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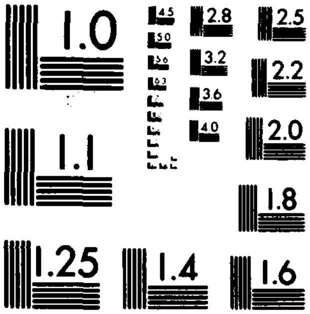

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RESEARCH AND DEVELOPMENT TECHNICAL REPORT

DELET-TR-80-16

# RELIABILITY EVALUATION OF PLASTIC ENCAPSULATED HYBRID MICROCIRCUITS DEVELOPED FOR ARMY FUZE APPLICATIONS

Edward B. Hakim
John Erickson
ELECTRONICS TECHNOLOGY & DEVICES LABORATORY

August 1980

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| Monolithic Integrated Circuit | |

20. ABSTRACT (*Continue on reverse side if necessary and identify by block number*)

A major Army rocket system may incorporate the use of an electronic fuze timer fabricated using two plastic encapsulated hybrid microcircuits and one encapsulated monolithic integrated circuit. The Electronics Technology and Devices Laboratory at Fort Monmouth, New Jersey was tasked with assessing the storage reliability of these devices through accelerated testing and detailed failure analysis to determine failure mechanisms. From this analysis, corrective actions would be proposed which could permit attainment of the desired reliability.

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# RELIABILITY EVALUATION OF PLASTIC ENCAPSULATED HYBRID MICROCIRCUITS DEVELOPED FOR ARMY FUZE APPLICATIONS

## INTRODUCTION

In an effort to reduce cost, an Army rocket system program considered the use of plastic encapsulated microcircuits in the electronic fuze timer circuit of this missile. The three device types used in the timer circuit are a precision hybrid oscillator, an interface hybrid and a Metal Nitride Oxide Semiconductor (MNOS) monolithic memory/timer microcircuit.

These devices were the result of Manufacturing Methods and Technology (MM&T) Programs managed by the Harry Diamond Laboratories. The objective of these programs was to define manufacturing methods for high volume/low cost devices. A pilot production lot was produced for each contract which demonstrated the contract requirements.

The Electronics Technology and Devices Laboratory (ET&DL) program objective was to obtain qualitative information on the long term storage reliability of each of the three devices. Screens and accelerated environmental tests were devised for this analysis.

## PROGRAM DESCRIPTION

The test program is outlined in the Flow Chart, Figure 1. Device quantities were dictated by availability of MM&T Pilot Line units.

## DEVICE DESCRIPTION

a. 10 kHz Hybrid Microcircuit Oscillator - Figure 2 illustrates four stages in the packaging of this unit. Assembly features of this hybrid include:

(1) A tape automated bonded (TAB) amplifier chip. This chip uses aluminum interconnect metalization, passivation of $SiO_2$ and CVD $Si_3N_4$, gold bonding bumps, and eight tin plated copper leads.

(2) The thick-film alumina substrate contains the TAB amplifier chip, four chip capacitors, and three thick film resistors. (See Fig. 3.)

(3) Component mounting technique: Amplifier chip epoxy mounted using Abelstik 789-3 non-conductive epoxy; capacitors and three external leads attached by solder reflow.

(4) Conformal coating over entire substrate using Dow Corning R6100 silicone junction coating.

(5) Final package assembly: Immersion of assembled substrate into a formed metal can with a ground terminal, filled with Hysol ES4128 epoxy encapsulant. The purpose of the metal can is to provide electrical shielding.

b. Interface Hybrid Microcircuit - Figure 4 shows the substrate layout of the interface hybrid. Assembly features are:

(1) The custom monolithic integrated circuit (IC) chip. Aluminum metalization is used at bonding pads and interconnects. Ball bonded gold wires are used from chip to substrate. There is no passivation over the metalization. The die attachment to the substrate is accomplished using silver-loaded epoxy.

(2) A silicon controlled rectifier (SCR) chip. Die attach using gold-silicon eutectic bonding.

(3) Bonding of leads to substrate is performed using a solder paste and solder reflow. The package is an oversized 14 lead dual in-line configuration, 1.410 cm x 2.172 cm (0.555 in x 0.855 in).

(4) Jumper wires on substrate. Four gold wires are used to connect various substrate conductors.

(5) Encapsulation technique. Hysol Epoxy ES4228 is used as a coating over the IC and SCR chips and the four jumper wires prior to package molding with Dow Corning 307 silicone encapsulant.

c. Memory/Timer - This is an MNOS monolithic microcircuit, with a chip measurement of 0.249 x 0.191 cm (0.098 x 0.075 in), which is packaged in a 16 pin dual in-line plastic package. The encapsulant is Allied 2929B epoxy novalac. The lead frame consists of alloy-42, with selectively gold plated wirebond areas and solder dipped leads. The chip has aluminum interconnect metalization and bonding pads, plasma deposited silicon nitride passivation, eutectic die bonding and thermal compression gold wire bonds. A photo-micrograph of the chip is shown in Figure 5.

## TEST PROCEDURE

The tests were conducted as outlined in the flow chart in Figure 1. Measurements made at 20°C were repeated at 100°C for the initial end point tests and for end point tests for thermal shock. Testing was conducted and is described in the following sections. The failure criterion was no fuze timer circuit output at either 25°C or 100°C. Functional testing began one hour after removal from test and was completed within four hours.

