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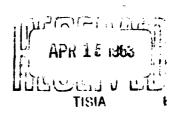
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(6) SOLID STATE MATRIX
QUARTERLY REPORT NR. 4

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AMERICAN MACHINE & FOUNDRY COMPANY
RESEARCH & DEVELOPMENT DIVISION

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AERONAUTICAL SYSTEMS DIVISION
AIR FORCE SYSTEMS COMMAND
UNITED STATES AIR FORCE
WRIGHT-PATTERSON AIR FORCE BASE, OHIO

FOREWORD

This is the fourth quarterly report for the Solid State Matrix Program and covers the period (1 January — 31 March 1963.) The program is being conducted under Contract Nr. AF 33(657)-8688, Project Nr. 8128, and Task Nr. 61084 for the Aeronautical Systems Division, Air Force Systems Command, United States Air Force. The program is under the direction of the Flight Accessories Laboratory with Mr. Lester E. Schott as project engineer.

The basic goal of the program is to develop an efficient and practical solid state transmission link (electrical power switching system) that will have positive advantages over the conventional electromechanical transmission links used in present-day aircraft. Primary emphasis is on reliability and long life.

This report presents: (1) additional design and planning data, and (2) test data. In the event of a conflict between data presented in this report and data presented in any earlier report issued under this program, the data of this report shall prevail.

Distribution of this report is being made prior to USAF review and/or acceptance, and, therefore, it may or may not reflect a USAF position.

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Project Engineer
American Machine & Foundry Company

Approved:

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I. INTRODUCTION

An electrical power system can be regarded as consisting of an energy source, utilization devices, and the transmission link that connects them. Components in the transmission link must often serve a dual purpose in that they not only control electrical energy flow but also provide protection against overloads. Present-day transmission links in aircraft consist of switches, contactors, relays, and circuit breakers, all of which utilize mechanical motion. Thus, they exhibit failures due to pitting, misaligned contacts, and other causes common to electromechanical devices.

The advent of space vehicles has placed increased emphasis on reliability and long life, and therefore, transmission links of increased reliability and longer life are required. Thus, the highly desirable goal of this program is to develop a highly reliable, efficient, and practical solid state transmission link that will have positive advantages over conventional electromechanical transmission links. These advantages must include higher reliability and longer life. Also, improved performance and reduced size and weight are highly desirable.

The basic approach for achieving the optimum solid state circuitry has been to subject the entire transmission link to an overall functional analysis, and then to redesign the logic system to make the most efficient use of solid state devices. Also, dual functions such as control and protection have been combined into a single power handling device wherever

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possible. The equivalent solid state circuit contains all the original circuit operational functions plus the improved functions or characteristics made possible by solid state technology.

This program consists of 2 phases. During the first phase, 2 transmission links of the F-106B were redesigned as solid state transmission links, and a general specification for the new solid state systems was prepared. During this part of the second phase, an experimental model of the solid state systems was fabricated and tested. Next, a design manual will be prepared that will set forth the design criteria, problem areas, and installation considerations necessary to apply solid state transmission links in aerospace vehicles. Thus, the program will furnish a sound basis for the future development of operational solid state transmission links for advanced aerospace vehicles.

The 2 transmission links of the F-106B which have been redesigned are the following:

(1) Schematic Diagram - Master Electrical, Surface & Engine Anti-Ice, nr. 8-69741, Rev. G, sheet 3 (presented in T.O. 1F-106A-2-10 as Figure 12-51, Surface and Engine Air Anti-Ice Schematic);

(2) Schematic Diagram - Master Electrical, D.C. Power, nr. 8-69770, Rev. B, sheet 5 (presented in T.O. 1F-106A-2-10 as Figure 12-90, D.C. Power Schematic, sheet 2 of 3).

II. SUMMARY OF WORK PERFORMED

The third quarterly report was prepared and submitted in January. Shortly after its submission this facility was visited by the ASD Project Engineer. The operation of several circuits was demonstrated and the status, problems, and future plans for the project were thoroughly reviewed.

A meeting was held on 18 February at this facility between project personnel, Chance-Vought personnel working on a similar program, and interested BuWeps personnel. The status of each program was discussed and the TR section circuitry was demonstrated.

The testing of the dc control section was completed. Then the TR section was constructed and tested. Finally, the experimental anti-ice system was constructed and tested. This completed all testing of the dc power and anti-ice systems. Results were good.

