



**Aerospace
Systems Division**

Investigation of Flight II Central Station
Overvoltage Condition

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The purpose of this ATM is to document the results of the Reliability/Engineering investigation of the overvoltage condition that occurred while performing the Flight II Central Station power dissipation test. The objective was to assess the flight worthiness of the C/S components and to identify any overstressed piece parts.

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The purpose of this ATM is to document the results of the Reliability/Engineering investigation of the overvoltage condition that occurred while performing the Flight II Central Station power dissipation test. The objective was to assess the flight worthiness of the C/S components and to identify any overstressed piece parts.

The investigation was accomplished in two phases: a functional PIA checkout at hot, cold and ambient temperatures for each C/S component; and an analytical analysis of each components' parts application. In addition, a special evaluation test on the Fairchild μ A702 and μ A709 operational amplifiers, used in the Command Decoder and Power Distribution Unit, has been performed. The results of this test will be covered under a separate report, ATM 801, scheduled for issue October 1, 1968. A brief discussion is included in this report.

In summary, the following abnormalities were disclosed.

1. Both transmitters S/N-11 & 15 were inoperative as a result of the overvoltage. These units were removed and returned to the vendor. Transmitters S/N10 and 20 were installed in Flight II.
2. The Command Receiver (SN7) was replaced with S/N 8. Preliminary checkout of S/N 7 at ambient temperature indicated no evidence of damage, however, because of schedule considerations it was more expedient to use S/N8 as the Flight II unit.
3. Resistor R33 in the PCU Switching Module was stressed in excess of its rated power. At Bendix's request, the manufacturer subjected identical parts to the same overvoltage condition to determine the degree of degradation or change in resistive value. The hot spot temperature rise caused a change in resistance of approximately 0.33%. This resistance shift is well within acceptable circuit application limits. Visual examination at X90 magnification showed no evidence of permanent damage. This test is considered a worst case application since it was performed in free air. The actual resistor is coated and heat sunked with Stycast 2850 FT which has good thermal properties, thus minimizing the hot-spot temperatures.
4. The Fairchild μ A702 and μ A709 operational amplifiers were stressed beyond the manufacturers maximum specified ratings. Although functionally these parts showed no evidence of damage during system checkout, the special test previously mentioned is designed to assess what detrimental effects the overvoltage may have induced relative to the op amps transfer function and common mode offset voltage. The stability of these parameters were measured and



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recorded as a function of voltage and time. The overvoltage application was duplicated then repeated, doubling the exposure time. The test results showed no evidence of damage.

5. Functional PIA checkouts and comparison with the original PIA test results disclosed no evidence of damage (transmitters excepted) attributable to the applied overvoltage condition.

It has been concluded from this investigation, that the central station assemblies, with exception to the transmitters were not adversely degraded as a result of the applied overvoltage. Therefore, the Flight II central station, as presently configured is considered flight worthy.

Description of Malfunction

The Flight II C/S power dissipation test was in progress per test procedure 2337925. The C/S was operating on PCU #1. In accordance with paragraph 6.5.3.1.1, Command SET 2 (OCTAL 062), "PCU #2 Select", was transmitted. After command execution the 12V Sense Meter on the STS pegged at the maximum value. Emergency RTG Shut off procedure was performed.

The malfunction was traced to an operator error. The break-out-box (B. O. B.) connected between C/S output connector J24 and P24 had a jumper cable missing. The missing jumper effected an open loop in the PCU #2 regulator shunt resistor/transistor circuit. The open circuit permitted the +16 volts to the PCU inverter to increase to +26V, thus resulting in the following system overvoltage condition.

Nominal Supply Voltage

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+29V	+47.2V
+15V	+23.4V
+12V	+19.5V
+ 5V	+ 8.1V
- 6V	- 9.75V
+16V	+26V
-12V	-20V

The duration of this overvoltage condition was determined to be one (1) minute. The amplitude of the overvoltage was calculated on the basis of 50 watts of reserve power available in the PCU. This represents the worst case condition. Start up and initial system check out disclosed that Transmitters A & B were inoperative.



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Investigation Results

A joint failure analysis investigation was undertaken by Reliability and Engineering to ascertain the degree of degradation experienced by the C/S electronic subsystems.

