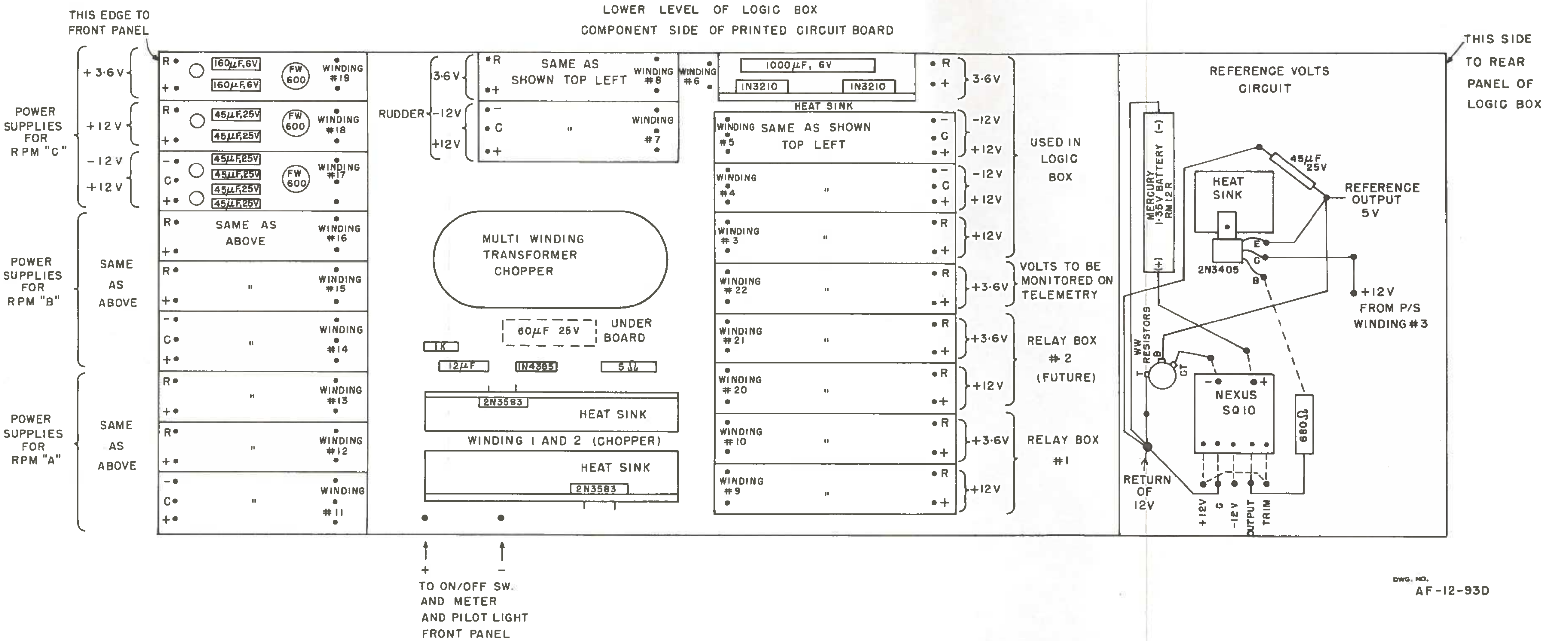


INTER BOARD TERMINAL TO COLUMN AND LAMP NUMBER

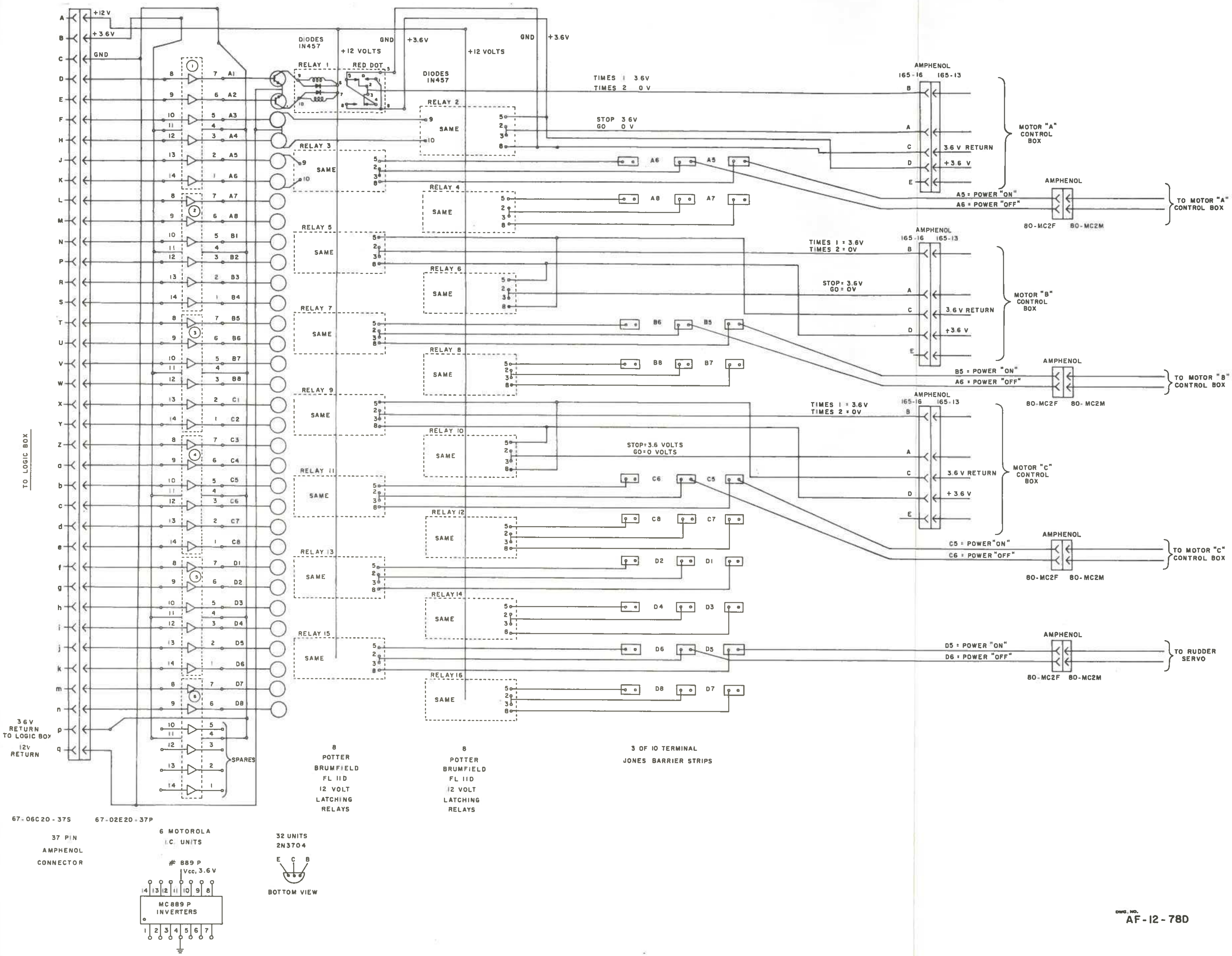
COLUMN	A	B	C	D	E	F	G	H
NUMBER	-	-	-	-	-	-	-	-
1	COL 1 L1	COL 3 L1	COL 5 L1	COL 7 L1	-	-	-	-
2	- L2	- L2	- L2	- L2	-	-	-	-
3	- L3	- L3	- L3	- L3	-	-	-	-
4	- L4	- L4	- L4	- L4	-	-	-	-
5	- L5	- L5	- L5	- L5	-	-	-	-
6	- L6	- L6	- L6	- L6	-	-	-	-
7	- L7	- L7	- L7	- L7	-	-	-	-
8	- L8	- L8	- L8	- L8	-	-	-	-
9	COL 2 L1	COL 4 L1	COL 6 L1	COL 8 L1	-	-	-	-
10	- L2	- L2	- L2	- L2	-	-	-	-
11	- L3	- L3	- L3	- L3	-	-	-	-
12	- L4	- L4	- L4	- L4	-	-	-	-
13	- L5	- L5	- L5	- L5	-	-	-	-
14	- L6	- L6	- L6	- L6	-	VCC COL 5 + 6	VCC COL 1 + 2	VCC COL 3 + 4
15	- L7	- L7	- L7	- L7	-	-	-	VCC COL 7 + 8
16	- L8	- L8	- L8	- L8	GND END COL 1 + 2	GND END COL 3 + 4	GND END COL 5 + 6	GND END COL 7 + 8

DWG. NO. AF-12-80D

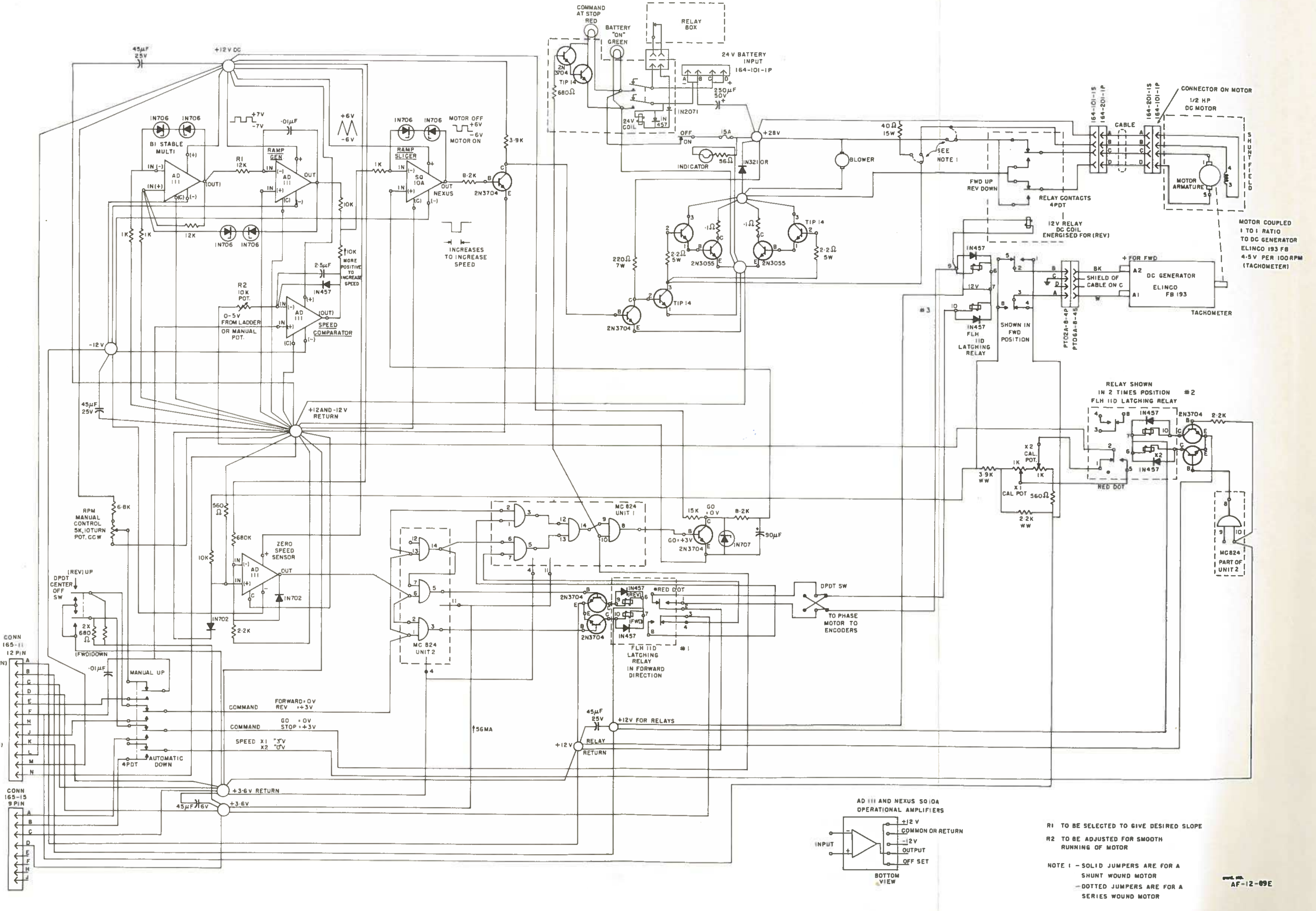

37 PIN AMPHENOL CONNECTOR 67-02E20-37S
REAR LOGIC BOX PANEL
2ND FROM LEFT SECOND ROW
FOR RELAY VOLTS IN #2 RELAY UNIT (FUTURE)
IN LOGIC BOX, TO USE
FOR MONITOR PURPOSE
LOGIC BOX (LADDER DRIVERS)
LOGIC BOX
BIT
TIMING
NEXUS
SQ10A
1.35V
680Ω
HEAT
SINK
2N3405
D/A LADDER REFERENCE VOLTS
5.15 V (REFERENCE VOLTS)
37.80Ω #33 WIRE
W.W. 5.95Ω PER FOOT (76.3")
13.40Ω #33 WIRE
W.W. (AS ABOVE) (27.05")
LOGIC BOX
I.C. UNITS
LAMPS
RETURN FROM D/A LADDER CKT.
5.15 V (REFERENCE)
BENDIX CONNECTOR
PTO 2A-16-8S
ON REAR PANEL OF LOGIC BOX
TO RUDDER CONTROL BOX
(FOURTH FROM LEFT TOP ROW)
37 PIN AMPHENOL CONNECTOR 67-02E20-37S
ON REAR PANEL LOGIC BOX
FOR RELAY VOLTS IN RELAY BOX #1
(FIRST FROM LEFT SECOND ROW)
AMPHENOL CONNECTOR #165-12 (RPM A)
ON REAR PANEL LOGIC BOX
(FIRST FROM LEFT TOP ROW)
AMPHENOL CONNECTOR #165-12 (RPM B)
ON REAR PANEL LOGIC BOX
(SECOND FROM LEFT TOP ROW)
AMPHENOL CONNECTOR #165-12 (RPM C)
ON REAR PANEL LOGIC BOX
(THIRD FROM LEFT TOP LEFT)
CHOPPER
CORE
2 MIL TAPE
CODE #500 38-24
ORTHONAL
WINDING #2
5 TURNS #22
WINDING #1
25 TURNS
#17 ENAMEL
HEAT
SINK
2N
3583
640
25V
1N2071
OR 1N4385
1K
12
25V
3 AMP
IN
3210R
AMPHENOL
CONNECTOR
164-101-1P
CONNECTOR
TO
BATTERY
24V
DPDT SW
POWER
ON/OFF
"ON" IN UP
POSITION
33K
PILOT
LAMP
28V
0-30
VDC
0-1MA METER
WITH RESISTOR
REAR PANEL
CONNECTOR
FUSE
ON FRONT PANEL (BOTTOM LEVEL)
ON/OFF SWITCH
METER
PILOT LAMP
2N3210
HEAT SINK
1000
6V
NOTES
FW 600 SILICON RECTIFIER
FULL WAVE BRIDGE
(RPM C) CONNECTOR HAS
"REFERENCE VOLTS" TO PIN H
TO USE THIS CHANNEL AS A
SECOND RUDDER MOTOR CONTROL
OR USUAL RPM MOTOR CONTROL
ALL RESISTORS IN OHMS UNLESS
OTHERWISE SHOWN. ALSO ALL
CAPACITORS IN MICROFARADS
DWG. NO.
AF-12-94D