The drawing presentation of the solid state systems was improved, and the transient problem was given further attention.

III. DESIGN AND TEST DATA

Special Note: All figure numbers in this report refer to
the figures of the phase I report.

III. A. Design Data

The transient problem can be divided into 2 categories.   The first
is for power switches that are on; the second is for power switches that are
off.   For the second category a dual approach has been taken.   Transient
suppressors are used for high voltage spikes of short duration;   however,
the power switches themselves have been selected with voltage ratings suf-
ficient to withstand the long-duration (compared to the thermal time con-
stant of semiconductor devices), lower-amplitude transients.

For the first category, the transient suppressors are al . so useful.
However, the current surges through the power switches due to   the long-
duration transients must be handled in one of 2 ways.   Either the power
switch must have sufficient thermal capacity to withstand the current surge,
or cycling interruptive circuit breakers must be used to limit the surge.
Both approaches are under investigation.

Considerable effort has been made to improve the drawing presenta-
tion of the solid state system.   This effort is distinct from mere correction
of the drawings to conform to circuit changes.   Although not entirely satis-
factory, the modified presentation is a considerable improveme nt.

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In the TR section, the controlled, 3-phase, full-wave bridge rectifier was considered unsatisfactory because of the high ripple condition at the lower output voltage. The logic was redesigned to utilize tap switching in the transformer primary instead. As a separate modification, the TR detection circuit was deleted from the system by means of a logic simplification.

III. B.   Test Data

Test data for the solid state matrix is presented in the following sections. The data given represents only a portion of the data which was taken, all of which is now being reduced for presentation in the final report. In general, the circuits operated properly as designed, but in a few cases modifications of the original design were necessary. All circuits were evaluated at -55° C, $+25^\circ$ C, and $+80^\circ$ C.

No contact bounce problem was experienced in the systems. However, since X2a and X2b of the dc control section are transistor output stages, they reflected the slight bounce of the switches that operated them. Fortunately, their use in the system is such that this is not a problem.

III. B. 1. Test Equipment

The following is a list of test equipment used in evaluating circuit performance and a brief description of each type.

Volt-Ohm-Milliammeter, Triplett Model 630

DC accuracy 3%
DC volts sensitivity, 20,000 ohms/volt

Volt-Ohm-Milliammeter, Weston Model 980

DC accuracy 2%
AC accuracy 3%
DC volts sensitivity, 20,000 ohms/volt
AC volts sensitivity, 1000 ohms/volt

DC Ammeter (50 amp), Weston Model 931

Accuracy 1/2%

AC Ammeter (5 amp), Weston Model 904

Accuracy 1/4% to 1000 cps

Current Transformers, Weston Model 461

25-500 cps
Accuracy 1/4%

DC Ammeter, Weston Model 45

Accuracy 1/4%

Oscilloscope (with HP152A dual channel amplifier), Hewlett-Packard Model 150A

Pass Band: DC to 10 ncps
Sensitivity: 0.05 v/cm to 50 v/cm
Input Impedance: 1 megohm shunted with 30 pf.
Calibration Sweep: 3% accuracy
Amplitude, Calibration: 3% accuracy (peak to peak)

True RMS Volt Ammeter,
 Sensitive Research Model THACH

      DC and AC to 4 KCPS
      Accuracy 2/10%

Temperature Indicator, Leeds and Northrup

      Accuracy $\pm 1^{\circ}$ F

Three-Phase Variac, General Radio Model W-10

      10 amp capacity
      210 vac line to line

AC Voltmeter, Hewlett-Packard Model 400D

      Accuracy 2%

Transient Voltage Indicator, Trott Model TR741B

      Accuracy $\pm 2\%$
      May be calibrated at specific voltages to $\pm 1/4\%$
      Detection Sensitivity: DC to 1 microsec at above
        accuracy; 0.5 microsec at reduced accuracy
      Input Impedance: 1 megohm shunted by 5 pf.

DC Power Supply, Sorenson Model MA 28-125

      18 - 36 vdc, 125 A
      Regulation 1%

Motor Generator, Type N324P, S324P,
 Continental Electric Co.