Burn-in for all devices was performed in accordance with Method 1015.2, MIL-STD-833B, bias life test. Bias was applied to each unit for 168 hours at 125°C. End point measurements were performed at 25°C.

The thermal shock test was conducted in accordance with Method 1011.2, MIL-STD-883B, Test Condition B (-55°C to 125°C). A total of 50 memory/timers, 50 oscillators, and five interfaces were subjected to 30 test cycles. Upon completion of the 30 cycles, 25 timers and 40 oscillators were transferred to the humidity test. The remaining 25 timers, 10 oscillators, and five interfaces were subjected to 300 cycles in 30 cycle increments, and thereafter to a total of 2000 cycles in 100 cycle increments. End point measurements were made at both 25°C and 100°C.

Humidity testing was performed in accordance with the test method developed by ET&DL (Appendix A). A total of 175 timers, 93 oscillators, and 20 interfaces were put on test. End points were measured at approximately 25, 50, 100, 150 and 250 hours and at increasingly longer intervals. End point measurements were made at 25°C.

The end point measurement test circuit is shown in Figure 6. A "Static-Safe" work station was developed for handling the MNOS timer. The work surface was covered with conductive foil and grounded. Test personnel at the work station were equipped with a wrist band in direct contact with the skin and grounded. Figure 7 shows the "Static-Safe" work station including the test fixture which simulates the fuze timer circuit, the XM36E1 Fuze Setter and test meters. The fuze time is manually set using the XM36E1 Fuze Setter and the time is presented by a light emitting diode (LED) display. A catastrophic failure in the fuze timer circuit or setter will cause the display to indicate error, "E". The end point measurement procedure follows:

a. Memory/Timer

Measurements are made at 25°C. The device under test, DUT, is inserted in the test fixture (furnished by Harry Diamond Laboratories). Power is switched "ON" and current drain measured (current drain limits are 2.5 mA minimum and 11 mA maximum). With the power "OFF", fuze setter settings of 178.6 seconds and 4.0 seconds, respectively, are applied to the test fixture. Power is switched "ON" and output waveform observed on an oscilloscope. A typical output waveform is shown in Figure 8. For the thermal shock test, the above measurements are repeated at 100°C.

b. Oscillator

Measurements are made at 25°C. The DUT is inserted in the test fixture. Power is switched "ON" and average current drain measured (current drain limit is 2.7 mA maximum). The output duty cycle and period are measured using an oscilloscope (duty cycle limits are 45 to 50% and period limits are 96 microseconds minimum and 107 microseconds maximum). If the period is marginal, a more precise measurement is made using a HP 5304A Timer/Counter. Typical output waveform is shown in Figure 9. For the thermal shock test, the above measurements are repeated at 100°C.

c. Interface

Measurements are made at 25°C. The DUT is inserted in the test fixture. A fuze setter setting of 4.0 seconds is applied to the test fixture. Power is switched "ON" and output waveform observed on an oscilloscope. The required output waveform is the same as for the memory/timer. For the thermal shock test, the above measurements are repeated at 100°C.

## TEST RESULTS

### Pre- and Post Burn-In Electrical Results:

The following table indicates the number of units tested and the total number of failures for each device type:

|  | Units Tested | Failures Pre Burn-In | Post Burn-In |
|---|---|---|---|
| Oscillator | 110 | 5 | 2 |
| Interface | 25 | 0 | 0 |
| Memory/Timer | 200 | 0 | 0 |

a. Thermal Shock:

After completion of the initial 30 cycles of thermal shock, 40 oscillator units and 25 memory/timer units were removed and placed on the 85$^{o}$C/85% RH test. The cumulative number of failures at each readout are shown below:

Thermal Shock Cycles (-55$^{o}$C to +125$^{o}$C)

|  | Units Tested | 30 | Units Remaining | 60 | 150 | 500 | 600 | 700 | 800 | 900 |
|---|---|---|---|---|---|---|---|---|---|---|
| Oscillator | 50 | 0 | 10 | 0 | 0 | 1 | 2 | 5 | 6 | 7 |
| Interface | 5 | 3 | 2 | 5 |  |  |  |  |  |  |
| Memory Timer | 50 | 0 | 25 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

|  | 1000 | 1500 | 1600 | 2000 |
|---|---|---|---|---|
| Oscillator | 8 | 9 | 10 |  |
| Interface |  |  |  |  |
| Memory/Timer | 0 | 0 | 0 |  |

100% of the oscillators (10/10) failed after 1600 cycles. Total failure of the interface devices (5/5) occurred after only 60 cycles.

b. Steady State Humidity (85$^{o}$C/85%RH):

The total number of oscillator and memory/timer devices included 40 and 25 units, respectively, that had received 30 cycles of thermal shock. The cumulative number of failures for each readout time (in hours) is presented below:

|  | Units Tested | 87 | 179 | 314 | 428 | 570 | 733 | 897 | 1062 | 1120 |
|---|---|---|---|---|---|---|---|---|---|---|
| Oscillator | 93 | 1 | 4 | 5 | 11 | 12 | 15 | 20 | 30 |  |
| Interface | 20 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 2 |  |
| Memory/Timer | 175 | 0 | 0 | 0 |  | 1 |  |  |  | 2 |

|  | 1222 | 1382 | 1427 | 1582 |
|---|---|---|---|---|
| Oscillator | 32 | 34 |  | 34 |
| Interface | 4 |  |  | 5 |
| Memory/Timer |  |  | 3 |  |

Because of the large number of memory/timer devices and the time required to make the electrical measurements, they were not read at every interval. An effect which occurred mainly with the oscillator hybrid was the recovery to normal behavior of a device which initially failed. This would occur usually after storage at room temperature for 24 hours. This effect is discussed in the next section.

