Bendix

Aerospace Systems Division

ALSEP Automatic Switchable Load Study Final Report	NO. ATM-749	REV. NO.
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A study was conducted to establish feasibility of adding a feature which automatically adjusts power subsystem loading. This ATM reports the results of this study.

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1.0 INTRODUCTION

The Automatic Switchable Load Study (ASLS), which started on 11 January 1968, was directed toward an investigation of Automatic Radioisotope Thermoelectric Generator (RTG) load adjustment to prevent underload/overload conditions on the 40 Watt (nominal range) shunt regulator. Excess (reserve) power, that is, power available less system requirements, would be used to limit the minimum thermal plate temperature during the lunar night and dumped externally during the lunar day.

The study plan included analysis to establish design parameters, effects on system operation, breadboard and test of switching circuits.

2.0 ANALYSIS

An investigation of the interaction between the proposed automatic switchable load and the current ALSEP design was conducted. Results are described in the following paragraphs.

2.1 AMOUNT OF POWER TO BE SWITCHED

The Automatic Switchable Load should adjust the total electrical load on the Power Subsystem to a value within the operating range of the PCU regulator. Of primary concern are the underload conditions, those which occur with maximum power RTG and minimum PCU load situations.

Basic assumptions are:

a) RTG output 74 W

b) Regulator range (nominal) 40 W

c) INPUT voltage 16 V

The nominal 40-watt regulator uses a 5.37-ohm external resistance with an assumed 0.7-ohm harness and connector resistance. At 16 volts, its maximum dissipation is about 39.6 watts.

The minimum PCU load condition, with all experiment loads and dumps commanded OFF, is about 12.3 watts. The converter efficiency is about 94% (after fixed losses of 5 watts). Thus, the PCU requires an additional 5.8 watts to supply this minimum load which gives a total minimum load including the conversion loss, of 18.1 watts.

The maximum reserve power under these conditions is 74 - 18.1 or 55.9 watts. Of this, the regulator can handle 39.6 watts, leaving a balance to be dissipated in the switchable load of 16.3 watts.

2.2 RESERVE POWER LEVELS FOR LOAD SWITCHING

The automatic switch circuitry should introduce the switchable load at that level of reserve power at which the execution of a single additional command could increase the reserve power sufficiently to cause the PCU to go out of regulation.

In the present design, CD-8 (PDR #2 OFF) is the command which makes available the largest increment of reserve power. This increment is the nominal 14 watts of resistor dissipation plus the converter loss for this power, 0.8 watts, for a total of 14.8 watts. The trip circuitry should, thus, switch in the load at a regulator reserve power level of 39.6 - 14.8 or 24.8 watts.

This high level of reserve power could occur with RTG's having a power output in excess of 70 watts during lunar day, and, under contingency conditions, with lower powered RTG's; for example, the loss of an experiment (or the intentional switching OFF of its power by the ground controller) could cause the reserve power to rise to the trip level defined above. Therefore, to avoid getting into an out-of-regulation situation at the overload end of the regulator range, there is a need for automatic removal of the switchable load.

Assuming a nominal "minimum" RTG power of 63 watts with the same regulator range and the automatic dump as defined above, there exists the following situation:

RTG output	63.0 W
Less Minimum Load	18.1
	44.9 W

Thus, the automatic switchable load circuit will function to maintain regulation, reducing the reserve power to 28.6 W (44.9 - 16.3).

If, now, the operator by ground command, switches ON the experiment (Flights 1 and 2) "night" load, (35.1 watts) and, coincidentally, the central station heater turns ON (9.9 watts) the additional load, plus converter losses of 2.7 watts, would result in a power deficit of 19.1 watts. As the "ripple-off" circuit provides a relief, at night of only 10.2 watts, the system would be out-of-regulation by 8.9 watts. Thus, there is a possibility that the ALSEP ground controller could exceed the overload as well as the underload limit of the regulator. An automatic load removal feature, effectively a priority ripple-off, would minimize the chances of overloading. The trip level should be set at about five watts of reserve power to ensure that Experiment 4 ripple-off is not initiated by normal operating transients before the automatic switchable load is removed. This five watt setting also provides a comfortable margin against the minimum "dump-ON" level of 8.5 watts (25.8 - 16.3), and thus precludes overly-frequent cycling of the dump switch.

2.3 SOURCE AND LEVELS OF SWITCH SENSOR SIGNAL

The sense voltage for initiating the automatic switch is already available in the PCU having been provided for the ripple-off circuit. Depending upon which return is used (+ or - RTG line), the sense signal line provides either the voltage across the regulator transistor or across the regulator resistor (including that of the harness and connector).