To determine the functional status of the C/S subsystems, each unit was subjected to a Hot-Cold-Ambient PIA test. With exception to the Transmitters, S/N 11 and 15 all subsystems passed with no evidence of failures. Both transmitters were found to be inoperative.

The "as-run" test data was compared with the original PIA test data for each respective subsystems. The objective was to determine if any discernable shift, off set, etc., was evident that might indicate that some degradation occurred as a result of the overvoltage condition. The test data was found to be within acceptable tolerance limits specified by the test procedures. No significant deviations were noted to indicate evidence of damage and/or degradation present in the C/S subsystems.

The above PIA test established the operational status of the C/S electronic subsystems. However, to determine which components (piece part) were overstressed, an analytical analysis of each subsystem's electronics was performed. The analysis was extended to all subsystems exposed to the overvoltage condition and are tabulated below.

1. Transmitters - S/N 11 and 15
2. Receiver, S/N 7
3. Command Decoder S/N 5
4. Data Processor, S/N 7
5. 90 Channel Multiplexer/Converter, S/N 10
6. Power Distribution Unit, S/N 7
7. Power Conditioning Unit, S/N 5
8. Passive Seismic C/S Electronics, S/N 2

It was recognized by Bendix that a comprehensive analysis was essential if the flight worthiness of the system was to be assured. This was accomplished through the use of the existing Parts Application Analysis (PAA), for each assembly. By use of the PAA's, a quick reference was available to identify those parts that were potentially overstressed while effectively eliminating undue time spent on parts that obviously would not be damaged as a result of the overvoltage condition.



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An understanding of the failure mechanisms of the parts utilized in ALSEP is essential in order to determine what degradation or catastrophic effects may have occurred. There are two basic damage and/or failure mechanisms which may result from an overvoltage condition. The first relates to direct voltage breakdown which might occur in capacitors operated beyond their rated voltages, or in semiconductor junctions when reverse bias is excessive. The second mechanism of damage occurs from excessive current through a part, which, although used within its voltage rating, its power dissipation (I^2R) becomes excessive. This mechanism would apply to resistors, thermistors, coils, transformers, and semiconducting devices operating in the forward biased condition. These mechanisms, as they apply to types of parts are discussed in more detail in the following paragraphs.

Non-Electrolytic Capacitors (Types CKR, ECY, CMR, VKR, WOMZ)

The non-electrolytic capacitors selected and applied in the Central Station all have ratings well above the 29V primary, thus the overvoltage condition cited would not result in any instance where the rated continuous working voltage was exceeded.

Electrolytic Capacitors (Types CSR, 16K, and 202D)

The electrolytic capacitors are applied by standard derating practice (refer to ATM-241) at less than 67% of their rated voltage. In certain cases, experienced overvoltage condition could cause the applied voltage to approach or exceed the parts rating and therefore required careful scrutinizing. Electrolytic capacitors do carry a surge voltage rating about 15% greater than the continuous rating, thus providing additional margin for transient states. No electrolytic capacitors were found to have exceeded their manufacturer's rating.

Resistors, Composition, Film and Wirewound (Types RCR, RNR, RWR & RER)

The majority of resistors utilized are generally applied at less than 30% of their continuous power dissipation rating (ATM-241). Considering the worst case application of 50% rated power, a 50% voltage surge results in an increase of 12% more than the rated continuous power. These resistors are capable of withstanding a minimum of double the rated power. In the case of the RNR series, these resistors are typically burned-in at five (5) times rated power for one hour. Only two resistors were identified to have exceeded their rating, and are discussed elsewhere in this report. Thermistors and temperature sensors are applied at small fractions of their power-handling capability, thus the overload would only result in temporary inaccuracy due to self-heating.



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Coils, Chokes, and Transformers

Coils, chokes and transformers subjected to current overloads will rise in temperature in accordance with their thermal dissipation capability. Chokes and transformers in the PCU are thermally lagged to the structure, and are fabricated to MIL-T-27 class temperature which provides adequate margin for short (1-minute) current overloads.