## RESULTS

Test results on the memory/timer devices evaluated indicate that these devices are of high quality (evident by zero failure on pre- and post burn-in electrical) and possibly high reliability. At 85°C/85% RH, with the limited amount of data, the median life is predicted to be 100,000 hours. Electrical performance of the first failure varied from normal to partial output pulse, no output pulse, or no output recovery. The second failure occurred after 1120 hours. Output did not recover and the fuze setter displayed an "E" reading. The third failure had no output pulse and the fuze setter displayed an "E" reading.

The seven oscillator failures occurring after pre- and post burn-in electrical are not alarming, provided the oscillator manufacturer did not perform similar screens. A reject rate of 4.5% after initial electrical and 2% after burn-in, is within industry standards.

Device end point measurements were made for thermal shock and humidity tests after a one hour drying period. For many of the oscillator failures, maintained at room temperature, end point tests repeated within 24 hours indicated normal operation. These "restored" devices were returned to the environmental test and failed again on subsequent end point measurements. This failure/recovery cycle usually occurred several times until no recovery was observed.

Tests were conducted to determine the presence of electrical discontinuity in devices that passed end point tests at 25°C and failed at 100°C. Resistance measurements between pins for all pin combinations showed either stable or decreasing resistance for a temperature change from 25°C to 100°C.

Interface thermal shock failures included: No fuze setter display, "E" setter display, no output pulse, and/or no recovery of output pulse. The initial humidity failure at 897 hours had a sudden output pulse shift from the normal -21V to -26V at 0.5 seconds. The three additional humidity failures showed no output pulse and an "E" displayed in the fuze setter.

A significant finding was the importance of the 100°C parameter end point measurement following thermal shock. Of the 10 oscillator failures recorded, only 30% failed at room temperature while 70% failed at 100°C.

Preconditioning of the oscillator and memory/timer units with 30 cycles of thermal shock was not significant. Eight of the 32 oscillator humidity failures (23%) had been subjected to the 30 cycles of thermal shock. None of the three memory/timer humidity failures had been preconditioned by thermal shock.

## FAILURE ANALYSIS

### a. Procedure:

Standard failure analysis procedures were used in this investigation. Non-destructive electrical and X-ray radiographic techniques were performed prior to removal of encapsulation. Optical microscopy generated the most useful data. The SEM was used when required. The procedure developed for removal of the device from its package is detailed below.

### b. Oscillator:

The metal package was removed by grinding an edge on either side to the epoxy encapsulant. The shield was then pulled from the unit allowing the encapsulated assembly to be removed. Removal of the epoxy encapsulant and silicone junction coating was accomplished by immersion in heated Unresolve Plus solvent for several hours.

### c. Interface:

The bulk of the silicone encapsulant was removed by an abrasion tool. The remaining encapsulant is removed using the same procedure used with the oscillator.

### d. Memory/Time:

A cavity is formed in the epoxy encapsulant above the chip using a dumat grinding tool. The device is placed on a hot plate. Fuming nitric acid is dropped into the cavity in the package formed by the grinding tool. After several seconds, the device is rinsed in acetone. This procedure is repeated until the chip is exposed.

### e. Results:

Few of the failures studied indicated problems normally experienced with plastic encapsulated devices: open wires after thermal shock, aluminum corrosion following humidity.

Figures 10 through 13 are examples of oscillator failures. Figures 10, 11 and 12 are failures from humidity testing and Figure 13 is a thermal shock failure. Two of the three humidity failures are due to chip capacitor problems. These two failures were the result of C4 cracking. The third failure occurred due to fracture of the beam at pad 4 on the microcircuit chip. These failure modes are not failures usually associated with humidity testing.

The thermal shock failure was again the result of a chip capacitor. Figure 13 shows capacitor C3 separated from the substrate. If this was a poor bond initially, then thermal shock testing could have caused the bond fracture to be complete. The result would have been an intermittent failure with temperature, which it was.

Figures 14 and 15 are two interface humidity failures. Figure 14 shows an open jumper wire between two substrate conductors. Figure 15 illustrates an open wire bond at Pad 18 of the microcircuit chip.

A major deficiency with the interface hybrid has been poor quality control, particularly regarding wire bonds. Figure 16 illustrates three different substrate conductor wire bonds. Figure 16a is a 390X SEM photomicrograph of a typical substrate wire bond. Overpressure by the bonding tool has completely flattened the ball and induced neckdown of the wire. Figures 16b and 16c show the same type of bond (130X magnification). This time, only part of the flattened bond exists because of the poor placement of the bond on the conductor. These problems could have been eliminated by precap visual inspection.