      3 vac out, 208 v line to line, 36.5 amps
      Frequency: 410 cps

Stopwatch, Galco

      1/10 sec intervals

AMF Special Test Equipment

> Solid Circuit Mounting Fixture
> Input Simulator
> Motor Driven Valve Simulator

III. B. 2. DC Control Section

The dc power system is conveniently divided into the dc control section and the TR control section. The dc control section is shown in Figure 9; it is the section above the horizontal cutting line. Thus, it consists of the dc power regulator, the chute deploy overload circuit, X3, X3 turn-off, X2a, X2b, and a few associated gates and firing circuits.

The X3 turn-off circuit and X3 are shown in Figure 13. X2a and X2b switching circuits are shown in Figure 14. The dc overload circuit is shown in Figure 20. The dc power regulator is shown in Figure 25. Complete data for the dc power regulator was given in the third quarterly report and will not be repeated here.

DC Overload Circuit

The dc overload circuit provides dc overload protection for the chute deploy and is shown in Figure 20. Performance data was given in the third quarterly report for room temperature operation. Some supplementary data is given here.

The trip current varied from 4.0 amperes at $+80^\circ$ C to 6.2 amperes at -55° C. When power was applied into a 150% overload (7.5 amperes),

a trip occurred in 3.0 milliseconds at +27° C and at +80° C and in 4.0 milli-

seconds at -55° C. When a 150% overload condition existed and a manual

reset was attempted (after trip-out), the circuit tripped out again after con-

ducting for only 50 microseconds at all temperatures. Table 1 gives per-

formance data for the differential amplifier of the overload circuit.

Table 1

Differential Amplifier Performance Data at +27° C

Bus Volts	Q1B V_c	I_{load} (amp)
33 v	11.0	1.0
	11.0	3.0
	11.4	3.5
	11.8	4.0
	12.7	5.0
	13.0	5.5
27 v	10.8	1.0
	11.2	2.0
	12.0	3.0
	12.4	3.5
	12.8	4.0
	13.3	5.0

X2a and X2b

X2a is the external power interlock and X2b is the generator power

interlock. They are shown in Figure 14. Performance data was given in

the third quarterly report for room temperature operation. Some supple-

mentary data is given here.

The X2a and X2b switching circuits operated correctly over the full temperature range. The maximum saturation voltage of either was exhibited by X2a as it conducted 430 ma at +80° C ambient. This voltage was only 0.30 volts.

X2a switches on when F is present and off when $\overline{F}$ is present. X2b switches on when G and $\overline{F}$ are present and off when either $\overline{G}$ or F are present. The performance of X2a and X2b was determined by checking for saturation of the output transistors when the proper inputs were present. The saturation voltages are given in Table 2.

Table 2

Saturation Voltages for X2a and X2b

Switch	Temp (°C)	Bus (Volts)	Load Current (Amps)	$V_{ce\ sat}$ (Volts)
X2a	+80° C	28 v	0.365 A	0.26 v
	+80° C	33 v	0.430 A	0.30 v
	-55° C	28 v	0.365 A	0.16 v
	-55° C	33 v	0.430 A	0.20 v
X2b	+80° C	28 v	0.185 A	0.13 v
	+80° C	33 v	0.218 A	0.15 v
	-55° C	28 v	0.185 A	0.07 v
	-55° C	33 v	0.218 A	0.10 v

Battery Switch X3

Battery switch X3 can be regarded as consisting of X3 itself, its firing circuit, and its turn-off circuit. X3 and its turn-off circuit are shown in Figure 13. The firing circuit for X3 is shown in Figure 11. Data

for these circuits at room temperature was given in the third quarterly report. Some supplementary data is given here.

Battery switch X3 operated well over the full temperature range. The maximum load current that could be turned off varied from 46 to 35 amperes. However, additional capacitance could be added to increase load turn-off capability under high and low temperature operation. Turn-off capability for the battery switch is presented in Table 3.

Table 3

Turn-Off Capability of Battery Switch X3

Ambient Temperature ($^\circ$C)	Essential Bus Voltage (Volts)	Max. I_{load} Turned Off (Amps)
+80°C	27 v	35 A
↓	28 v	35 A
	33 v	40 A
+25°C	27 v	38 A
↓	28 v	39 A
	33 v	46 A
-55°C	27 v	35 A
↓	28 v	36 A
	33 v	43 A

The voltage drop across X3 from anode to cathode was measured with a load current of 40 amperes. It was 1.45 volts at +80°C (the case temperature was +125°C), 1.45 volts at +25°C, and 1.40 volts at -55°C. In the off-condition, the leakage current of X3 at a junction temperature of +125°C was 3.5 milliamperes.