The load should be switched ON at a reserve power level of 24.8 watts.corresponding to a regulator current, at 16 volts, of 1.55 amperes. This regulator current results in voltage drops of:

9.4 volts across the regulator resistor
or 6.6 volts across the regulator transistor.

The load should be switched OFF when the reserve power drops to a point approaching ripple-off. The selected level is five watts, corresponding to a regulator current of 0.313 amperes resulting in sense voltages of:

1.9 volts across the regulator resistor or 14.1 volts across the regulator transistor.

2.4 TEMPERATURE FOR INSIDE/OUTSIDE DUMPING DECISION

Any deliberate dumping of reserve power during lunar night should include provisions for utilizing this power to minimize the temperature swing of the Central Station. The automatic switchable load can be converted into a central station heater by including the option of dumping power inside or outside, as required, to optimize the thermal environment.

The back-up heater in the present central station is enabled (or inhibited) by ground command and is turned ON and OFF by a thermostatic switch. The nominal temperature setting of the thermostat gives a switch closure at -10^{o} ($\pm 10^{o}$) F.

An optimum temperature for the central station is about $+20^{o}$F, therefore, the temperature switch for inside/outside dumping of power should operate at or near this level. Thus, the presently included back-up heater would be energized only if the automatic switchable load circuit failed to function. The recommended difference in temperature control settings precludes any possible interaction of the two heater circuits.

3.0 CIRCUIT DESIGN

One possible method of implementing the switchable load is shown in the block diagram of Figure 1 where the additional circuits required are identified with dashed lines. Two input signals, one from each PCU regulator, and a return are required. These are available on Printed Circuit Board No. 1 (a harness terminal board) however there is, presently, no provision on the board, such as spare terminals, for routing the signals to the switching circuits. Thus, for implementation a new PCB design is required.

From Figure 1 it is seen that the reserve power levels will be used to generate ON/OFF commands to PDR #1 Control circuit in the PCU. Additionally, these commands are "or'ed" with commands from the MSFN to provide for ground control over-ride. The power dump circuit is telemetered to provide ON/OFF and INTERNAL/EXTERNAL DUMP STATUS.

3.1 BREADBOARD RESULTS

The breadboard design of the Automatic Switchable Loads has been completed. Referring to the schematic shown in Figure 2, amplifiers A1, and A2 are used to sense the reserve power level of the PCU by sensing the shunt regulator transistor voltage. When the Amplifier A1 senses the high voltage (+ 14) which indicates the reserve power is down to approximately 5 watts, the output of the amplifier becomes positive and supplies voltage to the unijunction oscillator Q1. After about 100 ms the unijunction triggers a "one shot" which generates a 20 ms command. The output of the one shot is gated by A1 to command the heater to the OFF position. Noise immunity is built into the system by the roll off capacitor C8 and the period of the unijunction oscillator.

The high reserve power level is sensed by amplifier A2. When the reserve power exceeds 26.5 watts (6 volts on the shunt regulator transistor) the output of A2 goes "high" supplying voltage to the unijunction oscillator and the same sequence explained above takes place, except that the output of the one shot is gated by amplifier A2 to command the power dump to the ON position.

The power dump can be turned "ON" or "OFF" by uplink commands as shown on the schematic. The breadboard, shown in Figure 3, verified circuit performance hence, should a future decision be made to proceed with Automatic Switchable Loads, the next logical steps would be as follows:

a) Design and fabricate a Printed Circuit board.

b) Assemble the printed circuit board using Hi-Rel parts.

c) Conduct the following tests:

1. Operation at high temperature (+ 160°F)
2. Operation at low temperature (-25°F)
3. Over voltage
4. Under voltage
5. Check switching points under all of above conditions.

d) Design test fixture.

e) Write test procedure.

3.2 POWER REQUIREMENTS

Estimated power drain is in the order of 300-400 milliwatts. Potentials of +15 volts, + 5 volts and -12 volts are available from the PDU at its connector. These voltages are provided for use by the ASE and by harness changes can also be provided to the switching circuits.

4.0 PACKAGING

A preliminary package concept consists of a three (3) layer Printed Circuit Board assembly with 2 signal planes and 1 heat plane. The assembly would be foam potted in a manner similar to other discrete component boards. The package size is approximately 3 1/2 x 2 1/2 x 5/8 inches to permit mounting on stand-offs directly over the command receiver heater.

5.0 RELIABILITY ASSESSMENT

A preliminary assessment of the auto switchable load indicates the addition of this function should have a minimal impact on the system's reliability prediction. A numerical assessment of the switching circuit was not completed.