The open memory/timer unit analyzed failed the humidity test as a result of an open aluminum metalization near the bond pad (see Fig. 17). Figure 17a is a 110X dark field photomicrograph indicating missing aluminum in the conductor leading from the bonding pad. Under higher magnification, 450X, it is seen in Figure 17b that a defect in the aluminum at the interface between the silicon nitride passivation and aluminum, indicated by the hash lines, was the probable cause of failure. Moisture, which entered the package, was permitted to chemically attack the narrow aluminum conductor by direct access to the metal through the defect. This failure could have been avoided by precap visual inspection.

## CONCLUSIONS AND RECOMMENDATIONS

The completed environmental testing and failure analysis does not indicate a plastic encapsulation related reliability problem. Results for the memory/timer monolithic microcircuit indicate excellent performance on both the thermal shock and 85°C/85% RH tests. The median life of the memory/timer device at the accelerated 85°C/85% RH test condition is predicted to be 100,000 hours using a Weibull probability plot, Figure 18.

The oscillator and interface failures cannot be attributed to the plastic encapsulation process. Classical failure mechanisms of aluminum corrosion or gold electrochemical reactions of devices tested in high humidity/temperature have not been observed. The problem of initial electrical failure of the oscillator after humidity testing, then recovery after a short drying period, could be classified as a packaging problem. However, improved packaging techniques and materials could possibly eliminate this effect.

Failure mechanisms attributed to the above two hybrid types are associated with assembly techniques and procedures. These include wire bond procedure, circuit layout and the solder reflow process.

The following recommendations are provided based on the tests and failure analysis performed:

a. Major changes in the assembly of the interface hybrid are required. Changes required include: improvement in wire bonding procedure; elimination of four jumper wires; use of standard lead frame assembly; use of accepted molding procedure and materials.

b. The oscillator hybrid requires a package redesign. Packaging should reflect accepted molding procedure and materials. A study should be made to determine the adequacy of solder reflow for component assembly.

c. Procurement of these devices should be by a drawing which requires screens, i.e., precap visual and burn-in, and Lot Acceptance Testing.

# APPENDIX A

## HUMIDITY, STEADY STATE (85°C/85%RH)

1. PURPOSE: This test is performed to evaluate the properties of materials used in components as they are influenced by the absorption and diffusion of moisture and moisture vapor. This is an accelerated environmental test, accomplished by the continuous exposure of the specimen to high relative humidity at an elevated temperature. These conditions impose a vapor pressure on the material under test which constitutes the force behind the moisture migration and penetration. Hygroscopic materials are sensitive to moisture, and deteriorate rapidly under humid conditions. Absorption of moisture by many materials results in swelling, which destroys their functional utility and causes loss of physical strength and changes in other important mechanical properties. Insulating materials which absorb moisture may suffer degradation of their electrical properties. This method, while not necessarily intended as a simulated tropical test, is of use in determining moisture absorption of insulating materials.

2. PROCEDURE:

a. <u>Chamber</u>. The chamber and accessories shall be constructed and arranged in such a manner as to avoid condensate dripping on the specimens under test, and such that the specimens shall be exposed to circulating air.

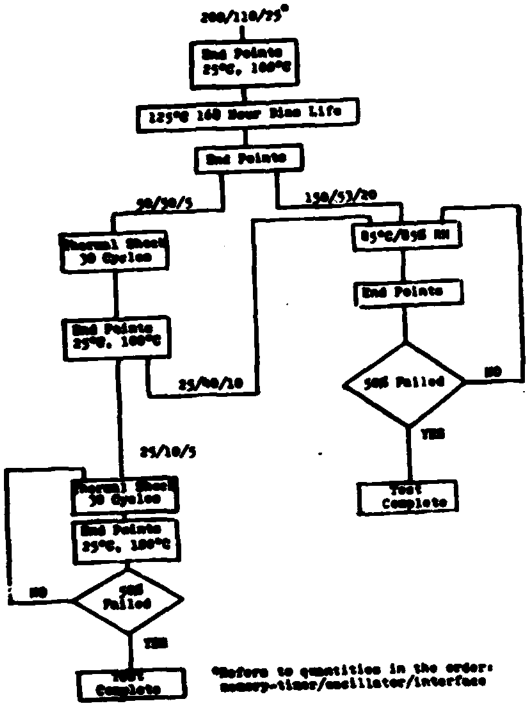
b. <u>Mounting</u>. Specimens shall be mounted by their normal mounting means, in their normal mounting position, but shall be positioned so that they do not contact each other, and so that each specimen receives essentially the same degree of humidity.

c. <u>Initial Measurements</u>. Prior to Step 1 of the first cycle, the specified initial measurements shall be made at room ambient conditions, or as specified.

d. <u>Exposure</u>. The specimens shall be placed in a chamber and subjected to a relative humidity of 80 to 85 percent and a temperature of 85° ±2°C until 50% of the population has failed or as specified.

3. MEASUREMENTS:

<u>After Drying Period</u>. Upon completion of exposure periods of 25, 50, 100, 150, 250, 500, 750, 1000, 1500, 2000, 3000, 4000, 5000 hours, the specimens shall be conditioned at room ambient conditions for not less than one hour, not more than two hours until otherwise specified, after which the specified measurements shall be performed at room ambient conditions.