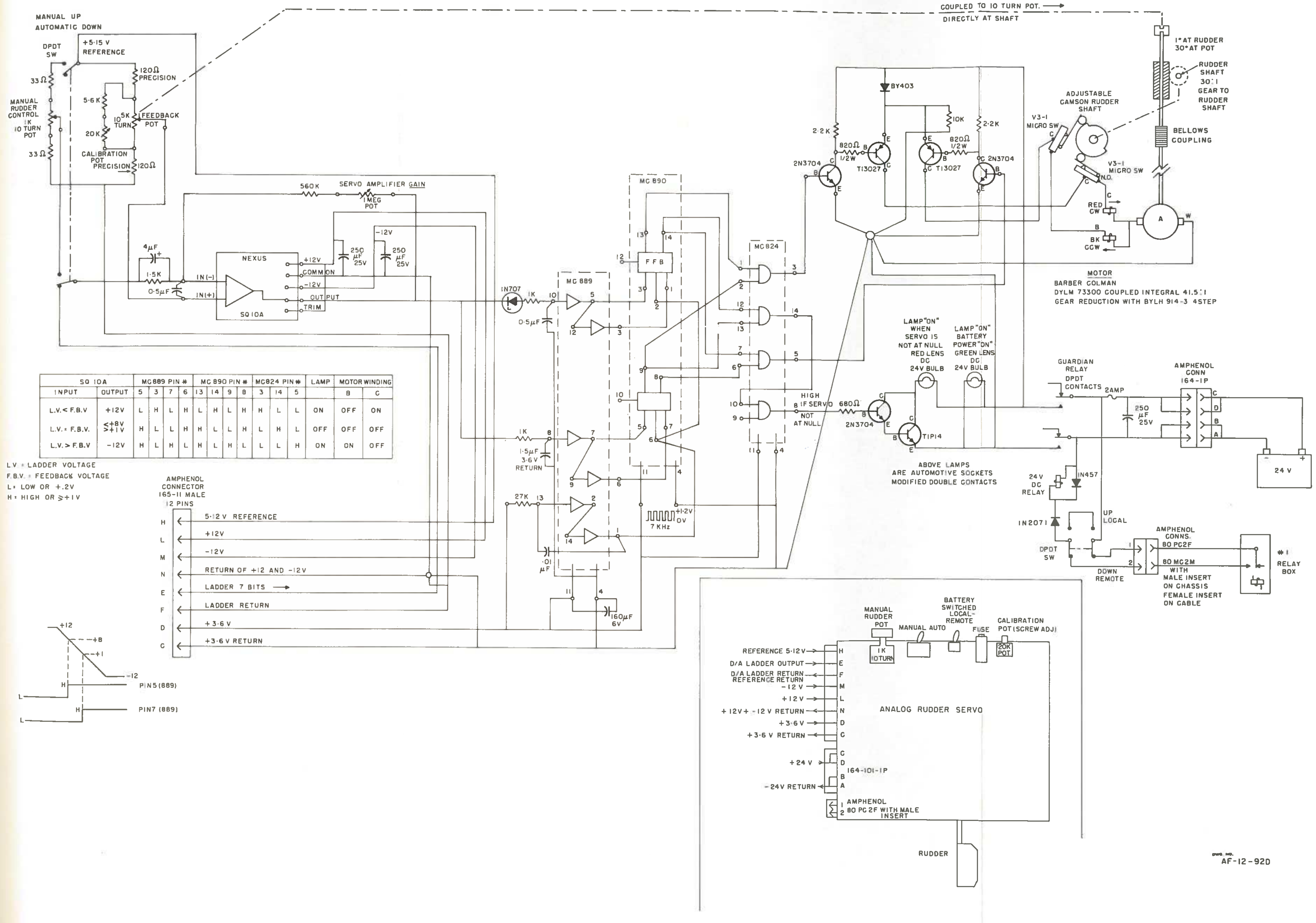
DWG. NO. AF-12-93D



DWG. NO. AF-12-78D



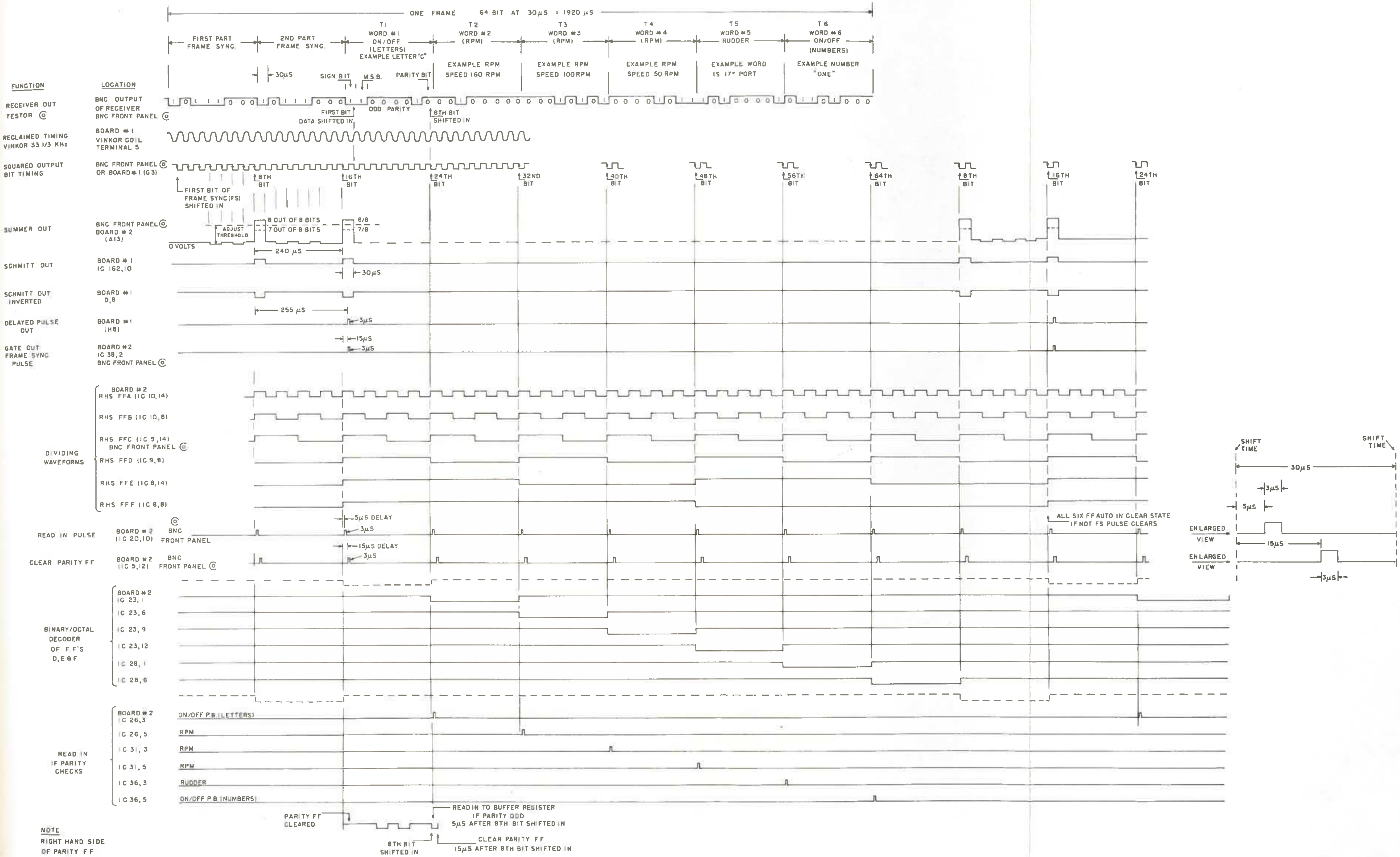
COMMAND AT STOP RED
BATTERY "ON" GREEN
RELAY BOX
24 V BATTERY INPUT 164-101-1P
TIP 14
680Ω
24V COIL
IN2071
IN 457
250μF 50V
OFF
ON
15A
+28V
INDICATOR
56Ω
IN3210R
40Ω 15W
SEE NOTE 1
BLOWER
FWD UP REV DOWN
RELAY CONTACTS 4PDT
12V RELAY DC COIL ENERGISED FOR (REV)
164-101-1S
164-201-1P
CABLE
164-201-1S
164-101-1P
CONNECTOR ON MOTOR
1/2 HP DC MOTOR
MOTOR ARMATURE
SHUNT FIELD
MOTOR COUPLED 1 TO 1 RATIO TO DC GENERATOR ELINCO 193 FB 4.5V PER 100RPM (TACHOMETER)
2N3055
220Ω 7W
2.2Ω 5W
2N3704
+12V DC
45μF 25V
IN706
BI STABLE MULTI
AD 111
R1 12K
RAMP GEN
+7V -7V
.01μF
+6V -6V
RAMP SLICER
SQ 10A
NEXUS
MOTOR OFF +6V MOTOR ON -6V
3.9K
8.2K
1K
12K
10K
INCREASES TO INCREASE SPEED
MORE POSITIVE TO INCREASE SPEED
2.5μF
IN457
R2 10K POT.
0-5V FROM LADDER OR MANUAL POT.
SPEED COMPARATOR
-12V
+12AND-12V RETURN
+ FOR FWD
BK
SHIELD OF CABLE ON C
W
DC GENERATOR ELINCO FB 193
TACHOMETER
IN457 FLH 11D LATCHING RELAY
SHOWN IN FWD POSITION
PTO2A-8-4P
PTO6A-8-4S
#3
RELAY SHOWN IN 2 TIMES POSITION FLH 11D LATCHING RELAY
#2
2N3704
2.2K
X2 CAL. POT.
X1 CAL POT
3.9K WW
560Ω
2.2K WW
RED DOT
MC824 PART OF UNIT 2
RPM MANUAL CONTROL 5K,10TURN POT. CCW
6.8K
560Ω
680K
ZERO SPEED SENSOR
IN702
2.2K
MC 824 UNIT 1
MC 824 UNIT 2
15K GO +0V
GO +3V
IN707
90μF
DPDT SW
TO PHASE MOTOR TO ENCODERS
IN457 (REV)
(FWD)
FLH 11D LATCHING RELAY IN FORWARD DIRECTION
#1
(REV) UP
DPDT CENTER OFF SW
2X 680 Ω
(FWD) DOWN
.01μF
MANUAL UP
AUTOMATIC DOWN
4PDT
CONN 165-11 12 PIN
+12V RELAYS (RETURN)
+12V RELAY
+3.6V (RETURN)
+3.6V
OUTPUT FROM D/A LADDER
LADDER (RETURN)
FOR/REV
FOR/REV V (RETURN)
+12V
-12V
+12 & -12V RETURN
TO LOGIC BOX
COMMAND FORWARD+0V REV +3V
COMMAND GO +0V STOP +3V
SPEED X1 "3"V X2 "0"V
56MA
45μF 25V
+12V FOR RELAYS
+12V RELAY RETURN
+3.6V RETURN
45μF 16V
+3.6V
CONN 165-15 9 PIN
GO/STOP
TIME 1 X 2
+3.6V (RETURN)
+3.6V
TO RELAY BOX
AD 111 AND NEXUS SQ10A OPERATIONAL AMPLIFIERS
INPUT
+12V
COMMON OR RETURN
-12V
OUTPUT
OFF SET
BOTTOM VIEW
R1 TO BE SELECTED TO GIVE DESIRED SLOPE
R2 TO BE ADJUSTED FOR SMOOTH RUNNING OF MOTOR
NOTE 1 - SOLID JUMPERS ARE FOR A SHUNT WOUND MOTOR
- DOTTED JUMPERS ARE FOR A SERIES WOUND MOTOR
AF-12-89E