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Voltage Sensor

The voltage sensor shown as circuit 3 in Figure 12 was constructed, given some preliminary checks, modified, and evaluated. The performance data is given in Table 4.

Table 4

Voltage Sensor Performance Data

Ambient Temp. (°C)	V_{in} (vdc)	V_{out} (vdc)
+80° C	16.2	0.30
	17.0	0.47
	20.0	1.22
	24.8	2.50
	30.0	3.90
	33.0	4.70
+27° C	16.0	0.30
	18.5	0.50
	20.7	1.00
	26.5	2.50
	30.0	3.50
	35.0	5.00
-55° C	15.9	0.30
	17.0	0.55
	20.0	1.35
	24.4	2.50
	30.0	4.00
	33.0	4.80

Storage Test

A storage test was conducted by storing the circuits at an ambient temperature of +122° C for approximately 2 hours. The temperature was then returned to +25° C and an operational check was performed. All circuits performed satisfactorily.

III. B. 3.   TR Control Section

The TR control section is shown in Figure 9; it is the section below the horizontal cutting line. Thus, it consists of X4, X5, X6, X8, over-current detection circuits, a regulated power supply, and a few associated gates and firing circuits. Extensive testing of the TR control section began after completion of tests of the dc control section. Test data is presented in the following sections.

AC Switch

The 3-phase ac switch appears in Figure 9 as X6 and then again as X8. It is shown in schematic form for a single phase in Figure 17. Preliminary operating checks were made on this circuit, and the firing circuitry was modified for better performance. Then detailed test data was taken.

The ac switch had an anode to cathode voltage drop of 1.5 V rms while conducting a load current of 4 A rms. The firing circuits permitted a maximum turn-on phase delay of less than 5°. The leakage in the off-condition at $+125^{\circ}$ C junction temperature was 3.5 milliamperes.

AC Overload Circuit

The ac overload circuit is shown in Figure 21. It was given a few preliminary operating checks and it was found desirable to modify it slightly to achieve excellent performance. Subsequently, detailed test data was taken.

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The maximum trip time when reset into 150% overload (7.5 amperes) was 1.2 milliseconds. It operated satisfactorily when turned on into short circuit. This applies to the complete temperature range. The overload circuit performance data is given in Table 5.

Table 5

AC Overload Circuit Performance Data

Ambient Temperature (°C)	Detector Supply Volts (vdc)	I_{trip} (rms amps)
+80° C	5.6	4.55
	5.8	4.80
	6.0	4.85
	6.2	4.90
	6.4	5.05
+25° C	5.6	4.70
	5.8	4.90
	6.0	5.00
	6.2	5.10
	6.4	5.20
-55° C	5.6	5.00
	5.8	5.05
	6.0	5.10
	6.2	5.15
	6.4	5.20

One-Shot Multivibrator

The one-shot multivibrator is shown in Figure 18. It was given preliminary operating checks and modified for better performance. Then the circuit was evaluated while integrated into the TR section. It provided

a 12 millisecond pulse at +80° C, a 9 millisecond pulse at +25° C, and an 8 millisecond pulse at -55° C. This pulse acts as a delay gate.

The delay gate performs two functions: first, it turns off either X6 or X8 depending on which is conducting at the time, thereby removing anode voltage from both X4 and X5; second, it turns off FC2 and FC3 so that the system becomes insensitive to contact bounce in the logic switches. Hence, the delay gate from OS1 assures that all control circuits are stable before the correct power switch (X4 or X5) receives its turn-on signal. The delay gate pulse from the one-shot performed its functions satisfactorily.

X4 and X5 Firing Circuit (FC2, FC3)

FC2 and FC3 are shown in block form in Figure 9 and are identical to FC1, which was used in dc control section tests. The circuit is shown in Figure 11. It was given preliminary operating checks and modified for better performance. Then FC2 and FC3 were evaluated while integrated into the TR section. They were considered to have performed satisfactorily if their respective power switches functioned properly when the inputs were correct for turn-on and turn-off. The firing circuits performed satisfactorily from +80° C to -55° C.