*Refers to quantities in the order: memory-timer/oscillator/interface

Figure 1. Test Program Flow Chart

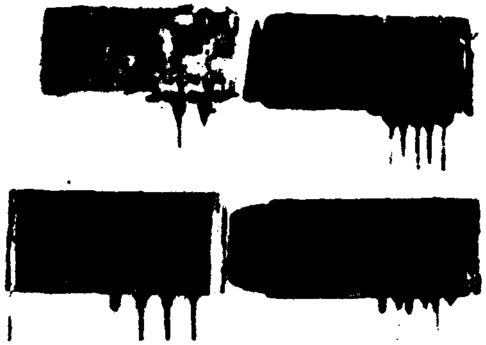


Figure 2. 10 kHz Hybrid Microcircuit Oscillator Package

Figure 3. Oscillator Thick Film Substrate

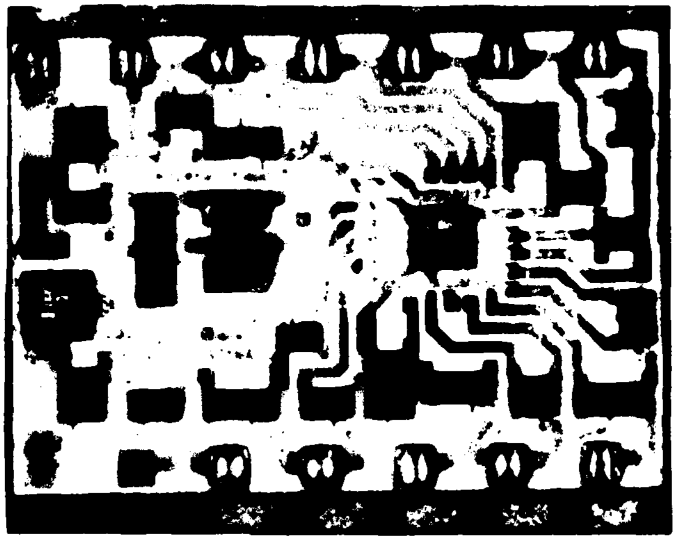


Figure 4. Interface Hybrid Microcircuit Substrate

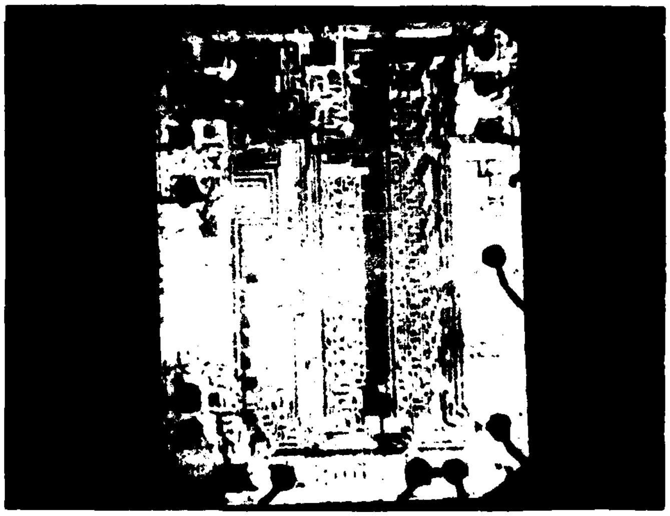


Figure 5. Memory/Timer MNOS Monolithic Chip