Reliability emphasis was concentrated in the areas of:

a) Part selection

b) Minimizing the probability of the most critical failure mode.

c) Precluding any single point failure sources.

6.0 IMPACT OF INTEGRATING INTO FLIGHT SYSTEMS

To minimize the impact of integrating the ASL into flight systems, the design was accomplished for minimum change to existing designs. In particular, as a general ground rule, no change was made to either the PCU or the PDU. It appears that the design impact can be limited to -

a) harness changes

b) Redesign of printed circuit board No. 1 (Part of wire harness)

c) Addition of a new package (component) containing the switching circuits.

d) the addition of both internal and external loads (resistors)

e) the addition of a temperature sensing circuit.

7.0 SUMMARY

Analysis confirmed the technical feasibility of incorporating automatic switchable loads with the 40 watt regulator design. In addition it has established recommended load on/load off reserve power levels and a temperature for the inside/outside power dump decision. The switching circuit design was completed, breadboarded and tested.

Near the end of breadboard testing, a system design change was made which changed the PCU regulator range from 40 watts to 55 watts. With this higher regulator range the system is able to handle the large amounts of system ΔP without going out of regulation. Therefore, the need for an automatic switchable load to keep the regulator within a dynamic range of 40 watts is removed. In view of this, work on the Automatic Switchable Load Study was terminated.