Relays (Types BR17, BR20 and Teledyne Current Sensors)

Relays used in the Central Station fall into two different application categories:

- (a) Babcock BR17 and BR20 latching relays are used for power control by ground station command and operate from a short duration pulse provided by the command decoder logic. The majority of these relays were not energized during the transient condition described, hence not effected. The excepted case is the transmitter select relay in the PDU.
- (b) Teledyne current sensing relays are connected in series with power lines to the experiments and/or subsystems. These relays are performing their normal function when energized as a result of an overload situation such as existed.

The transmitters' select relay and current sensing relays are covered in greater depth in the PDU section of this report.

Diodes, Rectifiers and Switching

Semiconductor diodes are applied well within their voltage and power dissipation ratings and the transient condition described in general would not produce any overload condition greater than the device's capability.

Diodes, Zeners

Voltage regulator (zener) diodes are operated at a "Zener Current" rating, which under light loads produces rated power in the diode. The characteristic curve for zener diodes is very non-linear in the operating region and an increase in applied voltage can produce an excessive current through the diode if the current-limiting resistor is small. This case would apply if the regulated voltage is only slightly less than the supply voltage.



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Actual load conditions for different zener currents and load resistances were established by calculation for the overvoltage condition. No misapplications were found to exist.

Transistors

Because of the variety of methods used in biasing transistors, and the different methods of loading these devices, it was necessary to investigate each circuit application for possible excessive dissipation, or voltage greater than rated maximum. Transistors found to have experienced an overstressed condition are covered in greater depth elsewhere in this report.

Integrated Circuits

Digital - The low-power DTL logic circuits (9040, 9041 & 9042) are rated at 6V, and applied in ALSEP at 5V. However, Fairchild tests these circuits for 8V capability which was only slightly exceeded (0.1V max) during the overvoltage state. The new specification sheets rate and test these DTL logic circuits at 8V thus providing the same condition experienced during the ALSEP overvoltage condition. On the basis of this information, it has been concluded the Fairchild digital logic circuits were not stressed beyond their capability, hence their reliability was not degraded.

TI and Westinghouse Logic Circuits utilized in the system are rated at 10V, hence were not overstressed.

Linear - The Fairchild μ A702A and μ A709C operational amplifiers were stressed beyond the manufacturer's specified rating for their respective applications. Although, functionally these elements checked out in the system with no evidence of degradation, additional tests have been performed at the piece part level and will be reported in a separate document.

702A - The 702A circuit is rated for a maximum supply voltage difference of 21V and is characterized at $V_+ = 12$, $V_- = 6V$. Input voltage maximum ratings are +1.5V or -6V with a maximum differential of 5V, either polarity. The nominal power supply voltages in the ALSEP application are +12V and -6V. The transient condition resulted in a maximum difference of 19.5 and -9.75 or 29.25V exceeding the rated maximum by 8.25V.

709C - The 709 circuit is rated for maximum supply voltages of +18V and is characterized at +15V. Input voltage maximum ratings are +10V with an allowable differential voltage of +5V. The nominal power supply voltages in the ALSEP application are +12V, and during the fault may have reached +19.5 and -20V, exceeding the rated maximum voltage by 3.5V.



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Fairchild was contacted to determine the allowable margins relative to the maximum voltage ratings. However, identification of the allowable overstress tolerances was inconclusive in that such data are not available. Consequently, BxA Reliability performed an evaluation test on sample units drawn from stock. The test was designed to measure the stability of the op-amp's transfer function and common mode offset voltage as a function of an overvoltage exposure. Examination of the test data confirms the $\mu A702$ and $\mu A709$ op-amp were not degraded as a result of the applied overvoltage. The results of this test will be published in a separate report (ATM 801). The test is being continued to determine the allowable safety margin inherent in these devices before deterioration of their parametric functions is detected.

Transmitter Assembly S/N 11 & 15

The transmitters were the only assemblies found to fail catastrophically. At the time of the overvoltage condition occurred, Transmitter B(S/N-15) was on. When the +29V supply increased to 47V, the +29V overload sensor tripped, * transferring power to transmitter A(S/N-11). It is suspected, that prior to transfer of power, the overvoltage caused a failure in the Power Amplifier module. Because the overvoltage condition was still present, the same failure mechanism was repeated in Transmitter A.