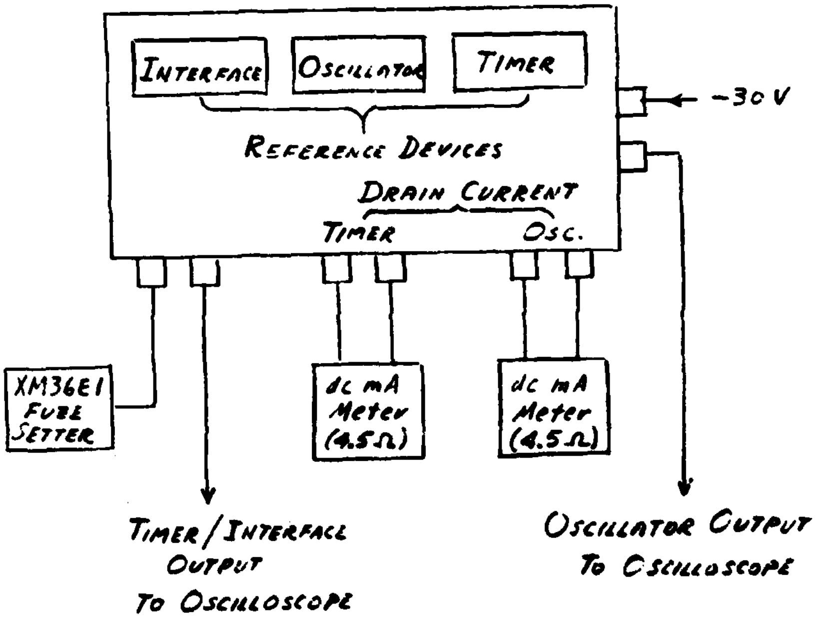


Figure 6. End Point Measurement Test Circuit

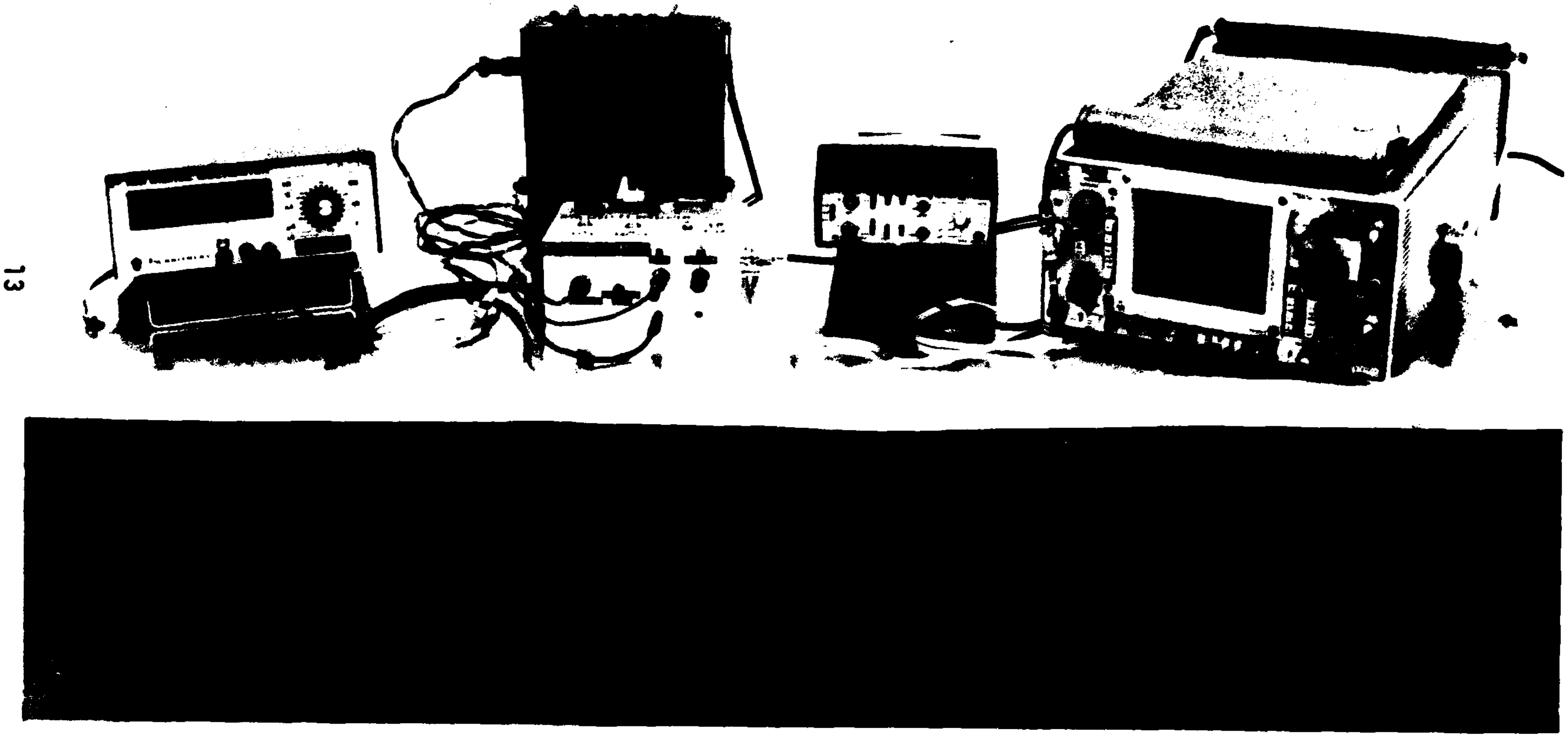


Figure 7.  Static - Safe Work Station

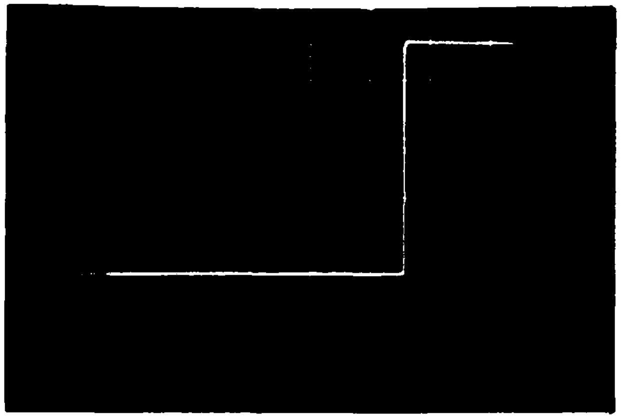


Figure 8. Memory/Timer and Interface Output Waveform (Vert. 5V/div, Horiz. 500ms/div)

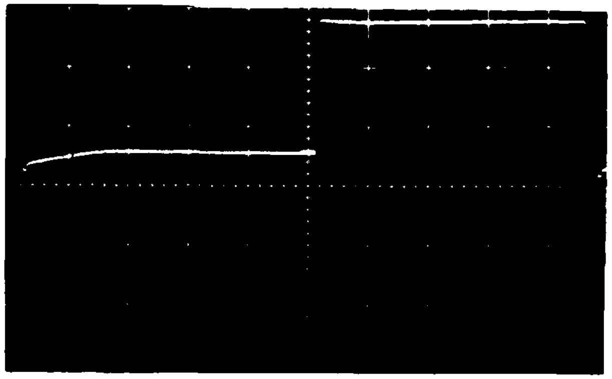


Figure 9. Oscillator Output Waveform (Vert. 5V/div, Horiz. 10μs/div)