SQ 10A		MC889 PIN #				MC 890 PIN #				MC824 PIN #			LAMP	MOTOR WINDING	
INPUT	OUTPUT	5	3	7	6	13	14	9	8	3	14	5		B	C
L.V. < F.B.V	+12V	L	H	L	H	L	H	L	H	H	L	L	ON	OFF	ON
L.V. = F.B.V.	≤+8V ≥+1V	H	L	L	H	H	L	L	H	L	H	L	OFF	OFF	OFF
L.V. > F.B.V	−12V	H	L	H	L	H	L	H	L	L	L	H	ON	ON	OFF

L.V. = LADDER VOLTAGE
F.B.V. = FEEDBACK VOLTAGE
L = LOW OR +.2V
H = HIGH OR ≥+1V

DWG. NO. AF-12-92D



NOTE
RIGHT HAND SIDE OF PARITY FF WHEN FIRST WORD EXAMPLE IS USED WHICH IS AN ODD PARITY WORD

LOW LOGIC LEVEL SHOULD BE 0.2 TO 0.3 VOLTS OR LESS
HIGH LOGIC LEVEL SHOULD BE OVER 1 VOLT
(EXCEPT SCHMITT OUTPUT)

AF-12-960

CODE

(GRAY CODE
6 BITS & SIGN)
THIS CODE IS GENERATED BY RUDDER AND RPM ENCODERS

SIGN	MSB					LSB
⋮						
0	0	0	0	1	0	0
0	0	0	0	1	0	1
0	0	0	0	1	1	1
0	0	0	0	1	1	0
0	0	0	0	0	1	0
0	0	0	0	0	1	1
0	0	0	0	0	0	1
0	0	0	0	0	0	0
* (1	0	0	0	0	0	0)
1	0	0	0	0	0	1
1	0	0	0	0	1	1
1	0	0	0	0	1	0
1	0	0	0	1	1	0
1	0	0	0	1	1	1
1	0	0	0	1	0	1
1	0	0	0	1	0	0
⋮						

* EXTRA CODE ADDED ONLY TO RUDDER ENCODER

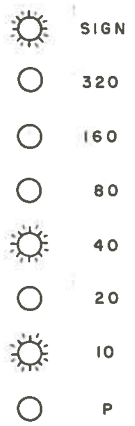
CODE

6 BITS & SIGN
(PURE BINARY)
USED FOR DRIVING RPM D/A CONVERTERS

SIGN	MSB					LSB
0	0	0	0	1	1	1
0	0	0	0	1	1	0
0	0	0	0	1	0	1
0	0	0	0	1	0	0
0	0	0	0	0	1	1
0	0	0	0	0	1	0
0	0	0	0	0	0	1
0	0	0	0	0	0	0
1	0	0	0	0	0	1
1	0	0	0	0	1	0
1	0	0	0	0	1	1
1	0	0	0	1	0	0
* 1	0	0	0	1	0	1
1	0	0	0	1	1	0
1	0	0	0	1	1	1
	READ 320 RPM	READ 160 RPM	READ 80 RPM	READ 40 RPM	READ 20 RPM	READ 10 RPM

WHEN LAMP IS "ON" (1) IN REGISTER READ AS INDICATED

EXAMPLE: *



50 RPM

TO CALCULATE THE OUTPUT VOLTAGE USE

$E_{OUT} = \frac{5.15}{64}$ (   )

CODE

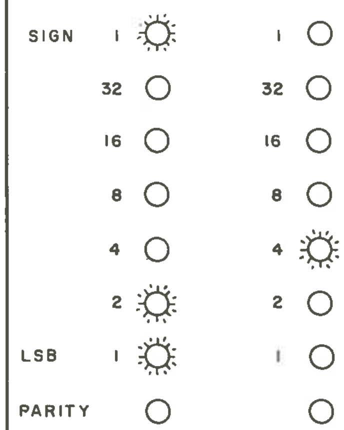
6 BITS & SIGN
(PURE BINARY)
THIS CODE IS INDICATED IN THE RUDDER REGISTER

SIGN	MSB					LSB	
0	0	0	0	1	1	1	
0	0	0	0	1	1	0	
0	0	0	0	1	0	1	
0	0	0	0	1	0	0	EXAMPLE #2
0	0	0	0	0	1	1	
0	0	0	0	0	1	0	
0	0	0	0	0	0	1	
0	0	0	0	0	0	0	
1	0	0	0	0	0	0	
1	0	0	0	0	0	1	
1	0	0	0	0	1	0	
1	0	0	0	0	1	1	EXAMPLE #1
1	0	0	0	1	0	0	
1	0	0	0	1	0	1	
1	0	0	0	1	1	0	
1	0	0	0	1	1	1	
READ 1°	READ 32°	READ 16°	READ 8°	READ 4°	READ 2°	READ 1°	

WHEN LAMP IS "ON" (1) IN REGISTER READ AS INDICATED

EXAMPLE: #1
1 0 0 0 0 1 1 = 4° PORT/STARBOARD
EXAMPLE: #2
0 0 0 0 1 0 0 = 4° STARBOARD/PORT CHOICE

TOP OF LAMPS COLUMN



EXAMPLE #1   EXAMPLE #2

CHECK TO SEE THAT AN ODD NUMBER OF LIGHTS ARE ON

7 BITS
(PURE BINARY)
USED FOR DRIVING THE RUDDER D/A CONVERTER

⋮							
0	1	1	1	0	0	0	
0	1	1	1	0	0	1	
0	1	1	1	0	1	0	
0	1	1	1	0	1	1	
0	1	1	1	1	0	0	
0	1	1	1	1	0	1	
0	1	1	1	1	1	0	
0	1	1	1	1	1	1	SEE EXAMPLE #3
1	0	0	0	0	0	0	
1	0	0	0	0	0	1	
1	0	0	0	0	1	0	
1	0	0	0	0	1	1	
1	0	0	0	1	0	0	EXAMPLE #4
1	0	0	0	1	0	1	
1	0	0	0	1	1	0	
1	0	0	0	1	1	1	
⋮							

OUTPUT OF D/A IS A VOLTAGE WHICH CAN BE CALCULATED AS FOLLOWS:

$$E_{OUT} = \frac{"E"_{REF}}{128}\left[64(\ )+32(\ )+16(\ )+8(\ )+4(\ )+2(\ )+1(\ )\right]$$

EXAMPLE #3   (RUDDER POSITION IS SET TO ZERO)

ASSUME E_{REF} = 5.15 VOLTS

$$E_{OUT} = \frac{5.15}{128}\left[64(0)+32(1)+16(1)+8(1)+4(1)+2(1)+1(1)\right]$$

$$\triangleq 63 \times \frac{5.15}{128} = 2.53 \text{ VOLTS}$$

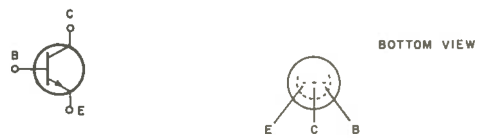
EXAMPLE (4)   (RUDDER POSITION IS 5°)

$$E_{OUT} = \frac{5.15}{128}\left[64(1)+32(0)+16(0)+8(0)+4(1)+2(0)+1(0)\right]$$

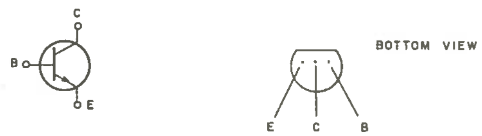
$$\frac{5.15}{128} \times (68) = 2.735$$

DWG. NO. AF - 12 - 77C

GE 2N2714 (NPN)

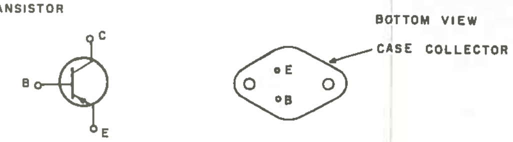


TI 2N3704 (NPN)

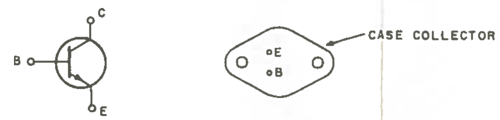


RCA POWER TRANSISTOR

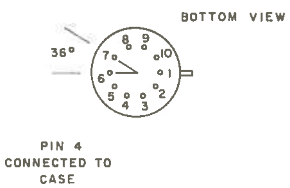
2N 3027 (PNP)

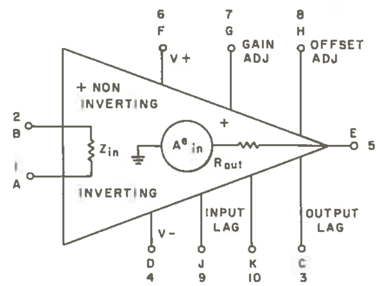


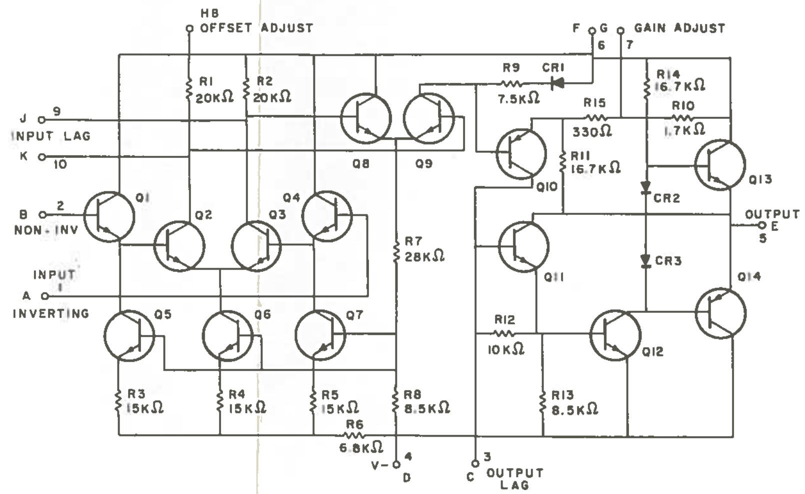
2N 3055 (NPN)



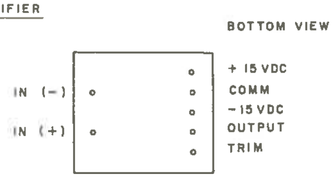
MOTOROLA
MC 1433 OPERATIONAL AMPLIFIER







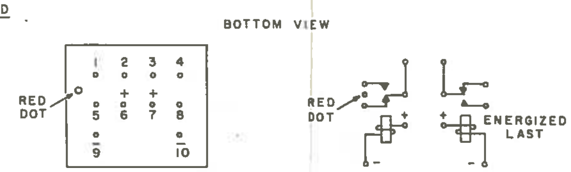
ANALOGUE DEVICES # 111
OPERATIONAL AMPLIFIER



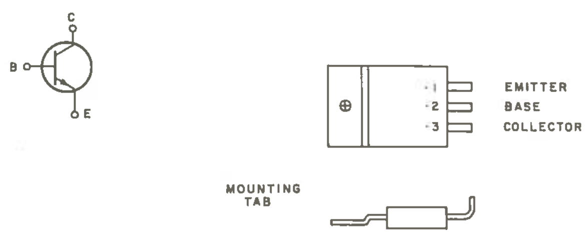
POTTER BRUMFIELD
LATCHING RELAY FL11D

COIL 12 VDC, 230Ω

CONTACT
3A AT 28VDC

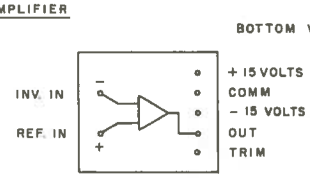


TEXAS INSTRUMENTS
TIP14 (NPN)
MEDIUM POWER TRANSISTOR



COLLECTOR IS IN ELECTRICAL CONTACT TO MOUNTING TAB

NEXUS
SQ 10A OPERATIONAL AMPLIFIER

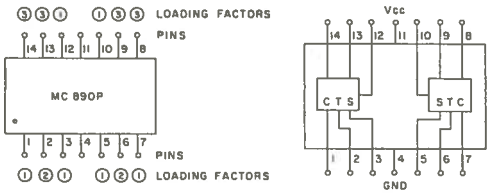


DWG. NO. AF-12-86D

LEGEND

MOTOROLA INTEGRATED CIRCUIT

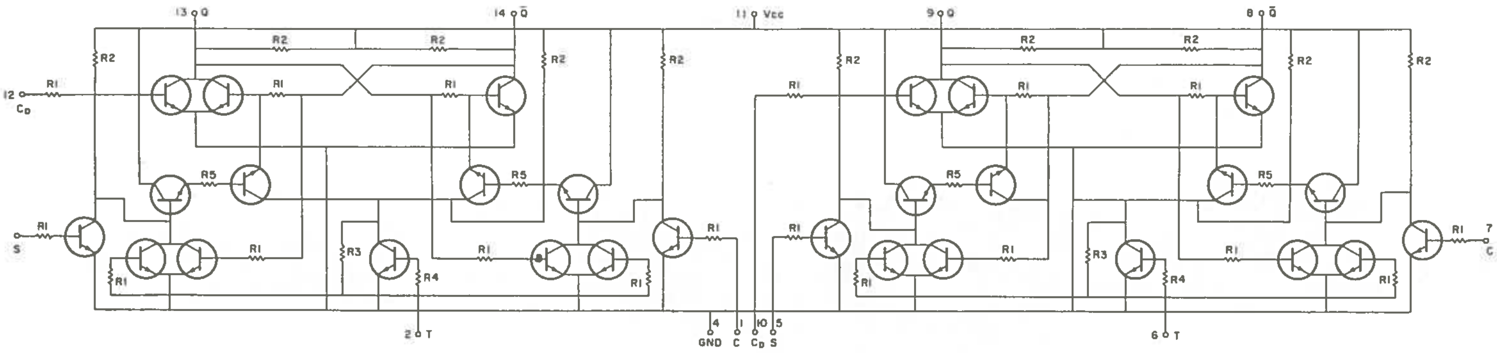
MC 890P DUAL JK FLIP-FLOP



NOTES RESISTOR VALUES FOR ALL INTEGRATED CIRCUITS ARE:-

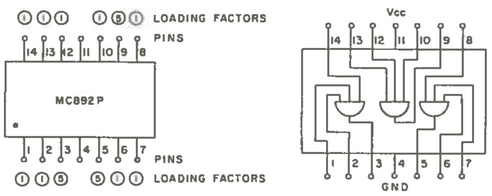
R1 = 450Ω
R2 = 640Ω
R3 = 510Ω
R4 = 225Ω
R5 = 300Ω