X4 and X5 Power Switches

X4 and X5 are shown in block form in Figure 9. They each consist of one SCR that is turned on by FC2 and FC3, respectively. The method

of turn-off for X4 and X5 is to remove anode voltage. This is done by switching off the primary current to the transformer at either X6 or X8 for 10 milliseconds with the delay gate. This has been accomplished at 20 amps for X4 and 10 amps for X5; the circuits operated satisfactorily.

The maximum current requirement for X4 is 43 amperes and for X5 is 10 amperes. Thus, X4 was not tested at maximum load but X5 was. This was due to the current limitation of the autotransformer which was used in testing. It limited the maximum load which could be placed on the TR section to approximately 20 amps dc. However, X4 is identical to X3 in all respects except for the method of turn-off. Since X3 performed properly under a 43 amp load, X4 will also. All thermal data applying to X3 applies to X4 since the same maximum load exists, the same type SCR is used, and the same type heat sink has been used.

X4 had a saturation voltage of 1.2 volts at a load current of 20 amperes and at a case temperature of +125° C. X5 had a saturation voltage of 1.4 volts at a load current of 10 amperes and at a case temperature of +110° C.

Three-Phase AC to DC Power Supply

The three-phase ac to dc power supply is shown in Figure 23. It was given preliminary operating checks and modified slightly. Then circuit performance data was taken. It is given in Table 6.

Table 6

AC to DC Power Supply Performance Data

V_{in} (vac)	V_{out} (+80° C) (vdc)	V_{out} (+27° C) (vdc)	V_{out} (-55° C) (vdc)	
109	30.0	30.0	29.5	
115	31.9	31.5	31.5	No Load
121	33.6	33.5	33.5	
109	25.6	26.0	26.5	
115	27.1	27.2	28.0	Full Load (300 ma)
121	28.7	28.5	29.5	

Negative Power Supply and Regulator

The negative power supply shown in Figure 22 and negative regulator shown in Figure 25 were constructed and evaluated at no load, 50 ma load, and 70 ma load over the temperature range with a maximum variation of input voltage. Performance of the combined power supply and regulator was good. Detailed data is given in Table 7.

Storage Test

A storage test was conducted by storing the circuits at an ambient temperature of +122° C for approximately 2 hours. The temperature was then returned to +25° C and an operational check was performed. All circuits performed satisfactorily.

Table 7

Negative Power Supply and Regulator Performance Data

V_{in} (vac)	V_{out} (-6 v unreg) +80° C (vdc)	V_{out} (-6 v unreg) +27° C (vdc)	V_{out} (-6 v unreg) -55° C (vdc)	
109	-6.8	-6.4	-6.4	
115	-7.2	-6.8	-6.7	No Load
121	-7.5	-7.1	-7.1	
109	-6.7	-6.3	-6.3	
115	-7.0	-6.7	-6.7	50 ma Load
121	-7.4	-7.1	-7.0	
109	-6.6	-6.3	-6.2	
115	-6.9	-6.6	-6.6	70 ma Load
121	-7.4	-7.0	-6.9	

V_{in} (vac)	V_{out} (-3 v reg) +80° C (vdc)	V_{out} (-3 v reg) +27° C (vdc)	V_{out} (-3 v reg) -55° C (vdc)	
109	-3.80	-3.75	-3.80	
115	-3.80	-3.80	-3.90	No Load
121	-3.85	-3.80	-3.95	
109	-3.45	-3.40	-3.50	
115	-3.50	-3.45	-3.60	50 ma Load
121	-3.60	-3.55	-3.70	
109	-3.30	-3.10	-3.40	
115	-3.35	-3.20	-3.50	70 ma Load
121	-3.45	-3.30	-3.60	

III. B. 4.　Anti-Ice System

The portion of the anti-ice system which was tested included the complete logic and control section, warning light section with overload circuit, motor driven valve section, and the temperature control with overload circuit. The dc to dc power supply was used to power these circuits, but no new test data was taken because it is basically identical to the power supply evaluated in the dc control section of the dc power system. The dc overload circuit performance was re-evaluated, but circuit voltages were not retaken and are the same as the dc overload circuit voltages recorded in the dc control section of the dc power system. The detailed logic of the control circuits performed properly after only 1 minor logic modification. The performance of the anti-ice system was good. The circuits operated properly over the entire temperature range.

Time Delay Circuits

The time delay circuits are shown as DD18 and DD60 in Figure 33, and as DD4 in Figure 34. The circuits were first given a few preliminary operating checks, and were modified slightly to improve their performance, which was then good.