Both transmitters were returned to the vendor for fault isolation and repair. As a result of the initial failure and stress analysis investigation by Bendix, the following components are suspected of being overstressed:

Module	Part	Stressed Parameter	Rating
A1, X2 Control Amplifier	Q3-2N3866	$V_{CE} > 47V$	$BV_{CEO} = 30V$
A2, X2 Pwr. Amplifier	Q1-2N4012	$V_{CE} > 47V$	$BV_{CEO} = 40V$
	Q2-2N4012	$V_{CE} > 47V$	$BV_{CEO} = 40V$
	R3	$P_{diss} / P_{rated} = 1.01$	
A4, X4 Multiplier	R4	$P_{diss} / P_{rated} = 1.01$	
	CRI-L8654F	$P_{diss} / P_{rated} = 1.0$	

Other components in the transmitter do not appear to have been overstressed and should be satisfactory for continued use as flight hardware.

The resistors, R3 and R4, in module A2 should not constitute a problem for continued use. The vendor has a contract to perform a detailed analysis and to repair the Xmtrs. Their analysis will be studied by BxA Reliability & Engineering for concurrence with their replacement recommendations.

*It is possible the +12V overload sensor caused the transferring of power to the alternate transmitter. However, the identified failures indicate the overload occurred in the +29V line.



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Receiver - S/N 7

Receiver S/N 7 has been removed from the Flight II C/S and replaced with S/N 8. Preliminary checkout of S/N 7 showed no evidence of damage. However, the receiver was replaced to allow for a more thorough checkout and evaluation to ascertain its flight worthiness.

Data Processor, Digital (S/N 7)

At the time of overvoltage, Data Processor Y was energized. The Data Processor does not feature automatic switchover, hence, only the Y side was suspect for possible damage. With exception to the network calibration circuit, and oscillator assembly, the Data Processor is composed of Fairchild DTL 9040, 9041, and 9042 micro logic elements. As stated previously, the +8V overvoltage was within the acceptable limits specified by Fairchild. All other discrete components (resistors, transistors, diodes, etc.) operated well within their power and voltage ratings.

90 Channel Multiplexer/Converter - S/N 10

The FET analog gates and FET gate drive circuits were the prime candidates for damage and/or failure resulting from the applied overvoltage. The analysis disclosed that the PNP transistors (Dynatronics P/N 04-000091-1) were subjected to an overvoltage from collector to emitter which exceeded the specified minimum BV_{CEO} rating of the part. BV_{CEO} for the subject part is specified at 30V minimum. During the overvoltage period, the applied collector-to-emitter voltage was 34V.

The transistor in question is a high speed switching device. When in the OFF state, which is the critical condition, the transistors breakdown voltage is analogous to BV_{CER} for one application, and BV_{CES} for the other. The BV_{CER} situation exists by virtue of a 4.7K Ω resistor between the base and emitter; and BV_{CES} by virtue for a forward biased diode coupling the base and emitter for the latter application.

According to Texas Instruments, the BV_{CES} rating of the transistor approximates its BV_{CBO} rating which is typically measured at 75V. BV_{CER} is generally specified for a value of 1K Ω between the base and emitter and will measure at some value less than, but approaching BV_{CBO} . For an impedance of 4.7K it can be concluded that BV_{CE} for the circuit application is greater than the specified BV_{CEO} although less than BV_{CBO} .



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Measured test data by T.I. for the subject part records the typical $BV_{CEO} = 55V$, and the three sigma limit $BV_{CEO(MIN)} = 45V$. Because the BV_{CEO} condition is the lowest voltage rating for an applied potential across the collector to emitter, circuit design parameters are limited to the lower or minimum specified value to ensure reliable operation. However, for the given circuit application combined with a high probability the actual breakdown voltage was less than 45V, results in the conclusion no damage or degradation has occurred as a result of the overvoltage condition.

No other piece parts utilized in the Multiplexer/Converter were found to exceed their respective ratings.

Power Distribution Unit - S/N 7

The relay(s) for the transmitter power control and the LA709 Fairchild operational amplifiers for the RTG Junction temperatures, PCU Reserve Power Sensors, and the Dust Detector Photo cell sensors, were subjected to an abnormal operating mode.