MC 890P DUAL JK FLIP-FLOP

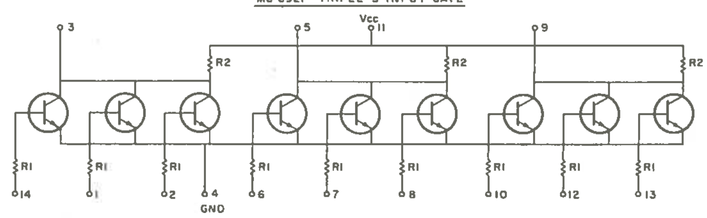


MOTOROLA INTEGRATED CIRCUITS

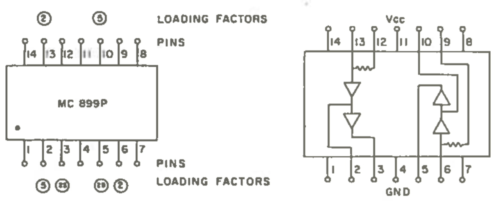
MC 892P TRIPLE 3 INPUT GATE



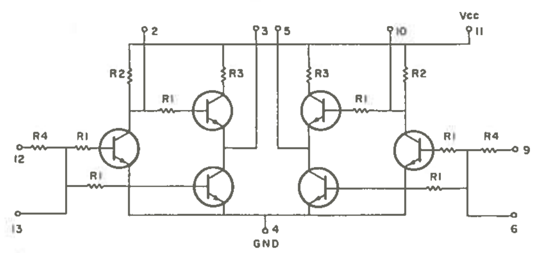
MC 892P TRIPLE 3 INPUT GATE



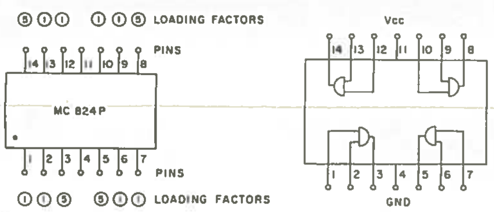
MC 899P DUAL BUFFER



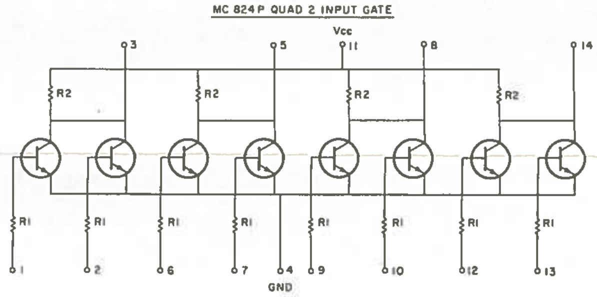
MC 899P DUAL BUFFER



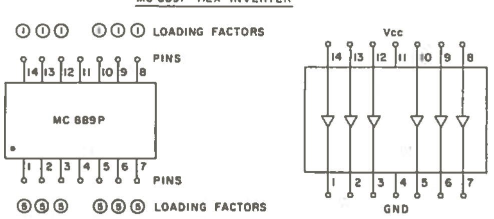
MC 824 P QUAD 2 INPUT GATE



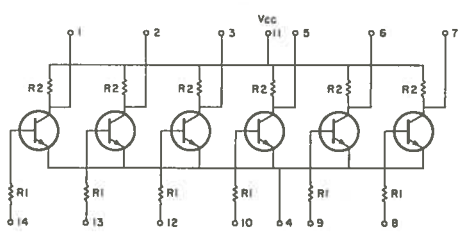
MC 824 P QUAD 2 INPUT GATE



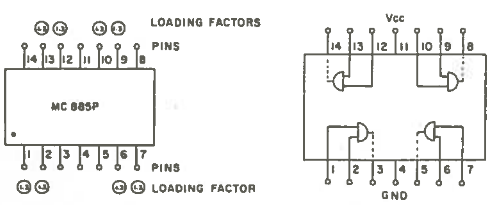
MC 889P HEX INVERTER



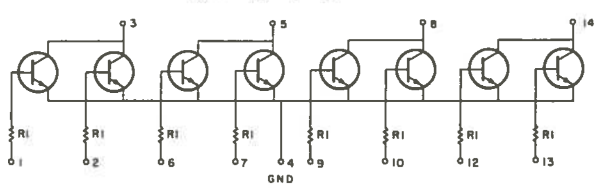
MC 889P HEX INVERTER



MC 885P QUAD 2 INPUT EXPANDER



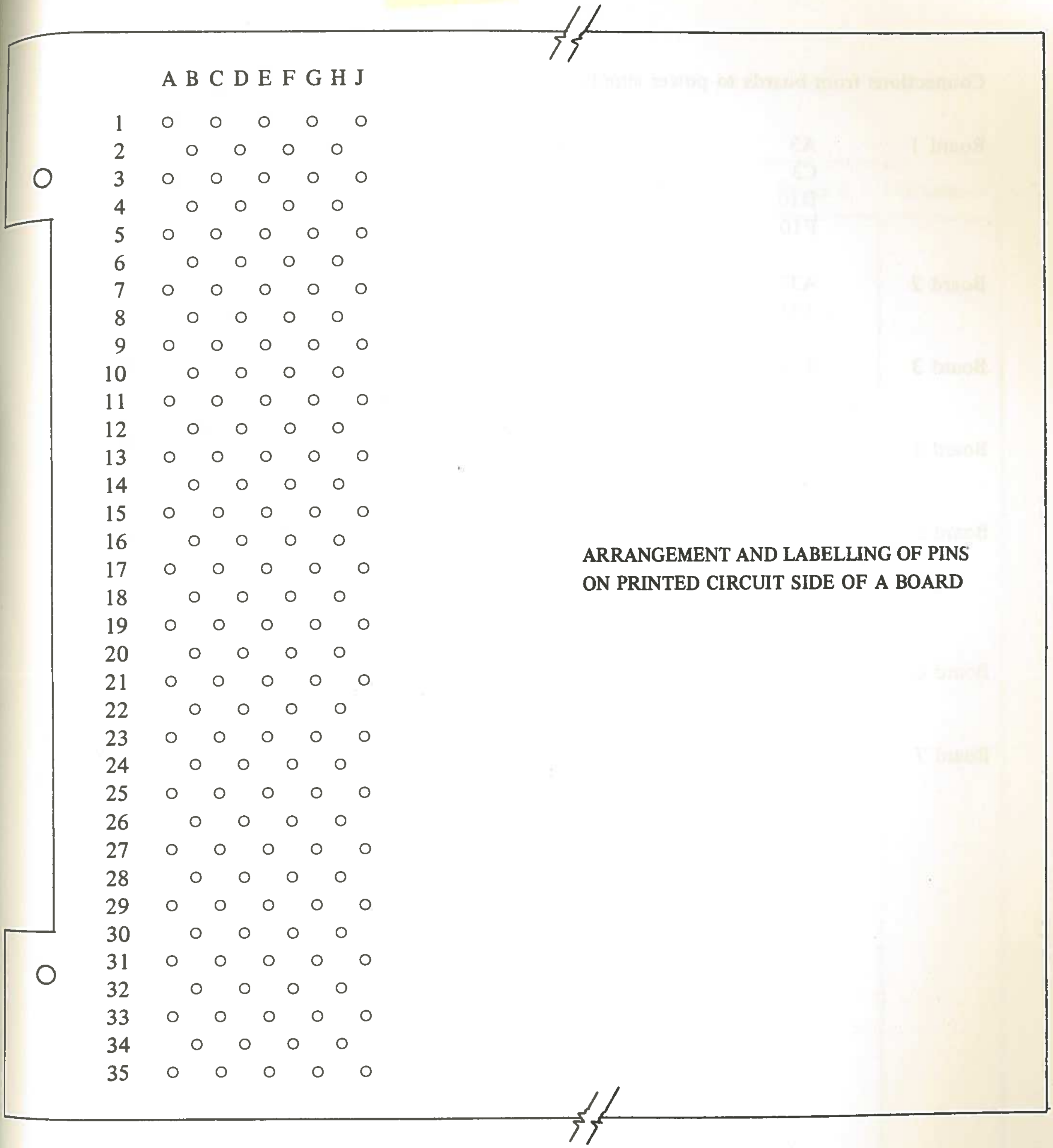
MC 885P QUAD 2 INPUT EXPANDER



Vcc CONNECTION TO PIN 11 NOT SHOWN

DWG. NO. AF-12-79D

APPENDIX B INTER-BOARD PIN CONNECTIONS



ARRANGEMENT AND LABELLING OF PINS ON PRINTED CIRCUIT SIDE OF A BOARD

Connections from boards to power supply

Board 1	A3	+12 volts dc (160 ma)
	C3	−12 volts dc (5 ma)
	D10	+3.6 volts dc
	F10	Gnd return to 3.6 volts
Board 2	A33	+3.6 volts dc
	A31	Gnd return to 3.6 volts
Board 3	B34	+3.6 volts dc
	D34	Gnd return to 3.6 volts
Board 4	A33	+3.6 volts dc
	C33	Gnd return to 3.6 volts
Board 5	Each D/A converter	
	black lead – ground to P/S	
	red lead – 'E' reference volts	
	white lead – +12 volts	
Board 6	J31	+3.6 volts
	J33	Gnd return to 3.6 volts
Board 7	Lamp column 1 + 2 (VCC) G14 to +3.6 volts	
	(GND) E16 to return of 3.6 volts	
	Lamp column 3 + 4 (VCC) H14 to +3.6 volts	
	(GND) F16 to return of 3.6 volts	
	Lamp column 5 + 6 (VCC) F14 to +3.6 volts	
	(GND) G16 to return of 3.6 volts	
	Lamp column 7 + 8 (VCC) H15 to +3.6 volts	
	(GND) H16 to return of 3.6 volts	

	Board 1	Board 2	Board 3	Board 4	Board 6
Receiver Output	A1				
	C1	A9			
	G3	A11			
	B6	A19			
	D6	A21			
	F6	A23			
	B8	A13			
	D8	A17			
	H8	A15			
		C21	G3		
		C23	G5		
		C25	G7		
		C27	G9		
		C29	G11		
		C31	G13		
		E9	A3		
		E11	A5		
		E13	A7		
		E15	A9		
		E17	A11		
		E19	A13		
		E21	A15		
		E23	A17		
		E25	A19		
		E27	A21		
		E29	A23		
		E31	A25		
		G9	A27		
		G11	A29		
		G13	A31		
		G15	A33		
		G17	B2		
		G19	B4		
		G21	B6		
		G23	B8		
		G25	B10		
		G27	B12		
		G29	B14		
		G31	B16		
		J9	B18		
		J11	B20		
		J13	B22		
		J15	B24		
		J17	B26		

	Board 1	Board 2	Board 3	Board 4	Board 6
		J19	B28		
		J21	B30		
		J23	B32		
			E3	J3	
			E5	J5	
			E7	J7	
			E9	J9	
			E11	J11	
			E13	J13	
			E15	J15	
			E17	J17	
			E19	J19	
			E21	J21	
			E23	J23	
			E25	J25	
			E27	J27	
			E29	J29	
			E31	J33	
			E33	J31	
			F2	H4	
			F4	H6	
			F6	H8	
			F8	H10	
			F10	H12	
			F12	H14	
			F14	H16	
			F16	H18	
			F18	H20	
			F20	H22	
			F22	H24	
			F24	H26	
			F26	H28	
			F28	H30	
			F30	G33	
			F32	H32	
				B20	D20
				B22	D22
				B24	D24
				B26	D26
				B28	D28
				B30	D30
				A31	D32
				A29	D34

Board 3	Board 4	Board 5	Board 6	
	E3		A3	
	E5		A5	
	E7		A7	
	E9		A9	
	E11		A11	
	E13		A13	
	E15		A15	
	E17		A17	
	E19		A19	
	E21		A21	
	E23		A23	
	E25		A25	
	E27		A27	
	E29		A29	
	E31		A31	
	E33		A33	
	D4		B4	
	D6		B6	
	D8		B8	
	D10		B10	
	D12		B12	
	D14		B14	
	D16		B16	
	D18		B18	
	D20		B20	
	D22		B22	
	D24		B24	
	D26		B26	
	D28		B28	
	D30		B30	
	D32		B32	
	F32		B34	
	C3		C3	
	C5		C5	
	C7		C7	
	C9		C9	
	C11		C11	
	C13		C13	
	C15		C15	
	C17		C17	
	C19		C19	
	C21		C21	
	C23		C23	
	C25		C25	
	C27		C27	
	C29		C29	
	C31		C31	