The delays were adjusted and timed using a Galco stopwatch. The 4 second delay was adjusted for 4 seconds. The upper and lower limits of adjustment were +0.2 and -0.5 seconds, respectively. The 18 second delay was adjusted for 18 seconds. The upper and lower limits of adjustment

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were +1.0 and -1.0 seconds, respectively. The 60 second delay was adjusted for 60 seconds. The upper and lower limits of adjustment were +1.2 and -1.5 seconds, respectively.

The delay circuits were evaluated throughout the temperature range and the performance data is presented in Table 8. The variations of delay are well within the tolerances of the electromechanical equivalents.

Table 8

Time Delay Circuit Performance Data

Nominal Delay (sec)	Actual Delay At +80° C (sec)	Actual Delay At +25° C (sec)	Actual Delay At -55° C (sec)
4	4.2	4.0	3.6
18	18.5	18.0	17.5
60	64.0	60.0	55.0

Warning System

The warning system is shown in Figure 37. It was evaluated while integrated into the anti-ice section by providing the proper inputs and observing operation of the warning lights. The power switch Q6 did not require a heat sink so it was evaluated at +80° C. Q6 had a saturation voltage of 0.1 vdc at a load current of 150 ma, and a saturation voltage of 0.5 vdc at a load current of 2 amperes. The leakage current in the off-condition at a junction temperature of +80° C was only 30 microamperes.

The warning light overload circuit is identical to the modified overload circuit of the dc power system except for the bistable element. In the

case of the warning light circuit, it is a Solid Circuit flip-flop. The normal

warning light current is approximately 160 ma, but due to the current

transient which occurs at turn-on the overload circuit trip was set at 2.5

amps. Initially, the circuit was adjusted for trip with a sensed voltage of

0.30 volts, and the sensing resistor was selected so that the voltage drop

across it with 2.5 amp flowing would be 0.30 volts.

The circuit trips when applying power into a 150% overload (3.7 amps)

in 5 milliseconds. This time is mainly determined by the contact bounce of

the main power switch. It trips with manual reset into a 150% overload (3.7

amps) in 50 microseconds. Circuit performance is recorded in Table 9.

Table 9

Warning Lamp Overload Circuit Performance Data

Ambient Temperature (^{o}C)	Essential Bus Voltage (Volts)	Tripping Current (Amps)	Max. Load Turn-On (Amps)
+80°C	27 v	1.6 A	1.5 A
↓	28 v	1.7 A	–
	33 v	2.3 A	2.1 A
+25°C	27 v	2.0 A	1.9 A
↓	28 v	2.1 A	–
	33 v	2.6 A	2.4 A
-55°C	27 v	2.2 A	2.1 A
↓	28 v	2.3 A	–
	33v	2.7 A	2.6 A

L4A and L4B Valve Motor Driver

The valve motor driver circuits are shown in Figure 37. Refer to Figure 30, detail A, for the circuit which simulated motor driven valve operation. Satisfactory operation of the drivers was observed over the temperature range of +80°C to -55°C.

Power switch Q9 had a saturation voltage of 2.3 volts at a case temperature of +114°C while conducting a load current of 6 amperes. In the off-condition at a junction temperature of +130°C, it had a leakage current of 1.5 milliamperes.

A general technique used to determine if a power switch was saturating was to decrease the load current while observing the collector-to-emitter voltage. If that voltage decreased linearly, then the switch was in saturation. This technique was used for Q9.

Temperature Sensor

The temperature sensor circuit controls the operation of the case heater, HR6; it is shown in Figure 36. The original circuit design was constructed and preliminary testing indicated a problem existed due to self-heating of the thermistor (R30). It was caused by the large current change required for switching of the unijunction transistor directly from the thermistor; hence, it was necessary to add amplifiers preceding the unijunction (which is operated in the bistable mode). The modified circuit operated

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well. It exhibited a snap-action turn-on with decreasing temperature at +13° C and a snap-action turn-off with increasing temperature at +18° C.