For the one minute duration while the overvoltage condition existed, the transmitter's circuit breakers in the +29V line * detected and generated a power transfer command from one transmitter to the other. Because the overvoltage condition existed regardless of which transmitter was operating, it is suspected the power control relays oscillated back and forth at a frequency commensurate with the delay times of the circuit breakers and relays. This occurred until the power amplifier frequency doubler transistor failed open. ** The parts in question are Babcock relay (BR17) K4, and Teledyne current sensors CB 2, 3, 4, and 5.

Assuming this condition occurred for a 5ms pull-in time, the number of actuation estimated to have occurred during the 1 minute overvoltage period is calculated to be 12,000. The operational life requirement for the relays in question is 100,000 cycles. Therefore, the operational life was not exceeded and was verified by the functional checkout of the P. D. U. A conservative estimate of the number of actuations this relay will be required to perform is less than 1,000. Therefore, the cyclic life is not expected to be exceeded.

* Though unlikely, the power transfer could have resulted from an overload in the +12V supply line.

** This transistor is located in the Transmitter Assembly.



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However, a potentially more critical problem is the damage to the relay contacts as a result of switching of an inductive load. This application is critical to the K4 relay only, since the circuit breaking contacts are switching ground signals in the base circuit for the K4 relay drive transistors.

In the case of relay K4, which switches the +29V and +12V supplies, the load looking into the transmitters is inductive. However, an analysis of the circuit discloses that the overload current sensors, in series with the relay contacts will trip at 700 ma and 150 ma respectively for the +29V and +12V supplies. The contact rating for the K4 relay is 1.0 amp inductive. Therefore, it has been concluded that, even though the relay and overload current sensors were operated in an abnormal manner, the properties of the suspected parts were not degraded.

The operational amplifiers (μ A709) are specified to operate between +18 Volts. The nominal operating voltage is +12 Volts. However, during the transient state these Op-amps saw approximately 40V, or 4 volts above the maximum specified rating. Because Fairchild could not guarantee operation beyond the specified rating, a special test designed to measure degradational effects as a function of overvoltage was conducted. Evaluation of the test data confirmed the op-amps were not degraded and therefore are considered flight worthy.

All other components within the PDU were found to be within their specified ratings. Excepting the transmitter circuit discussed above, all other relays and circuit breakers remained in a de-energized state, thus not functionally exercised or stressed. Resistors, capacitors and diodes were well within their manufacturers' ratings. The relay drive transistor (BxA #23351911) was only subjected to approximately 86% of its BV_{CEO} rating which was the worst case application found for any transistor(s). The digital logic elements, as stated previously, did not exceed the allowable test levels specified by Fairchild.

Command Decoder - S/N 5

The Fairchild μ A702A operational amplifiers in the Demodulator constitute the most serious potential problem. These integrated circuits are rated for 21 volts. As stated previously, the applied voltage across them during the transient state was 29.25V. The successful completion of the P. I. A. tests indicates no detrimental effects resulted from the applied overvoltage. However, certification as to the flight worthiness of the μ A702A was confirmed based on the results of the special evaluation test. For a comprehensive report, refer to ATM 801.



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Three electrolytic capacitors (C3, C5 and C19) were stressed to their maximum voltage rating. However, these capacitors have current limiting resistors and therefore are not believed to have been degraded. The remaining passive and semiconducting parts were found to be operating below their manufacturers' rating.

PCU - S/N 5

As previously stated, the open loop condition in the PCU #2 regulator was the cause of the Flight II overvoltage mishap. While the overvoltage condition existed, the analysis disclosed two (2) resistors were stressed beyond their nominal power rating. The identified resistors are listed below.