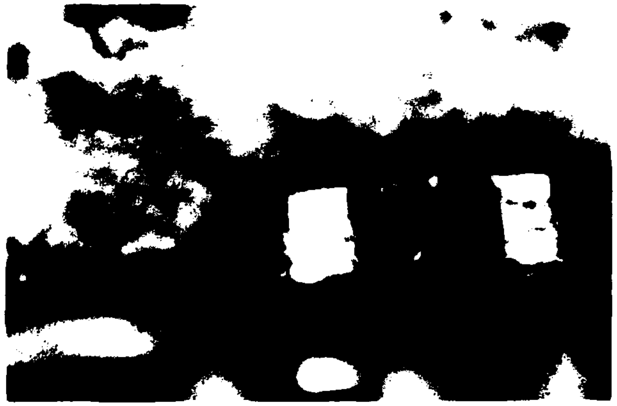


Figure 10. Oscillator C4 Humidity Failure

Figure 11. Oscillator C4 Humidity Failure

Figure 12. Oscillator IC Chip Bond Failure Following Humidity Testing

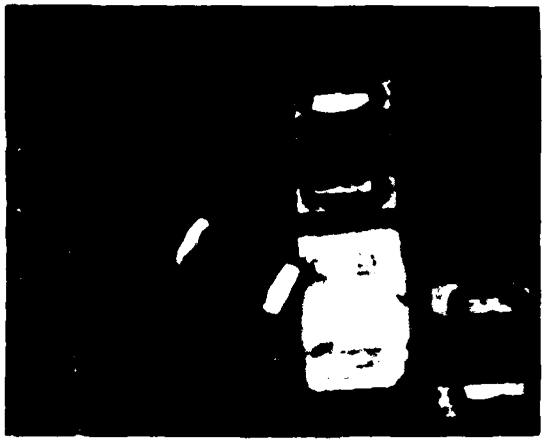
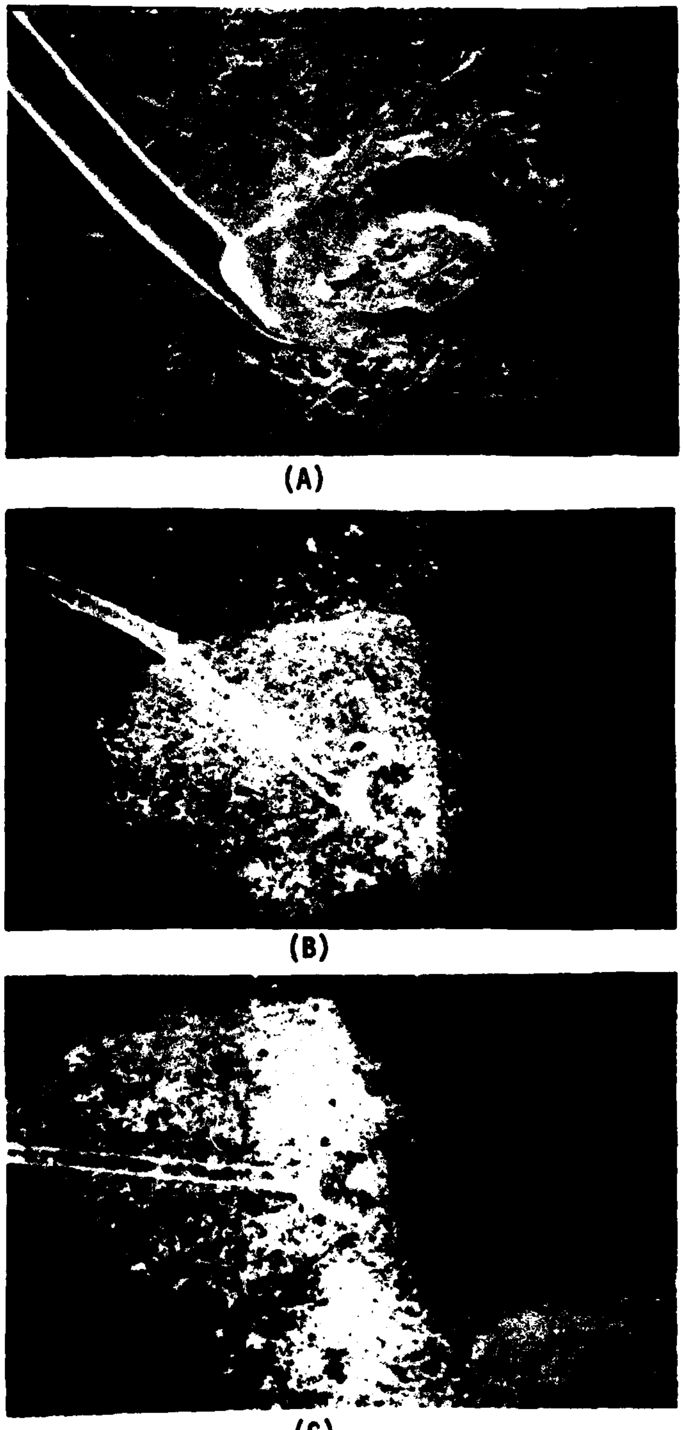