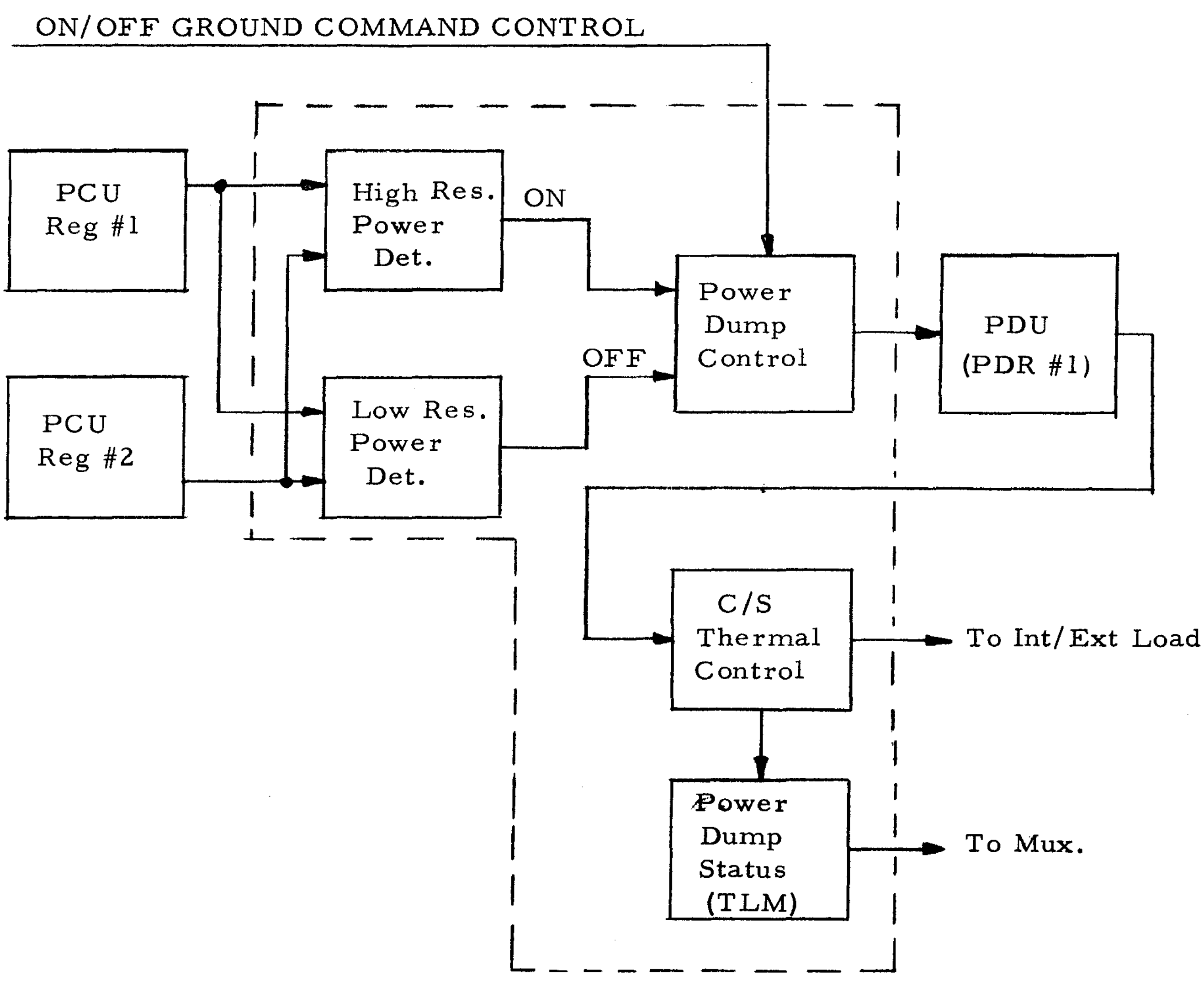
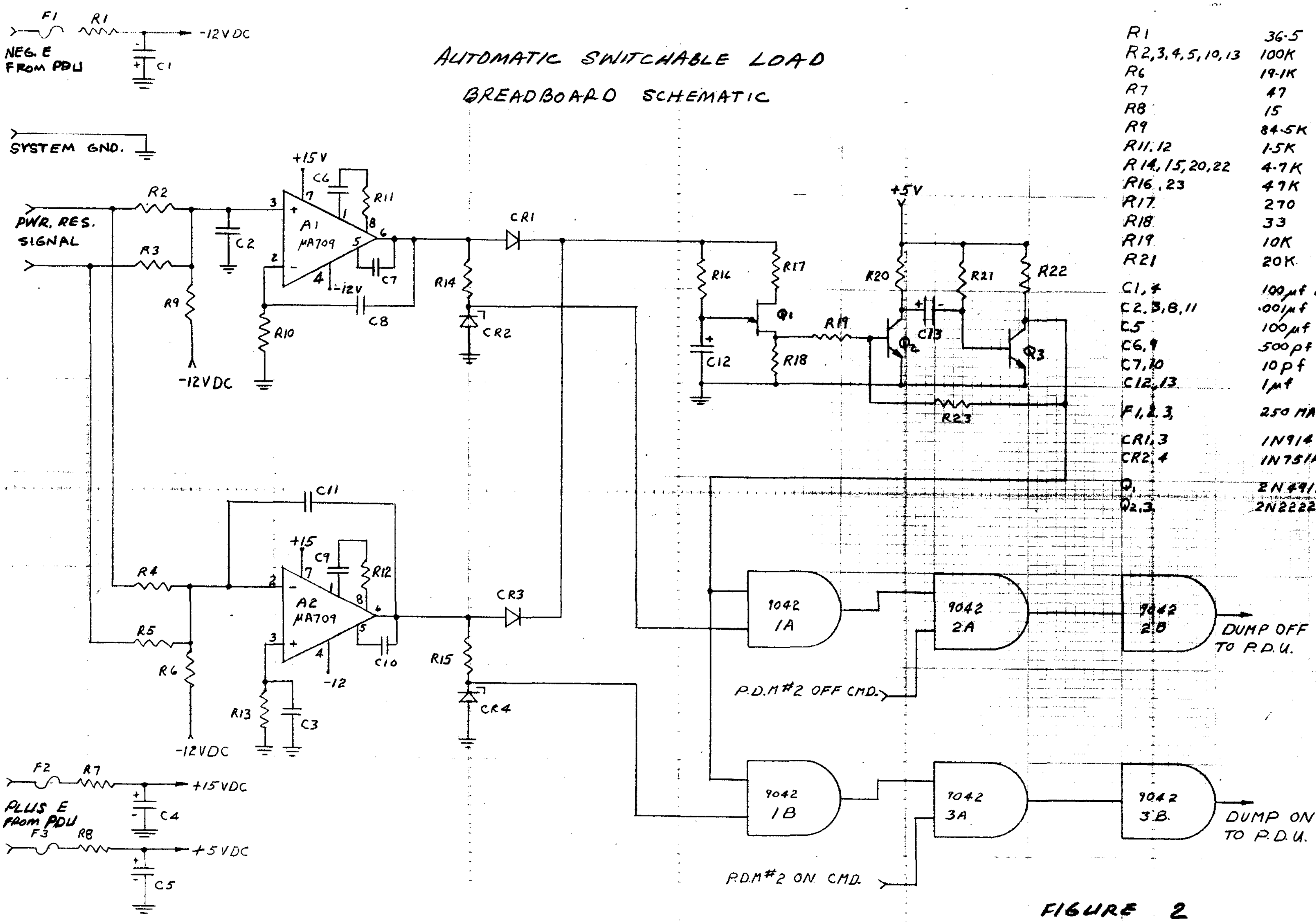