OVERSTRESSED RESISTORS

Submodule	Symbol	Ohms	Overvoltage	Rating	Stress Ratio
Regulator B	R37	909 Ω	11.5V	0.1 W	146%
Over/Under Switch	R33	301 Ω	15.5V	0.1 W	800%

Since the two overstressed resistors are MIL RNR Film Resistors that are burned in at 5 times rated power for one hour, it is apparent that R37 was capable of handling the 146% overload it dissipated for one minute. R33, however, dissipated 8 times rated power for the one minute during which the Switching Module, sensed an overvoltage. Mepco Inc., the supplier of the R33 resistors, was contacted to determine the effect of such an overload condition. Several RNR 55E resistors were drawn from Mepco's stock and repeatedly exposed, in air, to 8 times rated power. In approximately 13 to 15 seconds, the resistor's temperature rose 100°C above ambient. After one minute, the hot spot temperature rose to approximately 180°C to 184°C and the resistance drifted approximately 0.33%. Examination of the resistors under 90x magnification showed no damage. Mepco stated that the critical temperature for these resistors is 175°C but, as a result of their test, if exposure to the 800% overload is limited to one minute and that the application conducted heat away better than free air, the resistor would function normally.



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R33 is packaged in a cordwood assembly and conformally coated with Stycast 2850FT. (Refer to Figure 1) Stycast has good conductivity and therefore should aid in the dissemination of heat away from the resistor. It would be impossible to determine the actual hot spot temperature rise of resistor R33 without instrumenting and duplicating the overvoltage condition. However, it can be concluded the resistor did not exceed the 184°C temperature measured by the samples tested. In fact with the assistance of the stycast coating, it is highly probable the temperature did not exceed the 175°C which the manufacturer specifies as the maximum allowable temperature before degradation begins to occur.

Even assuming the worst case condition of 184°C temperature rise, the measured ΔR was only 0.33%. For the given application a resistance range of 100-3K Ω is acceptable before functional degradation will occur. Therefore, it has been concluded by BxA Reliability that any parametric change in R33 as a result of the overvoltage condition, is inconsequential to the functional capability of the PCU and the reliability of the system.

PSE - S/N 2

The PSE was in stand-by with a dummy load connected to the PSE/CSE in place of the sensor when the overvoltage was applied. A review of ESC drawing 233011 rev. D, PSE block diagram, revealed that in the stand-by condition only the 29V survival power is applied to the PSE. Analysis of the Power Converter "B", ESC drawing 324526 Rev. D, indicates that the applied overvoltage of 47.2V stressed the survival heater circuit components to a maximum of 60% of their capability. Therefore, the PSE was not exposed to any detrimental operating conditions that would degrade the operational reliability.

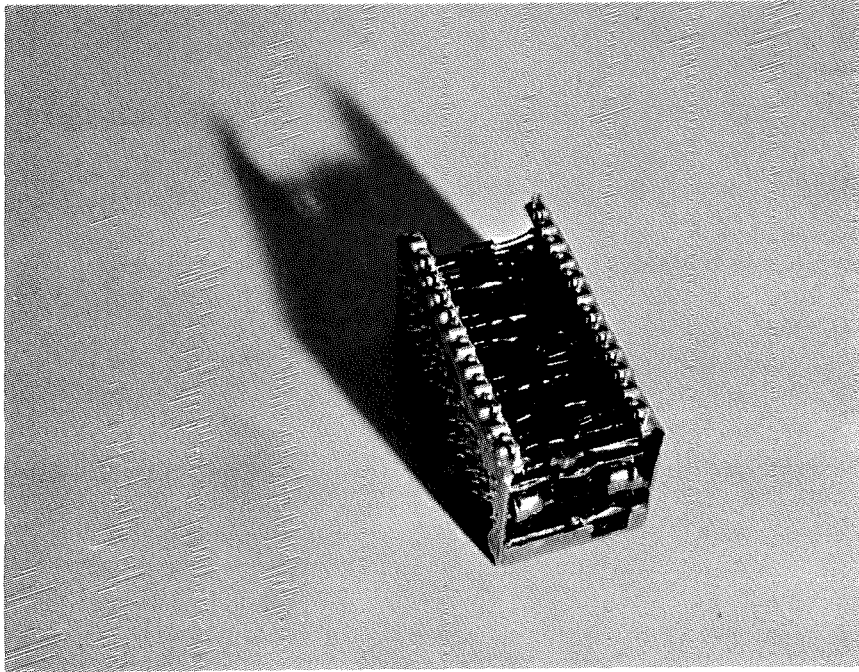


Figure 1

REGULATOR ASSEMBLY 2334964