Figure 13. Oscillator C3 Thermal Shock Failure

Figure 14. Interface Humidity Failure: Open Jumper Wire

Figure 15. Interface Humidity Failure: Open IC Wire Bond

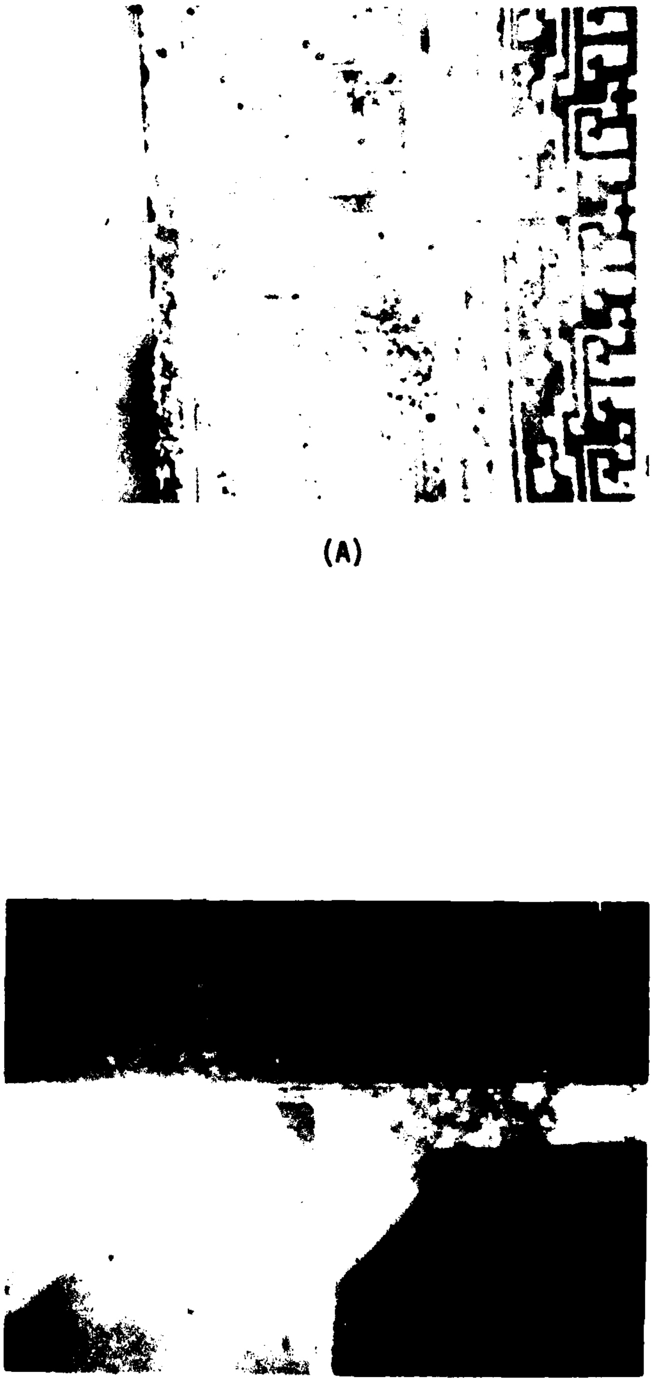


(A)

(B)

(C)

Figure 16. Typical Interface Wire Bonds



(A)

(B)

Figure 17. Memory/Timer Humidity Corrosion Failure

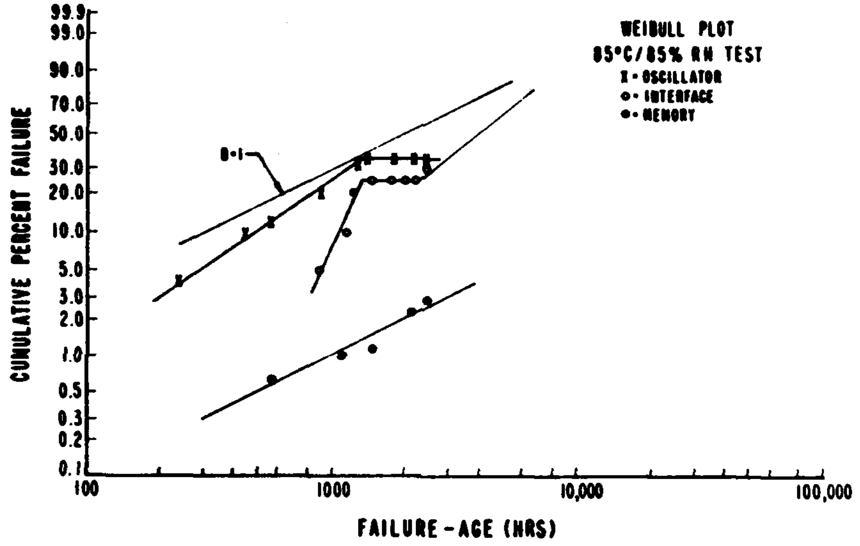


Figure 18. Weibull Humidity Plot