Circuit performance was determined as follows. First, the thermistor RT1 was suspended by its leads with a thermocouple mounted 1/2 inch away. Since +15° C is the design center of the allowable operating range, R2 was adjusted to turn on Q5 (with a load of 1.6 amps) at +13° C. Second, turn-off was then determined; it took place at +18° C. TS1 switched Q5 on in 40 microseconds with a temperature rate of change of +0.32° C/sec. (+4.5° C to +21° C in 55 seconds). TS1 switched Q5 off in 30 microseconds with a temperature rate of change of -0.10° C/sec. (+21° C to +4.5° C in 170 seconds).

In order to determine circuit performance at -55° C and +80° C, a 10 K potentiometer was substituted for R30 and then varied to the turn-on point when the rest of the circuit was at the temperature extremes of -55° C and +80° C. Then the values of R30 were determined experimentally over the temperature range. The turn-on resistance value was then converted to a temperature equivalent based on the known temperature-resistance characteristic of R30.

At -55° C, a resistance greater than 9 K ohms was required for turn-on; therefore, the equivalent temperature was +4° C. A resistance less than 6 K ohms was required for turn-off; therefore, the equivalent temperature was +16° C.

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At +80° C, a resistance greater than 5.1 K ohms was required for turn-on; therefore, the equivalent temperature was +20° C. A resistance less than 4.9 K ohms was required for turn-off; therefore, the equivalent temperature was +22° C.

Q5 does not require a heat sink and so its high temperature test was conducted at an ambient temperature of +80° C. The saturation voltage of Q5 was 1.1 volts while conducting 1.6 amperes; the case temperature was +115° C. In the off-condition at a junction temperature of +115° C, the leakage current was 0.5 ma.

The overload circuit for the temperature sensor circuit is shown in Figure 36. It was simplified and then circuit performance data was taken. This data is given in Table 10.

Table 10

Temperature Sensor Overload Circuit Performance Data

Ambient Temperature (°C)	Essential Bus Voltage (Volts)	Tripping Current (Amps)	Max. Load Turn-On (Amps)
+80° C	27 v	1.18 A	1.15 A
	28 v	1.27 A	—
	33 v	1.68 A	1.64 A
+25° C	27 v	1.46 A	1.40 A
	28 v	1.50 A	—
	33 v	1.86 A	1.85 A
-55° C	27 v	1.57 A	1.52 A
	28 v	1.60 A	—
	33 v	1.92 A	1.88 A

Storage Test

A storage test was performed by increasing the temperature to $+122^{\circ}$ C for 2 hours, then returning the temperature to $+25^{\circ}$ C. The circuit performed satisfactorily after storage at $+122^{\circ}$ C.

IV. WORK PLAN

During the coming fifth quarter, several alternate circuits will be evaluated and the final report will be prepared. The alternate circuits are intended to be available as improvements to the present system design. Their desirability is discussed in the following paragraphs.

It was pointed out in the phase I report (pp. 172 and 173) that the dc solid state fusing scheme was deficient in that ground switching was used for both control and fusing. However, it was suggested that an emitter-follower arrangement be used to eliminate this difficulty. It was also pointed out that an oscillator and rectifier operating from the +28 vdc (dc to dc power converter) could be used to develop a voltage more positive than the +28 vdc source. This is needed because a base driving voltage greater than +28 vdc is necessary to insure saturation of the power transistor. However, the designed systems have been tested with their original ground switching. Now, the suggested modification will be developed so as to be a unit replacement for the ground switches.

A second alternate circuit will be developed to simplify the chute overload circuit that is excessively complex. It is anticipated that a re-design will decrease by more than half the number of components required. In addition, other alternate circuits will be developed (insofar as time permits) to improve generally the dc overload scheme.

The final report will be submitted as specified in the contract and listed in the phase I report (p. 180). The drawings presented therein will be completely revised with respect to the drawings presented in the phase I report.

(AmF)

AMERICAN MACHINE & FOUNDRY COMPANY

Research & Development Division

1025 North Royal Street • Alexandria, Virginia

12 April 1963

ASTIA (TIPDR)
Arlington Hall Stn
Arlington 12, Virginia

Gentlemen:

This is the cover letter of transmittal for quarterly report nr. 4 of the solid state matrix program. This program is being conducted under contract nr. AF 33(657)-8688, project nr. 8128, and task nr. 61084 for the Aeronautical Systems Division, Wright-Patterson AFB, Ohio.

This report is being furnished to you in accordance with the government distribution list.

Very truly yours,

AMERICAN MACHINE & FOUNDRY CO.

R. N. Stock

R. N. Stock
Project Engineer

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