Board 3	Board 4	Board 5	Board 6	
	B32		C33	
	B4		D4	
	B6		D6	
	B8		D8	
	B10		D10	
	B12		D12	
	B14		D14	
	B16		D16	
	B18		D18	
C3 (T2)	→	→	→	(Sign bit to motor speed (control via panel connector (#1 Letter (J)
C5		MSB Input 2 TL D/A		TL : top left
C7		Input 3 TL Qtr.		
C9		Input 4 TL D/A		
C11		Input 5 TL D/A		
C13		Input 6 TL D/A		
C15		Input 7 TL D/A		
C19 (T3)	→	→	→	(Sign bit to motor speed (control via panel connector (#2 Letter (J)
C21		MSB Input 2 TR D/A		TR : top right
C23		Input 3 TR D/A		
C25		Input 4 TR D/A		

Board 3	Board 4	Board 5	Board 6	
C27		Input 5 TR D/A		
C29		Input 6 TR D/A		
C31		LSB Input 7 TR D/A		
D2 (T4)	→	→	→	(Sign bit to motor speed (control via panel connector (#3 Letter (J)
D4		MSB Input 2 BL D/A		BL : bottom left
D6		Input 3 BL D/A		
D8		Input 4 BL D/A		
D10		Input 5 BL D/A		
D12		Input 6 BL D/A		
D14		LSB Input 7 BL D/A		
D18 (T5)	Rudder	MSB Input 1 BR D/A		
D20		Input 2 BR D/A		
D22		Input 3 BR D/A		
D24		Input 4 BR D/A		
D26		Input 5 BR D/A		BR : bottom right
D28		Input 6 BR D/A		
D30		Input 7 BR D/A		

Board 4	Board 7	Board 3	
G3	D1		
G5	D2		
G7	D3		
G9	D4		
G11	D5		
G13	D6		
G15	D7		
G17	D8		
F4	D9		
F6	D10		
F8	D11		
F10	D12		
F12	D13		
F14	D15		
F18	D16		
	A1	IC 41,13*	*Refer to Drawing AF-12-81D
	A2	56,13	For example:
	A3	42,13	
	A4	57,13	41 : location of I.C.
	A5	44,13	13 : pin number on I.C.
	A6	59,13	
	A7	45,13	
	A8	60,13	
	A9	51, 9	
	A10	66, 9	
	A11	52, 9	
	A12	67, 9	
	A13	54, 9	
	A14	69, 9	
	A15	55, 9	
	A16	70, 9	
	B1	41, 9	
	B2	56, 9	
	B3	42, 9	
	B4	57, 9	
	B5	44, 9	
	B6	59, 9	
	B7	45, 9	
	B8	60, 9	
	B9	46,13	
	B10	61,13	
	B11	47,13	
	B12	62,13	

Board 4	Board 7	Board 3	
	B13	49,13	
	B14	64,13	
	B15	50,13	
	B16	65,13	
	C1	46, 9	
	C2	61, 9	
	C3	47, 9	
	C4	62, 9	
	C5	49, 9	
	C6	64, 9	
	C7	50, 9	
	C8	65, 9	
	C9	75, 3	
	C10	66,13	
	C11	52,13	
	C12	67,13	
	C13	54,13	
	C14	69,13	
	C15	55,13	
	C16	70,13	

Board 6	To #1 of 37 Pin Amphenol Panel Connector		
E3	D	A	+12V
E5	E	B	+3.6V
E7	F	C	GND
E9	H	p	3.6V return
E11	J	q	12V return
E13	K		
E15	L		
E17	M		
E19	N		
E21	P		
E23	R		
E25	S		
E27	T		
E29	U		
E31	V		
E33	W		
F4	X		
F6	Y		
F8	Z		
F10	a		
F12	b		
F14	c		
F16	d		
F18	e		
F20	f		
F22	g		
F24	h		
F26	i		
F28	j		
F30	k		
F32	m		
F34	n		

Board 6	To #2 of 37 Pin Amphenol Panel Connectors		
G3	D	A	+12V
G5	E	B	+3.6V
G7	F	C	GND
G9	H	p	3.6V return
G11	J	q	12V return
G13	K		
G15	L		
G17	M		
G19	N		
G21	P		
G23	R		
G25	S		
G27	T		
G29	U		
G31	V		
G33	W		
H4	X		
H6	Y		
H8	Z		
H10	a		
H12	b		
H14	c		
H16	d		
H18	e		
H20	f		
H22	g		
H24	h		
H26	i		
H28	j		
H30	k		
H32	m		
H34	n		

APPENDIX C – PLATES

Plate I   Transmitting equipment (original)

Plate II　Transmitting equipment (present)