Figure 1

Block Diagram - Auto Switchable Load

AUTOMATIC SWITCHABLE LOAD BREADBOARD SCHEMATIC



R1	36.5
R2,3,4,5,10,13	100K
R6	19.1K
R7	47
R8	15
R9	84.5K
R11,12	1.5K
R14,15,20,22	4.7K
R16,23	47K
R17	270
R18	33
R19	10K
R21	20K
C1,4	100µf 20V
C2,3,8,11	.001µf
C5	100µf 10V
C6,9	500pf
C7,10	10pf
C12,13	1µf
F1,2,3	250 MA.
CR1,3	1N914
CR2,4	1N751A
Q1	2N4918
Q2,3	2N2222A

FIGURE 2

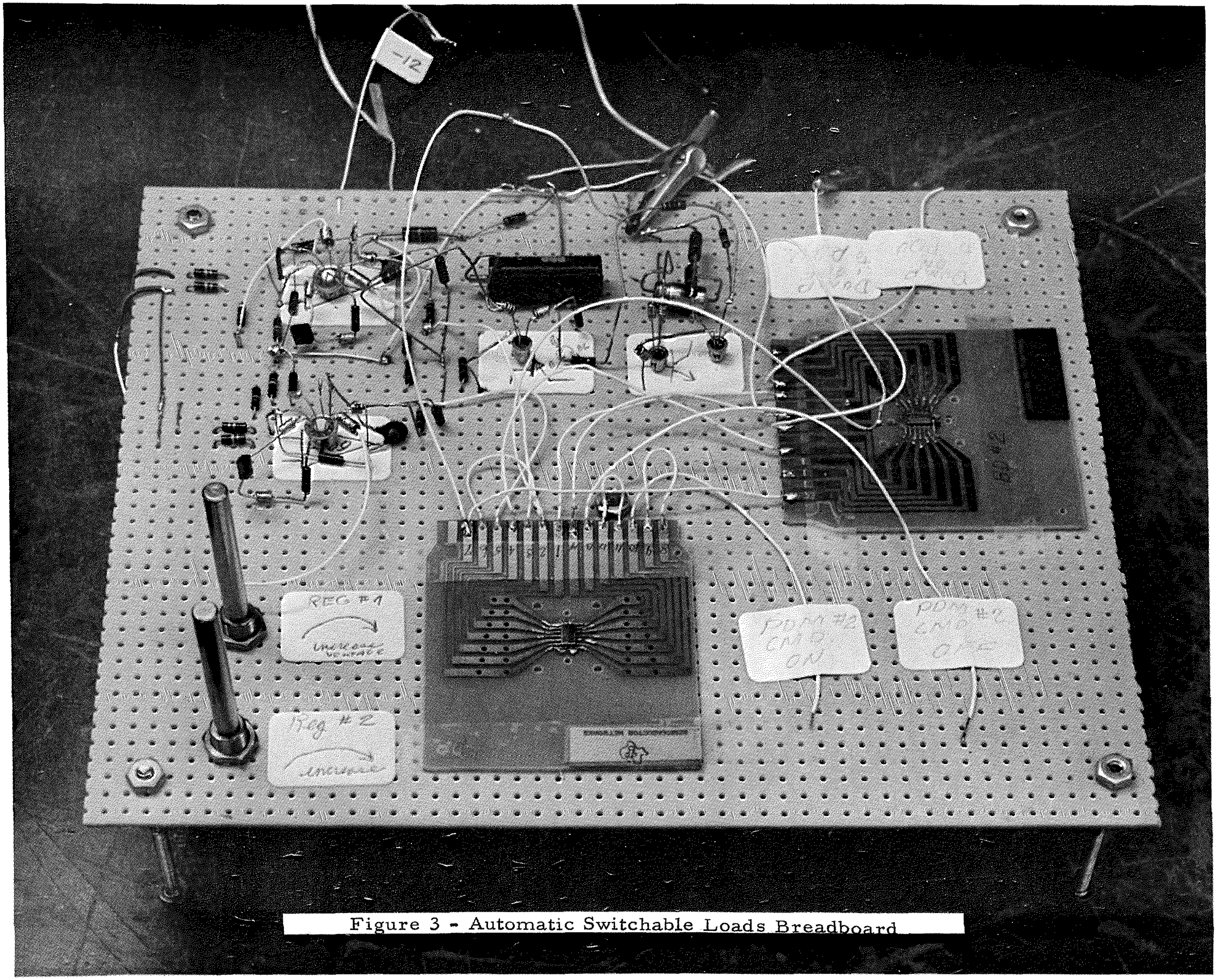


Figure 3 - Automatic Switchable Loads Breadboard