Plate III   Remote control of (single screw) model ship

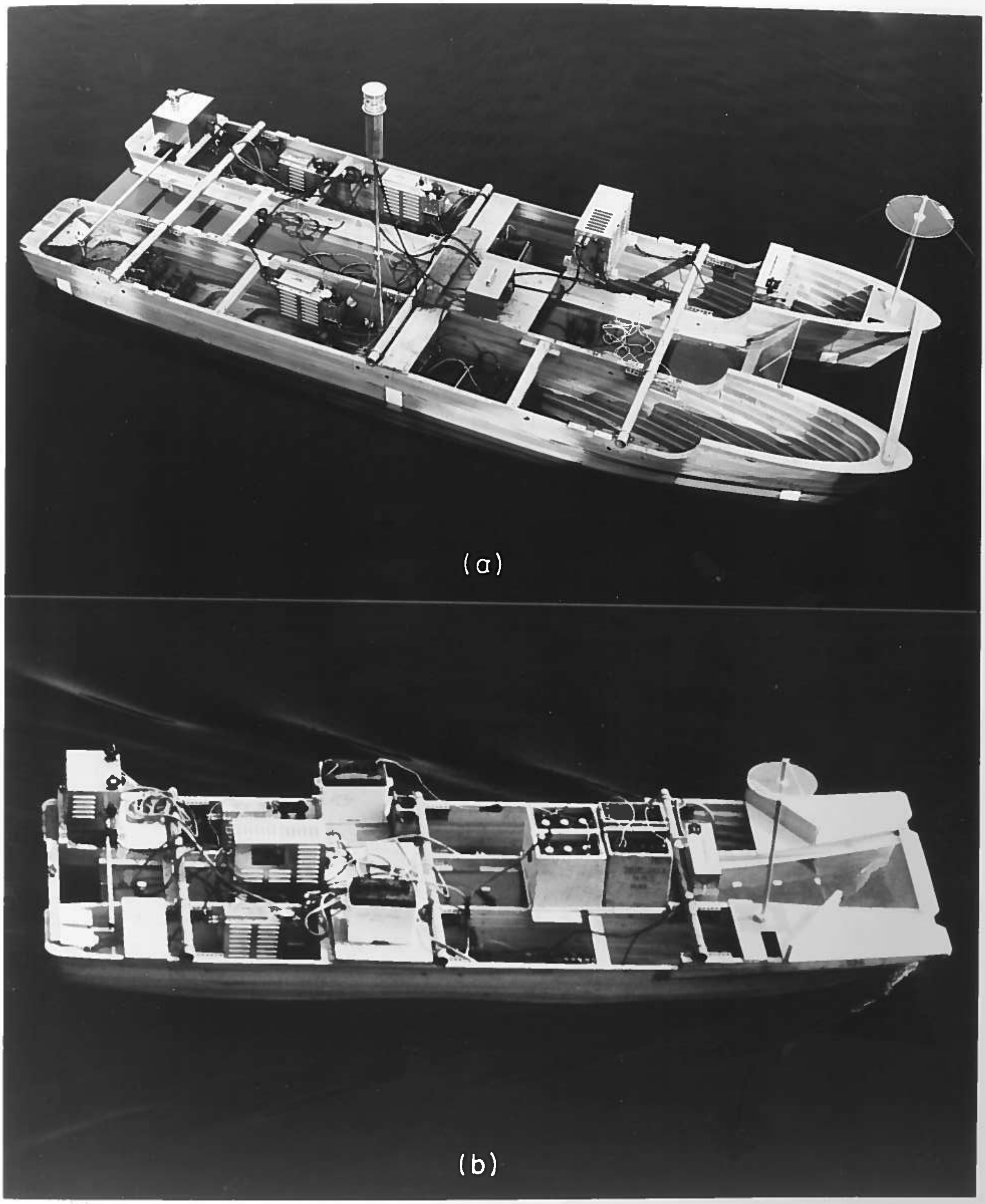


Plate IV Remote control of model catamaran

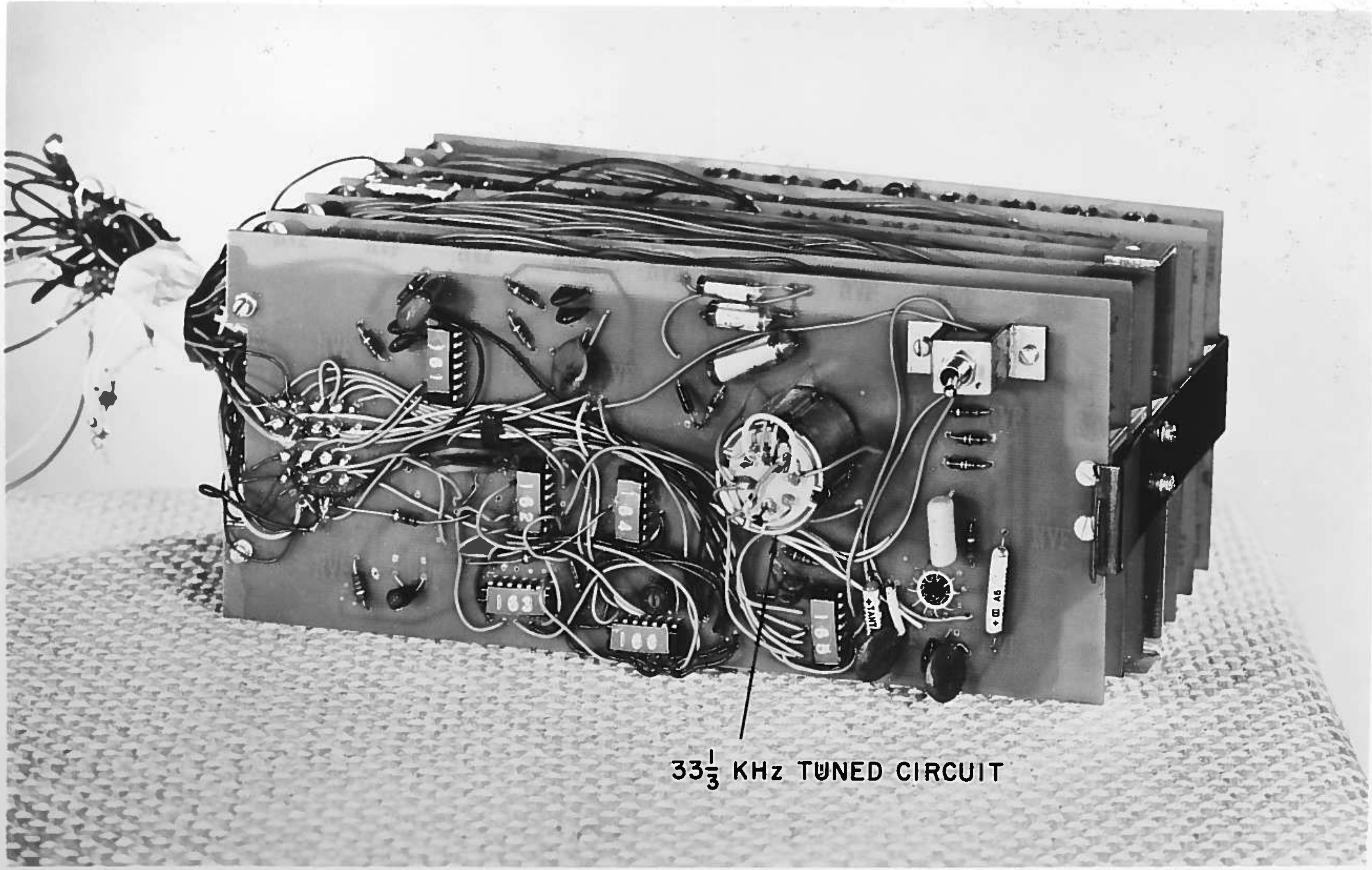


Plate V Board No. 1: circuits for recovering timing

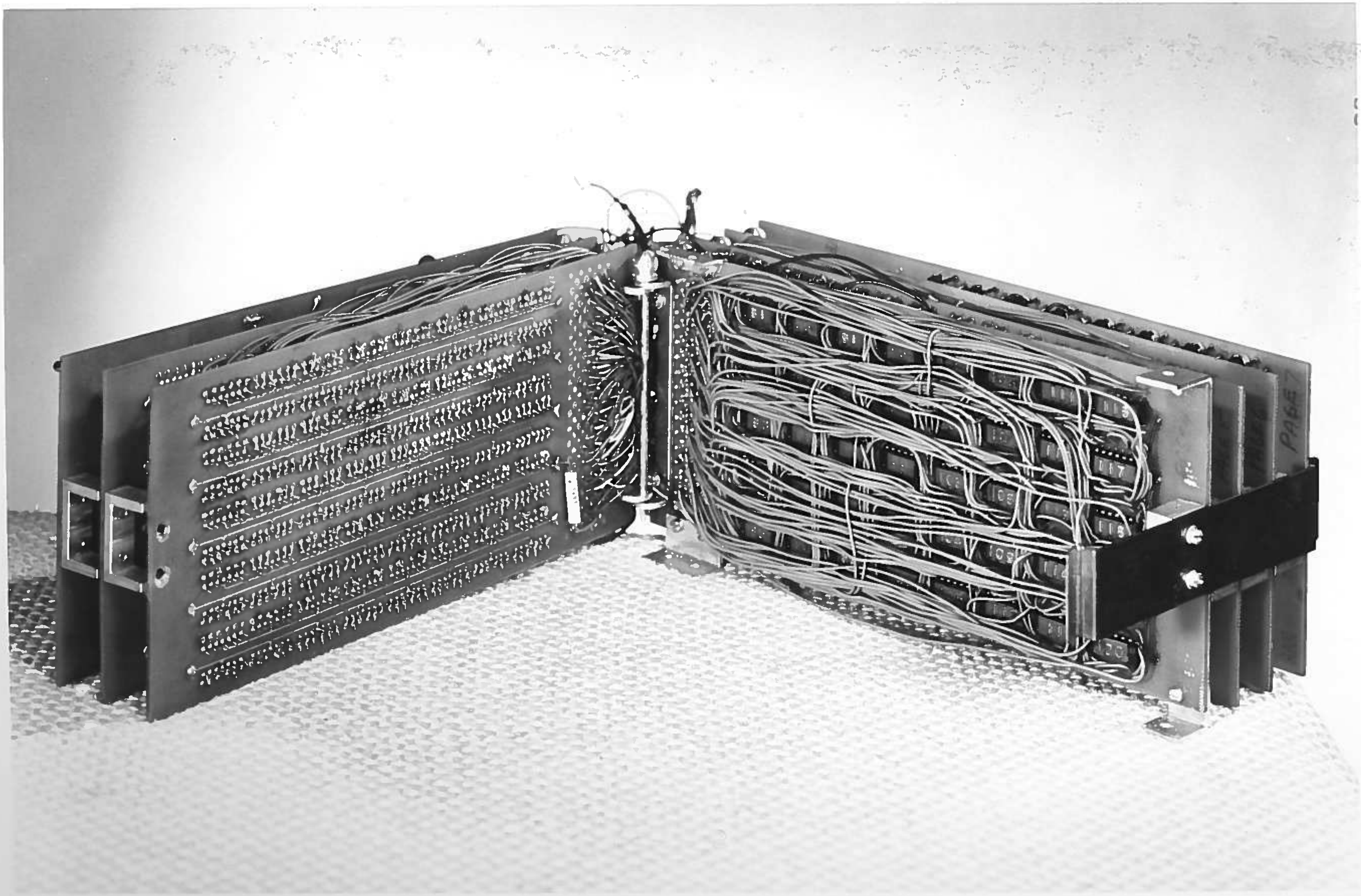


Plate VI Power distribution and circuit wiring

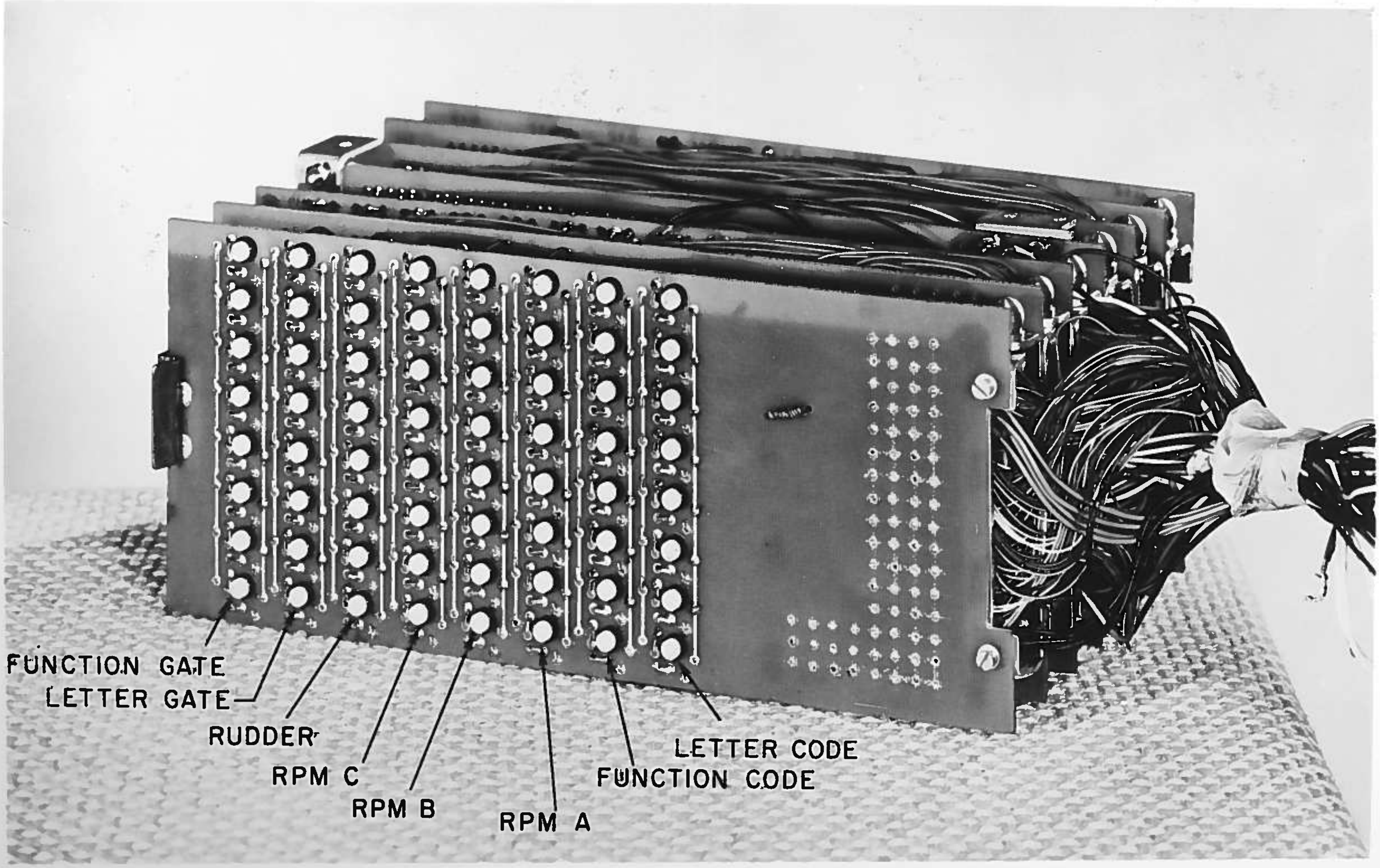


Plate VII Indicator lights on $3\frac{3}{4}$ inch by 9 inch board

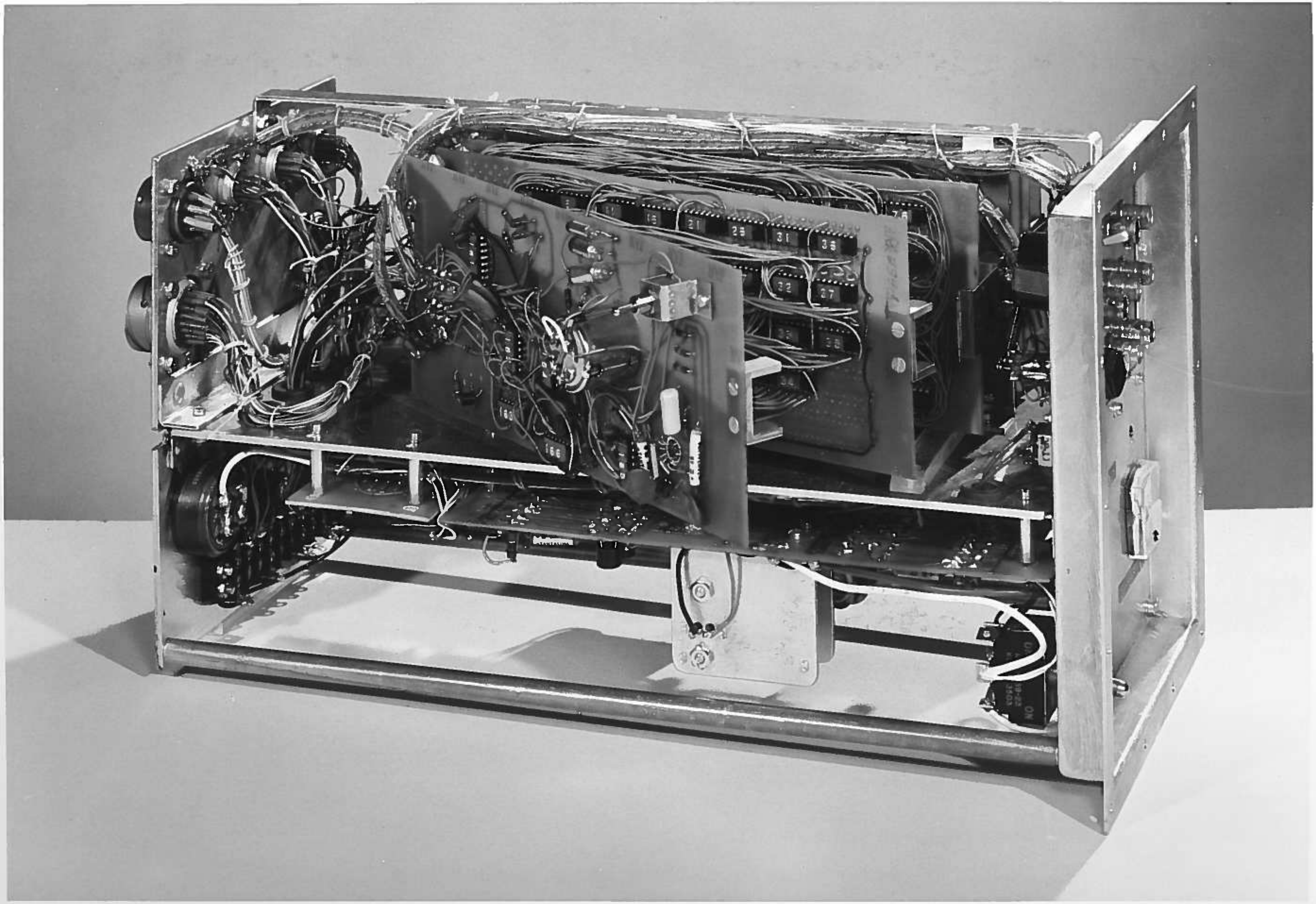


Plate VIII   Ship-board logic unit

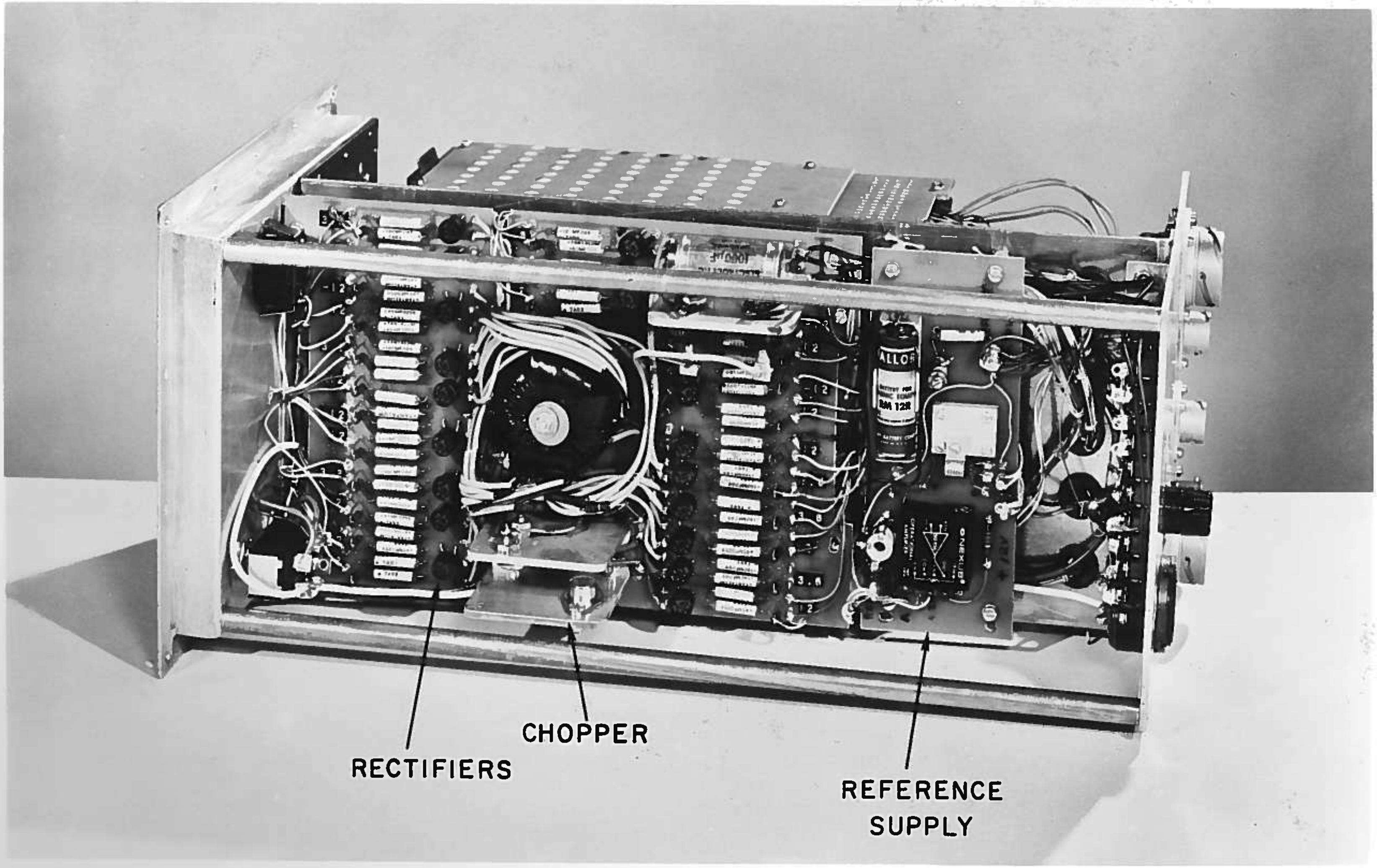


Plate IX   Power supplies for digital and analog circuits

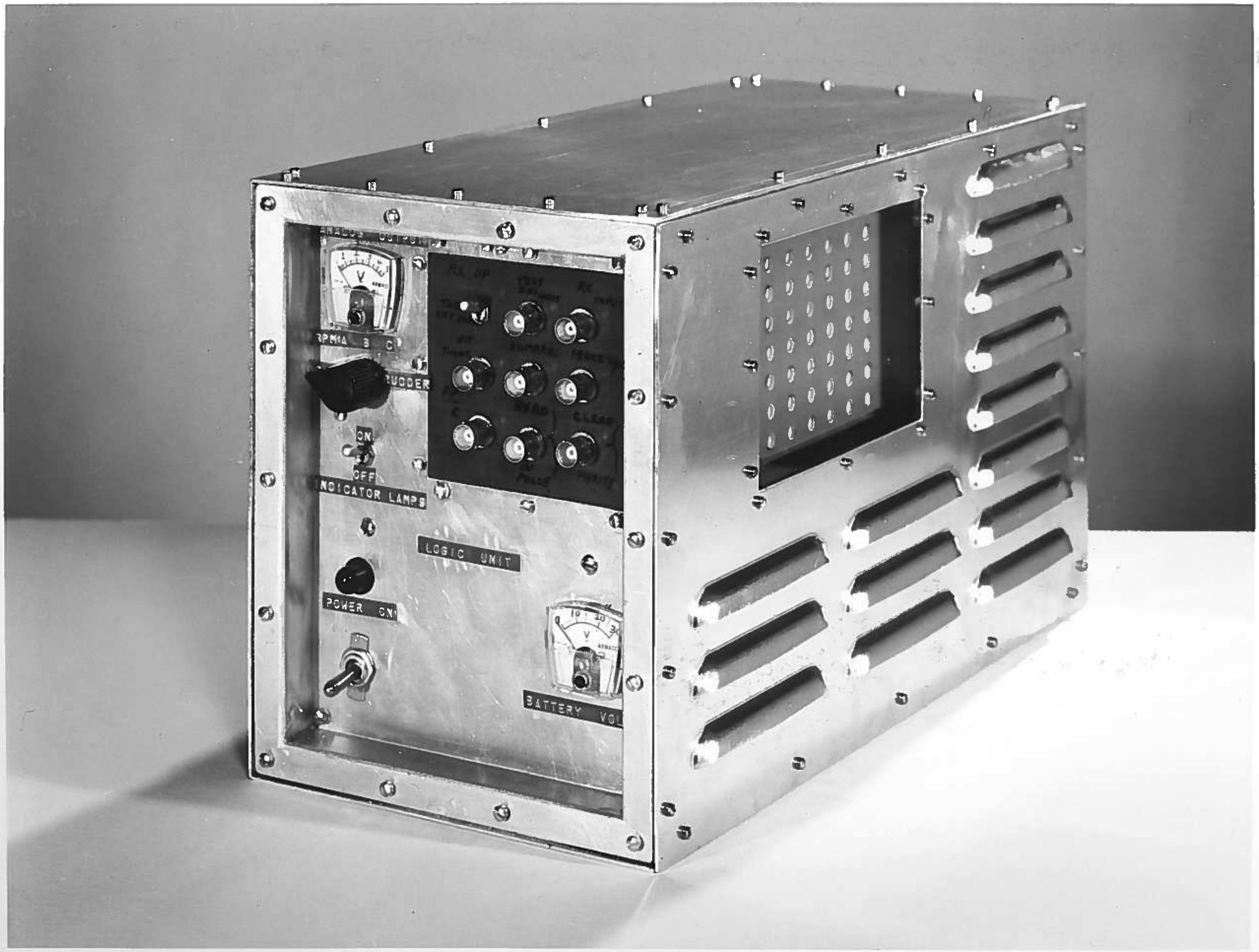


Plate X   Front panel of logic unit

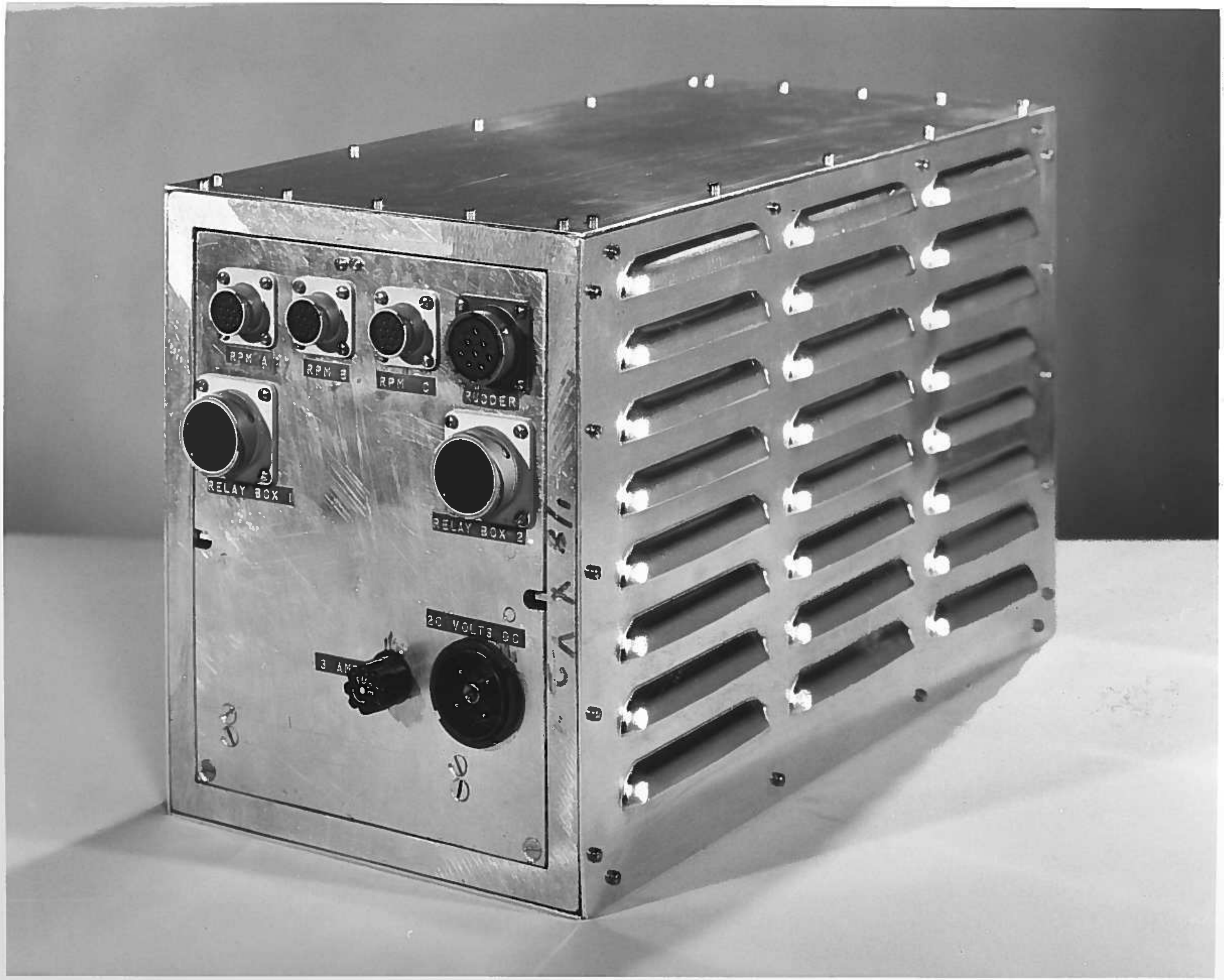


Plate XI Rear panel of logic unit

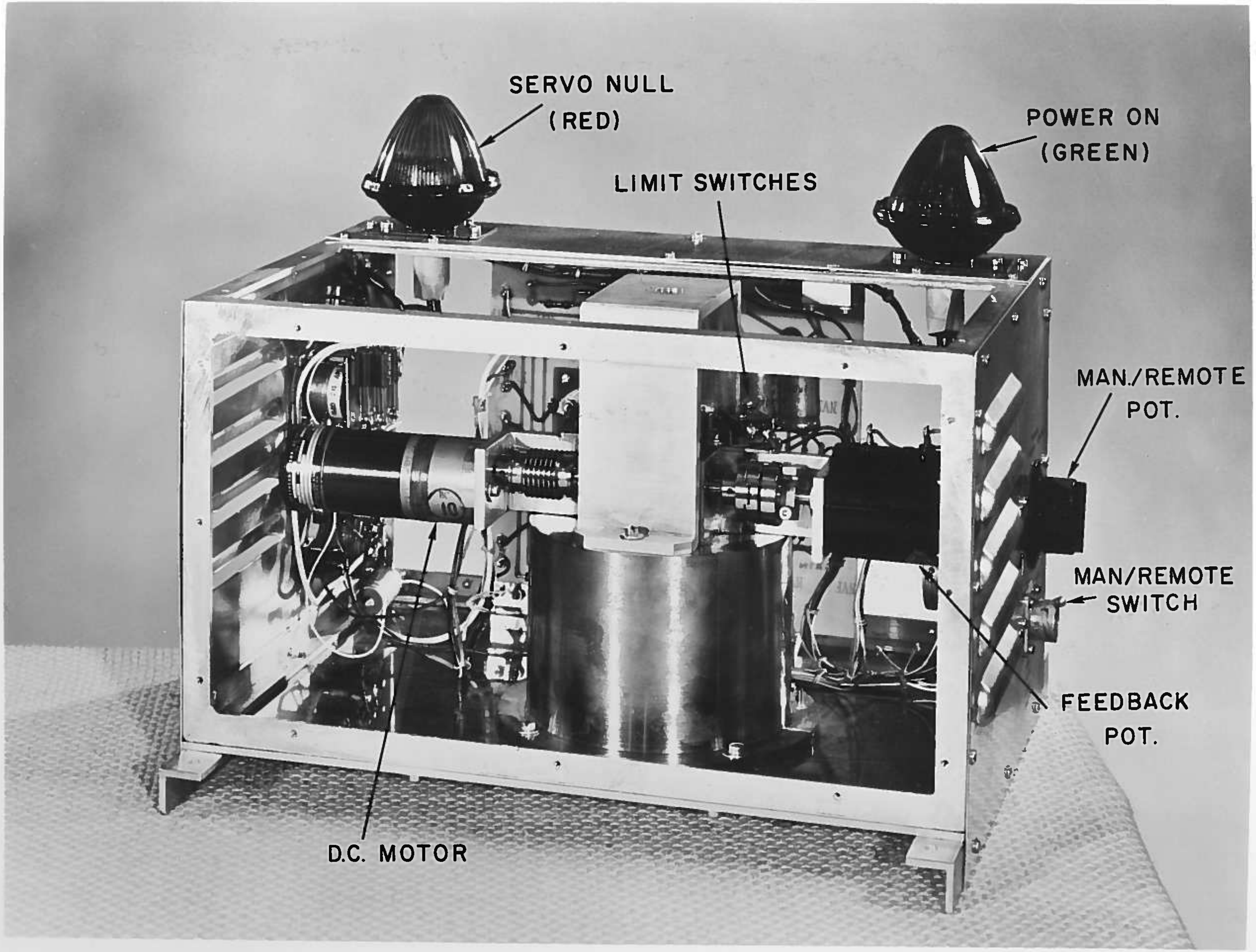


Plate XII Rudder servo unit

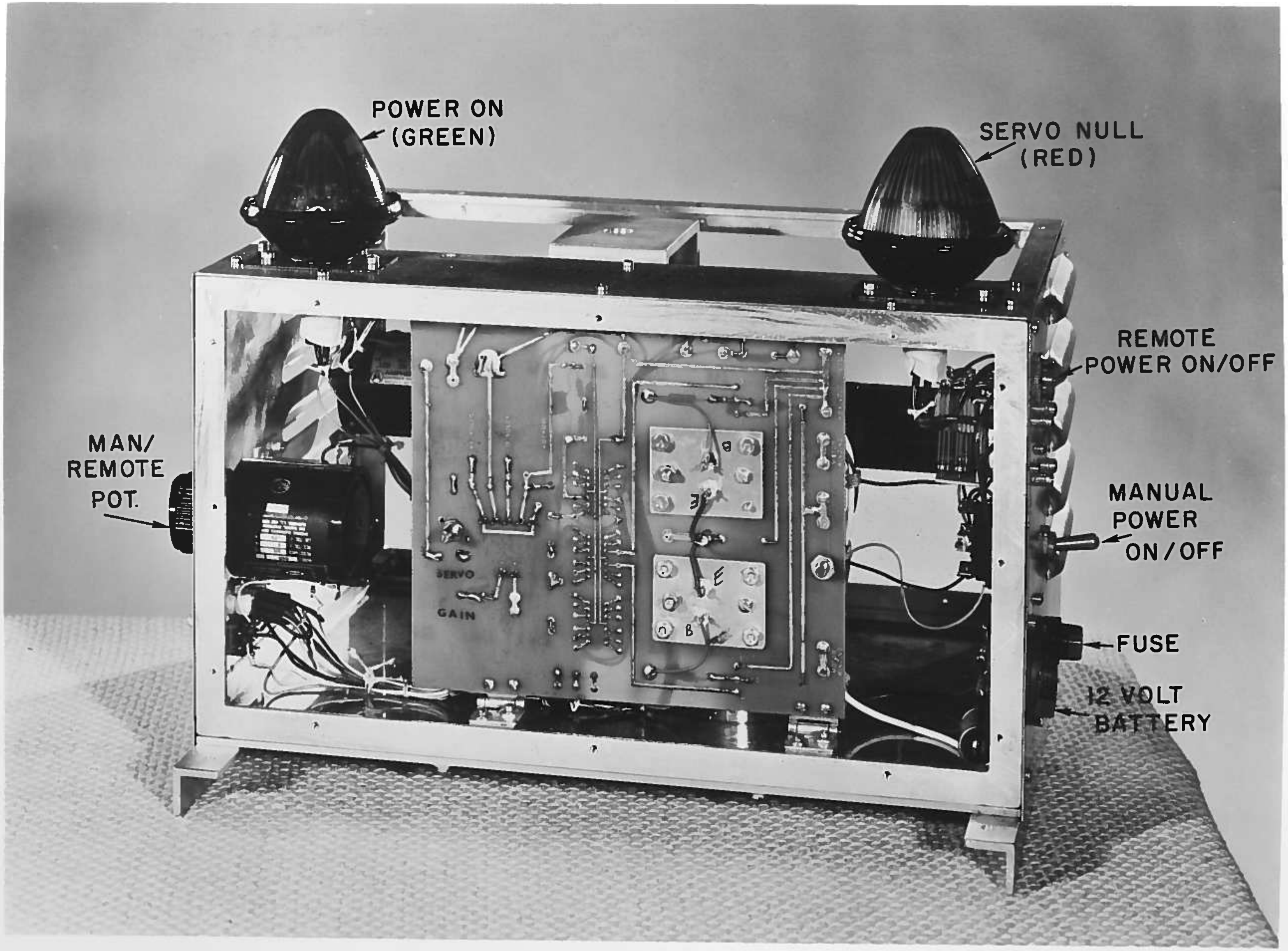


Plate XIII Rudder servo unit

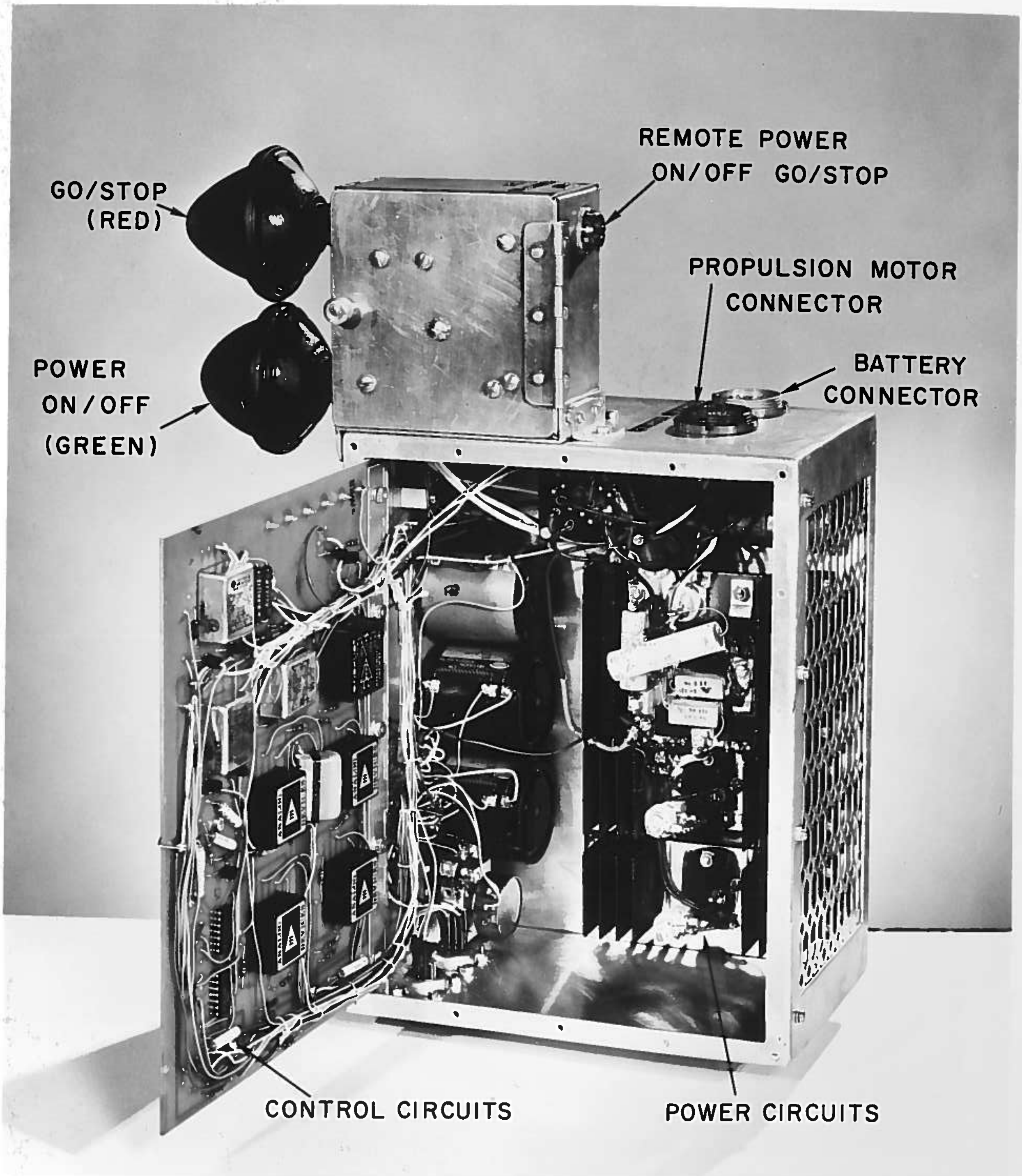


Plate XIV Speed control servo (interior)

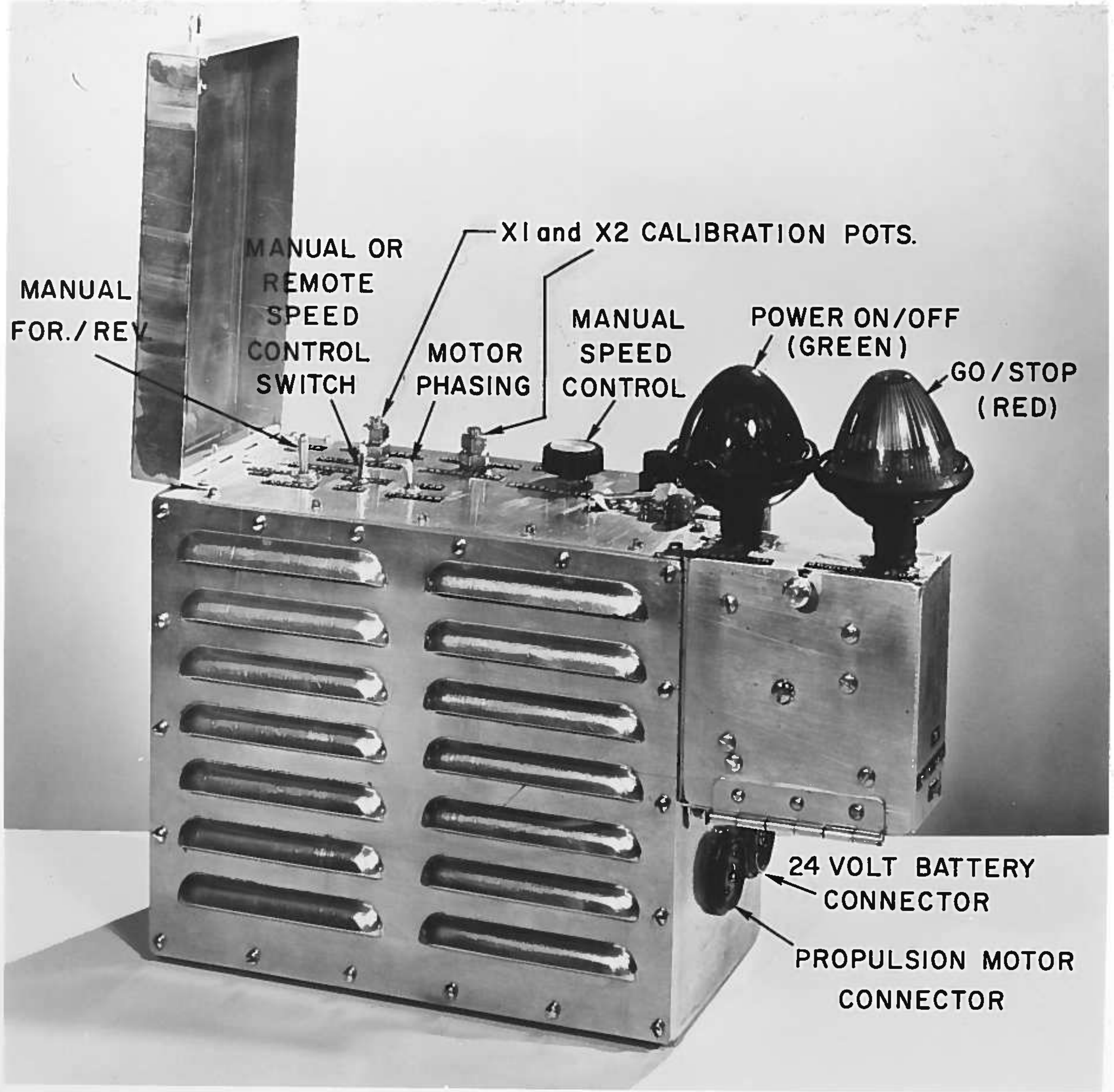


Plate XV Speed control servo

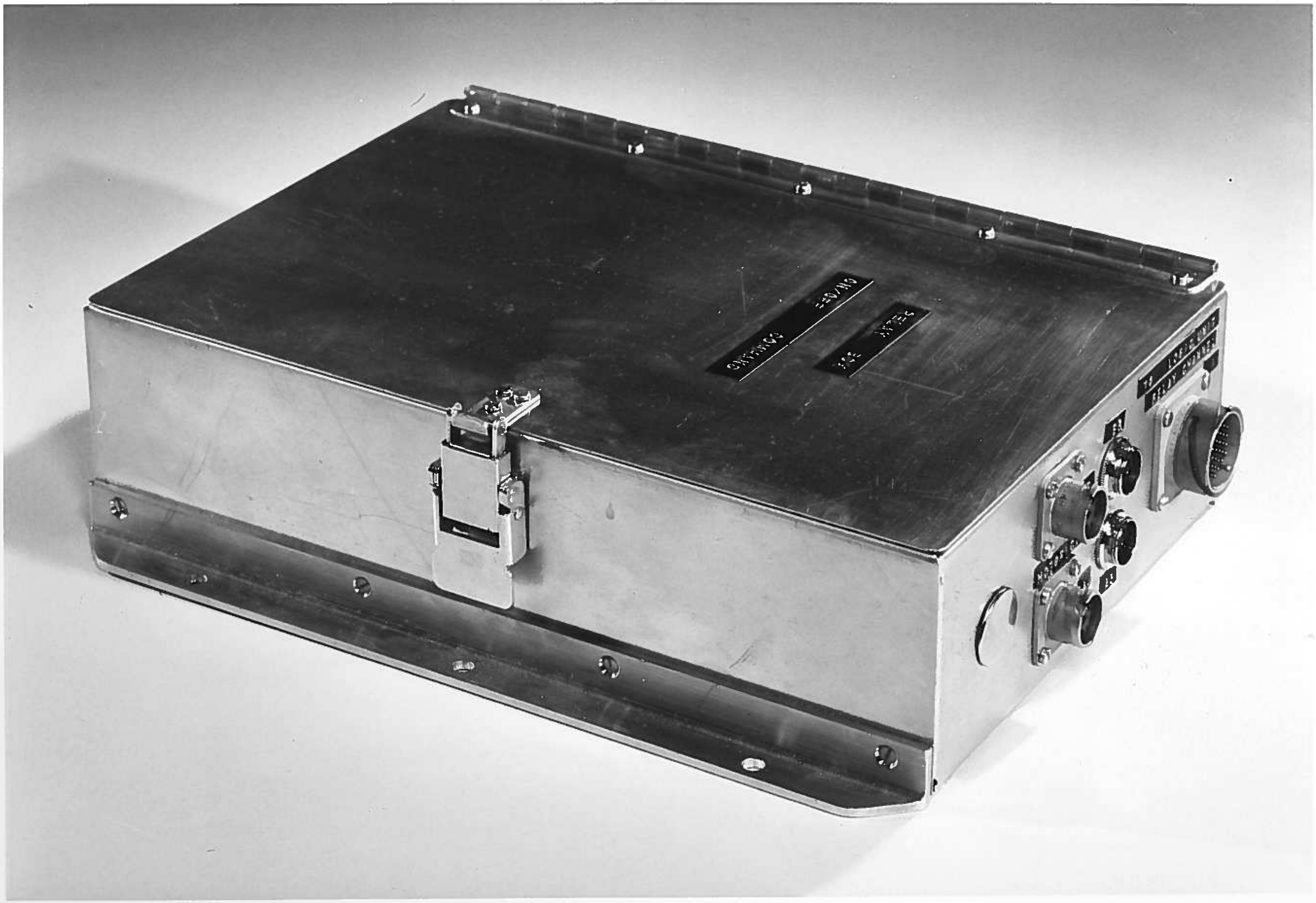


Plate XVI Relay unit (exterior view)

Plate XVII Relay unit (wiring)